Adoption Guidelines for Stormwater Biofiltration Systems

Cities as Water Supply Catchments – Sustainable Technologies

CRC for
Water Sensitive Cities

Australian Government
Department of Industry and Science

Business
Cooperative Research
Centres Programme

Adoption Guidelines for Stormwater Biofiltration Systems (Version 2)
Cities as Water Supply Catchments – Sustainable Technologies (Project C1.1)
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Preamble

These guidelines are based on extensive testing and development of biofiltration system designs that use readily sourced soil-based filter media and mainly Australian native plants. Other biofiltration systems with alternative design specifications to those listed in these guidelines can also be considered as effective stormwater treatment systems, provided they have been demonstrated under realistic conditions to achieve an acceptable pollutant removal and operational performance.

Acknowledgements

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This second version of the guidelines was authored by Emily Payne, Belinda Hatt, Ana Deletic, Meredith Dobbie, David McCarthy and Gayani Chandrasena of the Monash Water for Liveability Centre and the Cooperative Research Centre for Water Sensitive Cities (CRCWSC). Daniel Connellan (CRCWSC) managed formatting and graphic design, while Steve Pogonowski and Fiona Chandler (CRCWSC) and Louisa John-Krol (Monash Water for Liveability Centre) provided communication advice and editing to improve the reader's experience, particularly on the accompanying summary and fact sheet documents.

Our sincere thanks to our Industry Advisory Panel members for their invaluable contribution of time, knowledge, comments and insights throughout the review; Krish Seewraj and Antonietta Torre (Western Australian Department of Water), Sam Phillips (Natural Resources Adelaide and Mt Lofty Ranges, South Australia Department of Environment, Water and Natural Resources), David Beharrell (Hornsby Council), David Carew and Justin Lewis (Melbourne Water), Jay Jonasson (Ku-ring-gai Council), Dale Browne (E2DesignLab) and Adrian Crocetti (Brisbane City Council). The contribution of industry experts has added significant value to these guidelines.

We also greatly appreciate the input of Kerrie Burge (E2DesignLab), Sam Innes (City of Port Phillip), Greg Fitzgerald and Shane Howes (Daisy's Garden Supplies), Terry Woodcock (Sportsturf Consultants), Ruth Ward (Environmental Protection Agency, South Australia), Mellissa Bradley (Water Sensitive South Australia), Rob Allison (DesignFlow) and Nathan Wicker (City of Port Adelaide Enfield). Many thanks also to Katia Bratières (ClearWater) for her advice and assistance with the communication and distribution of these guidelines.

These guidelines would not have been possible without the research efforts of researchers and postgraduate students, past and present, working under FAWB, the Cities as Water Supply Catchments project and most recently, the CRCWSC, and affiliated projects, thus we extend our thanks to them.

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Chapter 1: Introduction

1.1 What are stormwater biofiltration systems and how do they work?

Water biofiltration is the process of improving water (stormwater and wastewater) quality by filtering water through biologically influenced media (Figure 1).

Compared with undeveloped catchments, urban areas generate stormwater runoff that is magnified in flow volume, peak and pollutant load. The poor water quality and altered hydrology are both highly detrimental to the health of receiving waters (e.g. streams, estuaries, bays). Stormwater biofiltration systems (also known as biofilters, bioretention systems and raingardens) are just one facet of a range of accepted water sensitive urban design (WSUD)[1] elements (Wong, 2006). They are a low energy treatment technology with the potential to provide both water quality and quantity benefits.

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

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

Small bioretention pods are often referred to as raingardens, while linear systems are commonly referred to as biofiltration swales. Biofiltration swales provide both treatment and conveyance functions, while basins are normally built off-line to protect them from scour. Biofilters include standard features and operate using the same basic principles (Figure 2). In all designs an elevated outlet is strongly recommended. This feature provides multiple benefits for water treatment, retaining moisture for plants, increasing retentive capacity, reducing the total head requirement and promoting exfiltration loss (in unlined systems) or a longer-lasting submerged zone (in-lined systems). However, design configurations are flexible to suit different site conditions, applications and objectives.

Projects will differ in their application of standard features versus more innovative biofilter designs. Regardless, **site-specific factors and performance objectives must be considered in the design process**. This will ensure optimal performance, with the system adapted to suit the local environment and address the target pollutants or relevant hydrological objectives.

Successful design and implementation require a multidisciplinary approach. This includes the fields of civil engineering, town planning, botany, ecology, chemistry, soil science, microbiology, hydraulics, hydrology, landscape architecture and social studies to foster community support. These guidelines draw the aforementioned diverse fields together to inform the designer and facilitate effective designs.

1.1.1 Hydrologic function

Stormwater runoff from urban areas is characterised by short, sharp peak flows and substantially larger volumes in comparison to runoff from undeveloped areas. A primary goal of best-practice stormwater management is to reduce runoff peaks, volumes and frequencies. Biofiltration systems can achieve this, for two reasons:

- Depending on their size relative to the catchment, and their infiltration properties, they may reduce below 1-year Average Recurrence Interval (ARI) peak flows by around 80%. Instead of runoff being delivered directly to the local waterway via the conventional drainage network, it is collected on the surface of the biofilter and slow filters through the soil media; and
- They reduce runoff volumes: a portion of every runoff event is retained by the filter media – this will then be lost via evapotranspiration and/or exfiltration, depending on design of the system. Small runoff events might even be completely absorbed by the biofilter (i.e., there is no discharge from the underdrain). Therefore, and particularly in the case of unlined systems with an elevated underdrain or no underdrain at all, they may substantially reduce runoff frequency to receiving waters, thus protecting aquatic ecosystems from frequent disturbance.

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[1] *WSUD is "...a philosophical approach to urban planning and design that aims to minimise the hydrological impacts of urban development on the surrounding environment" Lloyd, S. D., Wong, T. H. & Chesterfield, C. J. 2002. Water sensitive urban design: a stormwater management perspective..*

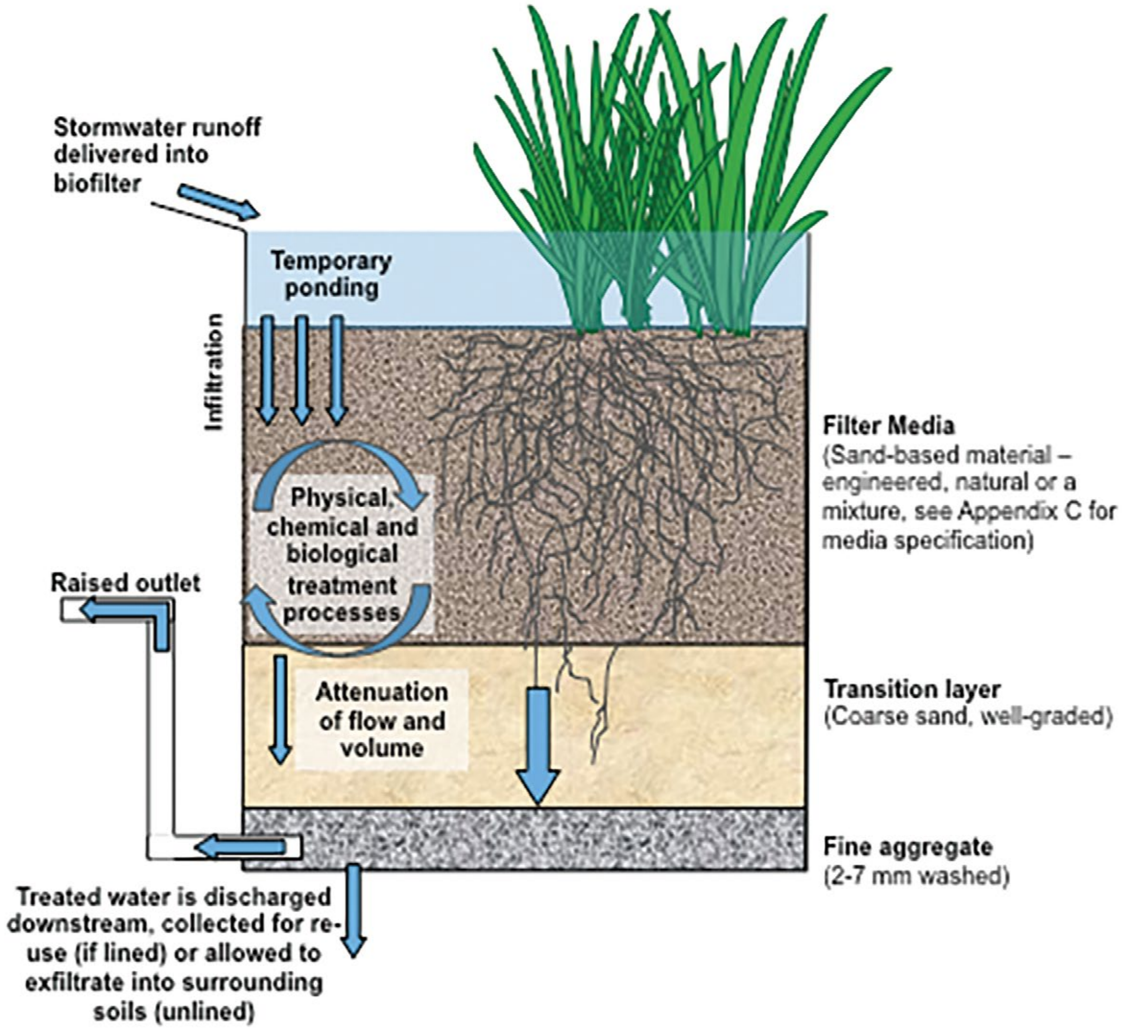

Figure 1. Key principles of stormwater biofiltration

1.1.2 Treatment processes

Stormwater runoff from urban areas contains pollutants that are detrimental to the health of receiving waters. Therefore, the other goal of stormwater management is to improve the quality of water being discharged to urban waterways. Biofiltration systems aim to replicate the following natural treatment processes:

- Physical: as stormwater enters the biofilter, the dense vegetation reduces flows, causing soil particles and particulates to settle out (sedimentation). In addition, particulates are filtered from the water as it percolates down through the soil media (mechanical straining);
- Chemical: soil filter media contains clay minerals and other chemically active compounds that bind dissolved pollutants (sorption); and
- Biological: vegetation and the associated microbial community take up nutrients and some other pollutants as growth components (e.g. plant and microbial uptake).

Further details on the range of biofilter treatment processes are provided in Section 3.3.2.


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Figure 2. Examples of stormwater biofilters, which can vary widely in their scale, appearance and design to suit treatment objectives and local site conditions. Photos supplied by Krish Seewraj and Antonietta Torre, Department of Water and Emily Payne, Monash University

1.2 Why might we choose a biofiltration system?

There have been many successful applications of biofiltration, but also some poor outcomes owing to inadequate design and construction, and poor maintenance. These guidelines seek to improve understanding of biofiltration and disseminate guidance borne out of successful applications, and research and development.

When used appropriately, biofiltration systems have been found to be viable and sustainable as a water treatment measure. The treatment performance for water quality and hydrological benefits are summarised in Section 2.4. In addition to reducing the impacts of urbanisation on catchment hydrology and improving water quality, biofiltration systems:

- Have an acceptably small footprint relative to their catchment (typically ranging from 2 - 4%, depending on climate);
- Are attractive landscape features which enhance urban amenity;
- Are flexible in their design and application;
- Are self-irrigating (and fertilising) gardens;
- Provide habitat and biodiversity values;
- Are an effective pre-treatment for stormwater harvesting applications;
- Are potentially beneficial to the local micro-climate (due to the cooling effect of evapotranspiration and shading);
- Are not restricted by scale; and
- Can be integrated with the local urban design (streetscape).

The wide-ranging benefits of stormwater biofilters are discussed in detail within Chapter 2.

1.3 Planning policy

The mechanisms for the adoption of biofiltration technology are embedded in multiple policy documents across local and state jurisdictions. Biofiltration, alongside all WSUD technologies, must be integrated into urban design, and as such a wide range of planning and other policy mechanisms can be relevant to its adoption. Key legislation and guidelines that regulate or promote WSUD have been summarised in Table 1. Additional regulations or planning instruments may be relevant to aspects of the use of biofiltration (e.g. related to road design or safety), or help to make the business case for its adoption. This section is not intended to provide a comprehensive overview of all relevant guidelines or legislation, but instead highlights some of the key policies and strategies.

Table 1. Key planning instruments addressing WSUD at the State and local scales

State	**Planning Instruments**	
	State planning legislation	**Local**
Queensland	WSUD is required in the design of developments. Stormwater management is also required for planning and development activities. State policy requires site based Stormwater Quality Management Plans for some developments and assists local governments to formulate regional plans. The Environmental Protection (Water) Policy outlines environmental values and water quality objectives to protect different waters in Queensland.	Various local council policies with ranging requirements. Local government planning schemes implement the state planning frameworks, and are authorised to develop and implement a Total Water Cycle Management Plan.
New South Wales	WSUD not prescribed in legislation and no mandated targets in regards to water quality. Obligations for management of urban waters by council directed by the Local Government Act 1993. Section 117 Direction requires stormwater discharge considerations in local environmental plans (LEPs).	WSUD initiatives primarily driven and policies developed by local councils. Various Development Control Plans (see www.wsud.org for complete list); deemed-to-comply requirements at some Councils.
Victoria	State Environment Protection Policy (SEPP) (Waters of Victoria) requires stormwater quality treatment for all activities on private and public land. The *Victoria Planning Provisions* include *State Planning Policy Framework Clauses* which allow councils to require WSUD for all residential, industrial and commercial developments. The *Best Practice Environmental Management Guidelines for Urban Stormwater* help to implement the SEPP requirements in design. Minimum water quality and quantity objectives must be met for developments.	Various WSUD guidelines, policies and action plans adopted by local councils. These promote and facilitate the implementation and maintenance of WSUD systems and may seek to achieve specific goals, such as stormwater quality and discharge targets.
Western Australia	Significant policy development in light of greatly diminished rainfall and population growth. Statement of Planning Policy 2.9 'Water Resources' promotes WSUD in new development but not mandatory. Obligation for sites to sites to protect or enhance water quality and quantity. Further guidance given in *Better Urban Water Management* (Western Australian Planning Commission 2008) and supported by *Stormwater Management Manual for Western Australia* (Department of Water 2004-2007), which outlines criteria to 'retain or detail stormwater runoff from constructed impervious surfaces generated by up to 1-year, 1-hour average recurrence interval (ARI) events on-site' (note – criteria currently under review) and encourages close-to-source treatment. Liveable Neighbourhoods (WAPC 2009) and Direction 2031 and Beyond (WAPC 2010) – further promotes sustainable development. For stormwater harvesting projects consult Guideline for the approval of non-drinking water systems in Western Australia – urban developments (Department of Water 2013) and for aquifer recharge - Operational policy 1.01 – Managed aquifer recharge in Western Australia (Department of Water 2011).	Within specific localities, local government planning policies vary; some promote the use of WSUD for stormwater treatment. Further, various Water Quality Improvement Plans and Drainage and Water Management Plans across WA support the use of biofiltration systems.
South Australia	WSUD is not mandatory but encouraged, through a range of government policies including the state's WSUD policy *Water sensitive urban design – Creating more liveable and water sensitive cities in South Australia*. It sets out the aims, objectives and guiding principles for WSUD in South Australia, and outlines the WSUD performance principles and performance targets. The state WSUD policy (2013) follows the 2011 *Stormwater Strategy – The Future of Stormwater Management*, the 2010 *30-Year Plan for Greater Adelaide*, the 2009 *Water for Good*, and the 2007 *Institutionalising WSUD in the Greater Adelaide Region*. The issues paper T*ransitioning Adelaide to a water sensitive city – Towards and Urban Water Plan for Greater Adelaide* was released in 2014 as part of the process of developing a new urban water plan intended to address all sources and uses of water. The initial draft urban water plan is expected in 2015. Water Sensitive SA is South Australia's emerging WSUD capacity-building program. Water Sensitive SA was launched in 2015 and delivers on Action7 of the state WSUD policy.	Each local government must have strategic management plans in accordance with the *Local Government Act 1999*. These plans may include policies relevant to WSUD to reflect the aspirations of the local government's constituents. A local government may prepare a stormwater management plan to meet the requirements of the Stormwater Management Authority. A stormwater management plan may consider WSUD.

