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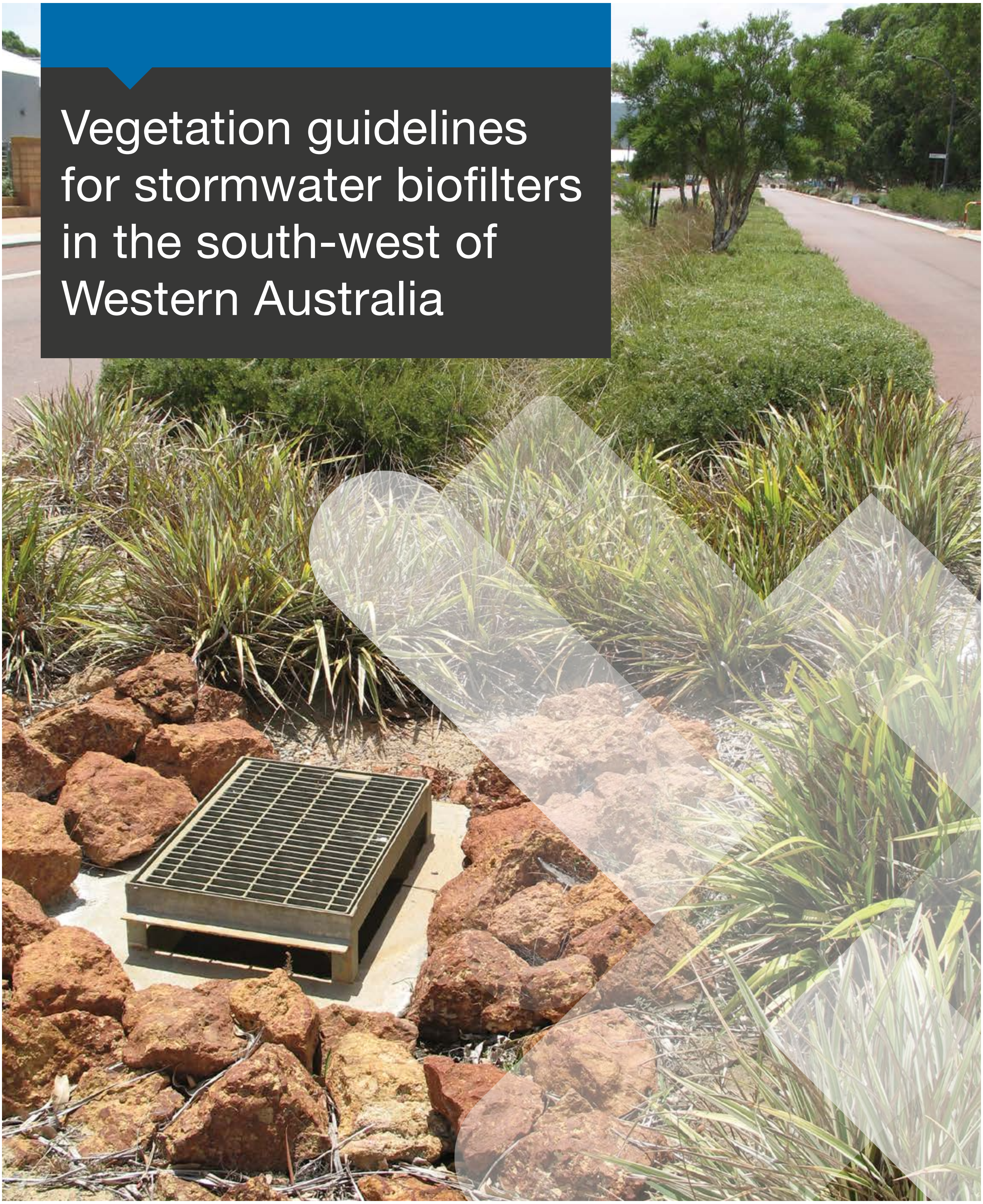
# Vegetation guidelines for stormwater biofilters in the south-west of Western Australia



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Cover photograph: Road median biofilters installed along Mead Street in The Glades urban development in Byford (Source: Department of Water, WA)

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# 1 Introduction

A stormwater biofilter is an excavated basin or trench filled with porous material that acts as filter media and growing media for the planted vegetation. Biofilters are a proven method of treating stormwater from urban areas. To function well, biofilters rely on both the filtering properties of the soil media and the pollutant uptake and/or transformation capacity of their plants and the associated microbial community. While these guidelines provide information on how to select the most appropriate plant species for biofilters within the south-west of Western Australia, the general principles are applicable to other regions.

Chapters 3 to 7 describe the results of the latest research into plant selection for biofilters, and the general principles derived from this research. Chapters 8 to 10 describe the practical aspects of establishing, monitoring and maintaining the vegetation.

A summary of the principles for choosing plants and improving biofilter performance is given in Chapter 7.

These guidelines provide design and planning principles. However, this document is not intended to be a complete design guide for biofilters, but a companion document to the *Adoption Guidelines for Stormwater Biofiltration Systems* (FAWB 2009a), which describes the biofilter design process. Please note that the FAWB adoption guidelines are currently being revised, and the revision is due to be completed at the end of 2014. The structural design of biofilters will depend on local conditions, including climate, geology, groundwater conditions, adjacent infrastructure and stakeholders' objectives.

To help decide which stormwater management practices are best suited to meet the site characteristics and objectives of your project, refer to the 'Structural controls' section of the *Stormwater Management Manual for Western Australia* (DoW 2004–2007) – Chapter 9, Section 1.7 How to select structural BMPs. If the site is suitable for a biofilter, then these guidelines can assist with the implementation.

A diagrammatic step-by-step summary of how to design and implement the vegetation component of a biofilter system is shown below (Figure 1).

**Determine if a biofilter suits the site characteristics and if it does, how these characteristics will influence the biofilter design** ↓

**Engage stakeholders as required in the biofilter design process** ↓

**Research and choose the style and set the objectives e.g. amenity, biodiversity** ↓

**Gain approval as required** ↓

**Choose the plants to match the site and style** ↓

**Establish the plants** ↓

**Maintain and monitor**

*Figure 1 Steps for designing and implementing vegetation in biofilters*

# 2 What are biofilters?

Biofilters (also known as biofiltration systems, bioretention systems and rain gardens) are excavated basins or trenches filled with porous material that acts as filter media and growing media for the planted vegetation. They retain or detain stormwater runoff, reducing the volume and rate of runoff from a drainage area. The filter media, vegetation, microbes and saturated zone (where present) remove pollutants from stormwater runoff through physical, chemical and biological processes. Biofilters typically have a high infiltration rate and only hold surface water during and for a short duration after storm events.

Saturated zones are incorporated into the biofilter design in situations where nitrogen removal and buffering against drought are critical objectives.

As well as treating and reducing the flow rate of stormwater, biofilters can provide secondary benefits within the urban environment, depending on their location, design parameters and the plant species used.

These secondary benefits include:

- landscape aesthetics and public amenity, including microclimate benefits
- biodiversity outcomes for urban areas (use of local native plant species and/or habitat creation)
- improved hydraulic capacity (increased groundwater recharge, reduced flow volume and velocity, and flood prevention)
- lower maintenance and costs for the downstream stormwater system
- water conservation, if the biofilter is used as part of a stormwater harvesting system or combined into landscaping systems.

# 3 Nutrient removal by plants

## 3.1 Introduction

Recent research has indicated that **the removal of nitrogen is the function that most requires the correct selection of plant species** (Read et al. 2008; Bratières et al. 2008; Fletcher et al. 2007). Biofilters can effectively remove a wide range of other contaminants such as metals, sediment, phosphorus and pathogens (Hatt et al. 2009; Chandrasena et al. 2014). The presence of plants contributes to the removal of many of these pollutants, but the selection of species is not as critical as for removing nitrogen. The choice of plant species can also influence pathogen removal (Chandrasena et al. 2012), and future versions of the *Adoption Guidelines for Stormwater Biofiltration Systems* (FAWB 2009a) will include advice on selecting plants to achieve this treatment objective, as it becomes available from research.

## 3.2 Variation in performance between plant species

The performance of different species in removing nutrients, particularly nitrogen, can vary greatly (Read et al. 2008; Bratières et al. 2008).

Why are nutrients so challenging to remove within biofilters? Unlike other contaminants such as metals and suspended sediment, nutrients are subject to a wide range of biological processes that can convert them between multiple organic and inorganic forms. In addition, both nitrogen and phosphorus may be recycled within the biofilter. If nutrients are taken up by living organisms, eventual decomposition of tissues can return some of these nutrients back to the system. Long-term retention may occur if nutrients are incorporated into long-lived plant tissues or soil organic matter that is inherently resistant to decomposition. Permanent nutrient removal can be achieved if the plant biomass is harvested, although this may not always be economically feasible. In the case of nitrogen, permanent removal can also occur through the transformation of nitrate into gaseous form via the denitrification process. These gases are then lost to the atmosphere (Figure 2).

In addition, plant uptake is influenced by a number of factors, including interactions with other elements (e.g. plants limited by iron deficiency reduce their phosphorus uptake to ensure that a sufficient balance of these ions is maintained); the accessibility of nutrients within the biofilter media (influenced in turn by whether plants have specialised roots or produce root exudates to extract tightly bound nutrients); the growth rate of the plant, the peak growth and nutrient uptake periods of a species, and the physiological limitations of the species, among other factors.

Certain species (such as legumes) are net generators of nitrogen, converting atmospheric nitrogen into ammonium nitrogen. These species can increase the nitrogen (nitrate) concentration in soils and groundwater (see Pate and Unkovich, 1999), and should be avoided in biofilters.

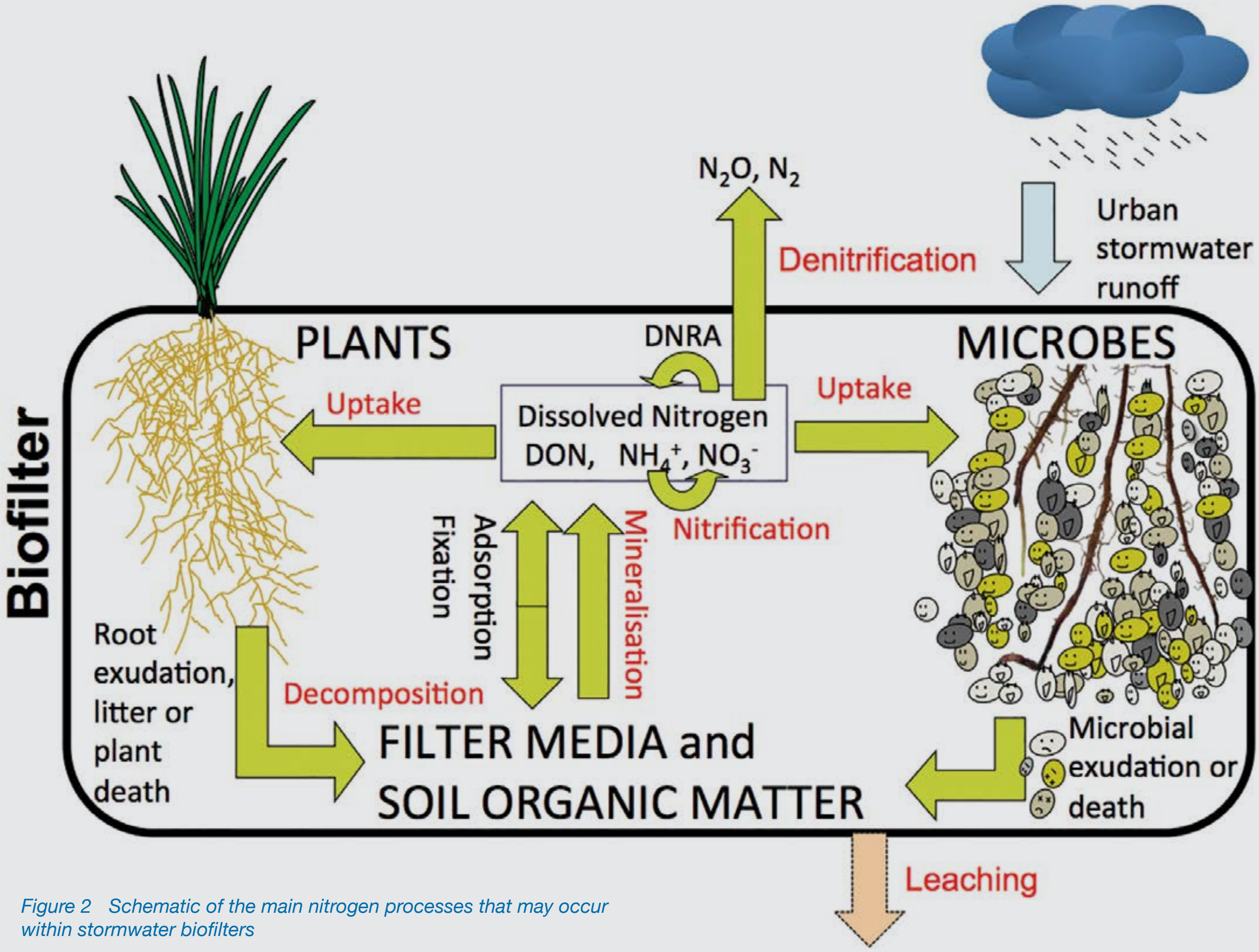


*Figure 2 Schematic of the main nitrogen processes that may occur within stormwater biofilters*

Previous studies have shown nutrient removal to vary broadly across plant species - from effective reductions through to no net reduction (Read et al. 2008; Bratières et al. 2008). However, when media with low organic matter is used, recent research has reported more consistent performance for nutrient retention between plant species (Payne et al. 2013a; Pham et al. 2012; Bratières et al. 2009). In a laboratory experiment using low-nutrient media, a range of native grasses, sedges, rushes and trees from Western Australia and Victoria were all significantly more effective at nitrogen removal compared to non-vegetated biofilters. All planted biofilters also effectively removed phosphorus. However, this consistent performance was observed under relatively wet conditions (i.e. twice-weekly inflows). When subjected to prolonged drying, nitrogen retention displays greater variation between plant species (discussed further in the following section).

This suggests that **a relatively wide range of plant species** selected from a palette of suitable plants **can be used in biofilters if filter media specifications for nitrogen and phosphorus content are met** as specified in the *FAWB Adoption Guidelines* (2009a).

Despite the greater consistency in retention when species were grown in low nutrient filter media, species still differ in their efficiency of nitrogen uptake. The relative nitrogen removal performance of plant species tested in laboratory column experiments is provided in Table 1 (Zhang et al. 2011; Payne et al. 2013a). Particularly effective genera include *Carex*, *Juncus* and *Melaleuca*. Conversely, *Dianella* has been noted in a number of studies for its relatively poor performance (Payne et al. 2013a; Read et al. 2008). Several lawn grasses such as Velvetene™ and Buffalo were tested in greenhouse trials and found to have promising performance (Payne et al. 2013a). However, these lawns were applied to the biofilter columns as roll on turf and included the clayey media in which the grasses were grown. The presence of clayey media affects the ability to attribute the nutrient retention performance to the lawn species themselves. Additionally, only small areas (in 150 mm diameter columns) were trialled and the results may not be the same across a whole lawn under field conditions. Further testing is required, taking into account factors such as mowing access and methods (e.g. whether clippings are removed) and potential compaction due to foot traffic.

# 3.3 Influence of wet and dry conditions

In practice, biofiltration systems rarely experience regular inflows. Rather, a key characteristic of biofilters is the wide fluctuation in moisture status; varying from flooded to extended periods of drying. This is particularly the case in the south-west of Western Australia.