Cont.

Table 1. Continued

State	**Planning Instruments**	
	State planning legislation	**Local**
Tasmania	Stormwater management and objectives outlined in the Tasmanian *State Policy on Water Quality Management 1997 (SPWQM)*, including Protected Environmental Values for waterways. Implementation is supported by the *State Stormwater Strategy* and requires pollutant reduction targets for nitrogen, phosphorus and suspended solids. New developments over 500 m^2 impervious surface required to incorporate best practice stormwater practices, including targets for stormwater quality.	Local planning schemes must require stormwater management strategies from development proposals, both for construction and operation. Both state and local governments are required by the SPWQM to develop strategies to reduce stormwater pollution as its source. Various local plans developed, such as the *NRM North Regional Stormwater Quality Management Strategy 2014-2017* and the Derwent Estuary Program's WSUD *Engineering Procedures: Stormwater for Southern Tasmania* (2006).
Australian Capital Territory	WSUD embodied in the *Waterways: Water Sensitive Urban Design code* in 2009. It replaces elements of the previous strategy; *Think water, act water – Strategy for sustainable water resource management in the ACT*. Targets are set for improved stormwater quality and quantity, and reduced mains water use. The stormwater targets are mandated for sites > 2,000 m^2, and further quality targets are required for sites > 5,000 m^2. A recent review, *Water Sensitive Urban Design – Review report*, investigated a range of WSUD implementation issues and identified recommendations.	N/A
Northern Territory	Environmental values and objectives stated in the *Water Act* via Beneficial Use Declarations for water bodies such as Darwin Harbour. Development proposals must adhere to these, as well as the requirements for stormwater pollution under the *Waste Management and Pollution Control Act*. The adoption of WSUD strategies are discussed in the report Water Sensitive Urban Design: The implementation of WSUD within the existing legislation and policy framework (2009). The *WSUD Strategy for Darwin Harbour* requires WSUD for new urban developments.	While local governments review and comment on development proposals, the Department of Planning and Infrastructure (and more specifically the division known as the Development Consent Authority) is responsible for approval of development applications. Stormwater is managed by both local and the Territory governments, and councils are responsible for stormwater drainage. Local government subdivision and development guidelines also set requirements for stormwater drainage.

1.4 Research underpinning the design of biofiltration systems

The first version of these guidelines was developed by the Facility for Advancing Water Biofiltration (FAWB) in 2009. FAWB was an unincorporated joint venture between the Institute for Sustainable Water Resources (ISWR), Monash University and EDAW Australia (previously Ecological Engineering). It also involved collaboration with industry partners from Adelaide and Mount Lofty Ranges Natural Resources Management Board (South Australia), Brisbane City Council (Queensland), Landcom (NSW), Manningham City Council (Victoria), Melbourne Water (VIC) and VicRoads (VIC). FAWB was primarily funded through the Victorian State Government's Science, Technology and Innovation (STI) grant, industry cash contributions and a direct cash contribution from Monash University.

This revision of the guidelines was undertaken by the Cooperative Research Centre for Water Sensitive Cities (CRCWSC). The guidelines have been revised to incorporate recent research work, much of which was undertaken under the original Cities as Water Supply Catchments Project, which later became the CRCWSC, or by associated projects funded by industry partners (Melbourne Water and the Department of Water, WA) and the Australian Research Council (ARC).

This update was undertaken in partnership with a number of industry partners who provided valuable input material, feedback and review of these guidelines. An Industry Advisory Panel had oversight and closely collaborated throughout the review process, incorporating seven industry partners from five Australian States:

- Department of Water, Western Australia (WA)
- Melbourne Water, VIC
- Ku-ring-gai Council, NSW
- Natural Resources Adelaide and Mt Loft Ranges, Department of Environment, Water and Natural Resources, SA
- Hornsby Shire Council, NSW
- Brisbane City Council, QLD
- E2DesignLab, VIC

Specific aspects of the guidelines were also developed in consultation with industry representatives, including input from:

- City of Port Phillip
- Daisy's Garden Supplies
- Sportsturf Consultants
- DesignFlow
- EPA SA
- Water Sensitive South Australia
- City of Port Adelaide, Enfield

1.5 How to use these guidelines

The purpose of this document is to provide guidance on how to apply the research findings in practice. The target audience includes planners, engineers, landscape architects, developers, constructors, and all other parties involved in urban design.

These guidelines are intended to be viewed as a reference – readers are encouraged to go to specific sections as required, and it is not expected to be read cover-to-cover. As a result, sections of the document are intended to stand alone to some extent.

The guidelines are presented as a series of chapters, each addressing a different aspect of implementation of biofiltration systems, as follows:

- Chapter 2 (*Business Case for Biofiltration*) outlines the broad suite of benefits and performance expected from stormwater biofilters. It also identifies the key stakeholders and discusses their relationships to the project. The costs and benefits of the technology are discussed and studies that have quantified aspects of the business case for biofiltration are presented.

- Chapter 3 (*Technical Considerations*) provides guidance on conceptual design and linking design outcomes to identified management objectives, a key step in biofilter design that is often overlooked. It then describes the main components of biofilters and key processes, as well as four fundamental design configurations. The key considerations in design are summarised, along with recommendations to achieve effective systems. Finally, sub-sections discuss each biofilter component in detail, from aspects of sizing, system hydraulics, media selection, vegetation, aesthetics, stormwater harvesting and other specific considerations.

- Chapter 4 (*Practical Implementation*) provides guidance on the construction, establishment, maintenance, and monitoring of biofiltration systems in Australia. The recommendations are based on the experience and observations of ecologists and engineers who have been actively involved in the design, on-site delivery and monitoring of biofilters.

Appendices provide additional information, either as summaries in the form of fact or field sheets, or more detailed information for specific reference:

- Appendix A – Fact Sheets: short summaries outlining:
    - Why choose biofiltration?
    - How does stormwater biofiltration work?
    - Stormwater biofiltration – What are the ingredients for successful systems?
    - Biofilter design to meet objectives and adapt to local site conditions
    - Vegetation selection for stormwater biofilters
    - Stormwater biofilter monitoring and maintenance
    - Biofilter construction checks
- Appendix B – Publications: research underpinning the Biofilter Adoption Guidelines
- Appendix C – Guidelines for filter media in stormwater biofiltration systems
- Appendix D – Enhancing pathogen removal using novel antimicrobial media
- Appendix E – Case studies
- Appendix F – Biofilters that look good – enhancing aesthetics, community appreciation and acceptance
- Appendix G – Detailed scientific monitoring
- Appendix H – Performance assessment of biofiltration systems using simulated rain events
- Appendix I – Measurement of hydraulic conductivity – using in situ and ex situ (laboratory) sampling methods
- Appendix J – Maintenance field sheet
- Appendix K – Maintenance requirements for biofiltration systems: Plan and checking tools

Note: Like all other WSUD elements, biofilters are most easily and successfully included in urban design when considered in an integrated manner i.e., in conjunction with all other elements of the urban layout. These guidelines should therefore be consulted **before** any detailed planning and design occurs.

1.6 Other relevant documents

These guidelines are intended to be relevant at the national scale and therefore cannot comprise a standalone document, as the final detailed design of biofilters will be influenced by local site conditions (e.g. soil type, rainfall intensity) and stormwater management requirements.

Other external documents including, but not limited to, the following should also be consulted in the design of biofiltration systems:

- Local planning policies and regulations (see Table 1 for further details)
- Local development guidelines (Table 1)
- Local stormwater management guidelines (Table 1)
- Local construction guidelines
- MUSIC modelling documentation (see www.toolkit.net.au/music)
- Australian Runoff Quality (Engineers Australia)
- ANZECC Water Quality Guidelines (see www.environment.gov.au/water/publications/quality/index.html#nwqmsguidelines)

Examples of successful and not-so-successful implementation and operation of biofilters are a valuable source of information. In some respects, ironically, the least successful examples may serve as the most useful reference points, in a cautionary sense. They can also provide creative ideas for sites that are constrained in some way. Many local water authorities and other related organisations compile this information, some of which is available from their websites. Useful websites include:

- Water Sensitive Urban Design (wsud.melbournewater.com.au)
- Water by Design (www.waterbydesign.com.au)
- Water Sensitive Urban Design in the Sydney region (www.wsud.org)
- New WAter Ways (www.newwaterways.org.au)
- urbanwater.info (www.urbanwater.info)
- CRC for Water Sensitive Cities (www.watersensitivecities.org.au)
- Water Sensitive SA (www.watersensitivesa.com)

It is also important to consult with the local water authority, particularly where design solutions are required for "problem" sites.

1.7 References

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2

Chapter 2:
The Business Case for Biofiltration

2.1 Introduction

Today's cities, and cities of the future, face mounting challenges from increasing population, housing density and climatic variability (CRCWSC, 2014). Without careful planning, these changes greatly reduce the liveability of the urban area. The built environment in its traditional form exacerbates hot temperatures, severely restricts green spaces and distorts the hydrological cycle. Amongst a sea of paved surfaces, the environment becomes unhealthy and inhospitable to both humans and ecosystems. The impervious environment introduces multiple dilemmas for planners and engineers, including the delivery of clean water, management of wastewater and stormwater runoff, mitigation of summer heat, support of urban and remnant ecosystems, and provision of spaces for the community to socialise, exercise and simply enjoy time (Figure 3). All of these functions must also be provided economically.

It is now well recognised that natural ecosystems have always alleviated many of the aforementioned problems for human populations, but the formers' functions have been undervalued. This has heralded the introduction of novel designs into the urban environment; technologies that harness natural processes within engineered systems. Collectively, implementation of these designs embodies the principles of water sensitive urban design (WSUD). Not only do WSUD technologies facilitate urban water management and benefit waterway health, but they also deliver additional and wide-ranging economic and amenity benefits in the urban environment. There is a need to identify and appropriately value these benefits to facilitate adoption of the technology. However, traditional cost-benefit analyses are not well suited to account for the multiple intangible benefits, spread across a range of stakeholders and long time frames (CRC for Water Sensitive Cities, 2014a). This is further complicated by the fact that it is often only one stakeholder that bears the financial cost of realising these benefits to many.

Biofiltration is one technology within the suite of options available as WSUD tools. With various landscape applications and flexibility in design, biofilters provide improvements in water quality, downstream hydrology, biodiversity, microclimate, aesthetics, urban greenery, human health and alternative water supply (Figure 4). These benefits should not be considered in isolation, but are best realised in catchment-wide treatment strategies that employ other WSUD technologies, such as rainwater tanks, swales, wetlands, porous pavements, detention ponds and green or living walls. The costs of construction and maintenance of WSUD techniques should be compared against the costs of traditional stormwater management, including waterway degradation, flood control, water pollution, maintenance of traditional drainage infrastructure and civic garden beds, loss of revenue to businesses dependent upon healthy

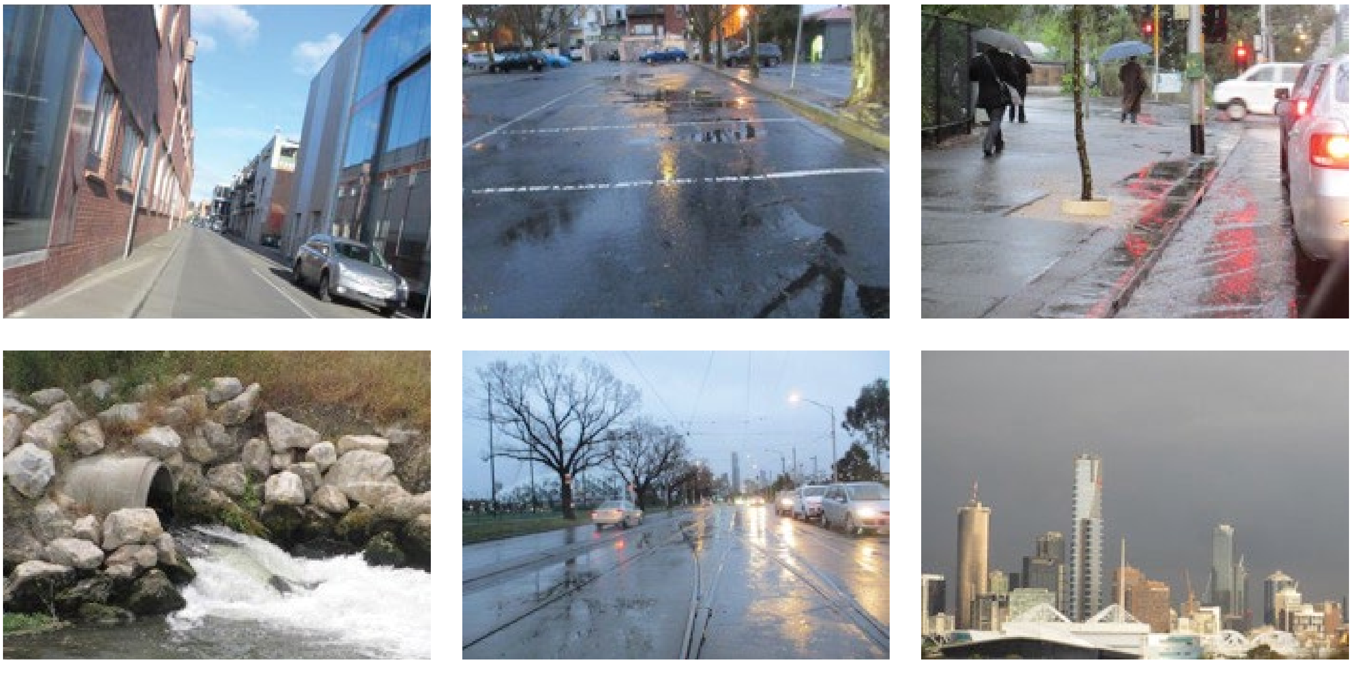

Figure 3. Traditional urban design with impervious surfaces brings challenges for water management, climate control, human health and wellbeing and waterway and ecosystem health

aquatic environments and loss of amenity to the community. Clearly defining and, where possible, quantifying the diverse services and cost savings provided by biofiltration is essential to developing a robust business case.

The purpose of this chapter is to draw upon the available resources to outline a business case for biofiltration that can be used by practitioners to justify and endorse adoption of the technology. Not all benefits can yet be quantified, but the economic evidence in support of stormwater biofiltration, or more broadly, any water-sensitive technologies for the urban environment, includes:

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

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

Figure 4. Water Sensitive Urban Design (WSUD) - of which biofiltration is one tool - benefits water quality, stream hydrology, microclimate, aesthetics, human health, alternative water supply and expansion of green spaces.
Photos supplied by A. Torre, Department of Water, WA.

2.2 Elements of a business case

Each project or case study should be assessed on an individual basis, taking into consideration its location, surrounding environment and objectives. The business case will also need to be tailored to suit the specific context of the organisation undertaking it, despite the wide range of stakeholders involved (Section 2.3). This chapter aims to provide guidance in the development of a business case, including key issues to consider, expected performance from stormwater biofilters, information to help substantiate the business case and references to existing cost-benefit assessments.

A researcher and industry partner workshop run by the CRC for Water Sensitive Cities in March 2014 (2014d) identified strategies for development of business cases specific to WSUD and outlined a framework for the key elements:

- Know the **audience** – who is the decision maker and what are their needs?
- Frame within a **broad picture** – outline the case within a wider context, linking to larger-scale problems, such as liveability, health, social well-being, economics and climate change
- **Stakeholder support** – demonstrate that the project has strong stakeholder engagement and support
- **Strong communication** – make the key messages clear and describe a common vision
- Frame the **base case in the future** – extend the 'status-quo' scenario (i.e. conventional stormwater management) forward 20-50 years in time, to provide a more compelling case relative to a continuation of current conditions
- Both **local and regional benefits** – ensure that benefits at both local and the broader catchment scale have been outlined, including long-term benefits
- **Valuation** of the broad costs and benefits **across the project life cycle** – including not only the benefits to those who will pay, but also the widespread benefits, and using qualitative assessment tools to assess intangible benefits (e.g. multi-criteria analysis)
- Recognition that the **multiple stakeholders will benefit but not all will pay** – recommends using a whole community perspective
- Understanding that many **benefits are realised over long timeframes** while costs are typically more immediate
- Include **stakeholders who will inherit the asset** and its maintenance legacy
- Direct recognition and addressing of **counter-arguments**
- A **clear source of funding** identified

2.3 Stakeholders

The diverse values generated by WSUD projects lead to multiple beneficiaries. This is relatively unique relative to traditional construction projects, with the benefits spread across a range of stakeholders (Figure 5). Further, not all beneficiaries will carry project costs, and the latter are typically upfront with benefits realised over the longer term (CRC for Water Sensitive Cities, 2014d). Nevertheless, to achieve success and widespread implementation, a WSUD project must meet the needs and expectations of each of these stakeholders. Identifying, engaging and communicating with these stakeholders is vital to developing robust designs and having the support required for successful operation of the system into the long-term.

The perspectives of each stakeholder group have been summarised in Table 2, including suggestions outlining their needs for engagement with implementation of biofiltration.

Figure 5. Common stakeholders in WSUD projects

Table 2. Details of stakeholder perspectives and possible engagement needs

Stakeholder	Relationship to project/perspective	Engagement needs
Community	• Aesthetic appeal is critical as biofilters help to define character of the local area and street • May fund projects via council rates • Commonly value sustainability and environmental values • Willingness to pay depends upon income and other factors (CRC for Water Sensitive Cities, 2014c) • Enjoy and take pride in the local environment • Utilise local waterways, waterbodies and green spaces	• Consultation on aesthetics, landscape design and incorporation into the local neighbourhood • Communication to understand the need and benefits of biofiltration systems • Capacity to provide feedback to designers and asset owner
Local Government	• May have project ownership throughout, or receive asset as a developer contribution • For contributed assets, become the owner, although may not have much input into design and construction phases • Responsible and pay the costs for ongoing maintenance and monitoring, also management of end-of-life • Likely to have very limited budget for maintenance and monitoring • Often managing a growing list of assets, and can be challenging to simply catalogue and track asset details and condition • Commonly concerned with cost of maintenance, risk of drought, high community expectations for level of service that may not be able to be delivered within budget	• Seek low maintenance systems (e.g. high drought resilience, well-established plant cover, structures that do not block readily, reduced clogging potential) • Easy and safe maintenance access • Straightforward maintenance • Communication with designers to understand maintenance issues and incorporate into design
Developers	• In some Australian states bound by regulatory policies to adopt WSUD technology (see Table 1). In other cases, must contend with varying policies between development jurisdictions (e.g. between councils). • Commonly owners and pay the costs during the design and construction phase • Commonly concerned with aesthetics of development (including landscaping early in process) and minimising footprint of land outside the developable area • May have substantial budget for initial maintenance and beautification works during early development • Interested in features that can add value or a unique marketing point to the development	• To see value added from the perspective of their customers • Meet regulatory requirements as easily as possible • Seek a marketable product • Seek systems that can be integrated into the design and construction of the whole neighbourhood
Households (form the community but here, needs on a more individual basis outlined)	• May be owners if system built on private land • Strong interest in streetscape systems that sit on their median strip or local road • Aesthetic appeal is critical – do not want weedy, bare, litter-filled, blocked or ugly systems • Do not want access or liveability impeded • May be highly supportive and willing to take some ‘ownership’ of system, helping to weed, water or remove litter • Take pride and enjoyment from local neighbourhood	• Consultation on aesthetics, landscape design and vision for the streetscape or neighbourhood • Communication to indicate the benefits and needs of biofiltration systems • Capacity to provide feedback to designers and asset owner
Business	• May rely upon the services provided by waterways, waterbodies and green spaces (both tangible and intangible) • Motivated by favourable cost-benefit analysis	• Seek clear definition of the benefits relative to the costs, including if possible quantification/assessment of willingness to pay and the intangible benefits

Cont.

Table 2. Continued

Stakeholder	Relationship to project/perspective	Engagement needs
State Government	• Set policies, regulations and guidelines that directly or indirectly affect the implementation of biofiltration - key driver of adoption • In some cases may pay costs to help support design, construction, maintenance and monitoring	• Seek clear definition and where possible, quantification, of the benefits relative to costs to inform the development of good policy and facilitate its adoption • Desire clear understanding by the electorate on the benefits, need and function of biofiltration
Environment	• May not be well understood by other stakeholders, including valuing services provided • Has diverse aspects to consider – waterways, terrestrial ecosystems, soil, groundwater and atmosphere	• Requires clear communication and definition of the need, multiple benefits and consequences of the 'base case' scenario amongst other stakeholders to define environmental costs and benefits

2.4 Biofilter performance for water treatment

The performance of stormwater biofilters will vary with characteristics of the design, site conditions, catchment, individual storm events, season and climatic variation. Optimal design will depend upon the objectives for the system, including the target pollutants, and contrasting conditions are often required for the removal of different contaminants. As a result, no single design can be expected to achieve optimal removal of all stormwater pollutants.

2.4.1 Pollutant removal performance

Evidence from laboratory studies and field monitoring has been compiled to indicate the concentration reductions that might be expected for each pollutant if 'best-practice' design, construction and maintenance are implemented to target that specific pollutant (Table 3). It is important to note that these are average performance metrics and performance can be temporarily reduced by extreme conditions, such as challenging wet or dry conditions or variable inflow concentrations.

Table 3. Pollutant removal capacity of biofilters, key design parameters and expected performance from systems that are optimally designed, constructed and maintained

Pollutant	Removal and critical design aspects	Expected concentration reduction if well designed and for 'typical' stormwater*
Nitrogen (N)	Removal is challenging, variable and highly sensitive to design parameters, retention time and climatic variability. Vegetation is essential and microbial processes important. Performance will benefit from careful plant species selection, minimal nutrient content in the media, inclusion of a submerged zone and carbon source, and measures to prevent extreme drying.	> 50% (Fletcher et al., 2007, Henderson et al., 2007, Zinger et al., 2007, Payne et al., 2014a)
Phosphorus (P)	Removal is challenging and sensitive to media composition, water dynamics and vegetation. Particulate-bound P is removed with sediment. Assimilation by plants and microbes also contributes, but similarly to N can be remobilised via decomposition. Importantly, P has no permanent removal pathway unless the plant biomass is harvested, so saturation can occur. Performance benefits from low media nutrient content, high cation exchange capacity (such as iron- or aluminium-rich media), prevention of extreme drying and maintaining aerobic conditions in the upper biofilter profile (Hatt et al., 2009, Hunt et al., 2006, Glaister et al., 2013, Glaister et al., 2014).	> 65% (Davis et al., 2006, Hsieh et al., 2007, Glaister et al., 2014)
Sediment	Physical removal via filtration by the media. Media composition is important, but removal is effective and consistent when fine-grained media (loamy sand) is used. Poorer performance is typically due to leaching of fine particles from the media itself (Hatt et al., 2008, 2009), hence appropriate transition layer design is important. Over time, clogging reduces infiltration capacity and will eventually require removal of the accumulated surface sediment.	> 95% (Blecken et al., 2007, Hatt et al., 2007)
Heavy metals	Removal is generally high irrespective of many design parameters (e.g. insensitive to vegetation or media depth). However efficiency and processing does differ between metals. A high fraction adsorbed to particulates, hence physical processes critical to removal. Hence, processes tend to follow those for sediment (above) with most removal in the surface layer. Plant uptake also contributes. Extreme drying should be avoided, and a submerged zone and carbon source can be beneficial (Hunt et al., 2008, Read et al., 2008, Hatt et al., 2007, Hatt et al., 2009).	> 90% (Blecken et al., 2009b, a)
Pathogens	Removal is challenging, with a wide range of pathogens and indicator species often present. Removal is influenced by wetting and drying variations, media composition, plant species, retention time and temperature. Retention is due to filtration, adsorption/desorption during wet periods and die-off during dry periods all important. Some drying and retention in a submerged zone is beneficial, but prolonged drying (>2 weeks) and back-to-back storm events are not (Chandrasena et al., 2012).	> 1 log reduction (i.e. > 90%) (Zhang et al., 2011, Zinger and Deletic, 2012, Chandrasena et al., 2014, Chandrasena et al., 2012)

Cont.

Table 3. Continued

Pollutant	Removal and critical design aspects	Expected concentration reduction if well designed and for 'typical' stormwater*
Organic micropollutants		
Hydrocarbons (TPHs)	Micropollutants incorporate a wide range of compounds, with varied chemical properties. Limited data on micropollutant processing is available. Many micropollutants can be retained by adsorption to the media during storm events and subsequently broken down over time by microbial respiration processes. However, the tendency for sorption and complexity of decomposition varies between compounds. In addition, the lighter hydrocarbons can volatilise. Removal can benefit from increased soil organic matter content (but this will compromise nutrient removal) and drying – even prolonged drying. Back-to-back storm events do not benefit removal as there is limited opportunity for decomposition and some adsorbed contaminants can be flushed. Removal of herbicides, chloroform and phenols can be particularly challenging with breakthrough possible (Zhang et al., 2014b). *It must be noted that biofilters cannot treat large oil spills, but can treat small quantities of hydrocarbons effectively.	> 99% Hydrocarbons*
PAHs (Pyrene and Naphthalene)		> 80% PAHs
Pesticides and Herbicides (Glyphosate, Atrazine, Simazine, Prometryn)		> 80% glyphosate <20 up to 50% atrazine & simazine
Other organic chemicals – **Phthalates (DBP, DEHP),** **THMs (Chloroform),** **Phenols (PCP, Phenol)**		< 80% TPHs and phthalates > 80% DBP and DEHP 20-50% Chloroform 50 to > 80 % Phenols (Zhang et al., 2014b)

**Note* – *Performance will vary with a range of factors including design, loading, climate, season etc. so this is a general indication only*

2.4.2 Hydraulic and hydrological performance

As stormwater moves through biofilters the flow hydrograph is altered. These hydrological changes help to shift the catchment response towards that of a natural catchment ('pre-developed'; without impervious urban surfaces), producing multiple benefits to stream health (Burns et al., 2012).

Biofilters slow stormwater flow rates and reduce the volume of stormwater discharged to downstream waterways. Water that is retained with the biofilter can then be lost via evapotranspiration, infiltration to surrounding soils (in unlined systems) and retention within the submerged zone or soil moisture storage. By slowing and retaining stormwater, runoff volumes and peak flow rates are significantly reduced, and the peak flow is delayed. In addition, biofilters can help to restore baseflow in urban streams, by increasing its contribution and persistence between events (Burns et al., 2012, DeBusk and Hunt, 2011). These changes to flow paths and rates will vary with evapotranspiration demand, biofilter design and characteristics of the catchment. Complying with filter media specifications (Appendix C), particularly in terms of low clay and organic matter contents, is important for optimal hydraulic performance, particularly under challenging wet conditions (Zhang et al., 2014b).

The hydrological performance of the biofilter itself is critical to its treatment capacity. Non-vegetated stormwater filters experience an inevitable reduction in infiltration rate over time, as a clogging layer of sediment accumulates on the surface of the filter media, and hydraulic loading leads to compaction. The degree of clogging will vary with sediment loading, pre-treatment measures (if present), filter size relative to its catchment and vegetation morphology (Virahsawmy et al., 2014). However, the vegetation present in biofilters can combat clogging and compaction because plant growth, stem movement and root turnover and senescence (creating macropores) acts to break the clogging layer and maintain porosity (Virahsawmy et al., 2014, Hatt et al., 2009).

Table. 4 Performance of biofilters for hydrological indicators, key design parameters and expected performance

Hydrological objective	Key design parameters	Examples of performance
Volume reduction	Will vary between different sized events, seasons and biofilter design (sizing, depth, evapotranspiration loss, water holding capacity of the media, use of a liner, inclusion of a submerged zone)	In a field system the outflow volume on average reduced by 33% of inflow volume, ranging from a 15-83% reduction (Hatt et al., 2009)
Peak flow reduction	Will vary with event, seasons and biofilter sizing to capture and attenuate the event (ponding depth, area, media depth, inclusion of a submerged zone).	A field biofilter reduced peak flow rates on average by 80%, varying from 37 – 96% across different events (Hatt et al., 2009)
Evapotranspiration loss	Will vary with seasons, climate, events, vegetation (species, density, presence of trees) and biofilter design	An unlined system surrounded by loamy sand and heavy clay soils, planted with sedges and in Melbourne's climate lost only 3% of inflows to evapotranspiration – approximately equal to its proportional sizing relative to its catchment (Hamel et al., (in press))
Infiltration rate	Vegetation helps to maintain long-term infiltration rate, reducing the effects of clogging. Plant species with thick roots are most effective.	Hydraulic conductivity will sharply decline initially (e.g. field system dropped from 300 mm/hr to 180 mm/hr in two weeks), may continue to fall (<100 mm/hr), but then recovers (e.g. to 150 – 200 mm/hr) as plants grow and establish (Hatt et al., 2009). Infiltration rate in vegetated areas of biofilters can be ~ 150 mm/hr higher than non-vegetated zones (Virahsawmy et al., 2014).

2.5 Benefits

The benefits of biofiltration extend far beyond the treatment of urban stormwater runoff (Table 5). These additional benefits can add substantially to social, economic and environmental values. Despite the challenges placing an economic value on many benefits, they should not be ignored as, in many cases, their contribution can justify the implementation of the technology alone.

Although the value of benefits will vary between regions and specific applications (CRC for Water Sensitive Cities, 2014a), the diverse range of values delivered by biofilters, and more broadly, by Water Sensitive Urban Design, will be realised in most projects. Values that can be most readily quantified have been discussed in Section 2.7.2 and Table 7.

Table 5. Multiple benefits of biofilters (both tangible and intangible), and more broadly, Water Sensitive Urban Design

Outcome delivered by biofilter	Resulting benefits	Evidence/Quantification
Improvement in quality of stormwater runoff	Improved water quality in local creeks, rivers, bays or lakes downstream (see Table 7). The improved health of riparian and aquatic environments: • Supports greater diversity and numbers of flora and fauna • Provides enhanced amenity for the local community & visitors • Improves community engagement and satisfaction with the local environment, • Increases the potential for use and enjoyment, which in turn delivers health benefits • Increases local property values • Reduces the need for expenditure on maintenance, management and works to restore degraded waterways and waterbodies • Increases commercial opportunities for fishing, tourism, sport and other activities associated with downstream waterbodies	• See Table 7 for studies that have quantified the economic benefits of pollutant reduction, increased property values and waterway restoration. • Business Case Analysis concluded WSUD does help to maintain and enhance economic uses of waterways (Water by Design, 2010a). • Living within close proximity to large and attractive areas of public open space increases the chances of more walking by 50% for members of the local community (Giles-Corti et al., 2005). • A survey highlighted the important social benefits provided by open and green environments within cities. People experienced positive emotions and benefits to their psychological well-being from interactions with nature within the urban environment (such as within an urban park) (Chiesura, 2004). • A survey and non-market analysis of a 1% increase in the reach length of healthy waterway was valued at $5.80/household/year across regions in Queensland. Similarly, a 1% gain in areas with good vegetation health was valued at $2.88/household/year. Healthy waterways were consistently valued higher than soil or vegetation values (Windle and Rolfe, 2006).
Pollutant collection – in sediment layer, media, vegetation	The concentration of pollutants at a central point allows: • Capture before pollutants are distributed widely throughout receiving environment – which increases costs and impacts • Appropriate management, including potential reuse or safe disposal	
Conversion of some pollutants into inert or stabilised forms	This transformation provides: • Permanent removal from the system (e.g. N into N_2 gas (denitrification), organic compounds into CO_2 and H_2O)	
Reduction in runoff volume and peak flow	Alteration of the hydrological regime towards pre-development conditions delivers: • Reduced erosion and scouring in downstream creeks and streams • Flow regime that better supports healthy macrophyte and aquatic invertebrate communities, and diverse and healthy in-stream and riparian vegetation	• Only 5-10% of connected impervious area within a catchment leads to poor stream health. However, the disconnection of stormwater runoff directly piped to streams can prevent this deterioration in stream health, and stormwater harvesting and treatment technologies are one potential solution (Walsh et al., 2012).