Severe drying leads to reduced nutrient removal or even to nutrient release following the next storm event. Sometimes previously stored nutrients can be released and flushed in these events, as desiccation leads to reduced microbial activity and bacterial death. Prolonged drying will also affect plant growth and function, and may result in root death, or even plant death if severe. In addition, as the biofilter media dries or is re-wet, the availability of moisture, nutrients and oxygen changes, which changes the zones available for different transformation processes. The water status of a biofilter is thus critical to its function.

Drying reduces the nitrogen removal performance of all vegetated biofilters, but to differing extents for each plant species. Some species were either consistently more or less effective than other species. Conversely, some species shifted their relative performance between wet and dry conditions – to be more effective under certain moisture availability conditions, but relatively poor performers under reversed conditions. The species tested in laboratory column experiments that were found to be effective at removing nitrogen under both wet and dry conditions are listed in Table 1.

Further, there is greater variation between plant species performance under dry conditions. In particular, nitrate and organic nitrogen are more difficult to remove from the stormwater.  Drying can slow, or completely stop, biological processes and lead to the release of nitrogen from the media, dead microbes and senesced root and shoot materials upon re-wetting (Payne et al. 2013b; Zinger et al. 2007). Drying also reduces phosphorus removal, but reductions may still take place if the sorption capacity of the media has not been saturated. Addition of materials such as vermiculite, perlite and iron-rich sands to the filter media can ensure high sorption capacity (Glaister et al. 2013).If site conditions are suitable for installation of an unlined biofilter system it may be possible to use groundwater to help plants survive or grow, depending on its proximity and quality. See Section 5.4 for further information.

**Biofilter removal of nutrients is most effective under conditions of regular water availability**, either:

- during times of frequent inflows
- if a saturated zone is included in the design
- if plants have access to groundwater
- if irrigation is undertaken during prolonged periods without rainfall.

Monitoring the depth of the saturated zone (if incorporated in the design) may help determine an appropriate irrigation regime to prevent complete drying.

*Table 1 Species performance for nitrogen removal in stormwater biofilters tested in laboratory column experiments (Payne 2013; Zhang et. al. 2011)*

| | Effective | Mixed – varies between wet and dry | | Medium range | Poorer |
|---|---|---|---|---|---|
| | | Effective in wet | Effective in dry | | |
| **Western Australian native species** | *Carex tereticaulis* (sedge) | *Juncus kraussii* (rush) | *Poa poiformis* (grass) | *Sporobolus virginicus* (grass) | *Rytidosperma caespitosum* (grass) |
| | *Melaleuca incana* (tree) | *Cyperus gymnocaulos* (sedge) | | | *Gahnia trifida* (sedge) |
| | *Baumea juncea* (sedge) | | | | *Astartea scoparia* (shrub) |
| | *Melaleuca lateritia* (shrub) | | | | *Hypocalymma angustifolium* (shrub) |
| | *Baumea rubiginosa* (sedge) | | | | *Austrodanthonia caespitosa* (grass) |
| | *Juncus subsecundus* (rush) | | | | *Dianella revoluta* (lily) |
| | *Carex appressa* (sedge) | | | | *Hakea laurina* (tree) |
| | *Juncus pallidus* (rush) | | | | |
| **Australian species non-native to WA** | | *Leptospermum continentale* (tree) | | *Poa labillardieri* (grass) | *Gahnia sieberiana* (sedge) |
| | | *Allocasuarina littoralis* (tree) | | *Poa sieberiana* (grass) | Dianella tasmanica (lily) |

## 3.4 Influence of a saturated zone and carbon source

The effects of drying can be partially overcome by including a saturated zone into the lower filter layers of the biofilter (Zhang et al. 2011; Zinger et al. 2007; Lucas & Greenway 2011). A saturated zone is created by sealing the biofilter using an impermeable liner and providing a raised outlet pipe or weir (Figure 3). The saturated zone stores a portion of stormwater between inflow events, allowing time for slower processes to reduce nutrient levels to background concentrations in spite of differences in plant nutrient uptake. It also provides anaerobic conditions to support processes such as denitrification (the conversion of nitrate to gaseous forms), and supplies moisture to help sustain plants and microbes, and minimise media desiccation during dry periods.

**Biofilter performance benefits significantly from the presence of a saturated zone, particularly in dry conditions.**

The saturated zone also improves the performance of poorer performing plant species by allowing continued processing between inflow events (Zinger et al. 2013; Payne et al. 2013a). The most effective plant species process nitrogen relatively rapidly, so they only benefit from a saturated zone in dry times. In this way, the saturated zone can act as an 'insurance policy' for plants that are poorer at removing nutrients.

Denitrification within the saturated zone is further improved by including a carbon source, such as wood chips, mixed into the lower drainage layers of the biofilter. The carbon source may not provide much advantage if designs include plant species with active and extensive root systems, which continuously provide carbon to the system (e.g. *Carex appressa*), but may be important if species with limited root systems are used.

## 3.5 The effects of seasonal climate variation

Biofilter performance, particularly for nitrogen removal, will vary in response to seasonal changes in water availability (Section 3.3). In the laboratory column experiment, wetting and drying exerted the dominant seasonal influence over performance. This variation in performance can be minimised by planting a variety of species, including a saturated zone and minimising severe drying across the full biofilter profile.

Seasonal performance for nutrient removal may be influenced by the seasonal shifts in plant biological functioning. Plant species will differ in the duration and timing of their growing season (Lucas & Greenway 2011; Hooper & Vitousek 1998). As a result, optimal periods

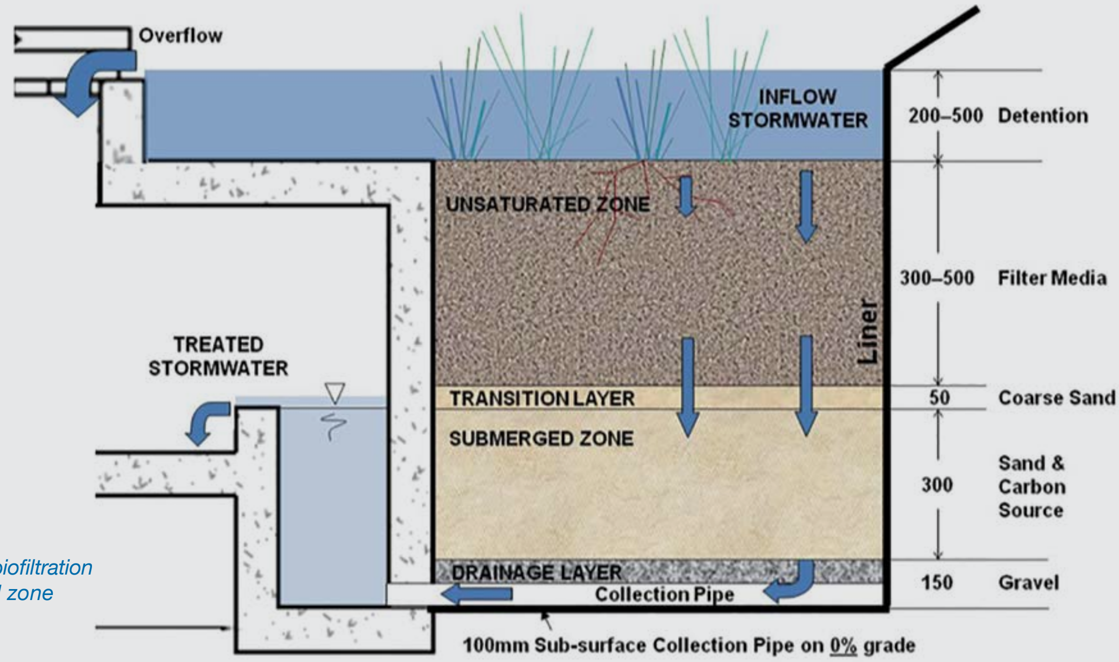


*Figure 3 Schematic of a biofiltration system with a submerged zone (Source: FAWB 2009a)*

for nutrient uptake and evapotranspiration loss, and the timing of senescence, will vary between species.

## 3.6 Nitrogen processing and long-term removal

Long-term performance studies of stormwater biofilters in the Western Australian setting are still scarce, and an understanding of the dynamics of nitrogen removal and internal mechanisms in these systems is still incomplete globally. Recent use of a nitrogen isotope tracer suggests that biotic uptake and microbial transformations in the rhizosphere are the dominant retention pathways for incoming nitrate early in a biofilter's life (Payne et al. 2014). In this study, denitrification only provided a minor removal pathway, despite the presence of a saturated zone and carbon source. However, denitrification may play a more dominant role in nitrogen processing over the longer term as plant growth slows, such as over winter or in mature biofilters. Further research is required to investigate the extent of denitrification in field biofiltration systems, and the potential to optimise the process.

Plant nitrogen uptake is likely to plateau once plants reach maturity and die back seasonally. To help maintain the uptake, it may be worthwhile to regularly harvest and remove vegetation from biofilters, where this can be done practically and without damaging other aspects of biofilter function, such as biodiversity and aesthetics. Further research is needed to determine the benefit of and best timeframe for harvesting. See Table 7 in the monitoring and maintenance chapter for more information on long-term management of the vegetation.

## 3.7 Desirable plant characteristics for optimising biofilter nitrogen removal

The effectiveness of plant species to remove nitrogen is related to certain plant characteristics (Read et al. 2010; Payne 2013). These characteristics provide a useful guide for selecting the best plant species to use in biofilters.

Root characteristics influence the effectiveness of nitrogen removal. Species with extensive and fine root systems (i.e. high total length of roots, surface area, and fine root mass and length) and high plant mass are generally most effective, particularly for nitrate removal.

In general, plants with fibrous roots, rather than thick taproots, perform better in biofilters. The root architecture dictates the extent of contact between the plants, biofilter media, stormwater and microbes. The microbes mainly exist in the narrow zone surrounding roots - the rhizosphere. Roots can directly process nitrogen via uptake, or can enhance microbial transformation through the provision of attachment sites for microbes, carbon, oxygen, or other alterations to the physiochemical conditions.

The relationships between performance and various root characteristics are strongest during wet conditions (Payne 2013). However species with these characteristics sometimes perform poorly during dry conditions due to moisture stress, which can cause contraction of the root biomass and death of microbes.

Plant species with minimal above-ground mass, reduced leaf mass and slower growth are better performers during dry conditions. While a large root mass and fast growth rate are determinants of performance in wet conditions, water conservative species generally perform better across dry periods. For example, those with lower evapotranspiration loss because of lower leaf area perform better under dry conditions. Characteristics, such as a high transpiration rate, may be advantageous under frequent inflow conditions, but may be a disadvantage at dry times, when a more conservative approach to resources is required.

While these contrasting relationships present a challenge for plant selection, they also further illustrate the importance of including a diversity of species with different characteristics. Species diversity is the best strategy to equip biofilters with resilience against a range of climatic conditions, allowing any reduction in one species growing within the biofilter to be compensated by another.

Despite different relationships under wet and dry conditions, a high root mass distinguishes the most effective species from those with consistently lower removal or mixed performance.

Factors to consider in selecting species for optimal nutrient removal in stormwater biofilters are summarised in sections 5.5 and 5.6.

# 4 Hydrologic requirements of biofilters and how these affect choice of plants

## 4.1 The hydrology of biofilters

Biofilter design requires a balance between maintaining the capacity to treat a sufficient volume of stormwater and providing the retention time needed for treatment processes and for plants and microbial communities to receive adequate moisture. This trade-off is inevitable and can be represented by the infiltration rate. A high infiltration rate allows the biofilter to process larger volumes of water, but decreases the retention time. Infiltration is influenced by characteristics of the filter media, plants and incoming stormwater hydrology and sediment load, as well as the maintenance regime. Designers also need to consider the potential for clogging, which invariably reduces the infiltration rate as fine sediments accumulate in the biofilter (Virahsawmy et al. 2013; Hatt et al. 2008).

The hydrologic performance of a biofiltration system depends primarily on three design parameters:

- filter surface area
- extended detention depth (i.e. ponding depth; the depth between the surface level of the filter media and the top of the overflow structure)
- filter media hydraulic conductivity.

Where one of these design parameters falls outside the recommended range, the infiltration capacity can still be maintained by offsetting another of the design parameters.

While the focus of this section is on the use of vegetation to maintain hydraulic conductivity of the media, the designer should consider providing an appropriate 'safety margin' in the design of a biofiltration system.  A safety margin, in relation to flood storage, is achieved by ensuring the **filter area and extended detention depth are sized assuming a final media hydraulic conductivity of between 33% and 50% of the design value** (see *Guidelines for Filter Media in Biofiltration Systems* (FAWB 2009b) for further information). Further, the design should account for local variations in climate, soils, land use and other factors affecting rainfall and runoff. Due to the importance of moisture, understanding the duration of the inter-event periods, and the continuous rainfall periods, is as important as determining the design flows.

## 4.2 The importance of plants for maintaining filter media infiltration rate

Much research has been conducted on selecting the optimal biofilter media. Use of media with a relatively high sand and low clay content (i.e. a loamy sand or even sand with appropriate ameliorants added) has been found to provide both sufficient water quality treatment and infiltration (Bratières et al. 2009). Despite the importance of filter media characteristics, it is important to note that this does not reduce the need for plants in biofilters. Vegetating biofilters with suitable plant species is critical for long-term effective stormwater treatment.

Plants play an important role by helping to maintain the infiltration rate (Virahsawmy et al. 2013). Even if severe surface clogging occurs, infiltration in the soil surrounding plant stems is higher than in unplanted areas due to:

- disturbance of the clogging crust by wind-induced plant stem movement
- creation of preferential flow paths[1].

This effect may vary with the differing morphology of

*[1] Note that these preferential flow paths generally do not extend all the way through the filter media and thus have not been observed to reduce treatment performance.*

plant species, but it is clear that plants are important for prolonging the functional life of a biofilter.

To maintain the desired filter media infiltration rate, biofilters should be planted at high density, with a mixture of plant types. Planting should include some thicker rooted species such as shrubs and trees, as well as sedges and rushes.

Design of the biofilter inlet is also critical as it dictates the distribution and velocity of incoming stormwater, and therefore the distribution of sediment deposits. Sediments will tend to accumulate near the inlet (Virahsawmy et al. 2013). Wide distribution and the use of multiple inlets will spread sediment across a wide area and reduce the development of zones of severe clogging. Alternatively, a sediment trap could be installed upstream of the biofilter, or a dedicated sediment capture area could be created within the system using a bank of vegetation to slow flows and deposit sediments, allowing a single maintenance point.

Use of pre-treatment devices, such as swales, buffer strips or sediment traps, helps reduce clogging and sustain biofilter lifespan. Scraping off the top few centimetres of the biofilter media or scarifying the surface as needed can reduce clogging and maintain infiltration over longer periods, particularly in zones surrounding the inlet. Table 7 provides more information on this long-term maintenance issue.

Infiltration rates can also be maintained by avoiding compaction of the media during construction and throughout the life of the biofilter. Designs should deter pedestrian access by planting with appropriate species to discourage access and therefore compaction. Maintenance crews should avoid using heavy machinery and minimise traversing within the biofilter. A non-compacted soil will also support better plant growth.