Cont.

Table 5. Continued

Outcome delivered by biofilter	Resulting benefits	Evidence/Quantification
	• Reduces the need to maintain or construct traditional stormwater drainage (e.g. piped underground networks) • Helps to mitigate localised flooding risk	• Scenario modelling revealed that harvesting of rainwater on-site reduces the volume of stormwater runoff exported, leading to moderate improvements in the flood risk – flood magnitude was reduced by ~20% for a high-density urban area with a significant degree of harvesting. On-site biofiltration will further reduce the risk of flooding (Burns et al., 2010). • Effective Imperviousness (a measure of the catchment area directly connected (i.e. piped) to streams) can be reduced from 45% on traditionally drained residential lots to 13% using permeable paving and a rainwater tank, and to 0% using a biofilter. In the streetscape, a further reduction from 26% using traditional drainage to 4% using streetscape biofilters can be achieved. Such changes on a catchment-scale can significantly improve stream health (Ladson et al., 2006).
Adds to neighbourhood aesthetics and improved land value	Improves the landscape and attractiveness of streetscapes, parking lots, median strips and other public or private spaces, which generates: • Increased local property values • Community satisfaction and sense of pride	• See Table 7 for studies that have quantified the economic benefits of pollutant increased property values, particularly those specific to raingardens. • Property values in Queensland estimated to increase by 0.25 – 1 % as a result of WSUD benefits for amenity and improved stream health (Water by Design, 2010a) • The conversion of a traditional main drain to a constructed stream in the Perth metropolitan area resulted in an increase in house prices by between $17,000 and $26,000 per house within 200 metres of the stream restoration project (CRC for Water Sensitive Cities, 2014b). This effect was in addition to the general trend of increasing house prices in the area. • Research around the world has consistently demonstrated that both housing and commercial developments near green space or water deliver increased property prices (E2DesignLab, 2011). • In Perth the value of a wetland was estimated to add $140 million AUD to property values within a 20 ha radius (Tapsuwan et al., 2009). • Rainwater tanks increase the value of house sales by up to $18,000 AUD in Perth, which exceeds the expected installation costs (Zhang et al., 2014a).

Cont.

Table 5. Continued

Outcome delivered by biofilter	Resulting benefits	Evidence/Quantification
Provides a green space, cooling and enhanced amenity in the urban environment	In the urban environment green spaces provide: • Microclimate benefits with significant cooling of the urban environment from evapotranspiration and shading – this reduces energy demand and benefits human health significantly. • Improvements to human health with increased mental wellbeing, exercise areas and socialising areas – providing a place in which people want to spend time. • Public amenity as cities approach higher density, with limited or no backyard environments. • Avoids the landscaping cost otherwise required for a garden bed or lawn occupying the space, instead providing additional benefits and functionality.	• As the density of the urban environment increases the proportion of heat stored increases, largely due to additional built surfaces but also reduced vegetation and albedo (Coutts et al., 2007). • Extreme heat is strongly related to adverse human health impacts, including deaths and increased hospital admissions (Loughnan et al., 2010). Without mitigation, increased heat waves from climate change are expected increase these impacts across vulnerable sectors of the community (Bi et al., 2011, Patz et al., 2005). For example, annual deaths related to hot weather in Australia have been predicted to increase to 2,300-2,500 by 2020 and 4,300-6,300 by 2050 (McMichael et al., 2003). • Views of gardens from hospital rooms have been related in various studies to lower patient anxiety, reduced pain and more rapid recovery. Studies have also related looking at natural vegetated scenes, even for only short moments, with relaxation and calmness following stress. Conversely, concrete and landscapes with hard features have the opposite effects (Ulrich, 2002). • Green spaces in urban environments provide a range of social, environmental and economic values including greater social inclusion, well-being, health, community cohesion, child development, scope for education, habitat provision and contaminant reduction (Swanwick et al., 2003). • Human health and well-being and strongly related to characteristics of the urban environment, particularly access to green spaces (Jackson, 2003). • Software developed in the US, i-Tree, provides a tool to quantify the ecosystem services of community trees at multiple scales. The tool enables valuation of the benefits of community trees in terms of pollution mitigation, storm water run-off reduction, carbon sequestration and storage and more. See https://www.itreetools.org/.
Visible water management	The treatment of stormwater above ground, where it is visible and available to provide additional benefits, creates: • Community engagement and education • Allows stormwater to be embraced as a valuable resource and part of the urban environment	• With good design, stormwater management adds value to urban amenity through opportunities for education, recreation and improved aesthetics and pleasure to the community. Much potential exists to integrate artistic influences into the design, which can further increase the amenity benefits (Echols and Pennypacker, 2008).

Cont.

Table 5. Continued

Outcome delivered by biofilter	Resulting benefits	Evidence/Quantification
Visible water management (cont.)	• Potential for unique and functional landscaped elements – a possible 'selling point' or increased brand for the area/development • Satisfaction among residents who seek sustainable lifestyle options	
Habitat and biodiversity	Provision of habitat for flora and some fauna generates: • Greater diversity and distribution of local indigenous plant species • Habitat for insects and birds in the urban environment	• Biofiltration systems enhance urban biodiversity with increased species, species richness, diversity and different composition when compared with traditional urban green spaces (such as garden beds and lawns) (Kazemi et al., 2009).
Supplies alternative and local water source (stormwater harvesting schemes)	In the case of stormwater harvesting projects, the recycled water supply allows: • A viable alternative water supply • Greener public spaces - supports larger irrigated areas and green spaces throughout the summer • Reduced demand for potable water • Reduced demand for water pumping across long distances • Increased security of supply - less subject to water restrictions and climate variability • Increases amenity for use (e.g. sports field) - delivering social and human health benefits	• A substantial portion of a city's water demand can be met with the volume of urban stormwater runoff (Walsh et al., 2012). • Stormwater harvesting helps to restore the hydrological regime and water quality within urban streams (as long as a volume exceeding pre-development flows is not extracted from the system) (Fletcher et al., 2007). • Stormwater harvesting projects offer multiple benefits and the potential for success is not generally limited by the available storage volume. Hydrological benefits include reduced volumes, peak flows and number of flow events, and good designs can at the same time also supplement the potable water supply (Mitchell et al., 2006). • Toilet flushing and garden water use comprises up to 45% of total demand – significant potential to reduce consumption of potable supply (City of Melbourne, 2009).
Passive and localised water treatment technology	Small-scale, distributed treatment of stormwater: • Has low energy requirements and no operational costs • Does not require large pipe collection/ distribution networks • Reduces need to invest in large centralised and heavily engineered infrastructure for water treatment plant • Reduces the need for irrigated garden beds and landscaping, instead providing 'self-irrigation'	
Provides shelter and screening	As a landscape element biofilters can be applied to provide: • Shelter from wind • Shading from the sun • A screen to improve the visual aesthetics (e.g. to conceal structures considered ugly), provide privacy or a visual barrier between carriageways	

2.6 Misconceptions

Many of the common concerns about biofilters can be addressed if the systems are well designed and constructed. Some typical concerns and their rebuttal or remedies are outlined in Table 6.

Table 6. Common concerns with the implementation of biofiltration and the reality or design solutions to mitigate the risk

Concern	Reality/mitigation with design,
Potential damage from infiltration in close proximity to sensitive structures (e.g. roads or high-rise buildings)	• Clear guidance on acceptable offset distances for infiltration in different soil conditions is provided in *Australian Runoff Quality* (Wong, 2006) • If required, a liner can be readily installed to form an impermeable barrier between the biofilter and the structure
Biofilters may provide mosquito habitat	• Biofilters are designed to dry out completely between storm events, and this drying will kill mosquito larvae • If properly sized, with healthy vegetation cover and sediment controls, water will not pond on the surface for more than approximately 6 hours after a storm ends – far shorter than the multiple days involved in the mosquito lifecycle.
Biofilters look ugly and messy	• Using good landscape design principles, careful plant selection (see Section 3.6.5) and maintenance, biofilters achieve the opposite effect, adding greatly to the aesthetics of the urban environment and providing multiple community benefits. • Plant species can be selected and layout designed to create a more formalised garden effect if desired (see Section 3.6.6).
Biofilters are expensive and difficult to maintain	• Unlike traditional civic landscapes, biofilters 'self-irrigate' and can also 'self-fertilise' if the incoming runoff contains elevated nutrients. • Once established, routine maintenance costs do not differ greatly from the maintenance of traditional street verge garden beds and urban landscaping. • In most cases the maintenance requirements are minimal and straightforward, if good design, construction and establishment principles have been implemented. Costly rectification works are usually required only in response to issues that arise from errors stemming from early in the project phase (E2DesignLab, 2014a).
Stormwater re-use presents health risks	• These risks are carefully managed via regulation and good design • Treatment via biofiltration systems offers significant and demonstrated pathogen removal from stormwater (see Section 2.4.1) • Re-use for toilet flushing and irrigation (particularly sub-surface) have low risk for human contact • The risk of drought can be managed using good design (e.g. options include use of a submerged zone, using deeper filter media, careful plant species selection, avoiding oversizing of the system, or allowing roots to access moisture in surrounding soils or shallow groundwater (if possible and appropriate for the site) (see Section 3.6.8) • Additional irrigation or 'topping up' of the submerged zone can maintain systems through extreme dry periods
Biofilters take up a lot of land	• If sized correctly (to treat small frequent storm events up to the 1 in 1 year ARI) the biofilter only needs to be approximately 2% of the effective impervious catchment area. Sizing for larger storm events is not required to meet water quality objectives – biofilters should neither be under- nor over-sized. • By undertaking stormwater management closer to source, for example implementing biofilters in road medians or verges, large biofilters in public open space are not required.

2.7 Cost-benefit analysis

2.7.1 Framework

Many of the benefits of stormwater biofiltration are intangible, which makes it particularly challenging to undertake a traditional cost-benefit analysis. Quantifying the economic value of social and environmental benefits is an area of ongoing research and projects are being undertaken, specific to WSUD technologies (for example (Polyakov et al., 2015, Zhang et al., 2014a)). However, currently there is still no accepted method for quantifying the less tangible benefits of stormwater biofilters.

In addition, willingness to pay, and equality of the distribution of benefits vs. costs, are challenging questions for WSUD business cases (Water by Design, 2010a). Despite widespread division of the benefits across time, the wider community and the environment, WSUD is generally financed at a more localised scale by the local residents, the developer and local council. Surveys have indicated that the community is willing to pay for environmental benefits such as improved stream health and cooler urban temperatures, but this is strongly and positively related to household income (CRC for Water Sensitive Cities, 2014c). It should also be noted that the costs of environmental degradation under traditional stormwater management are also shouldered by the wider community, including populations living downstream and future generations (Vietz et al. 2014). In addition, these costs magnify as damage accrues over time (Vietz et al. 2014).

This section outlines the key components and framework of a business case before summarising evidence of costs and benefits that have been quantified in various studies.

When assessing project costs, it is important to benchmark against the 'base case' (i.e. continuing to implement traditional drainage infrastructure and policies) scenario (Water by Design, 2010a, CRC for Water Sensitive Cities, 2014d). This should account for future scenarios without biofiltration (or more broadly, WSUD) implementation, and include the costs of:

- The economic, social and environmental costs from damaged waterway and water body health;
- Energy demands in hotter urban environments;
- Reduced human health and quality of life in urban environments that are hotter and less amenable to exercise and well-being;
- Maintenance of garden beds that may otherwise be situated in place of a biofilter;
- Increased flooding risk and the costs of additional drainage infrastructure to manage the risk using the traditional conveyance approach;
- Litter and sediment removal caught within pits and pipes in the conventional stormwater drainage network (Taylor and Wong, 2002);
- Increasing 'legacy' costs as the actions required to restore the health and function of damaged systems become more costly over time (as opposed to early intervention) (Vietz et al. 2014).

The framework of a business case for Water Sensitive Cities was developed at a workshop with researchers and industry professionals held by the CRC for Water Sensitive Cities (2014a). Although the costs and benefits were not quantified, the process drew upon evidence and industry experience to identify the implications of 'doing nothing' and the key benefits of adopting water sensitive principles. These are presented separately for each stakeholder, with the principle benefits attributed to different groups as follows:

Water authorities:
- Reduced investment in large-scale infrastructure
- Reduced operating costs for water management
- Enhanced business reputation
- Proactive management of future business risk e.g. addressing climate change risk
- Providing a range of service options for customers

Council or Government body:
- More green open spaces
- Lower costs for waterway management
- Reduced flood risk

Developers:
- Growth in land values
- Enhanced marketability and brand

Householders:
- Reduced water bills and increased property values
- Means to apply sustainability principles
- Increased water security and flexibility for water use (i.e. reduced restrictions)

Local community:
- Greener neighbourhoods that are more pleasant for walking and cycling
- Increased human health and well-being (e.g. better air quality and increased likelihood of walking and cycling) (For example, the RESIDential Environment Study (RESIDE), WA; (Hooper et al., 2014, Villanueva et al., 2015)).

Governments:
- Sustainable communities with less reliance on centralised systems
- Increased human health
- Greater affordability for water supply and avoids mounting future costs of doing nothing

2.7.2 Evidence

Costs vs. Benefits

Despite the challenges of undertaking cost-benefit analyses for WSUD projects, multiple studies have quantified the value of the project, or an aspect of the services provided (Table 7). While the relative benefits and costs will vary between locations and applications (Water by Design, 2010a), it is clear from Table 7 that **the multiple benefits of WSUD commonly exceed the costs of implementation.** This conclusion is simply supported by the few benefits that can be quantified – once methods have been developed to value the less tangible benefits, the business case will be further strengthened and justified. Importantly, a **comprehensive business case conducted by Water by Design (2010a) found that the benefits of nitrogen reduction alone exceeded the project life cycle cost, and that, similarly, the value of waterway restoration and enhanced property values also separately justified a large proportion of the total cost.**

Table 7. Evidence for a cost-benefit analysis of WSUD and stormwater biofiltration

Benefit/Cost	Outcome	References
Overall	Business case analysis concluded the **benefits of best-practice WSUD do surpass the costs**	Water by Design (2010a)
	A cost-benefit analysis in Pennsylvania highlighted the **broad range of environmental and social benefits** provided by Low Impact Development and Green Infrastructure systems which are **not typically provided by traditional approaches**.	U.S. EPA (2013)
Water quality	In Victoria a Stormwater Offsets Program operates to help developers meet the legislated reduction targets. **Nitrogen** (commonly the limiting nutrient in Port Phillip Bay) reduction is currently valued at **$6,645/kg N (in terms of annual total nitrogen load), based on the cost of stormwater treatment works implemented in the past by Melbourne Water** (effective 1st August 2014).	Melbourne Water (2015)
	Value of N reduction alone estimated to be **worth more than the project life cycle cost** (based on $515/kg N – cost to reduce load using wastewater treatment).	Water by Design (2010a)
Property values	**Increase in property values** from the greater amenity of healthy waterways estimated at **~90% of the capital costs of WSUD projects**.	Water by Design (2010a)
	The **amenity value of streetscape raingardens** in Sydney is realised in residential house prices, **increasing property values by around 6% ($54,000 AUD) for houses within 50 m and 4% ($36,000 AUD) up to 100 m away**. This demonstrates that raingardens are valued by the community, and a typical raingarden installation at a street intersection can generate around $1.5 million increase in residential value.	Polyakov et al. (2015)
	A **10% increase in tree canopy coverage on the street verge adds a property price premium of about AU$14,500**. A **broad leaf tree on the street verge** increases the median property price of a house by **AU$16,889** (4.27%).	Pandit et al. (2013)

Cont.