## 4.3 The importance of plants in the water balance

Evapotranspiration and exfiltration from biofilters help to reduce the overall volume and frequency of stormwater runoff. It restores the site's water balance towards its natural level. However, the amount of evapotranspiration depends mostly on the surface area of the biofilter. Typically, a biofilter will only evapotranspire around the same percentage of the annual rainfall as the percentage of the biofilter surface area relative to its impervious catchment area. For example, a biofilter that is sized at 3% of its impervious catchment area will evapotranspire around 3% of the inflow volume.

To increase evapotranspiration and maximise leaf area, biofilters need to be as large as practical (in relation to available space and water), be planted densely and preferably be planted with multiple layers of vegetation such as sedges, shrubs and trees. Ideally, plants selected should be those which have high rates of transpiration when water is available, but are able to 'down-regulate' their water use during periods of drought (Farrell et al. 2013). For example, a high root mass relative to total mass helps plants to regulate their water use.

# 5 How to select plants for a biofilter

## 5.1 Types of plants

Careful consideration is needed with regards to the type of plants used in biofilters. This is because the plants have to survive and grow well under the unique characteristics of inundation and drying. Importantly, different plant types can also influence biofilter function.  A description of each plant growth form and management considerations is provided in Table 2.

*Table 2 Description, benefits and management considerations for plant types*

| Plant type | Description | Benefits | Management notes |
|---|---|---|---|
| **Grasses** | Grasses are monocotyledons, of the Family Poaceae. Grasses are herbaceous type plants with narrow leaves growing from the base.  There are approximately 140 species of native grass in the south-west of Western Australia. | Grasses can form dense stands which assist in trapping sediments and gross litter. They are effective soil stabilisers and most native grasses are drought tolerant. Many native species prefer disturbed or degraded areas and enjoy a range of habitats making them ideal for biofilter colonization. Grasses also provide a source of food for native fauna. | Many grass species can be invasive and may out-compete more desirable species, smothering sedges and rushes. Grasses can also exhibit shallow fine roots which may clog filters, and may reduce biofilter performance where rooting depths are shallower than the filter media depth. Many invasive introduced grass species are highly aggressive and allelopathic, i.e. can release toxins into the soil to prevent other species growing. |
| **Graminoids* (Sedges and rushes)** | Sedges and rushes are terms commonly applied to species from the grass-like families (graminoids), and include submerged, floating and emergent aquatics and terrestrial species.   Sedges belong to the Family Cyperaceae, while rushes belong to the families Juncaceae and Restionaceae (Southern Rushes or restiads). | Sedges and rushes are known excellent performers in nutrient removal.  They accumulate significantly more nutrients in stems and rhizomes (underground stems) than most other plants, and support bacterial transformation of nutrients and other pollutants on their extensive root and rhizome mass. They are generally fast growing and form dense stands that slow water velocity and trap sediments and gross pollutants. When planted in dense stands, native rushes and sedges are excellent for weed control, excluding invasive species. Dense stands also provide habitat for invertebrates which then attract predators and pollinators. | Sedges and rushes need to be located according to their water requirements and pH and salinity tolerances to ensure survival. Sedges and rushes may require thinning or harvesting to maintain the hydraulics of a system and to remove nutrients from the system. The formation of dense stands will capture floating debris so plants should be placed deliberately to form collection areas. |

** Note – This plant type includes cattails (typha). However, cattails are not generally suitable for biofilters.*

| Plant type | Description | Benefits | Management notes |
|---|---|---|---|
| **Herbs** | This group are annual or perennial plants, with no woody tissue. They include many floating and submerged aquatics, emergent aquatic and terrestrial plants. | Herbs provide a useful understorey and are effective for soil stabilisation. Herbs attract pollinators and can improve the visual amenity of a site. Aquatic species (e.g. Triglochin, Villarsia) are often used in wetlands. | Many herbs have shallow fine roots. The nutrient removal capacity of many seasonal wetland species has not been assessed, however certain submergent and floating aquatics have been shown to be excellent in nutrient removal (e.g. Triglochin, Potamogeton, Lemna, Azolla). Use of these species in biofilters will depend on the frequency of inundation. |
| **Shrubs** | Shrubs are woody plants usually less than 5 m high and have many branches without a distinct main stem except at ground level. | Shrubs provide shade for herbs and groundcovers, attract pollinators, and provide habitat and a food source for fauna. They are effective soil stabilisers and some shrubs are effective at removing nutrients. Shrubs can form effective barriers or be used as hedging for access control. | Consider the size and habit when positioning shrubs within a biofilter. Some species can outcompete and smother understorey species if poorly positioned or densely planted. Also note the height in road verges and areas where maintaining a clear line of sight is important. |
| **Trees** | Trees are woody, perennial plants, usually with a well-defined stem trunk, normally greater than 4 to 5 m high; under certain environmental conditions, some tree species may develop a multi-stemmed or short growth form (less than 4 m high). | Trees provide refuge, food and habitat for native fauna. Trees typically exhibit a deep extensive coarse root system that can increase infiltration and evapotranspiration. This root system is also an effective soil stabiliser. Trees provide shade, absorb carbon and help to cool the urban environment. Positioned on the north side of a biofilter, trees will provide summer shade, lowering temperatures and protecting the understorey from long periods of exposure. Strategic placement of trees can shade pavements and roads, provide traffic calming and reduce energy demand by cooling buildings and homes and cutting air-conditioning needs. Tree-lined streets have also been found to increase property values (Science Network Western Australia 2013). | Extensive root systems and large canopies can cause damage if positioned incorrectly. The impact of shade needs to be considered in both tree placement and in the choice of understorey species. Physical root barriers may be needed where control is required. An assessment of surrounding infrastructure and services is required to determine whether trees are appropriate in the design. Some species, especially exotic trees, drop fruit, limbs and leaves in excess which can smother the understorey and increase nutrient export. Some trees species such as some Allocasuarina spp. and Eucalyptus spp. are suspected as having strong allelopathic properties (May and Ash 1990). Trees typically have a slow growth rate so planting mature tree seedlings may be preferred where an instant effect is required. |

## 5.2 Plant functions in biofilters

Table 3 describes the variety of functions performed by plants within biofilter systems and provides advice on how to maximise these functions through design. Multiple benefits are often achievable from the one biofilter system.

*Table 3 Plant function and role in biofilters*

| Function | Role of plants | Design tips |
|---|---|---|
| **Pollutant removal** | • filtration<br>• sedimentation<br>• biological uptake of pollutants<br>• microbial activity in the root zone<br>• improved soil aeration<br>• substrate for biofilm attachment (in wet systems)<br>• gross pollutant removal (e.g. trapping of coarse material)<br>• keeping biofilter media porous, maintaining the design infiltration rate | Utilise sedges and rushes wherever possible as they are capable of 'luxury' uptake of nutrients (i.e. take up more nutrients than they need to grow, storing them for later use).<br><br>Incorporate plants with dense root mats such as sedges, rushes and some grasses, so that there are plenty of surfaces for biological activity to take place, which results in greater opportunities for pollutant uptake.<br><br>Use irrigation, a saturated zone or high groundwater (or a combination) to keep plants growing over extended dry periods which will improve the nutrient retention of the system.<br><br>If there is no gross pollutant trap upstream, use a dense strip of sedges or rushes to capture gross pollutants near the inlet, allowing for easier cleaning and rubbish removal.<br><br>Utilise local species suited to the ephemeral edge of wetlands, as these can deal with the variety of conditions that biofilters will experience.<br><br>Make sure the biofilter media has a hydraulic conductivity between 150 and 300 mm/h.<br><br>Incorporate shrubs and trees where possible, as their root systems keep the biofilter media free draining, allowing more stormwater to infiltrate for treatment. |
| **Hydrology** | • vegetation reduces flow velocity and protects media from scour<br>• root growth and decay provides pathways for stormwater infiltration and prevents clogging of biofilter media<br>• transpiration by plants reduces stormwater runoff volumes | Use dense plantings of sedges or rushes around inlet points to slow stormwater and reduce erosion. This is also the wettest point of the system, which is preferred by many sedges and rushes.<br><br>Plant both rushes or sedges and shrubs or trees within the same system to allow the biofilter media to remain free draining. This is because each vegetation type has a complementary root morphology (e.g. trees – large structural roots, sedges – mass of fine roots).<br><br>Layering also increases the total transpiration by approximately 30%, helping to maintain the predevelopment groundwater regime and transpire more stormwater. |

| Function | Role of plants | Design tips |
|---|---|---|
| **Amenity and aesthetics** | • shade and microclimate benefits<br>• landscaping and green corridors<br>• colour and fragrance<br>• screening e.g. of walls, roads<br>• maintaining line of site<br>• discouraging access | Incorporate trees to provide shade and mitigate urban heat.<br><br>Choose flowering plants to add fragrance and colour.<br><br>Use plants that suit the surrounding landscape, e.g. architectural plants in highly urban settings.<br><br>Use dense plantings to discourage traversing across the biofilter and/or locate biofilters in areas where through traffic is unlikely. Alternatively provide a crossing within the system to encourage the public to view the system in a controlled manner.<br><br>Utilise tree pit systems to gain both street trees and water management in one system.<br><br>Where plants do not have access to groundwater for the entire year, incorporate an irrigation system to allow plants to survive and remain attractive during extended dry summers.<br><br>Utilise the higher and/or drier areas of the system for drought tolerant plants. This will provide visual diversity in larger systems.<br><br>Place biofilter systems where they can screen unsightly areas or form a backdrop for an important landscape.<br><br>Place biofilters around the edges of public open space to collect runoff from adjacent impervious surfaces, without compromising the usability of the open space. |
| **Biodiversity** | • can increase biodiversity in urban areas<br>• create faunal habitat and food<br>• structural diversity contributes to habitat value<br>• reduce mosquito and midge risk<br>• suppress weed growth<br>• wildlife corridors<br>• bird and insect attracting | Choose locally native species wherever possible to provide increased habitat across urban areas that complements the surrounding ecosystems.<br><br>Include a range of plant types, e.g. shrubs and understorey so that a variety of habitats are provided.<br><br>Plan the biofilter to link to other biofilters and areas of native vegetation to assist with fauna movement.<br><br>Choose plants with flowers and seed favoured by key local fauna to provide new food sources in urban areas.<br><br>Make sure the system has been designed to completely empty in less than 72 hours to stop nuisance insect breeding.<br><br>Plant densely to allow the vegetation to rapidly colonise the system, reducing the opportunity for weed growth.<br><br>Maintain the system through irrigation during dry periods, weeding and general plant care to provide an effective ongoing habitat. |

## 5.3 Hydrologic requirements

As mentioned earlier, biofilter design requires balancing the need for treatment capacity with the need for sufficient retention time for treatment processes and for plants and microbial communities to receive adequate moisture.

In general, all plant species should be able to withstand inundation as well as periods of drought. Many of WA's wetland plants that occur in seasonal sumplands or damplands are naturally able to withstand these extremes, making them ideal for biofilter systems.

**Inundation and waterlogging tolerance**

One of the main aspects to consider is that the species chosen must be able to withstand at least some inundation and temporary waterlogging of their roots.

The plants on the base of the biofilter system are most prone to these conditions and should be able to withstand frequent inundation. In larger systems, plants higher up, or away from the inlet zone, may experience less inundation and the species selection should reflect this change.

Plants need to be chosen to match the expected inundation frequency and duration of the biofilter to ensure that they do not suffer from waterlogging. The duration of inundation after a storm event can be calculated as:

$$Ti = EDD/Ks$$

where:

$Ti$ = time of inundation (h)
$EDD$ = extended detention depth (mm)
$Ks$ = saturated hydraulic conductivity (mm/h)

For example, a biofilter with a 300 mm extended detention depth has a design infiltration rate (Ks) of 150 mm/h. However, over time, this rate is expected to drop to around 33% to 50% of the design value, that is 50 to 75 mm/h. The average inundation time of this system is expected to be around 300/50 = 6 h after a storm ends. For most biofilters in the region, inundation is unlikely to cause significant plant stress.

**Drought tolerance**

Biofilters in the south-west of Western Australia can also have long periods (up to four months) with no rainfall. This means species also need to be able to deal with prolonged drought or a supplementary watering system should be included in the design or maintenance plan.

## 5.4 Influence of groundwater

When designing a biofilter it is important to understand the quality and depth of groundwater below it. If local data is not available, groundwater quality and depth measurements may need to be collected over a long enough timeframe, including both wet and dry periods, to ascertain their range.

If groundwater with poor quality lies within approximately 300 to 500 mm of the biofilter base it is recommended to either fully line the biofilter or, where appropriate, design a shallower biofilter, in the form of a swale. This is to reduce the risk of mobilising polluted groundwater. A fully lined biofilter with shallow groundwater will need to incorporate a saturated zone with an outlet above the maximum height of the groundwater to allow it to drain and prevent backflow. Where the groundwater quality is acceptable and within 2 m of the surface, the biofilter may be left unlined at the base. This will allow some biofilter plants to use the water source during dry periods, as often happens in the south-west of Western Australia, before the groundwater level drops below the root zone.

The relationship between the depth to groundwater and how it may support plant growth is very dependent on the characteristics of the plants and the seasonal depths of the groundwater. In general, sedges and rushes need groundwater to be around 1 m or closer to the surface in summer to maximise the benefit to them. Most trees and shrubs however, can chase groundwater down beyond 3 m. The characteristics of plants in relationship to summer and autumn groundwater levels will need to be carefully considered in the design phase.

Where groundwater is shallow and the biofilter is likely to experience long periods under saturated conditions, plant selection will need to include species which are adapted to such conditions. Species which are more suited to shallow seasonal wetlands (damplands or palusplains) are likely to be most effective. In the case of saline, alkaline, acidic or similarly challenging groundwater, plants should be selected from appropriate 'habitat templates' or 'local reference sites', such as ephemeral brackish wetlands or alkaline soils for instance. This is important to ensure that the species selected have the necessary level of salt or pH tolerance. There are many locally native wetland species in the south-west of Western Australia that are suited to high groundwater and/or saline conditions. Plant species that are suited to the above conditions can be found in Table 5.

If groundwater is sufficiently deep, an unlined or partially unlined biofilter design will help dissipate stormwater flows, promote evapotranspiration and thus restore a more natural water balance, as well as providing runoff reduction benefits to downstream waterways. Alternatively, a fully lined biofilter with a saturated zone could be designed to discharge treated stormwater into an infiltration system. However, consideration must be given to the proximity of structures that may have foundations sensitive to increased soil moisture, such as roads or certain buildings (see Table 4). Note that the offset distances provided in Table 4 are not applicable if an appropriate liner is placed to prevent infiltrating water from affecting infrastructure.

*Table 4 Offset distances (Source: Melbourne Water 2005)*

| Soil Type | Saturated hydraulic conductivity m/s (mm/hr) | Min. distance from structures and property boundaries (m) |
|---|---|---|
| **Sand** | > $5 \times 10^{-5}$ (180) | 1.0 |
| **Sand clay** | $1 \times 10^{-5}$ to $5 \times 10^{-5}$ (36 – 180) | 2.0 |
| **Weathered or fractured rock** | $1 \times 10^{-6}$ to $1 \times 10^{-5}$ (3.6 – 36) | 2.0 |
| **Medium clay** | $1 \times 10^{-6}$ to $1 \times 10^{-5}$ (3.6 – 36) | 4.0 |
| **Heavy clay** | $1 \times 10^{-8}$ to $1 \times 10^{-6}$ (0.036 – 3.6) | 5.0 |

## 5.5 Nutrient removal ability

At least 50% of plants within the biofilter should be species known to be highly effective for nutrient removal. Research by Monash University identified the following desirable floristic attributes for nutrient removal (Read et al. 2010; Payne 2013.):

- **Select species with extensive and fine roots** (i.e. high total root length, surface area and mass, high root:shoot ratio and high abundance and density of fine roots). Ideally, roots should occupy a high proportion of the filter media volume, across its depth and area, which can be achieved using a range of plant types with a diverse range of root depths. These are likely to include a mixture of sedges, rushes, shrubs or trees, but are less likely to be native grasses. Figure 4 illustrates the root systems of effective and poorer performing species for biofilter nutrient removal.

- **Select species with relatively fast growth rates and a large total plant mass.** However, rapid growth is not a desirable characteristic unless it is combined with an extensive root system (as above) and the **capacity to 'down-regulate' water use during periods of drought** (Farrell et al. 2013). Plants with water conservative characteristics perform better across dry periods, and this includes species with lower growth.

In general, **use of species with thick taproots and few lateral roots, a low root biomass and short root length** (but not necessarily root depth) **should be minimised**, particularly if the species has a low leaf area relative to plant mass. In particular, minimise the use of woody species with limited root systems, small biomass or low growth rate, as these are likely to be mediocre or ineffective for nitrogen removal. Herbaceous plants tend to be more flexible, and if not effective in wet conditions, some species were found to be useful in dry periods, which is likely due to lower transpiration loss. **A small number of species with thick roots may be useful, however, for maintaining the infiltration rate of the media** (see Section 4.2), so a compromise is required. It is suggested that for every thick rooted plant, at least 20 plants with extensive fine roots and high growth should be used.

The performance of nitrogen fixing plant species has been variable between studies, from moderate performance (e.g. *Allocasuarina, Pultenaea*) to poor performance (e.g. *Acacia*). In general it is recommended **to avoid the use of nitrogen-fixing species in biofilters** due to the potential for nitrogen-leaching.

The listed attributes are only provided in this guideline for those species tested by Monash University. The results are provided in Table 1(and summarised in Table 5, Part A). The majority of native melaleucas, sedges and rushes exhibit the attributes listed above and provide dense cover of the biofilter base helping to reduce weed invasion.

## Effective*

*Carex appressa*

*Carex tereticaulis*

*Juncus pallidus*

*Melaleuca incana*

## Poorer performers*

*Gahnia trifida*

*Hypocalymma angustifolium*

*Hakea laurina*

*Astartea scoparia*

*Figure 4 Illustrations of effective and poorer performing species for biofilter nutrient removal*

**Note – Photos illustrate root systems from a laboratory column experiment and so their form is influenced by pot-bound conditions and frequent watering*

# 5.6 Diversity of species and form

**Choosing a diversity of plants is one of the most important principles in biofilter design.**

A diverse range of plants, including sedges, rushes, groundcovers, shrubs and trees, will improve the resilience – its ability to adapt to changing conditions – and performance of the biofilter.

Choosing a single species or form increases the vulnerability of the biofilter to changes, particularly in water quality and levels of inundation.

Creating multiple canopy levels will provide shade and protection for understorey species during extended dry periods.

Using dense sedge and rush layers also assists with reducing weed invasion, through competition provided by these plants.

When assessing species, first **compare characteristics between species of the same type**. Different plant types will differ in their biomass allocation. As a result, the root system of a grass should be compared to the root systems of other grasses. A grass with extensive and fine roots relative to other grasses may perform relatively well, despite lower root length than sedges or trees.

**Similarity in broad plant type or general above-ground appearance is a poor guide** for predicting performance. Sedges and rushes, shrubs and trees vary across the spectrum from poor to effective nitrogen removal. For example, *Gahnia* spp. visually resemble *Carex* spp. above ground and both are sedges, but *Gahnia* spp. performs poorly for nitrogen removal in biofilters and lacks the extensive root system and high biomass.

In the context of similar native environments, **species within the same genus may be expected to demonstrate similar nitrogen removal performance**. Although there are some performance differences, the research to date suggests that different species within the same genus do not tend to lie at opposite ends of the treatment spectrum. For example, in the context of Australian native plants, consistently effective performance has been noted within the *Carex*, *Juncus* and *Melaleuca* genera, mid-range to good performance of *Poa* spp. and poor performance of *Dianella* spp. More research is however needed to confirm this under south west conditions, across a wider range of species, and differing biofilter characteristics.

Incorporate a mixture of species, with some that are likely to perform well in wet periods and others in dry seasons. Species diversity is also likely to provide more consistent function across seasons. Exceptionally performing species can exert a dominant influence on nitrogen processing, even when present in a mixed planting (Ellerton et al. 2012).

Where increasing biodiversity is an objective, utilise suitable local native species. Table 5 provides the biogeographic region for each species to help designers select native species specific to a particular region.

Species may be chosen specifically for their effectiveness at removing nutrients, but lower performing species that provide faunal, biodiversity or other values, such as habitat creation or attracting pollinators, should also be considered.

## 5.7 Consider water quality

If possible, determine the likely quality of the water that may enter the system. Most plants are tolerant of general urban stormwater quality. However, if saline inflows or saline subsurface conditions exist, then salt tolerant plants should be used. Highly alkaline (limestone areas) or acidic areas (where acid sulfate soils are present) affect plant survival, so their presence needs to be taken into account when selecting plants.

## 5.8 Consider the scale and context of the installation

The potential height and cover of the species chosen must be suitable to the scale and context of the biofilter. Trees and shrubs that have large and/or invasive root systems or canopies, such as many large melaleucas and eucalyptus, can cause considerable damage to any services and other infrastructure located nearby. A root barrier may need to be included in the system.

## 5.9 Plant densely

The importance to biofilter function of having a high root biomass suggests that **relatively dense planting is advantageous**. However, this needs to be balanced against the available moisture to avoid excessive competition and drying. Inclusion of a saturated zone, high groundwater (within the root zone of the planted species) or irrigation during extensive dry periods may help support a higher planting density, and lead to higher overall performance.

The density of planting depends on the species being planted. A denser planting of the chosen understorey species assists with reducing erosion and precluding weed encroachment into the system. A general rule is to plant at a density where the plants will cover the majority of the biofilter surface area within one year.

Recommended densities to achieve this rapid cover include:

- clumping sedges and rushes — 6 to 9 plants/$m^2$
- spreading sedges and rushes — 4 to 6 plants/$m^2$
- shrubs and trees (over sedges and rushes) — 1 plant per 2 $m^2$ for small shrubs and 1 plant per 5 $m^2$ for larger trees.

# 6 The plant table

## 6.1 Introduction

Table 5 provides a reference list to guide the selection of native plant species for biofilters in the south-west of Western Australia.

Table 5, Part A provides the details of species that were tested and found to be effective for nitrogen removal in stormwater biofilters in laboratory column experiments (Payne 2013; Payne et. al. 2014a; Payne et. al. 2014; Zhang et al 2011). Table 5, Part B provides a list of other species likely to be suitable for biofilters based on the following attributes:

- species whose native range includes the south-west of Western Australia botanical province
- species that prefer sand and sandy loam soil
- species that are readily available as nursery tubestock
- species that can tolerate regular or temporary inundation.

The attributes for each species provided in Table 1 (Section 3.3) and Table 5 should be used in conjunction with the guidelines given above in sections 5.1 to 5.9.

Growth form of individual species is provided within the table to assist designers in achieving their desired vegetation structure and composition.

The species in Table 5, Part B are yet to be fully tested and their pollutant uptake capacity is unknown. However, they should function well due to their general characteristics. For optimum performance, the species in Table 5, Part B should be mixed with the high performers in Part A.

It is important to note that the list given in Table 5 is not meant to be exhaustive or exclusive. Other useful sources of information include local plant experts, local government authorities, nurseries and reference books. Native species are preferred, but introduced species may be useful. Decisions about their use should be determined by:

- biodiversity considerations
- site conditions
- design objectives, for example treatment and habitat creation
- surrounding landscape, for example aesthetic considerations and shade.

## 6.2 Explanatory notes

**Inundation tolerance**

Regular – the plant species is able to handle inundation on at least a weekly basis to a depth of 0.3 m and will perform well in these conditions.

Temporary – the plant species can withstand inundation weekly, but grows best in areas with permanent soil moisture and inundation monthly or less.

Dry – the plant species prefers not to be inundated and best suited to the driest areas of a biofilter such as the edges away from the inlet zone. Species can withstand inundation if frequency is monthly or less and the water generally drains within a day.

**Growth rates**

These growth rates are subjective and relate to similar type of plants.

Sedges and rushes are compared to each other.

Shrubs are compared to shrubs.

Trees are compared to trees.

The growth rate is based on how quickly the plant gains biomass, as well as how long it takes to reach a mature state, when the growth will tend to slow.

**Nutrient removal**

The level of nutrient removal is based on how effective the plant species, in combination with the filter media and the microbes these support, was in removing nutrients in controlled laboratory conditions. Note that the effectiveness under field conditions may vary from the laboratory results.

‘Effective’ species were selected as the top few performing species with relatively consistent performance in wet and dry. ‘Poor’ performing species were the bottom few species that were relatively least effective in removing nutrients.

Refer to Zhang et al. (2011) and Payne et al. (2013a) for data showing the variability in percentage reductions in nutrients. Where 'unknown is' recorded, there is no current information on how this species may perform in biofilters in relation to nutrient removal effectiveness.

'Suspected effective' means that species with similar growth forms and in the same genus have been tested and showed that they were effective in removing nutrients – suggesting that this species may be also under a similar climate and conditions.

*Table 5 Western Australian plants to consider for biofilters*

## Part A: Western Australian plants tested by Monash and UWA found to be effective at removing nitrogen in stormwater biofilters

| Family | Genus | Species | Common Name | Root Length (cm) | Root Type | Habit | Inundation Tolerance | Drought tolerant |
|---|---|---|---|---|---|---|---|---|
| Cyperaceae | *Carex* | *tereticaulis* | | 60 | CF | Sedge -C | RTD | N |
| Cyperaceae | *Carex* | *appressa* | Tall sedge/Tussock sedge | 60 | CF | Sedge -C | RTD | Y |
| Myrtaceae | *Melaleuca* | *incana* | Grey Honey Myrtle | 25 | F | Shrub | T | N |
| Cyperaceae | *Cyperus* | *gymnocaulos* | Spiny flat sedge | 25 | C | Sedge -C | RT | N |
| Poaceae | *Poa* | *poiformis* | Coastal poa | 20 | C | Grass | TD | Y |
| Poaceae | *Sporobolus* | *virginicus* | Marine Couch | 7 | C | Grass | TD | N |
| Juncaceae | *Juncus* | *pallidus* | Pale Rush | 50 | F | Rush -C | TD | Y |
| Juncaceae | *Juncus* | *kraussii* | Sea Rush | 25 | F | Rush -C | RT | N |
| Cyperaceae | *Baumea* | *juncea* | Bare twig sedge | 30 | F | Sedge -S | RTD | N |
| Cyperaceae | *Baumea* | *rubiginosa* | Soft twig sedge | | F | Sedge -S | RT | N |
| Juncaceae | *Juncus* | *subsecundus* | Finger Rush | | F | Rush -C | RTD | Y |
| Myrtaceae | *Melaleuca* | *lateritia* | Robin redbreast bush | | F | Shrub | RTD | N |

## Part B: Other Western Australian plants likely to be suited to biofilters

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Myrtaceae | *Agonis* | *flexuosa* | WA Peppermint | 150 | | Tree | D | Y |
| Casuarinaceae | *Allocasuarina* | *lehmanniana* | Dune Sheoak | | | shrub | | |
| Haemodoraceae | *Anigozanthos* | *flavidus* | Tall Kangaroo Paw | | | Herb | RTD | N |
| Haemodoraceae | *Anigozanthos* | *manglesii* | Kangaroo paw | | | Herb | | |
| Haemodoraceae | *Anigozanthos* | *humilis* | Cats paw | | | Herb | TD | Y |
| Apiaceae | *Apium* | *prostratum* | Sea celery | | | Herb | | |
| Myrtaceae | *Astartea* | *fascicularis* | | | C | Shrub | | |
| Myrtaceae | *Astartea* | *scoparia* | | | C | Shrub | TD | Y |
| Proteaceae | *Banksia* | *littoralis* | Swamp banksia | | | Tree | RT | N |
| Cyperaceae | *Baumea* | *articulata* | Jointed twig sedge | | F | Sedge - S | RT | n |
| Cyperaceae | *Baumea* | *preissii* | | | F | Sedge - S | RT | N |
| Cyperaceae | *Baumea* | *vaginalis* | Sheath twig sedge | | F | Sedge - S | RT | N |
| Myrtaceae | *Beaufortia* | *elegans* | | | | Shrub | TD | Y |
| Cyperaceae | *Bolboschoenus* | *caldwellii* | Sea Club sedge | | | Sedge - S | RT | N |
| Myrtaceae | *Callistemon* | *phoeniceus* | Lesser Bottlebrush | | | shrub | TD | y |
| Myrtaceae | *Calothamnus* | *hirsutus* | | | | Shrub | TD | Y |
| Myrtaceae | *Calothamnus* | *lateralis* | | | | Shrub | RTD | N |
| Myrtaceae | *Calothamnus* | *quadrifidus* | one sided bottlebrush | | | Shrub | TD | Y |

*Root type:*
*C – Coarse*
*F – Fine*

*Habit (for sedges and rushes):*
*C – Clumping*
*S – Spreading*

*Inundation tolerance:*
*R – Regular*
*T – Temporary*
*D – Dry*

*Drought tolerant:*
*Y – Yes*
*N – No*

*If a box is blank, the parameter is unknown and needs further investigation*

| Height (m) | Nutrient removal | Avon Wheatbelt | Esperance Plains | Geraldton Sandplains | Jarrah Forrest | Mallee | Swan Coastal Plain | Warren | Growth rate | Flower colour | Salinity tolerance | pH preference (if known) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.5 | H | N | Y | N | Y | N | Y | Y | F | *white/yellow* | F | A-N |
| 1.8 | H | N | N | N | Y | N | Y | Y | F | *white/yellow* | F | A-N |
| 3 | H | Y | N | Y | Y | N | Y | Y | M | *white* | F | A-N |
| 1 | M (H in wet) | Y | N | Y | Y | N | Y | Y | M | *brown* | FB | A-N |
| 0.9 | M (H in dry) | N | Y | Y | Y | Y | Y | Y | M | *green/yellow* | F | |
| 0.5 | M | Y | Y | Y | Y | Y | Y | Y | F | *green/purple* | FBS | A-N-L |
| 1.5 | H | Y | Y | Y | Y | Y | Y | Y | F | *straw* | FB | A-N |
| 1.2 | M (H in wet) | N | N | N | Y | Y | Y | Y | M | *brown/red* | FBS | A-N |
| 1 | H | Y | Y | Y | Y | N | Y | Y | M | *white/yellow* | FB | A-N |
| 1 | H | Y | Y | Y | Y | N | Y | Y | M | *white/yellow* | FB | A-N |
| 1 | H | Y | Y | Y | Y | Y | Y | Y | F | *straw* | F | A-N |
| 2.5 | H | N | Y | Y | Y | N | Y | Y | M | *red* | FB | A-N |
| | | | | | | | | | | | | |
| 10 | U | N | Y | N | Y | N | Y | Y | S | *white* | FB | A-N-L |
| 4 | U | Y | Y | Y | Y | Y | Y | Y | L | | | |
| 3 | U | N | Y | N | Y | N | Y | Y | M | *yellow* | FB | |
| 1.2 | U | N | N | N | N | N | Y | Y | M | | | |
| 0.5 | U | Y | N | Y | Y | N | Y | N | M | *yellow* | | |
| 1 | U | N | Y | Y | Y | N | Y | Y | M | | F-B | |
| 2 | S | N | Y | N | Y | N | N | N | M | | | |
| 2 | L | Y | N | N | Y | N | N | Y | M | *white* | F | |
| 12 | U | Y | Y | Y | Y | N | Y | Y | S | *yellow/orange* | FB | |
| 2.5 | H | Y | Y | Y | Y | N | Y | Y | F | *white/yellow* | FB | A-N |
| 1 | H | N | Y | N | Y | N | Y | Y | M | *white/yellow* | FB | A-N |
| 1.2 | H | N | Y | N | Y | N | Y | Y | M | *white/yellow* | FB | A-N |
| 1 | U | Y | N | Y | Y | N | Y | N | M | *red/pple/pink/w* | F | |
| 1.2 | S | Y | Y | Y | Y | N | Y | Y | F | *white/yellow* | FB | A-N-L |
| 6 | U | Y | N | N | N | N | N | N | F | *red* | FBS | A-N |
| 1.5 | U | Y | N | Y | Y | N | Y | N | M | *red* | F | |
| 2.5 | U | N | N | N | Y | N | Y | Y | S | *red* | FB | A-N |
| 1.5 | U | Y | Y | Y | Y | Y | Y | N | M | *red* | FB | A-N-L |