Table 7. Continued

Benefit/Cost	Outcome	References
Space and cost in new developments	With good design and early implementation **it is possible** to incorporate WSUD technologies into a development **without reducing the footprint of development land**. **Cost of implementation** equivalent to **< 1% of cost of a new residence**.	Water by Design (2010a)
Construction / capital costs	**Construction cost** of WSUD in new residential developments **can be no higher than traditional costs**, particularly if contractors are familiar with these systems	Fletcher et al. (2004), Lloyd et al. (2002)
	Concluded **LID projects** in most cases lead to **reduced costs while also providing environmental benefits**. Cost savings often due to less need for site levelling and preparation, infrastructure to convey stormwater, paving and landscaping. Capital costs reduced by 15-80% using LID in many cases. Few exceptions where costs were higher for LID relative to traditional techniques. Notes not all benefits quantified e.g. enhanced aesthetics, recreation potential, higher property values, increased units developed, marketability and rapid sales, also many environmental benefits.	U.S. EPA (2007)
	Case study of streetscape tree pits suggested using **WSUD technology had a lower cost in detailed design** ($9000 compared to $15000 for conventional systems) **and construction** ($90,000 for WSUD compared to $150,000 for conventional)	City of Melbourne (2009)
	Across multiple projects in Lenexa, Kansas, **capital cost savings** (~$10,000's-$100,000's) **from Low Impact Development (LID) and Green Infrastructure (GI)** across various developments. Savings stem from site work requirements and cost of infrastructure.	U.S. EPA (2013)
	Evidence from a review of case studies and literature illustrates the **capital cost savings and multiple benefits** that can result from a WSUD approach.	Taylor and Wong (2002)
	A literature review assessing the use of WSUD to treat stormwater runoff in port facilities suggested the same benefits can be achieved at a **lower cost than traditional stormwater treatment methods**.	Harne (2013)
Maintenance costs	Cost-benefit analysis highlighted the **economic benefits of pro-active maintenance. Increased maintenance is accompanied by higher costs, but found this cost was offset by the benefits** (quantified value of nitrogen reduction, reduction in potable water demand, community willingness to pay, protection of seagrass) **and savings** (i.e. reduced frequency of renewal). *Note – not all recognised benefits could be quantified, including: i.) supporting fish and bird populations, and fishing and tourism industries; ii.) improved waterway health; iii.) flood mitigation; iv.) aesthetic benefits and improved property prices; and v.) enhancements to microclimate – higher ET and heat retention.	Browne et al. (2013)

Cont.

Table 7. Continued

Benefit/Cost	Outcome	References
Waterway restoration costs	**Saved costs from waterway restoration works** (required under the base case scenarios) **valued at ~70% of project life cycle cost.**	Water by Design (2010a)
	The **business case** for water sensitive approaches to stormwater **is powerful** when the **costs of saved waterway restoration works are added to the localised benefits. The cost of 'doing nothing' is predicted to exceed the cost of implementing WSUD**. Avoided downstream costs include works to address erosion of stream channels and riparian zones, flood mitigation infrastructure and potential damage, poor amenity and reduced stream and riparian biodiversity, reduced capacity to process nutrients and poor health in the receiving coastal environment.	Vietz et al. (2014)
Community support	Examples of **strong community support for WSUD projects** (> 90% in support) and value the outcomes for water quality and amenity of the local area	Fletcher et al. (2004) , Lloyd et al. (2002)
Community value	A cost-benefit analysis undertaken in Sun Valley, California, illustrated the **higher value to the community from multi-objective stormwater projects**, relative to those with the single objective of flood control.	U.S. EPA (2013)

Life-cycle costs

Estimated costs from the life cycle of biofiltration systems are summarised in Table 8. These are divided between different types of systems due to variation in their costs. **Factors driving differences in cost** include:

System size– the benefit of economies of scale for larger systems is evident in the capital costs expressed per unit area (Table 8). Moreover, a cost review undertaken by Knights et al. (2010) found greater cost variation for the construction of small streetscape systems (<50 m^2, \$500 - \$2000/m^2), yet more consistency for the cost of larger systems (> 100 m^2; \$500-\$750/m^2). This was attributed to a higher ratio of edge to media area for small systems - as the edge requires varying construction techniques from concrete to earthen walls - and to the higher standard expected of visible streetscape systems.

The general, the pattern of decreasing costs with system size continues for maintenance costs, except for the very large systems where the interior is farther from vehicle access, which can reduce time and labour efficiencies. However, in terms of rectification costs, economies of scale do not necessarily apply, as there is more at stake if larger systems fail.

- **System complexity** – systems with more sophisticated hydraulics and engineered structures (e.g. underdrain, pits and pipes), or those with highly novel configurations, will require additional design, construction and maintenance costs relative to simpler systems.
- **Site characteristics** – the slope, access, subgrade and other aspects of the site will influence the design requirements and construction techniques employed, all of which can significantly influence the cost (Knights et al., 2010). For example,
    - ¬ In particular, **features at the perimeter of the system** (batters, walls, rock, drainage) demand a high fraction of the cost.
    - ¬ **Steep sites** require more cut and fill and higher retaining walls.
    - ¬ If **site access** crosses through steep terrain greater sediment control is required. Consider access requirements and costs during the initial feasibility assessment of the project.
    - ¬ **Online systems** can cost more than offline systems due to interruptions during wet weather, and higher sediment and litter loads. Construction of a bypass is critical for online systems.
    - ¬ The **cost of excavation** will depend upon site geology, depending upon the characteristics of underlying sand, clay or rock material. However, rocky sites are not necessarily more expensive, particularly in soft rock such as sandstone. Excavation may be a cheaper option than wall construction with less excavation.
    - ¬ **Earthworks and drainage** require a sizeable portion of the cost, generally comprising 10-30% and 15-25% respectively.
    - ¬ **Wall construction**, if required for large and steep sites, can comprise 10-15% of the total cost, and **rock excavation and roadworks** can cost up to 20% of the total cost. However, Knights et al. (2010) also found that biofiltration systems can still be constructed on steep or challenging sites without deviating from the same general cost relationship applicable to other sites.
- **Disposal of excavated soil** – can also be a significant cost driver and depends upon the quality of the material, with contaminated or weedy soils more costly to dispose. Take care to factor this in to the total cost. Before the project proceeds, conduct preliminary site investigation and soil testing if feasible, particularly if soil contamination is likely. If appropriate, the cheapest option is on-site re-use but if spread across the surrounding area a capping layer of topsoil is recommended, to limit the maintenance costs of weed management and re-establishing vegetation (Knights et al., 2010).
- **Presence of a canopy layer** – Biofilters have lower maintenance costs when a canopy layer of trees is present (<\$1/m^2 filter media/year), relative to those with understorey plants alone (\$5/m^2 filter media/year). This has been anecdotally reported and confirmed with an analysis of maintenance data by Water by Design (2015). It was attributed to the shading effect of trees and their litter in reducing weed invasion (Water by Design, 2015). Trees may also help to prevent severe drying of the biofilter surface and drought effects on understorey plants. Water by Design (2015) provides examples of resilient neighbourhood-scale systems with canopy layers that have lacked regular maintenance for many years.
- **Grouping or isolation of biofilter** – Another trend quantified by Water by Design (2015), streetscape biofilters may cost half as much to maintain if grouped within the same street, rather than separately located systems.
- **Level of service provided by council or the asset owner** – this will be influenced by the level expected for the community and may be higher for systems in highly visible public places (City of Melbourne, 2009).
- **Catchment characteristics** – some sites will experience high sediment or plant litter loads, which will require more frequent inspection and maintenance, particularly those with a high level of construction in the catchment.

- **Experience of personnel** – using experienced and skilled staff or contractors, with an understanding of how the system works (or willingness to consult with the designer) and key construction risks (Section 4.2) can reduce long-term costs. Poor workmanship or errors can lead to a failed system and expensive rectification works (Knights et al., 2010).
- **Flexibility of the design** – while a detailed design from the outset is vital, the capacity for appropriate review and revision by the designer if unexpected site characteristics are discovered, can save substantially on costs (Knights et al., 2010).
- **Internal (in-house) versus external contractors** – in-house works can lead to significant cost advantages and other benefits (e.g. skill development and knowledge retention), but the cost saving does not always result and without appropriate experience construction quality can suffer (Knights et al., 2010).

Table 8. Life cycle cost estimates for biofiltration

Stage/s	Source	Estimated typical cost
		Tree pits
Design	(Little data available)	
	Knights et al. (2010)	Generally 10-15% of total cost
Construction – Capital costs	Parsons Brinckerhoff (2013)	Small <10 m^2 – \$4000-\$8000/m^2 *Medium 25 m^2 – \$2,000/m^2* *Large > 50 m^2 – \$1,000/m^2*
	Browne et al. (2013)	*\$1,040/m^2*
	Department of Planning and Local Government (2010)	
	City of Melbourne (2009)	*~\$1,300/m^2*
	Knights et al. (2010)	*\$500-\$2000/m^2 (retrofitted systems in Sydney)*
	Water by Design (2010b)	\$400/m^2 (small or complex) *All costs for design & construction, including landscaping
Establishment	Parsons Brinckerhoff (2013)	~ 2-5 times routine costs
Routine maintenance	Parsons Brinckerhoff (2013)	Contract rates: Good access & min traffic management -\$20-\$180/yr/asset Traffic management/access difficulties/grate lifting difficult - \$150-\$700/yr/asset
	Browne et al. (2013)	\$31.20/m^2
	City of Melbourne (2009)	

In addition, long-term expenditure can be minimised by proper establishment of the system (early investment is compensated for by prolonged lifespan and avoided rectification costs) and proactive and regular maintenance. Budget planning is also facilitated by separating the costs of routine maintenance from unplanned and costly rectification or renewal works, which skew estimated costs (Mullaly, 2012). Tips for long-term success with minimal maintenance costs are provided in Sections 2.7.3, 3.6.1 and 4.3.1.

For a detailed cost analysis on maintenance for different types of biofilters, readers are referred to Water by Design's *Guide to the cost of maintaining bioretention systems* (2015).

Raingarden / Street-scale biofiltration	**Bioretention basin/larger systems**	**Biofiltration swale**
Small 5-50 m^2 – $1,000-$2,500/m^2 *Medium 100 m^2 –$750/m^2* *Large > 250 m^2 –$500/m^2*	Small 100 m^2 – $800/m^2 *Medium 300 m^2 – $250/m^2* *Large 500 m^2 – $50/m^2*	$130-$170/m^2
$380/m^2		
$137/m^2 of bioretention trench (or $410/m length of trench for 3 m x 1 m wide system)		
	$500-$750/m^2 for systems >100m^2	
Typical total cost breakdown: drainage (15-25%), earthworks (10-30%), media placement (<10%), planting (<10% but up to 20%), landscaping (5-10%) *If required, wall construction (10-15%) and rockworks and roadworks (up to 20%)*		
$365/m^2 (medium)	$270/m^2 – no sediment protection $300/m^2 – sediment protection during construction in catchment	
~ 2-5 times routine costs	~ 2-5 times routine costs	~ 2-5 times routine costs
Contract rates: Small > 50 m^2 – $20-$35/yr/m^2 Medium 100 m^2 – $15/yr/m^2 Large > 250 m^2 – $5-$10/yr/m^2 In-house & case studies data: <100 m^2 – $5-$16/yr/m^2	In-house & case studies data: 400-700 m^2 – $3-$5/yr/m^2	$2-$6 /yr/m^2
$11.40/m^2		
$8.80/m^2 (low maintenance) $13.25/m^2 (high maintenance)		

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Table 8. Continued

Stage/s	Source	Estimated typical cost	
		Tree pits	
	Water by Design (2015)		
	Water by Design (2010b)		
Renewal	Parsons Brinckerhoff (2013)		
	Browne et al. (2013)	$780/m^2	
	Knights et al. (2010)		

Comparison against the base-case

The costs association with biofilter construction, establishment and maintenance should be **compared with costs that would be incurred for the base case** (i.e. traditional stormwater drainage and land development). These include:

- **Landscaping costs** – biofilters provide landscape amenity and are largely self-watering and self-fertilising gardens. In many cases traditional civic landscaping would be otherwise be developed in place of a biofilter. Landscaping Victoria suggests an average project cost of $150-$350/m^2 (data from May 2009, assumes 60% soft landscaping and 40% hard landscaping works) (Landscaping Victoria website). Lower cost estimates were used in a biofiltration business case analysis by Water by Design (2010a). Garden bed landscape design and construction was estimated at $55/m^2 and maintenance costs $2.50/m^2/year (using guidance from landscape architects), while turf areas were estimated to cost $15/m^2 in design and construction and $1/m^2/yr for maintenance.

- **Traditional drainage network capital costs** – these costs are considerable. Quick reference to several Stormwater Asset Management Plans from city councils indicate replacement costs for the stormwater pipe network can be in the order of $185,000/km (CT Management Group, 2011, Moreland City Council, 2006), and in other cases up to $430,000/km (City of West Torrens, 2012, Adelaide City Council, 2008). Replacement costs increase further if other stormwater infrastructure such as pits, junctions, culverts and gross pollutant traps are included (e.g. ~$240,000/km of pipe network (Moreland City Council, 2006), $280,000/km (CT Management Group, 2011, City of Playford, 2012), $570,000 (Adelaide City Council, 2008, City of West Torrens, 2012).

- **Sediment and litter removal from conventional drainage network** – the council Stormwater Asset Management Plans also indicate the high cost of maintaining the traditional drainage network. Pipe cleaning and inspection can cost in the order of $1,000/km of pipe network, or $1,850/km if general maintenance, inspection and cleaning of pits are included (please note this figure is based on one council report only; (CT Management Group, 2011)).

Combined, the evidence provides a compelling business case for adoption of stormwater biofiltration, with benefits far exceeding those of the narrow services provided by traditional stormwater infrastructure.

Raingarden / Street-scale biofiltration	Bioretention basin/larger systems	Biofiltration swale
Understorey vegetation only : \$20-\$30/yr/m^2 (isolated system) \$10-\$15/yr/m^2 (grouped same street) (cost per m^2 filter media, excludes administration costs)	Precinct-scale (100-800m^2) - Understorey vegetation only: \$5/yr/m^2 Canopy and understorey: <\$1/yr/m^2 Large systems (>800m^2) – Understorey vegetation only: ≥ \$5/yr/m^2 Canopy and understorey: ≥ \$1/yr/m^2 (cost per m^2 filter media, excludes administration costs)	
Establishment maintenance (first 2 years) - \$15/m^2/yr (including landscaping cost of \$2.50/m^2/yr) – weeding, replanting, sediment removal Ongoing maintenance - \$5/m^2/yr		
2Sediment removal & disposal – unknown Minor re-set – \$50-\$100/m^2		
\$285/m^2		
Estimate 20-40% of original construction cost (based on cost of excavation and replacement of filter media, re-planting), but not including cost of disposal of potentially contaminated media, nor any structural rectification works to correct poor design or construction.		

2.7.3 Planning for effective maintenance (and reduced long-term costs)

Maintenance costs are frequently a concern to asset owners. In particular, uncertainty surrounding the long-term costs and a growing asset base can pose management challenges. However, these difficulties can be significantly reduced if maintenance is planned for early in design and clearly differentiated from rectification works. If well designed and implemented, biofilters require minimal maintenance. Tips for designing low-maintenance systems are outlined in Sections 2.7.3, 3.6.1 and 4.3.1, but maintenance requirements and cost can be minimised with planning at an organisational level by:

- Seeking **input from the maintenance team early in design** and throughout the project to ensure maintenance issues are addressed and well planned (e.g. access, ease of checking and cleaning pits and pipes).

- **Clearly distinguishing routine maintenance activities from rectification** works. The City of Port Phillip has clearly defined the distinction and this facilitates planning and budgeting, with funds sourced from separate council budgets (E2DesignLab, 2014b).

- In addition, **maintenance during the establishment period should also be differentiated** in terms of planning and requirements – maintenance needs will be higher during this period, while tasks and frequency of maintenance must be tailored accordingly. However, this **early investment in system establishment will lead to reduced long-term costs** for maintenance and rectification works.

- **Allocating sufficient budget early** in the project, as the total budget is scoped, to support a high level of maintenance during establishment and ongoing routine maintenance.