*Nutrient removal:*
*H – High*
*M – Moderate*
*L – Low*
*U – Unknown*
*S – Suspected effective*

*Growth rate:*
*F – Fast*
*M – Moderate*
*S – Slow*
*U – Unknown*

*Salinity tolerance:*
*F – Fresh*
*B – Brackish*
*S – Saline*

*pH preference:*
*A – Acid*
*N – Neutral*
*L – Alakaline/Limestone tolerant*

| Family | Genus | Species | Common Name | Root Length (cm) | Root Type | Habit | Inundation Tolerance | Drought tolerant |
|---|---|---|---|---|---|---|---|---|
| Cyperaceae | *Carex* | *fascicularis* | Tassel sedge | 60 | F | Sedge - S | RT | N |
| Cyperaceae | *Carex* | *inversa* | Knob sedge | | F | Sedge - S | RT | |
| Casuarinaceae | *Casuarina* | *obesa* | Swamp sheoak | | | Tree | RTD | Y |
| Cyperaceae | *Chorizandra* | *enodis* | Black Bristlerush | | | Sedge - S | RT | N |
| Cyperaceae | *Chorizandra* | *multiarticulata* | | | | Sedge - S | RT | N |
| Proteaceae | *Conospermun* | *stoechadis* | Common smokebush | | | Shrub | TD | Y |
| Haemodoraceae | *Conostylis* | *aculeata* | Spiny cotton heads | | | Herb | RTD | Y |
| Haemodoraceae | *Conostylis* | *candicans* | grey cottonheads | | | Herb | TD | Y |
| Haemodoraceae | *Conostylis* | *setigera* | Bristly Cottonhead | | | Herb | TD | Y |
| Myrtaceae | *Corymbia* | *ficifolia* | Red flowering gumn | | | Tree | TD | N |
| Asteraceae | *Cotula* | *cotuloides* | Smooth cotula | | | Herb | RTD | Y |
| Cyperaceae | *Cyathochaeta* | *avenacea* | | | | Sedge - S | RTD | N |
| Goodeniaceae | *Dampiera* | *trigona* | Angled stem dampiera | | | Herb | RT | N |
| Goodeniaceae | *Dampieria* | *diversifolia* | | | | Herb | RTD | Y |
| Goodeniaceae | *Dampieria* | *linearis* | Common Dampiera | | | Herb | RTD | Y |
| Cyperaceae | *Eleocharis* | *acuta* | Common Spikerush | | F | Sedge - S | RT | N |
| Scrophulariaceae | *Eremophila* | *glabra* | Tar bush | | | Shrub | TD | Y |
| Myrtaceae | *Eucalyptus* | *rudis* | Flooded gum | | | Tree | RTD | N |
| Cyperaceae | *Ficinia* | *nodosa* | Knotted club sedge | 20 | F | Sedge - C | TD | Y |
| Frankeniaceae | *Frankenia* | *pauciflora* | Sea Heath | | F | Shrub | TD | Y |
| Cyperaceae | *Gahnia* | *trifida* | Coast saw sedge | 20 | C | Sedge | RTD | N |
| Cyperaceae | *Gahnia* | *ancistrophylla* | Hooked Leaf Saw Sedge | | | Sedge | RTD | N |
| Proteaceae | *Grevillea* | *obtusifolia* | Obtuse Leaved Grevillea | | | Shrub | TD | N |
| Proteaceae | *Grevillea* | *preissii* | | | | Shrub | TD | Y |
| Proteaceae | *Grevillea* | *quercifolia* | Oak Leaf Grevillea | | | Shrub | TD | Y |
| Malvaceae | *Guichenotia* | *ledifolia* | | | | Shrub | TD | Y |
| Haemodoraceae | *Haemodorum* | *simplex* | | | | Herb | TD | N |
| Haemodoraceae | *Haemodorum* | *spicatum* | Mardja | | | Herb | TD | Y |
| Proteaceae | *Hakea* | *prostrata* | Harsh Hakea | | | Shrub | TD | Y |
| Proteaceae | *Hakea* | *trifuriata* | Two leafed hakea | | | Shrub | TD | Y |
| Proteaceae | *Hakea* | *varia* | Variable leaved hakea | | | Shrub | TD | N |
| Proteaceae | *Hakea* | *laurina* | Pin cushion Hakea | 10 | | Tree | TD | Y |
| Proteaceae | *Hakea* | *lissocarpha* | Honey Bush | | | Shrub | TD | Y |
| Proteaceae | *Hakea* | *undulata* | Waxy leaved Hkea | | | Shrub | TD | Y |
| Poaceae | *Hemarthria* | *uncinata* | Mat grass | | | Grass | TD | Y |
| Lamiaceae | *Hemiandra* | *pungens* | Snake bush | | | Shrub | TD | Y |
| Dilleniaceae | *Hibbertia* | *hypericoides* | Yellow buttercups | | | Shrub | TD | Y |

| Height (m) | Nutrient removal | Avon Wheatbelt | Esperance Plains | Geraldton Sandplains | Jarrah Forrest | Mallee | Swan Coastal Plain | Warren | Growth rate | Flower colour | Salinity tolerance | pH preference (if known) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | M | N | N | N | Y | N | Y | Y | F | | F | A-N-L |
| 0.5 | M | Y | Y | N | Y | Y | Y | N | F | | F | A-N-L |
| 10 | S | Y | Y | Y | Y | Y | Y | N | F | | FBS | A-N |
| 1 | M | Y | Y | Y | Y | Y | Y | Y | S | *brown* | FB | |
| 0.6 | U | Y | Y | N | Y | N | Y | N | S | *brown* | FB | |
| 1.5 | U | Y | N | Y | Y | Y | Y | N | M | *white* | FB | |
| 0.5 | U | Y | Y | Y | Y | Y | Y | Y | M | *yellow* | FB | |
| 0.5 | U | Y | N | Y | Y | N | Y | Y | M | *yellow* | FB | |
| 0.3 | U | Y | Y | Y | Y | Y | Y | Y | M | *yellow* | FB | |
| 10 | U | N | N | N | Y | N | Y | N | M | *red* | F | A-N |
| 0.2 | U | Y | Y | Y | Y | Y | Y | Y | M | *yellow* | FBS | |
| 1.6 | U | Y | Y | Y | Y | Y | Y | Y | M | *brown* | FB | |
| 0.5 | U | N | N | N | Y | N | Y | Y | M | *blue/ white* | FB | |
| 0.75 | U | Y | Y | N | Y | Y | N | N | M | *blue* | FB | |
| 0.6 | U | Y | Y | Y | Y | Y | Y | Y | M | *blue* | FB | |
| | S | Y | Y | Y | Y | Y | Y | N | M | | FBS | |
| 3 | U | Y | Y | Y | N | Y | Y | N | F | *red* | FB | |
| 20 | S | Y | Y | Y | Y | Y | Y | Y | F | *white* | FB | A-N |
| 1 | L-M | Y | Y | Y | Y | Y | Y | Y | M | *brown* | FB | A-N-L |
| 0.5 | U | Y | Y | Y | Y | Y | Y | N | M | *white/pink* | BS | A-N-L |
| 1.5 | L | Y | Y | Y | Y | Y | Y | Y | H | | FBS | |
| 0.8 | L | Y | Y | Y | Y | Y | Y | Y | M | | FB | N-L |
| 2 | U | N | N | N | Y | N | Y | N | M | *red* | F | |
| 1.5 | U | N | N | Y | Y | N | Y | N | M | *red* | F | |
| 0.7 | U | N | N | N | Y | N | Y | Y | M | *pink* | F | |
| 2 | U | Y | Y | Y | Y | Y | Y | N | M | *pink* | FB | |
| 0.65 | U | Y | Y | Y | Y | Y | Y | Y | M | *black* | F | |
| 2 | U | Y | Y | Y | Y | N | Y | Y | M | *black* | F | |
| 3 | U | Y | Y | Y | Y | Y | Y | Y | M | *white* | FB | |
| 3.5 | U | Y | Y | Y | Y | Y | Y | Y | M | *white* | F | |
| 4 | U | Y | Y | Y | Y | Y | Y | Y | M | *white* | F | |
| 6 | L | Y | Y | N | Y | Y | Y | N | M | *red* | FB | |
| 3 | U | Y | Y | Y | Y | Y | Y | Y | M | *cream* | F | |
| 2 | U | Y | Y | Y | Y | N | Y | Y | M | *white* | F | |
| 0.4 | S | N | Y | Y | Y | N | Y | Y | M | | | |
| 0.5 | U | Y | Y | Y | Y | Y | Y | Y | M | *pink* | FB | |
| 1.5 | U | Y | Y | Y | Y | Y | Y | Y | M | *yellow* | FB | |

| Family | Genus | Species | Common Name | Root Length (cm) | Root Type | Habit | Inundation Tolerance | Drought tolerant |
|---|---|---|---|---|---|---|---|---|
| Asteraceae | *Hyalosperma* | *cotula* | | | | Herb | RTD | Y |
| Myrtaceae | *Hypocalymma* | *robustum* | Pink myrtle | | C | Shrub | TD | N |
| Myrtaceae | *Hypocalymma* | *angustifolium* | White myrtle | 10 | C | Shrub | TD | Y |
| Cyperaceae | *Isolepis* | *cernua* | | | | Sedge -C | RT | N |
| Juncaceae | *Juncus* | *pauciflorus* | Loose Flower rush | | F | Rush - C | RTD | Y |
| Myrtaceae | *Kunzea* | *ericifolia* | Spearwood | | | Shrub | RTD | Y |
| Myrtaceae | *Kunzea* | *recurva* | Pea shrub | | | Shrub | RTD | Y |
| Myrtaceae | *Kunzea* | *glabrescens* | Spearwood | | | Shrub | RT | Y |
| Goodeniaceae | *Lechenaultia* | *biloba* | Blue Lechenaultia | | | Shrub | TD | Y |
| Cyperaceae | *Lepidosperma* | *effusum* | Spreading Sword Sedge | | | Sedge - S | RT | N |
| Cyperaceae | *Lepidosperma* | *gladiatum* | Coast saw sedge | | | Sedge - S | TD | Y |
| Cyperaceae | *Lepidosperma* | *longitudinale* | Pithy Sword Sedge | | | Sedge - S | RT | N |
| Asteraceae | *Leucophyta* | *brownii* | | | | Shrub | TD | Y |
| Campanulaceae | *Lobelia* | *anceps* | Angled lobelia | 20 | | Herb | TD | N |
| Zamiaceae | *Macrozamia* | *riedlei* | Zamia palm | | | Herb | TD | N |
| Restionaceae | *Meeboldina* | *scariosa* | Velvet rush | | | Rush-C | RT | N |
| Restionaceae | *Meeboldina* | *coangustatus* | | | | Rush -C | RT | N |
| Myrtaceae | *Melaleuca* | *cuticularis* | Saltwater paperbark | | F | Tree | RT | N |
| Myrtaceae | *Melaleuca* | *pauciflora* | | | F | Shrub | RT | Y |
| Myrtaceae | *Melaleuca* | *preissiana* | Moonah | | F | Tree | RT | N |
| Myrtaceae | *Melaleuca* | *rhaphiophylla* | Freshwater paperbark | | F | Tree | RT | N |
| Myrtaceae | *Melaleuca* | *thymoides* | | | F | | RTD | Y |
| Myrtaceae | *Melaleuca* | *viminea* | Mohan | | F | Tree | RTD | Y |
| Myrtaceae | *Melaleuca* | *fulgens* | Scarlet Honeymyrtle | | F | Shrub | TD | Y |
| Myrtaceae | *Melaleuca* | *lanceolata* | Rottnest Tea tree | | F | Tree | RTD | Y |
| Myrtaceae | *Melaleuca* | *pulchella* | Claw Flower | | F | Shrub | TD | Y |
| Myrtaceae | *Melaleuca* | *seriata* | | | F | Shrub | RTD | Y |
| Myrtaceae | *Melaleuca* | *teretifolia* | Banbar | | F | Tree | RTD | Y |
| Myrtaceae | *Melaleuca* | *scabra* | Rough Honey Myrtle | | F | Shrub | TD | Y |
| Poaceae | *Microlaena* | *stipoides* | Weeping Grass | | F | Grass | TD | Y |
| Scrophulariaceae | *Myoporum* | *caprariodes* | Slender myoporum | | | Shrub | RTD | Y |
| Poaceae | *Neurachne* | *alepecuroidea* | Foxtail mulga grass | | | Grass | TD | Y |
| Iridaceae | *Orthrosanthus* | *laxus* | Morning Iris | | | Herb | TD | Y |
| Iridaceae | *Patersonia* | *occidentalis* | Purple flag | 15 | | Herb | TD | y |
| Myrtaceae | *Pericalymma* | *ellipticum* | Swamp tea tree | | | Shrub | RTD | N |
| Rutaceae | *Philotheca* | *spicata* | Pepper and Salt | | | Shrub | TD | Y |
| Malpighiales | *Phyllanthus* | *calycinus* | False Boronia | | | Shrub | TD | Y |
| Thymelaeaceae | *Pimelea* | *rosea* | Rose banjine | | | Shrub | TD | N |

| Height (m) | Nutrient removal | Avon Wheatbelt | Esperance Plains | Geraldton Sandplains | Jarrah Forrest | Mallee | Swan Coastal Plain | Warren | Growth rate | Flower colour | Salinity tolerance | pH preference (if known) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.25 | U | Y | N | Y | Y | Y | Y | Y | M | *white* | F | |
| 1.5 | U | Y | N | N | Y | N | Y | Y | M | *pink* | F | |
| 1.5 | L | Y | Y | Y | Y | Y | Y | Y | M | *white, pink* | F | |
| 0.3 | S | Y | Y | N | Y | N | Y | Y | M | *brown* | FBS | |
| 1 | S | Y | Y | Y | Y | N | Y | Y | F | *straw* | FB | A-N |
| 4 | U | N | Y | N | Y | N | Y | Y | S | *white* | F | A-N |
| 2 | U | Y | Y | Y | Y | Y | Y | Y | S | *purple* | F | A-N |
| 4 | U | Y | N | N | Y | N | Y | Y | S | *yellow* | F | A-N-L |
| 1.6 | U | Y | Y | Y | Y | Y | Y | Y | M | *blue* | F | |
| 2.5 | S | N | Y | N | Y | N | Y | Y | M | *white/yellow* | FBS | A-N |
| | S | N | Y | Y | Y | Y | Y | Y | M | *white/yellow* | FB | A-N-L |
| 1 | S | Y | N | Y | Y | N | Y | Y | M | *white/yellow* | FB | A-N |
| 1 | U | N | Y | N | Y | N | Y | Y | M | *yellow* | FB | |
| 1.2 | L | Y | Y | Y | Y | Y | Y | Y | M | *purple* | FB | |
| 3 | U | N | Y | N | Y | N | Y | Y | S | | F | |
| 1 | M | Y | Y | N | Y | N | Y | Y | F | *red brown* | F | A-N |
| 1 | U | Y | Y | Y | Y | N | Y | Y | M | *red brown* | F | A-N |
| 7 | S | Y | Y | N | Y | Y | Y | Y | S | *white* | FBS | A-N-L |
| 3 | S | N | Y | N | Y | N | Y | Y | M | *white* | FBS | |
| 9 | S | Y | N | Y | Y | Y | Y | Y | M | *white* | F | A-N |
| 10 | S | Y | Y | Y | Y | Y | Y | Y | F | *white* | FBS | A-N |
| 2 | S | Y | N | Y | Y | N | Y | Y | M | *yellow* | FB | |
| 5 | S | Y | Y | Y | Y | Y | Y | Y | M | *white* | FBS | |
| 3 | S | Y | Y | N | Y | Y | N | N | M | *red* | F | |
| 5 | S | Y | Y | Y | Y | Y | Y | Y | M | *white* | FBS | A-N-L |
| 2 | S | N | Y | N | N | Y | N | N | M | *pink* | FB | |
| 1 | S | Y | N | Y | Y | Y | Y | N | M | *pink* | F | |
| 5 | S | Y | N | Y | Y | N | Y | N | M | *white* | F | |
| 1.5 | S | N | Y | Y | N | Y | N | N | M | *pink* | FB | |
| 0.75 | S | Y | Y | Y | Y | N | Y | Y | M | *purple* | F | |
| 3 | S | N | Y | Y | Y | N | Y | Y | S | *white* | FB | |
| 0.8 | U | Y | Y | Y | Y | Y | Y | Y | S | *green* | F | |
| 0.5 | U | Y | Y | Y | Y | N | Y | Y | M | *purple* | F | |
| 0.5 | L | Y | Y | Y | Y | Y | Y | Y | M | *purple* | F | |
| 3 | U | Y | Y | N | Y | Y | Y | Y | M | *white/pink* | F | |
| 1 | U | Y | N | Y | Y | N | Y | Y | M | *pink* | F | |
| 1.2 | U | Y | Y | Y | Y | Y | Y | Y | M | *white/yellow* | F | |
| 1 | U | N | N | Y | Y | N | Y | Y | M | *pink* | FB | |

| Family | Genus | Species | Common Name | Root Length (cm) | Root Type | Habit | Inundation Tolerance | Drought tolerant |
|---|---|---|---|---|---|---|---|---|
| Thymelaeaceae | *Pimelea* | *ciliata* | White Bajine | | | Shrub | TD | Y |
| Myrtaceae | *Regelia* | *ciliata* | Limnaea | | | Shrub | RT | N |
| Myrtaceae | *Regelia* | *inops* | | | | Shrub | RTD | Y |
| Poaceae | *Rytidosperma* | *caespitosum* | Common wallaby Grass | 15 | C | Grass | TD | Y |
| Primulaceae | *Samolus* | *junceus* | | | | Herb | RT | N |
| Primulaceae | *Samolus* | *repens* | Creeping Brookweed | | | Herb | RTD | Y |
| Goodeniaceae | *Scaevola* | *lanceolata* | | | | Herb | RT | N |
| Myrtaceae | *Scholtzia* | *involucrata* | Spiked scholtzia | | | Shrub | TD | Y |
| Proteaceae | *Synaphea* | *petiolaris* | Synaphea | | | Shrub | TD | Y |
| Myrtaceae | *Taxandria* | *linearifolia* | Swamp peppermint | | | Tree | RTD | Y |
| Hemerocallidaceae | *Tricoryne* | *elatior* | Yellow lily | | | Herb | RTD | Y |
| Myrtaceae | *Verticordia* | *densiflora* | Bushy featherflower | | | Shrub | RTD | Y |
| Myrtaceae | *Verticordia* | *plumosa* | Plumed Featherflower | | | Shrub | RTD | Y |
| Fabaceae | *Viminaria* | *juncea* | Swish bush | | | Shrub | RT | N |
| Xanthorrhoeaceae | *Xanthorrhoea* | *preissii* | Grass tree | | | Herb | TD | Y |

| Height (m) | Nutrient removal | Avon Wheatbelt | Esperance Plains | Geraldton Sandplains | Jarrah Forrest | Mallee | Swan Coastal Plain | Warren | Growth rate | Flower colour | Salinity tolerance | pH preference (if known) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | U | N | N | N | Y | N | N | N | M | *white* | F | |
| 3 | U | Y | N | Y | Y | N | Y | N | M | *pink* | F | |
| 2.5 | U | Y | Y | N | Y | Y | Y | N | M | *pink* | F | |
| 0.9 | L | Y | Y | Y | Y | Y | Y | Y | M | | F | |
| 1.2 | U | Y | Y | Y | Y | Y | Y | Y | M | *white* | F | |
| 1 | U | N | Y | Y | Y | Y | Y | Y | M | *white/pink* | F | |
| 0.5 | U | Y | Y | Y | Y | N | Y | Y | M | *white* | F | |
| 1.5 | U | Y | N | Y | Y | N | Y | N | M | *pink* | F | |
| | U | N | Y | N | Y | Y | Y | Y | M | *yellow* | F | |
| 4 | U | Y | Y | N | Y | N | Y | Y | F | *white* | F | A-N |
| 0.6 | U | Y | Y | Y | Y | Y | Y | Y | M | *yellow* | F | |
| 2 | U | Y | Y | Y | Y | N | Y | N | M | *pink* | F | |
| 1.5 | U | N | Y | N | Y | Y | Y | Y | M | *pink* | F | |
| 3 | U | Y | Y | Y | Y | N | Y | Y | F | *yellow* | FB | |
| 3 | U | Y | N | Y | Y | N | Y | Y | S | *white* | F | |

# 7 Summary of principles for choosing plants and improving biofilter performance

*Table 6 Summary of principles for choosing plants and improving biofilter performance*

| Principle | Reason |
|---|---|
| Plant a mixture of plant types and include a diversity of species. | • because species that are good at removing nitrogen in wet conditions may not perform as effectively during dry conditions, or vice-versa<br>• provides diversity in plant morphology and physiology<br>• to make biofilter performance more resilient against a range of climatic conditions and across seasons<br>• to achieve a range of treatment objectives |
| Select plants that can withstand at least temporary inundation and waterlogging of their roots, as well as prolonged drought. | • improves plant survival and resilience to the range of conditions experienced within biofilters |
| Select plants that are able to grow in sandy, free draining soils. | • because plants need to be suited to the sandy loam filter media used in biofilters |
| Include species with extensive and fine root systems, relatively fast growth and high total plant mass. | • to optimise nitrogen removal, particularly under conditions of regular stormwater inflows<br>• these characteristics allow effective plant uptake of nitrogen and support microbial processes |
| Avoid species with limited root biomass and total root length. | • these characteristics are associated with reduced nitrogen removal capacity |
| Include some thicker rooted species such as shrubs and trees, as well as sedges and rushes. However, avoid a high proportion of these species if nitrogen removal is a key objective. For every thick rooted plant, at least 20 plants with extensive fine roots and high growth should be used. | • to maintain the desired filter media infiltration rate<br>• root systems dominated by thick roots are less effective for nitrogen removal |
| Avoid selecting plant species based upon similarity in above-ground appearance. | • above-ground characteristics do not provide a good indication of performance capability, particularly for nitrogen removal |
| Include species with long growing seasons and various periods of growth covering the autumn, spring and summer periods. | • to improve year-round biofilter performance |
| Plant with multiple layers of vegetation such as sedges, shrubs and trees. | • increases evapotranspiration and maximises leaf area<br>• provides shading of the media and understorey layers, which may reduce the negative effects of prolonged dry periods |
| Select plants with high rates of transpiration when water is available, but are able to 'down-regulate' their water use during periods of drought. | • increases evapotranspiration, which reduces the volume of stormwater and the exported pollutant load<br>• allows plants to survive dry periods<br>• mitigates the reduction in nitrogen removal performance during dry periods |

<table>
<tr><th>Principle</th><th>Reason</th></tr>
<tr><td>Include a range of species suited to different hydrologic zones that may exist within the biofilter.</td><td>• allows ‘zonation’ of species suited to drier or wetter conditions</td></tr>
<tr><td>Avoid the use of nitrogen-fixing species.</td><td>• due to the potential for nitrogen-leaching</td></tr>
<tr><td>Ensure that at least 50% of plants within the biofilter are species known to be highly effective for nutrient removal.</td><td>• provides flexibility to meet other objectives, such as amenity and biodiversity, while still providing effective nutrient removal</td></tr>
<tr><td>Note that species within the same genus may be expected to demonstrate similar nitrogen removal performance in the context of similar native environments.</td><td>• different species within the same genus in the same climatic zone do not tend to lie at opposite ends of the treatment spectrum (however more research is required)</td></tr>
<tr><td>Plant at high density.</td><td>• provides high contact between the plant roots, biofilter media and stormwater<br>• supports an extensive microbial community alongside the roots – this optimises the opportunity for pollutant removal processes<br>• to maintain the desired filter media infiltration rate<br>• maximises evapotranspiration</td></tr>
<tr><td>Include a saturated zone in climates with long dry spells in summer.</td><td>• improves plant survival across dry summer periods<br>• reduces the need for irrigation<br>• biofilter performance for nitrogen removal benefits significantly from the presence of a saturated zone, particularly in dry conditions<br>• helps to ‘even-out’ performance differences between different plant species for nitrogen removal<br>• provides an opportunity for denitrification to permanently remove nitrogen from the system</td></tr>
<tr><td>Prevent severe or complete drying out of the biofilter system.<br><br>Irrigate to improve plant performance and to top up the saturated zone during prolonged periods without rainfall.<br><br>Alternatively, if goundwater is of suitable quality and within the root zone, the biofilter may be left unlined at the base to utilise this water source over dry periods.</td><td>• biofilter removal of nutrients is most effective under conditions of regular water availability<br>• drying out leads to reduced nutrient removal or even to nutrient release upon rewetting<br>• desiccation leads to reduce microbial activity and bacterial death<br>• affects plant growth and function and may lead to root and plant death</td></tr>
<tr><td>Use low-nutrient filter media, as specified in the Adoption Guidelines for Stormwater Biofiltration Systems (FAWB 2009a).</td><td>• provides more consistent biofilter performance for nutrient retention between plant species<br>• enables a relatively wide range of plant species selected from a palette of suitable plants to be used in biofilters</td></tr>
<tr><td>Use media with a relatively high sand and low clay content (i.e. a loamy sand or a sand with appropriate ameliorants added), as specified in the Adoption Guidelines for Stormwater Biofiltration Systems (FAWB 2009a).</td><td>• provides both sufficient water quality treatment and infiltration</td></tr>
</table>

# 8 Practical considerations for establishing a biofilter

## 8.1 Assess the site

A thorough site assessment is needed to determine the various constraints and opportunities for biofilter design, and hence to define feasible project objectives.

The site assessment should provide the following information.

**Location, access, tenure and boundaries**

- local context – landowner, primary land use, immediate adjacent land use including any existing landscaping themes
- landform, slope and location of the biofilter in the catchment treatment train
- the area available for biofilter installation compared to the ideal area required for water quality treatment for the biofilter's catchment
- site access for construction and maintenance
- other land uses that may be required for the area and surroundings in the future.

**Stakeholders and opportunities for social benefits**

- stakeholder consultation, including landowners, authorities and local community
- roles and responsibilities – identify post-construction land manager and consult with construction and maintenance personnel during the design phase
- possible Indigenous heritage considerations and consultation
- social and cultural context of existing community, facilities and infrastructure (e.g. type of landscaping preferred in the local area)
- opportunities to improve amenity (e.g. shade footpaths)
- opportunities for partnerships (e.g. with local environmental community groups or university research initiatives)
- potential for signage and educational resources associated with the project.

**Climate**

- understand the predicted rainfall and temperature range and duration to help in the selection of suitable species that can tolerate the extremes in conditions (e.g. frost, inundation and drought tolerance)
- look at microclimates of the site such as shading, heat traps and wind tunnelling.

**Available budget**

- review options for staging works to satisfy budget constraints, or look at alternative design methods
- estimate lifecycle costs of the biofilter, including maintenance
- carry out a valuation of the biofilter compared with other stormwater management options, including social, environmental and economic costs and benefits.

**Hydrology**

- catchment characteristics including the site's catchment boundary, historical and future land use, expected runoff rates and volumes (storm, seasonal average and wet and dry year extremes), and timeframe between rain events
- groundwater – level of groundwater interception, seasonal variation in level, groundwater quality, acid sulfate soil risk, salinity, and tidal intrusion
- water quality and contamination conditions
- survey of existing site features and drainage infrastructure
- access to irrigation or top up hand watering.

Further information on how to design a pre-development hydrological monitoring program is provided in *Water monitoring guidelines for better urban water management strategies and plans* (DoW 2012).

**Soil**

Even though the biofilter is likely to have an engineered soil profile, it is important to understand the regional and local soil characteristics to make sure the biofilter is effective. An assessment should include a physical and chemical characterisation of the in situ soil to determine whether exfiltration from the biofilter to the surrounding soil is appropriate. In sandy soils, the walls of the biofilter will need to be lined so that stormwater infiltrates and is treated by the biofilter media, rather than short circuit the biofilter and flow through the surrounding soil. In heavy soils, additional sub-soil drainage may be required and/or connection to the downstream stormwater system. If acid sulfate soils may be present, refer to the Department of Environment Regulation's guidelines on identification, investigation, treatment and management of acid sulfate soils (DEC 2011; DEC 2013).

**Vegetation and fauna**

An understanding of the site's surrounding vegetation helps when choosing species that are suited to the local climate and that will help to maintain or increase local biodiversity.

An interim biogeographic regionalisation for Australia: a framework for setting priorities in the National Reserves System Cooperative Program (Australian Nature Conservation Agency 1995) classifies regions of Australia based on geology, landform, vegetation, fauna and climate. There are seven regions within the south-west of Western Australia. Table 5 identifies which bioregion to which each species belongs.

- identify local reference sites and sources of provenance stock where required and complement as necessary with known effective nutrient removal species
- use local reference sites to determine the expected structure and composition of vegetation
- review potential weed species in the vicinity that may invade the biofilter
- assess fauna that may hinder the establishment of vegetation (e.g. grazing animals or birds that may pull out unguarded seedlings)
- assess existing native fauna in the area that may benefit from increased habitat and food.

**Policy and legal considerations**

- what approvals are required? (e.g. local government authority, Department of Water, Water Corporation, Department of Environment Regulation
- area zoning provisions under town planning scheme
- requirements under a water management plan for the area
- objectives in stormwater management plans or catchment management plans for the area.

**Public health and safety**

- height or area restrictions to avoid interfering with surrounding infrastructure (e.g. buildings, roads and powerlines)
- restrictions based on maintaining field of view
- road traffic and pedestrian safety.