- Implementation of **good design, construction and establishment procedures.** This avoids costly rectification works in the majority of cases, leaving only relatively minor and inexpensive routine maintenance tasks (E2DesignLab, 2014b, a). Hence, a greater upfront commitment of funds to develop a functioning system can be more than offset by savings from reduced long-term maintenance and rectification.

- Undertaking **timely and regular maintenance** allows any issues to be identified early and corrected before the problem escalates to require more costly rectification works. This approach has been demonstrated to be significantly more cost-effective than no or infrequent maintenance by Browne et al. (2013) and Mullaly (2012). For example, if blocked outlets or overflow structures are discovered and cleaned before the system experiences prolonged flooding, the cost of replanting can be avoided.

- **Budgeting for asset renewal and including the depreciation cost of assets**. This is not always factored into planning, but including these costs allows justification of the benefits of spending on maintenance (Browne et al., 2013).

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Chapter 3: Technical Considerations

3.1 Introduction

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

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

3.2 Setting management objectives

3.2.1 Performance targets for biofiltration

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

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

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

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

3.3 How does a biofilter work?

3.3.1 Components of a biofilter

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

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

1. **Hydraulic controls:** These are structures that control both the inflow rate and the volume of stormwater into the plant/filter media zones of the biofilter. They incorporate the following:
    a. Inflow zone – controls the inflow rates into the system;
    b. Overflow or bypass capacity – controls the volume of water that is treated, allowing high flows to exit or bypass the system; and
    c. Ponding/detention depth on top of the media – controls the volume of water that is detained for treatment (and thus determines the frequency of bypass).
2. **Vegetation:** Plants are crucial for both removal of nutrients and maintenance of hydraulic conductivity (K_s). Plant roots also harbour the majority of the microbial community (in the zone surrounding the root; the rhizosphere), which are also essential for pollutant removal and transformation processes. Plants also contribute to the reduction of outflow volumes via evapotranspiration, which can additionally help the local microclimate. Vegetation should therefore be carefully specified according to the system objectives as well as the local climate.
3. **Filter media:** The purpose of the filter media is to both remove pollutants (through physical and chemical processes), as well as to support the plants and microbial community that are responsible for biological treatment. The filter media also reduces peak flows and outflow volumes by detaining and retaining runoff. The different media layers are designed to facilitate pollutant removal and allow the system to drain. The filter media generally has three layers:
    a. Soil/sand-based media, where most treatment occurs;
    b. Transition layer, which serves to prevent washout of filter media; and,
    c. Drainage layer – collects treated water at the bottom of the filter and conveys it to the drainage pipes;
4. **Raised outlet (creates a temporary submerged zone):** This provides benefits irrespective of whether the system is unlined or lined. The raised outlet allows water to pond in the lower layers of the biofilter, creating a submerged zone which provides moisture to plants (vital across extended dry periods), prolonged retention and superior pollutant removal (particularly for nitrogen). If connected to a conventional stormwater drainage system, a reduced drop in head is required to achieve a given biofilter depth. If the system is unlined a raised outlet promotes exfiltration to surrounding soils, and if combined with a liner it will create a longer-lasting submerged zone.

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

1. **Liner (creates a longer-lasting submerged zone in conjunction with a raised outlet)**: This will prevent exfiltration into surrounding soils, which is desirable to collect treated water for re-use in stormwater harvesting schemes, if sensitive structures nearby require protection (refer to *Australian Runoff Quality* (Wong, 2006) for allowable offset distances), or if interaction with shallow groundwater is not desirable. With a raised outlet, a liner provides a more durable submerged zone, which is essential and strongly recommended in dry climates (where > 3 weeks dry periods are common). Without this moisture retention, desiccation can lead to plant death and significantly reduced water treatment.
2. **Carbon source (e.g. wood chips):** Recommended when a liner and submerged zone are present to provide electrons to drive denitrification, particularly in early biofilter life before plant roots establish at depth (as roots also release carbon that can be utilised by microbes). It is mixed throughout the media comprising the submerged zone (i.e. the sand transition and drainage layers).
3. **Outflow controls:** These dictate how treated water leaves the system, which may be through exfiltration into the surrounding soils (if the system is unlined or partly unlined) and/or direct outflow through a drainage pipe. If outflows are collected for an outflow pipe a slotted pipe may be included as an underdrain to help flow conveyance out of the system.

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

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

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

Essential components and function	**Key information can be found within Biofilter Adoption Guidelines (CRC for Water Sensitive Cities, 2015), Section…**	
Inflow	Delivers stormwater into biofilter	3.6.3
Overflow	Allows high flows to bypass to avoid damage to system	3.6.3
Ponding	(or detention zone) Increases treatment capacity by allowing stormwater to pond before infiltration	3.6.2
Vegetation	Serves multiple roles in water treatment via uptake, transformation to organic forms, carbon provision to microbes, transpiration reducing stormwater volume, stabilising media surface, helping to maintaining infiltration rates, provides cooling to surrounding environment, amenity and aesthetics. The microbial community associated with plant roots facilitates uptake, decomposition and transformation of stormwater pollutants and plant litter.	3.6.5
Filter media	Provides physical filtration of particulates, physiochemical pollutant removal processes such as adsorption, fixation, precipitation, supports vegetation growth and the infiltration of stormwater attenuates and reduces the magnitude of the outflow hydrograph (providing stream health benefits)	3.6.4
Transition layer	Coarse sand. Provides a bridging layer to prevent migration of fine particles from the upper filter media to the gravel drainage layer	3.6.4
Drainage layer	Gravel. Allows the system to drain, either into a collection pipe and outflow point or infiltration into surrounding soils, also provides higher porosity to temporarily store stormwater between pores	3.6.4
Unlined	Allows infiltration into surrounding soils, either for the entire or only part of the system	3.6.3
Pre-treatment	Collects coarse sediment and litter, helping to protect the biofilter itself from premature clogging and blockages, and facilitating maintenance. Recommended for all systems except those whose impervious catchment is < 2ha in size without identifiable sediment sources, or systems only receiving roof runoff (Water by Design, 2014).	3.6.3
Additional components (depending upon treatment objectives and site conditions)		
Collection pipe	Underdrain formed with slotted pipe and used to drain and collect effluent from the system. May not be needed for small systems, nor for those with only exfiltration and no outflow pipe.	3.6.3
Raised outlet; creates temporary submerged zone	Strongly recommended, providing multiple benefits for water treatment and plant survival. Allows ponding in the lower portion of the biofilter, increasing moisture availability for plants and providing larger retention capacity for the temporary storage of stormwater. If the system is unlined, the raised outlet promotes exfiltration and creates a temporary submerged zone. Alternatively, if combined with an impermeable liner, it provides a longer-lasting submerged zone which benefits nitrogen removal via denitrification.	3.6.3

Cont.

Table 9. Continued

Essential components and function	**Key information can be found within Biofilter Adoption Guidelines (CRC for Water Sensitive Cities, 2015), Section...**	
Submerged zone (or Saturated zone)	Created using a raised outlet, but may be temporary (if system unlined) or longer-lasting (if lined). Serves multiple roles: i.) provides a water supply to support plant and microbial survival across dry periods; ii.) benefits N removal, particularly following dry periods; iii.) provides anaerobic conditions for denitrification; iv.) provides prolonged retention for a volume of stormwater – which allows longer processing time.	3.6.3
Liner; creates long-lasting submerged zone	Prevents infiltration and may fully or only partially line the system	3.6.3
Carbon source	(wood chips) Mixed throughout the submerged zone when a liner is present. As the carbon source decomposes, it provides electrons to drive denitrification	3.6.4

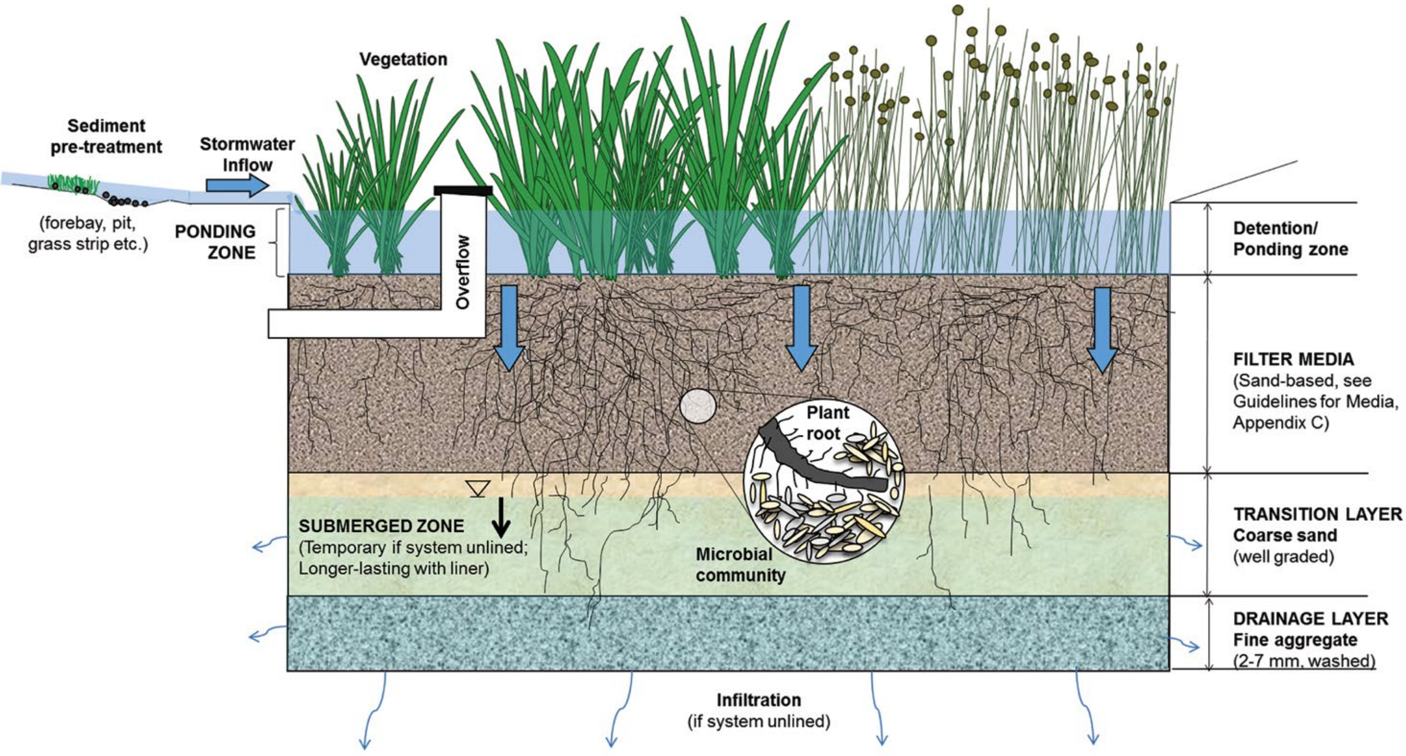


Figure 6. Essential components for stormwater biofilters (although note that configurations can vary widely from the general illustration shown above)

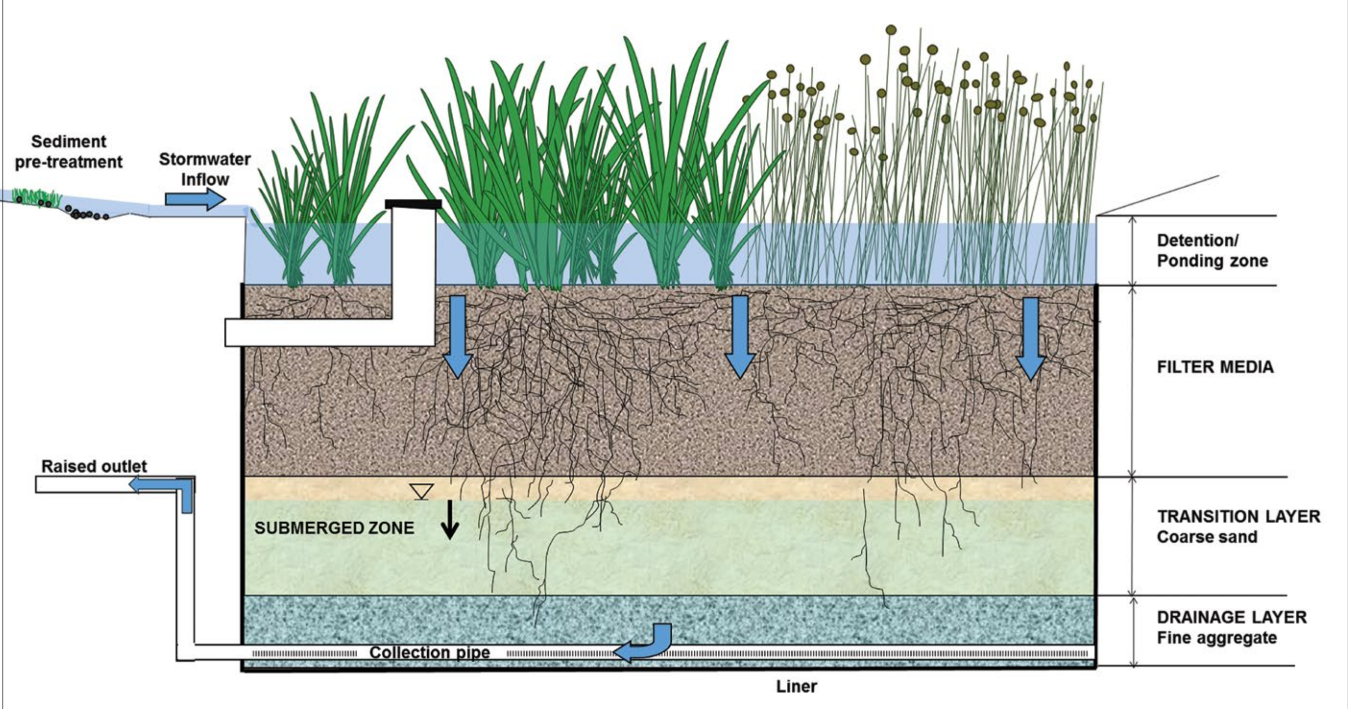


Figure 7. Typical biofilter configuration recommended for dense urban areas and/or where prolonged dry spells are experienced

3.3.2 Biofilter functioning and processes

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

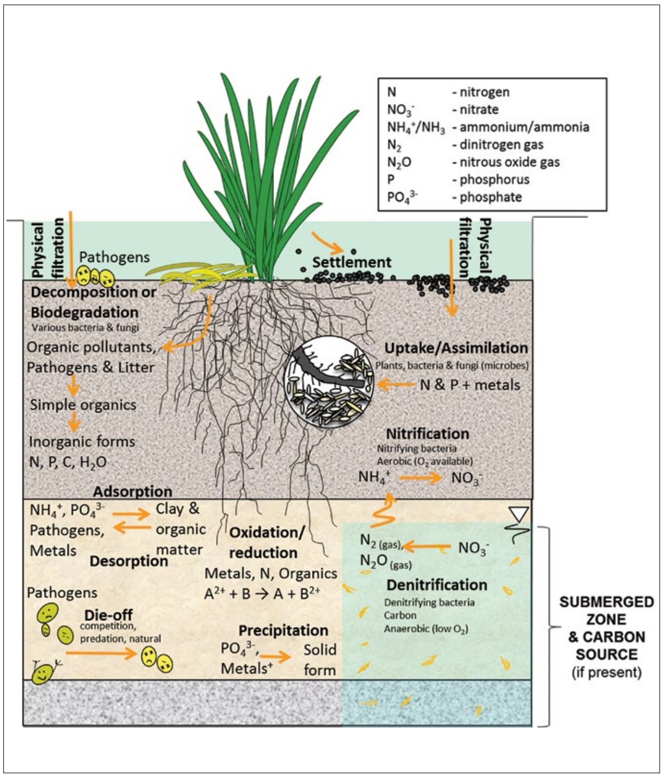


Figure 8. Key processes involved in pollutant attenuation, removal or transformation in stormwater biofilters

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

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

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

3.4 Conceptual design

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

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

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

Conceptual design tip

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

Important!

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

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

3.4.1 Linking design parameters to management objectives and site conditions

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

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

Possible objectives are discussed in Section 3.2.1 and could include:

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

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

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

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

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

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

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

Cont.