**Services investigation**

Excavation for biofilter construction and vegetation with extensive root systems or canopies can damage services if not considered within the design. Conduct a thorough service investigation prior to any site works. Contact 'Dial before you dig' to request information on services for the site. 'Dial before you dig' does not cover all services that may be within an area; recent service installations or modifications, local drainage infrastructure and irrigation services may not be covered. Contact the local government authority for more detail on services before commencing site works. Services investigation is particularly important when undertaking a retrofit project.

## 8.2 Define the design objectives for the installation

Suitable design objectives are based on site assessment, stakeholder needs (including requirements of approval agencies), and the objectives outlined in any statutory planning documents or catchment or stormwater management plans for the area. Once objectives are developed, the decisions related to biofilter vegetation can be determined.

The principle objective of installing a biofilter is to improve water quality. However, there are other benefits that the system may provide, as mentioned in Section 2.

# 8.3 Public health and safety

Functioning biofilters do not support mosquito and other nuisance insect breeding. There is no ponding water for more than a few hours following a storm. Stormwater infiltrates quickly into the porous filter media that typically has a hydraulic conductivity of 150 to 300 mm/hr. The ponding or extended detention depth is typically a maximum of 300mm and does not pose a significant public safety issue.

Biofilters integrated into public open space should preferably have embankment slopes no steeper than 1V:6H to prevent safety issues and, where relevant, to enable vegetation management. Barriers or vegetation features such as hedging to manage access may be required to prevent trip hazards for pedestrians.

# 8.4 Decide whether to include a saturated zone

Inclusion of a saturated zone helps plants to survive during dry periods. It is recommended that a saturated zone be incorporated in climates with long dry spells in summer, such as Perth, otherwise more frequent irrigation will be necessary. Beyond five consecutive weeks without rainfall, irrigation or topping up of the saturated zone will be required regardless of whether the system has a saturated zone. Where the groundwater is high and the system is unlined, the need for a saturated zone or irrigation may be reduced, depending on the plant type and root access to the seasonal groundwater.

Saturated zones assist with nitrogen removal and help to minimise the effects of drought.

See Section 5.4 – influence of groundwater for more information on making this decision.

# 8.5 Select the plants

Once the site conditions and objectives are known, the most suitable plant species can be chosen for the biofilter system. See chapters 5 and 6 for information on this step.

# 8.6 Design the plant layout

Zonation may develop, with different species in drier and wetter zones, in all but the smallest biofilter systems. These zones mainly relate to how often the section receives stormwater and the volume of stormwater. Conditions are influenced by the distance of the plants from the inlet and height from the base of the system. Further complicating conditions is the addition of vegetation which, based upon root structure, can change the permeability of filter media. For example, plants with coarse deep roots may increase permeability while dense shallow roots may form barriers and cause parts of a system to clog.

The design of the biofilter bathymetry may deliberately include low and high points to create a range of conditions that support a greater diversity of species. In the wettest areas, around the inlet and in the deepest parts of the base of the system, species that thrive on inundation and a wet root zone are appropriate. In larger systems, as distance increases up the sides of the system or away from the inlet, more drought tolerant species should be chosen.

Given that our knowledge of specific plant species tolerances is limited, use of a diversity of species provides insurance against otherwise sub-optimal choices. Over time, when a range of species are incorporated into the system, the species tend to 'self-select' and move to their preferred hydrologic zone. It is recommended that species be positioned within the biofilter based on their shared water requirements or preferred zone. Table 5 classifies each species tolerance to inundation as regular(R), temporary (T) or dry (D).

Care should be taken around the inlet and outlet zones so that the plants do not clog these structures, reducing the design flows. Using mortared rock pitching or similar around the structures will stop the plants growing up to and within the inlet and outlet pipes.

Plant placement to create a landscaping feature can also be considered. A landscape architect can be utilised to match the type of plants and their arrangement with the surrounding urban characteristics.

The other aspect to consider in designing the plant layout is that as the plants grow, they will create their own microclimate, producing shade and reduced air flow. This may allow more sensitive species to be planted at a later date. The shade requirements of plants should be considered in planting lay-out.

## 8.7 Design the biofilter and construct the physical works

This document is not a complete design guide, but a companion document to the *Adoption Guidelines for Stormwater Biofiltration Systems* (FAWB 2009a), which provides the design procedure and advice on construction of biofilters.

The *Bioretention Technical Design Guidelines* (Water by Design 2012) and *Construction and Establishment Guidelines: Swales, Bioretention Systems and Wetlands* (Water by Design 2009) provide step-by-step guidance for civil design, construction, building phase protection and landscape establishment. These guidelines were developed in collaboration with local government compliance officers, site superintendents, civil and landscape contractors, and practitioners with significant on-ground experience, and provide clear and practical guidance for constructing and establishing biofilters.

## 8.8 Plant the plants

**When to plant**

Generally, the best time to plant in the south-west of Western Australia is June. This provides the whole of winter and spring for the plants to establish with (generally) regular watering from rain and stormwater. Where irrigation can be utilised, the planting can be extended into spring or autumn. Rushes and sedges can establish more rapidly in summer, as this is when their peak growth period occurs, provided there is a water supply. However, summer is usually too hot, resulting in extensive deaths or excessive water usage for irrigation. The timing of local site activities (e.g. subdivision works and lot development) is an important consideration in determining when to plant.

**Ordering plants**

Ideally, plants should be ordered at least six months before needed (i.e. by October or November in the year before a June planting), especially when ordering unusual or large numbers of species. Where local provenance (e.g. within 50 km of the site and from a similar habitat) is a requirement or desired, the ordering of plants will also need to cover the timeframe required to acquire suitable seed or propagating material which is often in the spring–summer period. Discussing your requirements with a suitably experienced wholesale native nursery is well worthwhile.

**Plant quality**

Good quality planting stock will increase the likelihood of plants establishing effectively. Tubestock that is the right age for the size of the container it is growing in increases the survival of new plants (e.g. not root bound or so young for the pot that it falls apart when removed). The tubestock should ideally be grown in root pruning cells, so that the plants are not root bound. Plants should show signs of active growth while in their pots, indicating that they are healthy. Wilted plants should be trimmed. Check plants for signs of disease and do not plant if there are signs of disease, mites or other problems. Use an accredited nursery where possible.

**Site preparation**

Any accumulated sediment and weeds that may be present on the biofilter surface should be removed prior to planting. Each different planting zone identified on the vegetation plan should be clearly marked out on site, for example by using stakes or flagging.

**Planting techniques**

Due to the flooding nature of biofilter systems, direct seeding is not usually a viable option. The most effective and cost-effective option generally is small tubestock. In more natural type systems, pinning down brushing that contains seed may result in germination and will provide some early habitat. However, this method should not be relied on to give acceptable coverage and should only be seen as an additional technique to planting tubestock.

Larger trees may also be incorporated where a more instant effect is desired. These may require staking. If possible, the potting mix should be low in nutrients so that it doesn't affect the early performance of the biofilter.

**Handling tubestock**

Plants should be removed gently from their cells or tubes to minimise root damage. Roots may be lightly teased out. Generally, plants should be placed in a hole and back filled so that the surface of the tubestock or cell potting mix is level with the top of the biofilter media. The soil should be gently compressed back around the plant to minimise air gaps. When planting tubestock, it is highly recommended that the plants are watered in well to maximise their early survival.

The plants should be placed in their preferred zone and at the required density by an experienced operator to minimise incorrect planting. Planting in rows can assist with obtaining the correct density, but rows that are evenly aligned should be avoided to prevent short-circuiting and the creation of preferential flow paths along the biofilter. Plants should be planted in rows perpendicular to the flow path, with each row offset to the adjacent rows to create resistance to flows (Figure 5).

**Mulch**

Generally, mulch is useful in assisting the growth of plants. Coarse mulch can be useful in stabilising underlying media.

There are however some considerations that affect the use of mulch within biofilter systems. Organic mulch can cause problems due to its tendency to float when the system is full of water, often floating downstream and clogging the stormwater system. Some organic mulch can also add considerable unwanted nutrients to the system and may also contain weed seeds.

Inorganic mulches can heat up the surface of the system causing small or young plants to struggle and die. The mulch can sometimes include fines if it hasn't been adequately washed and these fines can clog the surface of the biofilter.

An issue can arise when large quantities of sediment from the feeding catchment cover the mulch. In this situation, it may be difficult to clean out the biofilter system.

Both inorganic and organic mulch types add expense and complexity to the installation of the biofilter system. Coarse aggregates with rough surfaces will tend to bind and make it difficult to install plants.

Recent experience suggests that planting at higher densities can reduce or remove the need for mulch, especially if the system is irrigated to encourage early growth. The denser rate and irrigation means that the sedge and rush layer rapidly colonises the biofilter surface, providing protection to the media. Planting rates around 6 to 9 plants/m2 should be sufficient to achieve this outcome.

Generally, fertiliser should not be applied to the biofilter. A foliar spray (e.g. seaweed extract) may assist during the initial establishment phase (one or two applications only). There is no requirement for ongoing applications, as the plants should derive their nutrient requirements from the stormwater. Non-foliar fertilisers should not be applied.

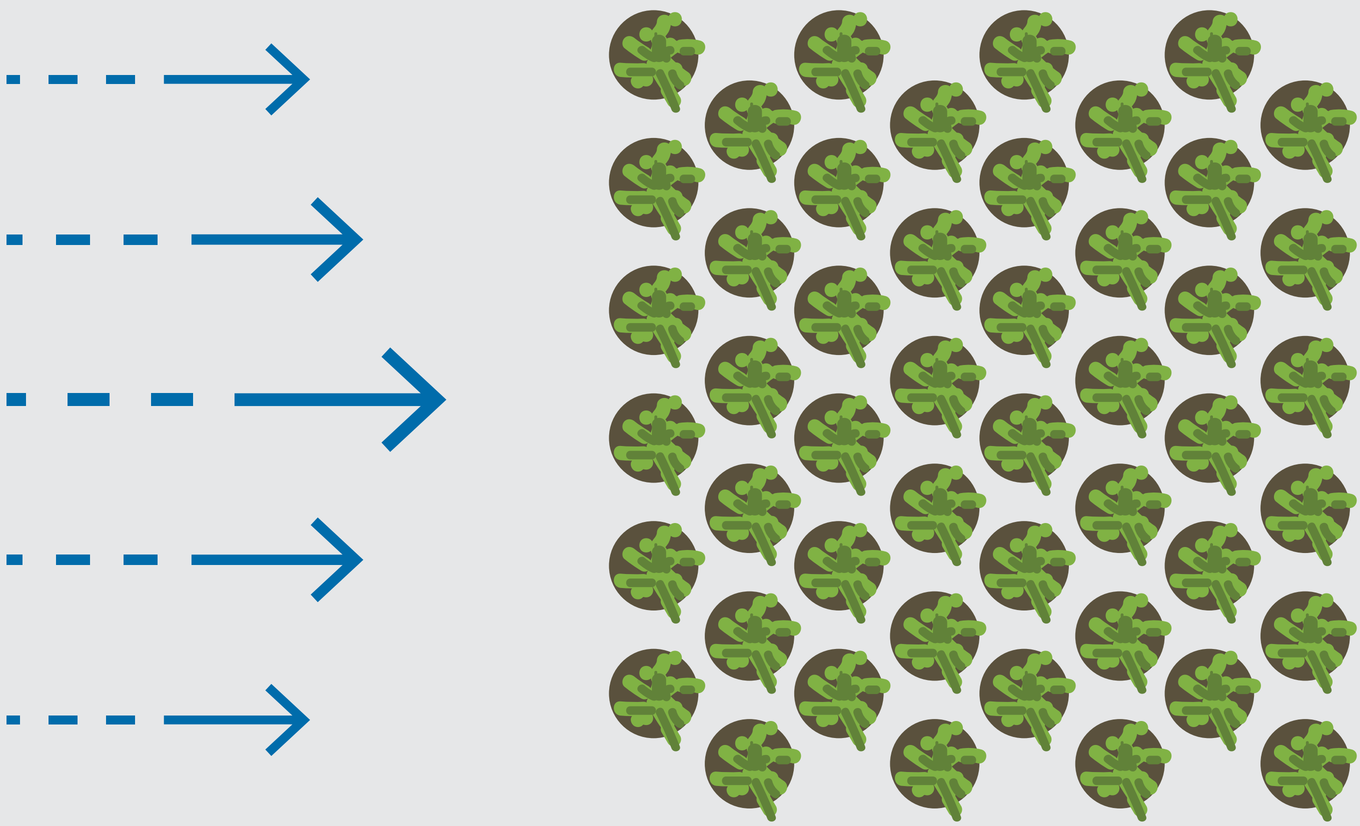

*Figure 5 Planting layout – Rows of plants offset to create resistance to flows*

# 9 Monitoring and maintenance

For effective vegetation establishment, regular monitoring and maintenance is required in the first two years after planting. Monitoring can be a visual drive by the biofilter and can be less labour intensive than required for traditional drainage infrastructure that may require lifting of lids or grates to enable inspection. Different monitoring programs may be designed to meet different purposes, for example to inform maintenance, assess performance or for research purposes. Monitoring activities may include photo monitoring to record changes over time, water quality sampling to measure pollutant removal or tissue sampling to assess the nutrient status of plants.

Monitoring regimes will be dependent on the system installed and the characteristics of the upstream catchment. Table 7, at the end of this chapter, provides a general monitoring and maintenance regime, which can be modified as needed.

In a well-designed system, the maintenance requirements should be minimal, especially if issues are dealt with early. This supports the need for a regular monitoring and preventative maintenance program. Critically, weeds should be controlled as soon as they appear. Hand weed in first instance if possible to reduce risk of chemical drift to desirable plants. Once the system is well established, weeds should be less of an issue, due to the strong competition provided by the desired plants.

## 9.1 Sediment and coarse pollutant removal

Sediment and other coarse pollutants should be removed as required, for example when restricting inlets, reducing infiltration or impacting amenity. Removing these pollutants allows the system to continue to function effectively and keeps them looking presentable within the urban landscape.

## 9.2 Irrigation

It is recommended that vegetation health and vigour be monitored regularly to check if their water needs are being met. A piezometer can be installed in the system to enable monitoring of the saturated zone depth to help determine irrigation requirements.

Irrigation can greatly increase the success rate when establishing biofilter systems. This is especially true of drier climates and during drier than normal summers. Wherever possible, irrigation should be used for at least the first two years of establishment. Drip irrigation is best if possible. It is best to give plants a good soak when watering so they are not encouraged to develop shallow roots and so the remaining soil does not draw water from the soil surrounding the plant. It is recommended to irrigate in the morning so moisture does not sit on leaves overnight.

Irrigation may also be beneficial in the longer term where there is no groundwater available for plant roots to draw upon. It allows the plants to continue functioning during extended dry periods, reducing senescence and the ultimate loss of nutrients and other pollutants from the system. Additionally, irrigation assists in maintaining the microbial community and biofilm that are important in achieving the desired water quality outcome. Early irrigation should be kept to a level that encourages good root growth by making the roots expand in search of water (i.e. avoid overwatering, since this favours high shoot mass but lower root mass and weaker roots).

## 9.3 Vegetation protection

**Grazing**

In areas close to bush and water bodies it may be necessary to protect establishing plants from grazing pressure. Some native and introduced water fowl will uproot sedges and rushes. Kangaroos and rabbits can graze young plants, sometimes to the point of death. In areas where grazing is likely to be a problem, control methods should be included during the establishment phase. Control methods may include fencing and cover netting.

**Access**

Uncontrolled access by pedestrians and vehicles can lead to compaction of the biofilter media, and disturbance of the plants will result in reduced plant function (and therefore reduced pollutant removal) as well as the likelihood of greater weed invasion. Control of access can be achieved by barriers and by locating the system out of the way of general traffic flow. Providing clear access and maintenance points,

fencing to prevent access or utilising vegetation features such as hedging to manage access may be required to protect vegetation and prevent trip hazards for pedestrians.

**Plant management and weeds**

It is critical that the people monitoring and maintaining the system understand how biofilters work. They also need to have good knowledge of the desired flora likely to be in the system. Identification of the desirable species and weed species, and how to effectively manage both, including judicious pruning, is critical to the long-term functioning of the system. Generally, any vegetation pruned or cut within the system should be removed to assist with the general removal of nutrients and pollutants from the biofilter.

Weeds can be a major problem to the long-term success of biofilter systems. The incorporation of weed barriers around a biofilter can assist with reducing the initial invasion of weeds. The barriers should include root barriers to minimise the invasion of lawn grasses. Dense planting, as mentioned above, will also reduce future weed invasion.

Stormwater can transport large quantities of weed seed that will invade biofilters. Regular weed control and seasonal infill planting will be required.

Clean tools, boots, equipment and machinery should be used when building and maintaining the biofilter to help prevent the spread of weeds.

**Adjacent land use and development**

Some failed attempts at biofilter construction were due to poor timing of installation and the lack of protection during vegetation establishment. New biofilters constructed within a residential development will be affected by site disturbance, roadworks and service installation. These activities generate sediment and debris that can smother vegetation and clog biofilters. It is generally advisable to limit planting of the understorey until extensive roadworks or house building works are completed in the upstream catchment. In the interim, the media within the biofilter should be protected from excessive fine sediments and gross pollutants. One option is to place a geofabric or artificial lawn to cover the biofilter surface. This can be easily removed, along with the sediments, once the catchment is stable, prior to later planting. Should some vegetation be desired in the interim, larger trees can be planted through holes in the geofabric or artificial lawn. Upstream sediment and dust management should also be put in place, where possible, to reduce the loads entering the biofilter.

## 9.4 Monitoring and maintenance checklist

Table 7 provides a checklist which can be used to develop a monitoring and maintenance regime.

*Table 7 Monitoring and maintenance checklist*

| When | Points to check | Possible actions |
|---|---|---|
| At planting | Is density as per design specifications? | Modify density as required. |
| | Are plants in their right location or zone? | Replant into right area as required. |
| | Is irrigation (if used) installed and working? | Fix irrigation system. |
| One week after planting | General plant health – e.g. has there been grazing, are there dead or dying plants, plants pulled up or disturbed? | Grazing – put up barrier to grazers.<br>Determine cause of death e.g. lack of water (see below) or poor soil condition.<br>Pulled or disturbed plants – put up barrier to grazers or vandals and replant plants. |
| | Soil moisture – is it adequate for plant growth? | Determine why soil is too wet or dry and rectify e.g. increase or decrease irrigation, check infiltration rate and determine why media may be holding water or draining too quickly and rectify (e.g. remove fine sediment from surface or loosen to allow water penetration).<br>Check that inflow and outflow of biofilter are not blocked. Check system for leaks (if the system is lined and has a saturated zone that is meant to hold water). |
| After first rain and after subsequent major rain events | Presence of erosion or media displacement? | Reduce flow velocity if possible or protect plants with geofabric or rocks while establishing. |
| | Presence of sediments or pollutant loads entering system? | Put in sediment trap area. Determine cause of sediment from upstream and rectify at source. |
| | Are plants being washed out or tipped over? | Reduce flow velocity if possible or protect plants with geofabric or rocks. If plants continue to be washed out, then a redesign of the entire system to better suit the flow parameters may be needed. A free-draining pit at the entry to the biofilter or bubble up inlet will reduce inflow velocities and trap gross pollutants. |

*Table 7 Monitoring and maintenance checklist* (cont.)

| When | Points to check | Possible actions |
|---|---|---|
| One month after planting | General plant health – e.g. has there been grazing, are there dead or dying plants, plants pulled up or disturbed? | Grazing – put up barrier to grazers.<br>Determine cause of death e.g. lack of water (see below) or poor soil condition.<br>Pulled or disturbed plants – put up barrier to grazers or vandals and replant plants. |
| | Soil moisture – is it adequate for plant growth? | Determine why soil is too wet or dry and rectify e.g. increase or decrease irrigation, check infiltration rate and determine why media may be holding water or draining too quickly and rectify (e.g. remove fine sediment from surface or loosen to allow water penetration). Check that inflow and outflow of biofilter are not blocked. Check system for leaks (if the system is lined and has a saturated zone that is meant to hold water). |
| | Saturated zone – is moisture present for plant growth? | Check if there is water in the saturated zone. If not, irrigate. If water is above outlet height, check why outlet is not working. This assumes a piezometer has been installed, so won't be relevant for all biofilters. |
| | Presence of erosion or media displacement? | Reduce flow velocity if possible or protect plants with geofabric or rocks while establishing. |
| | Presence of sediments or pollutant loads entering system? | Put in sediment trap area. Determine cause of sediment from upstream and rectify at source. |
| | Are plants being washed out or tipped over? | Reduce flow velocity if possible or protect plants with geofabric or rocks. If plants continue to be washed out, then a redesign of the entire system to better suit the flow parameters may be needed. A free-draining pit at the entry to the biofilter or bubble-up inlet will reduce inflow velocities and trap gross pollutants. |
| | Are weeds present? | Remove weeds. If possible, remove source of the weeds or put in barrier to slow movement into system. |
| Every three months for first two years | *As per first month plus the following items* | |
| | Plant survival percentage | Determine if new plants will need to be planted. Order plants in time for next appropriate planting time. |
| | Plant coverage of biofilter surface | Determine if more plants will need to be planted. Order plants in time for next appropriate planting time. Alternatively, increasing irrigation may assist with increasing the growth rates over the drier months. |
| Every six months for life of system (after first two years) | *As per first two years plus the following items* | |
| | Need for pruning or harvesting | Determine if some species would benefit from careful pruning if obstructing traffic, or if parts of the plant are dying. Remove any pruned or harvested material so these nutrients are taken out of the system. |

# 10 Western Australian biofilter examples

Biofilters come in a variety of shapes, sizes and appearances, depending on their location in the landscape and the other attributes they have been designed to address. A stylised biofilter cross-section, that has a natural looking theme, is shown in Figure 6. A range of other examples are also shown on the next pages.

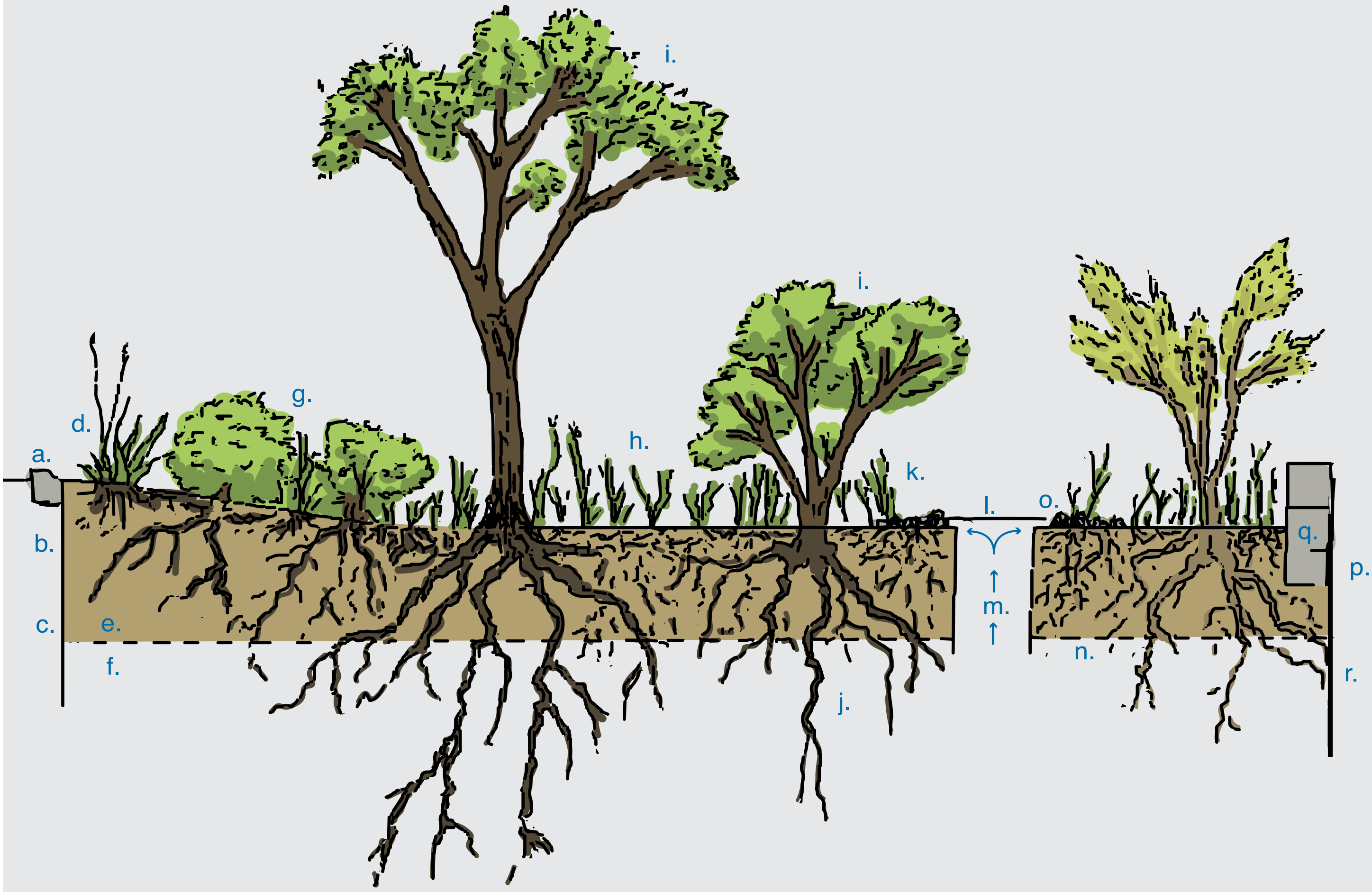


*Figure 6 Cross-section of biofilter vegetation with a natural focus*

*a. Kerb/edging*
*b. Natural soil/fill*
*c. Root barrier*
*d. Potential for small numbers of attractive, low nutrient removal plants to be included to suit landscaping*
*e. Filter media*
*f. Natural soil/fill*
*g. More drought tolerant plants utilised in higher/drier parts of the biofilter*
*h. Sedge/rush layer across the base of the biofilter surface*
*i. Shrubs/trees used to provide biodiversity and help maintain media infiltration rates*
*j. Larger roots of trees/shrubs to maintain infiltration in media*
*k. Dense sedges/rushes around inlet point to capture coarse litter (allowing sufficient areas so that inlet doesn't block)*
*l. Inlet point*
*m. Water flow*
*n. Fine dense layer of roots from sedges/rushes within media to absorb pollutants*
*o. Rock pitching (or similar) around inlet point to reduce erosion and allow inlet to flow freely*
*p. Natural soil*
*q. Wall/ landscape edge*
*r. Root barrier*

## WA biofilter case studies

**Kelvin Road biofilters, City of Gosnells, Western Australia**

Two biofilters were installed along Kelvin Road in the City of Gosnells, Perth, Western Australia. The vegetation planted in December 2012 includes *Juncus subsecundus, Ficinia nodosa, Baumea juncea* and *Melaleuca lateritia*. The biofilters have a 600mm deep saturated zone, which significantly helps buffer against summer droughts. Three deep waterings of the vegetation were required over the long summer drought in 2013/14, which replenished the saturated zone. Gingin Loam was used for the filter media.

**Mead Street biofilters, Byford, Western Australia**

The Glades Stage 1A is a Water Sensitive Urban Design development in Byford, Perth, Western Australia. Site development began in mid-2008 and building construction began in 2009. The site is characterised by a shallow layer of sand over clay and perched groundwater. The stormwater treatment elements were designed to treat up to the 1-year, 1-hour average recurrence interval rainfall event (equal to 17.4 mm). These small events infiltrate through the soil media and into underlying subsoil drains that flow directly to biofilters. A series of three biofilters are located along the Mead Street road median. Gingin Loam was used as the filter media. The biofilters experience seasonal groundwater interaction, with the shallow water table rising following storm events.

The biofilters were planted with a mixture of trees, shrubs and rushes, including *Melaleuca preissiana, Dianella tasmanica* 'Variegata' and *Ficinia nodosa. Grevillea thelemanniana* 'Grey' was used to form hedging along the biofilter, which protects the biofilter from pedestrian and vehicle traffic, as well as creates an attractive landscape feature. The plant species are drought tolerant and require minimal irrigation. An irrigation system has been installed for the central median swales on a stand-alone station. This has the added benefit of being able to switch the irrigation off once the vegetation has become established. The irrigation system can be switched on during prolonged dry periods to maintain landscape aesthetics. Benefits of the biofilter system include reducing the volume and frequency of stormwater runoff, improving water quality, mitigating urban heat island effects, improving biodiversity and habitat connectivity for fauna and enhancing urban amenity.

## Barlee Street biofilter, City of Busselton, Western Australia

The Barlee Street biofilter was built in June 2009 in the light industrial area of Busselton, Western Australia. The plant species include *Dianella brevicaulis, Ficinia nodosa, Juncus kraussii, Melaleuca lateritia* and *Melaleuca incana*. The biofilter was designed as a retrofitted system to treat stormwater runoff from the road, roof and car park in the surrounding catchment. The biofilter is sized at approximately 2% of the impervious catchment area, providing adequate treatment of the design inflows and protecting the Lower Vasse River downstream. Winter groundwater levels intercept the base of the biofilter. The biofilter was lined to prevent mobilisation of nutrient rich groundwater. A 150 mm deep saturated zone was created in the biofilter by sealing the system and using a raised slotted pipe outlet that is connected to the piped stormwater network. Spearwood red sand/sandy loam was used as the filter media.

Further information about the design, construction costs and monitoring of the Barlee Street biofilter is available at http://www.newwaterways.org.au/page/Research/Advancing-Biofilters-in-Western-Australia-Research-Seminar.

*Previous page: Kelvin Road biofilter in the City of Gosnells, Western Australia (Source: Toby Rees, City of Gosnells)*

*Left: Road median biofilters installed along Mead Street in The Glades urban development in Byford (Source: Department of Water, WA)*

*Below: Biofilter on Barlee Street in the light industrial area of Busselton (Source: Department of Water, WA)*

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## Further information

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## Photographs

Page 3 – Biofilters on Queen Street, City of Busselton, Western Australia (Source: Peter Roberts, Design Workroom)

Page 25 – Biofilter incorporated into public open space, Parkfield Boulevard, Bertram, City of Kwinana, Western Australia (Source: Brendan Oversby, TME Town Planning Management Engineering Pty Ltd)

Page 32 – Biofilters on Queen Street, City of Busselton, Western Australia (Source: Peter Roberts, Design Workroom)

Page 42 – Biofilter in Riverlea Estate, City of Bunbury, Western Australia (Source: Brendan Oversby, TME Town Planning Management Engineering Pty Ltd)

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