Table 11. Continued

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

3.5 Key design configurations

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

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

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

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

Important!

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

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

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

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

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

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

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

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

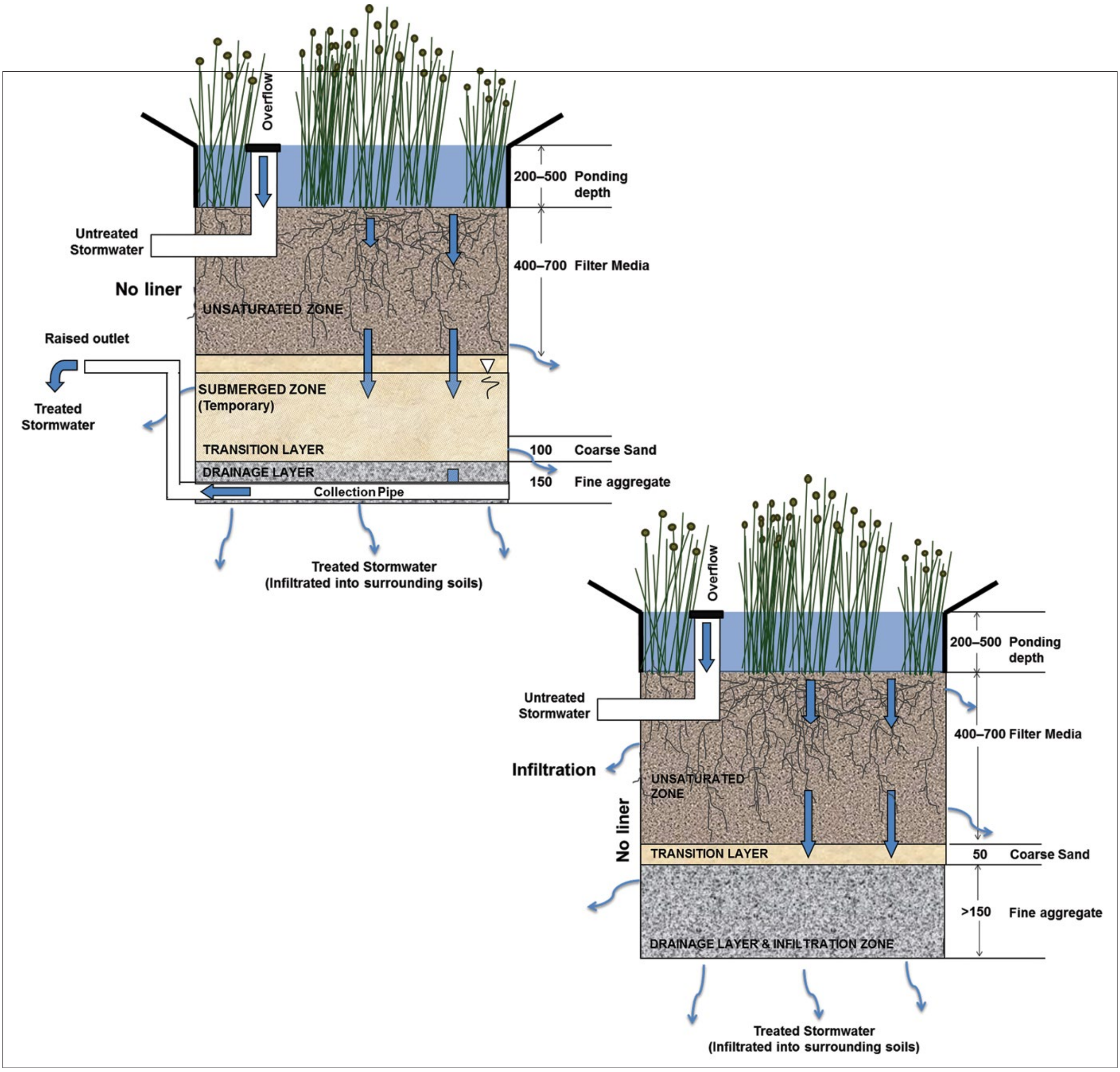


Figure 9. Unlined standard biofiltration system with raised outlet (top) and without formal outflow drainage (i.e. all exfiltration; bottom)

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

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

This type of biofilter is optimal for the following cases:

- Climates that have very long dry spells (because the longer-lasting submerged zone will act as a water source to support the plants and microbial community for several weeks without rainfall; Section 3.6.3);
- Sites where exfiltration is not possible. For example, where

there is a need to protect built infrastructure, or interaction with a shallow groundwater table is undesirable. Refer to *Australian Runoff Quality* (Wong, 2006) for allowable offset distances from specific structures;

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

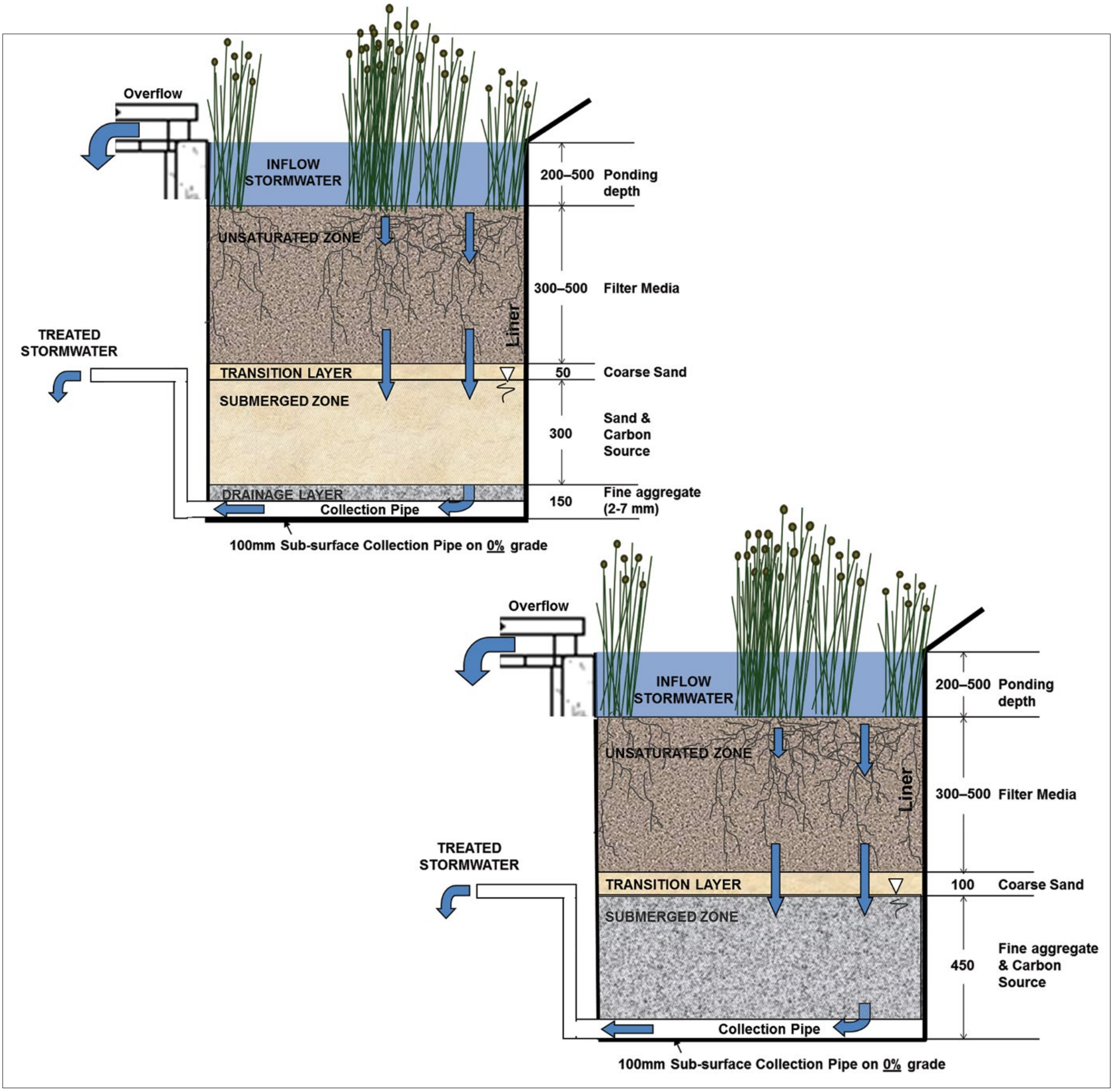


Figure 10. Lined biofiltration system with submerged zone comprised of sand (top) and fine aggregate (bottom)

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

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

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

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

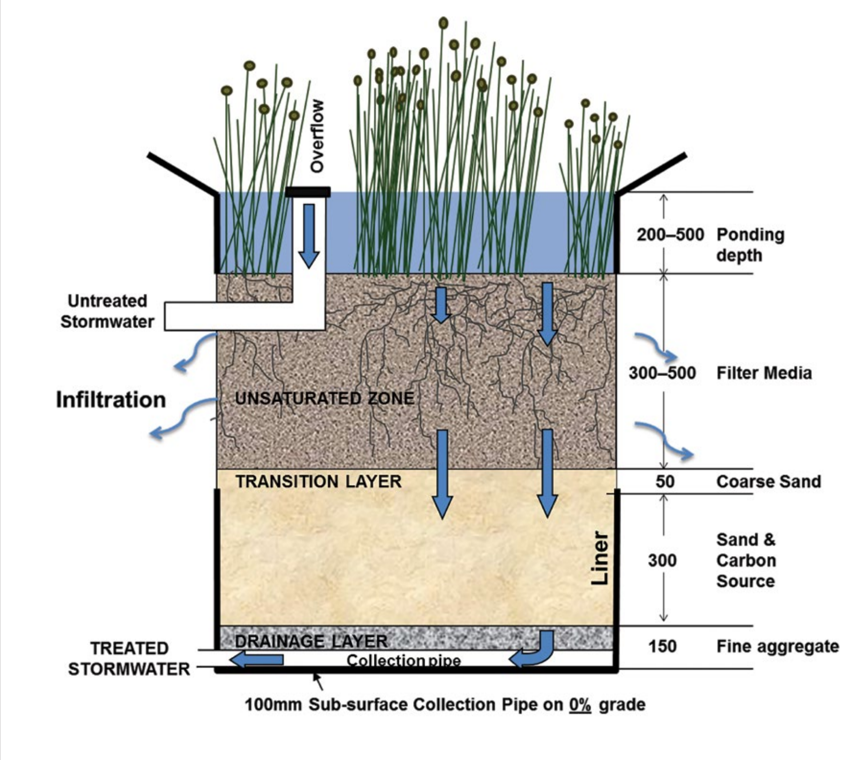


Figure 11. Partially unlined biofiltration basin with submerged zone

3.5.4 Bio-infiltration system with both lined and unlined cells

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

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

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

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

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

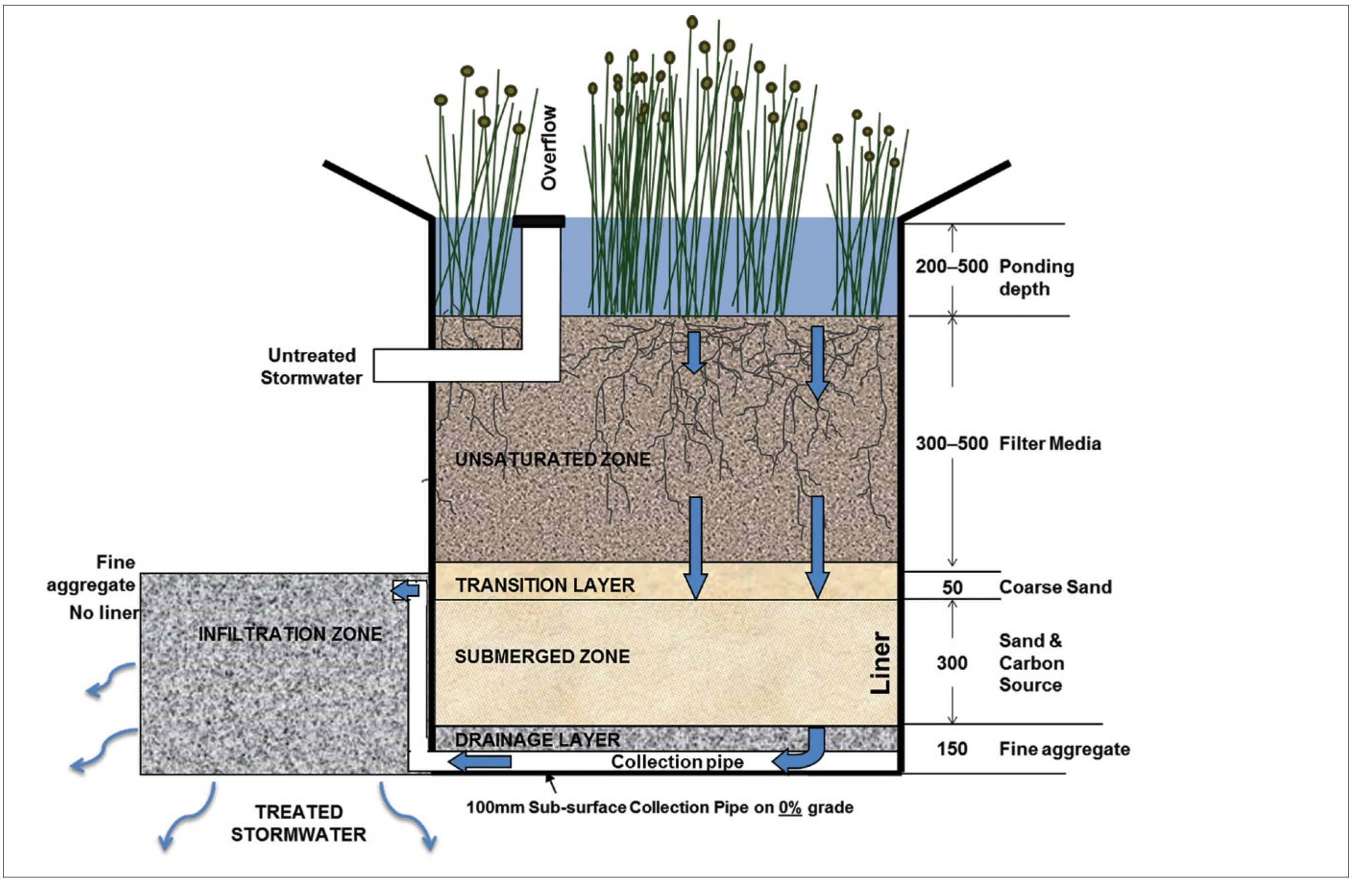


Figure 12. Schematic of a bio-infiltration system containing a submerged zone.

3.6 Design procedure

3.6.1 Introduction; Designing for successful long-term operation

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

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

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

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

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

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

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

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

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

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

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

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

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

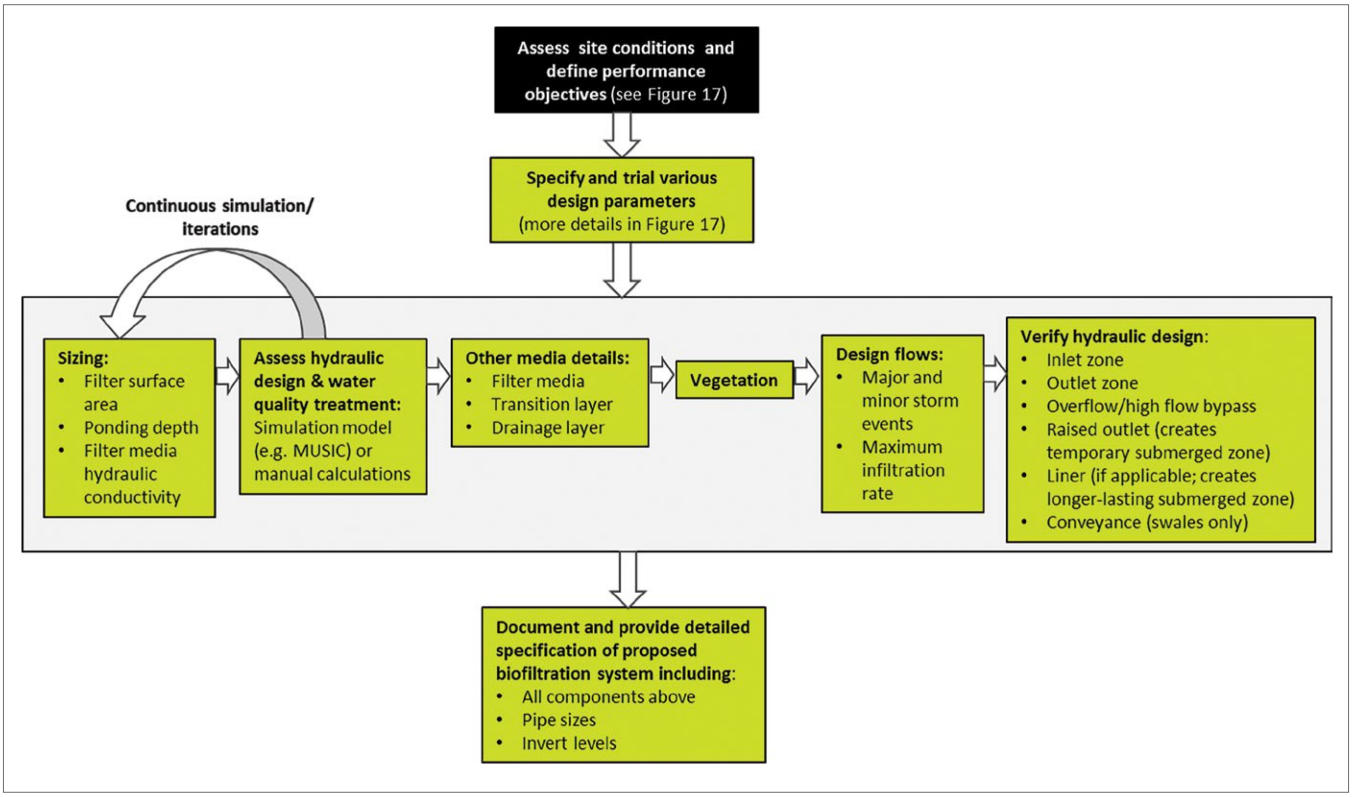
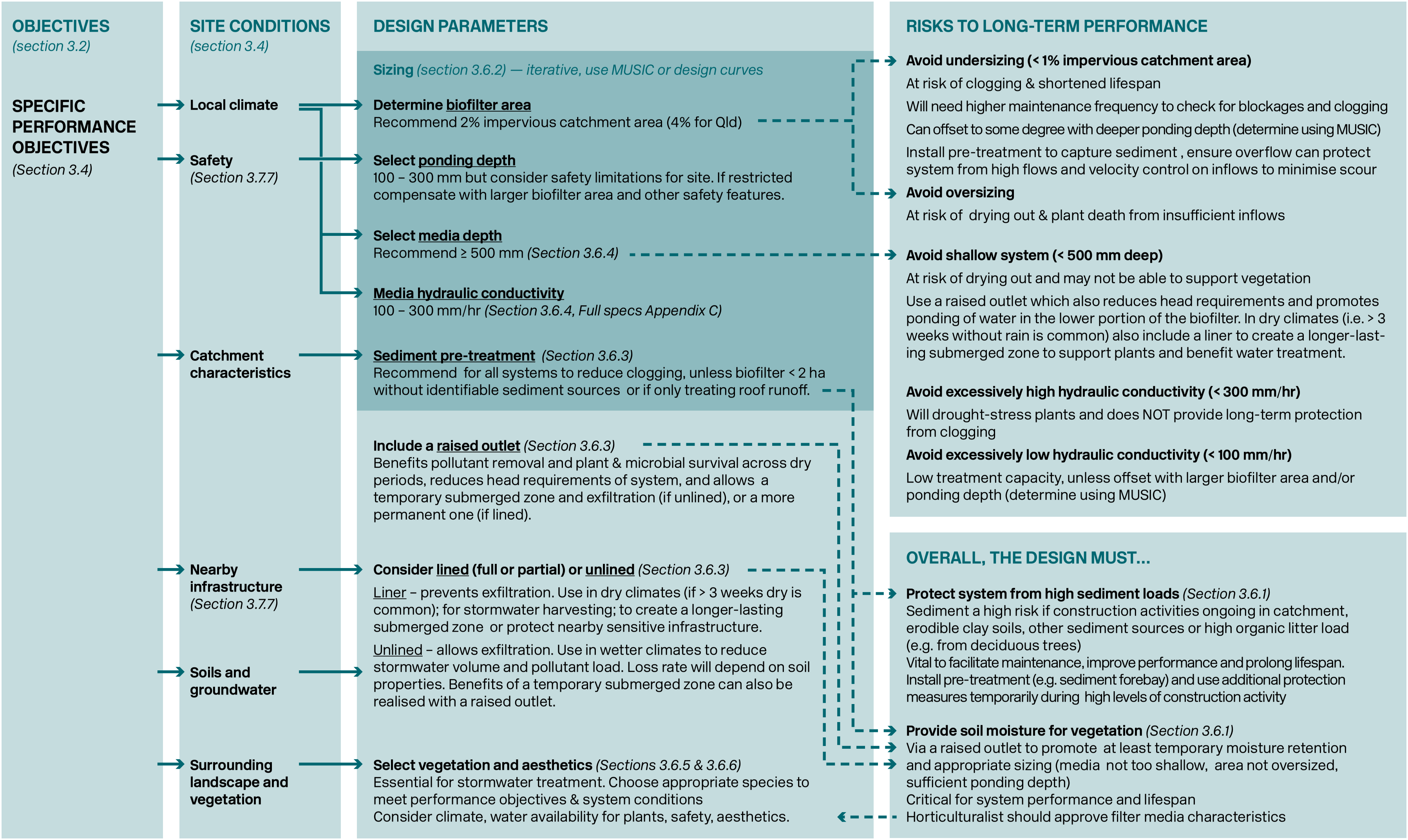


Figure 13. Overview of the design process for specifying the components of a biofiltration system (with detail provided in Figure 15).



OBJECTIVES
(section 3.2)

SPECIFIC PERFORMANCE OBJECTIVES
(Section 3.4)

SITE CONDITIONS
(section 3.4)

Local climate

Safety
(Section 3.7.7)

Catchment characteristics

Nearby infrastructure
(Section 3.7.7)

Soils and groundwater

Surrounding landscape and vegetation

DESIGN PARAMETERS

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

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

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

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

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

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

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

Consider lined (full or partial) or unlined *(Section 3.6.3)*
Liner – prevents exfiltration. Use in dry climates (if > 3 weeks dry is common); for stormwater harvesting; to create a longer-lasting submerged zone or protect nearby sensitive infrastructure.
Unlined – allows exfiltration. Use in wetter climates to reduce stormwater volume and pollutant load. Loss rate will depend on soil properties. Benefits of a temporary submerged zone can also be realised with a raised outlet.

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

RISKS TO LONG-TERM PERFORMANCE

Avoid undersizing (< 1% impervious catchment area)
At risk of clogging & shortened lifespan
Will need higher maintenance frequency to check for blockages and clogging
Can offset to some degree with deeper ponding depth (determine using MUSIC)
Install pre-treatment to capture sediment , ensure overflow can protect system from high flows and velocity control on inflows to minimise scour

Avoid oversizing
At risk of drying out & plant death from insufficient inflows

Avoid shallow system (< 500 mm deep)
At risk of drying out and may not be able to support vegetation
Use a raised outlet which also reduces head requirements and promotes ponding of water in the lower portion of the biofilter. In dry climates (i.e. > 3 weeks without rain is common) also include a liner to create a longer-lasting submerged zone to support plants and benefit water treatment.

Avoid excessively high hydraulic conductivity (< 300 mm/hr)
Will drought-stress plants and does NOT provide long-term protection from clogging

Avoid excessively low hydraulic conductivity (< 100 mm/hr)
Low treatment capacity, unless offset with larger biofilter area and/or ponding depth (determine using MUSIC)

OVERALL, THE DESIGN MUST...

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

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

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

3.6.2 Sizing

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

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

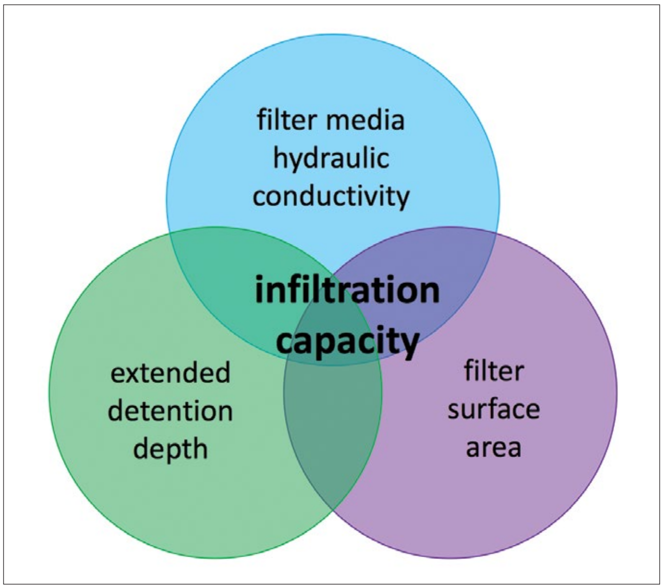


Figure 15. Relationships between design parameters for system sizing and infiltration capacity

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

- Design flows are used to estimate the biofilter size. The following design flows should be estimated:
    1. The minor storm event (5 year ARI for temperate climates, 2 year ARI for tropical climates, or according to local regulations), to size the inlet zone and overflow structure, and to check scouring velocities;
    2. The major storm event (100 year ARI for temperate climates, 50 year ARI for tropical climates, or according to local regulations), if larger storms will enter the biofilter (i.e., are not diverted upstream of the system), to check that erosion, scour or vegetation damage will not occur; and
    3. The maximum infiltration rate through the filter media, to size the underdrain. For small systems (contributing catchment area < 50 ha), use the Rational Method to estimate minor and major flows. For large systems (contributing catchment area > 50 ha), use runoff routing to estimate minor and major flows.
- Performance curves, such as those provided in the Water Sensitive Urban Design Technical Design Guidelines for South East Queensland (BCC and WBWCP, 2006), where the surface area can be selected according to the ponding depth and desired pollutant removal performance. The hydraulic conductivity of the filter media should also be considered.
- Note that sizing needs to be conducted with specific reference to the local climate - performance curves representative of the local climate should be used; similar curves exist for most States and Territories.
- As a starting point, a biofiltration system with a surface area that is 2% of the impervious area of the contributing impervious catchment, a ponding depth of 100 – 300 mm and a hydraulic conductivity of 100 – 300 mm/hr would be a fairly typical design in order to meet regulatory load reduction targets for a temperate climate.
- However, the hydraulic conductivity may need to be higher in tropical regions in order to achieve the required treatment efficiency using the same land space and ponding depth (i.e., ensuring that the proportion of water treated through the media meets requirements).
- Where one of these design elements falls outside the recommended range, the treatment capacity can still be met by offsetting another of the design elements. For example, if there is a desire to use a particular plant species (landscape consideration) but that plant requires wetter conditions than can be provided with a filter media that drains at 200 mm/hr, use of a slower draining filter media to support healthy plant growth may be feasible if the surface area of the system can be increased to compensate.
- However, problems can arise if properties deviate too far outside the recommended range – likelihood of drought conditions, clogging and sediment accumulation, or a risk to public safety may increase. Some of the various design possibilities have been summarised in Table 12 and, if considered, should be investigated using a model such as MUSIC.

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

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

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

Design tips

- Design and model using a filter media hydraulic conductivity of half the desired value (to allow for gradual reduction in the hydraulic conductivity of the filter media over time).

- The bigger the system relative to its contributing catchment, the greater the volumetric losses will be, however this may require specification of different planting zones to accommodate different wetting and drying conditions (i.e., how often each zone receives stormwater, which will be influenced by the distance from the inlet and the height from the base of the system).

- Ideas to increase effective size:

    - Break up the catchment if space is limited.

    - Increase ponding depth (use novel design to ensure safety).

- Remember that undersizing systems might provide short-term cost savings but leaves a long-term cost legacy for the asset owner with a likelihood of higher maintenance and renewal costs due to clogging, accumulation of sediments and pollutants and potential plant death from flooding.

- Equally, avoid excessive oversizing as it can lead to more frequent drought conditions, plant death and system failure from drought. Also avoid oversizing pre-treatment devices for the same reason.

- Conversely, in the specific case of tree pits, the pit itself should be adequately sized to facilitate maintenance access for cleaning.

- Consider factoring in buffer space to the ponding zone to accommodate sediment and litter accumulation.

3.6.3 System Hydraulics

Pre-treatment (clogging prevention)

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

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

- Biofilters that only receive roof runoff;

- Biofilters with catchments < 2 ha without identifiable sediment sources;

- In the case of biofiltration swales, the swale component is likely to provide sufficient pre-treatment to protect the biofiltration component.

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

Inlet Zone

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

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

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

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

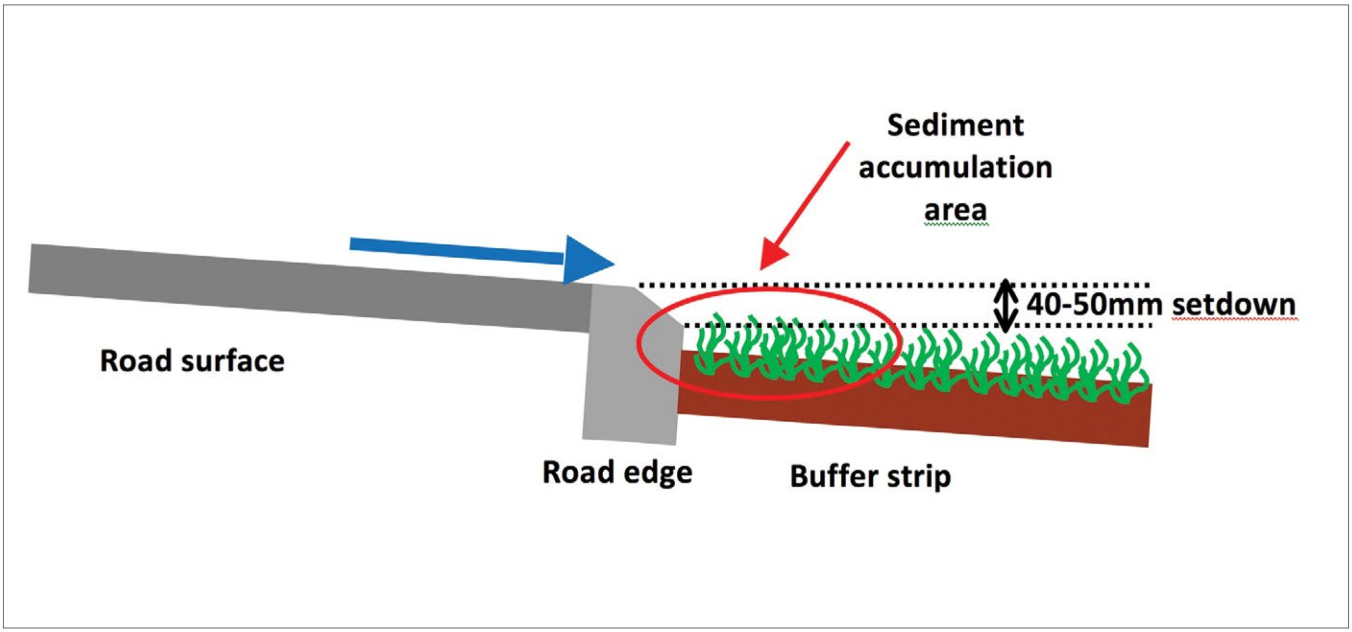


Figure 16. Edge detail of biofilter inlet zone showing setdown (source: Melbourne Water, 2005)

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

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

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

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

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

Design tips

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

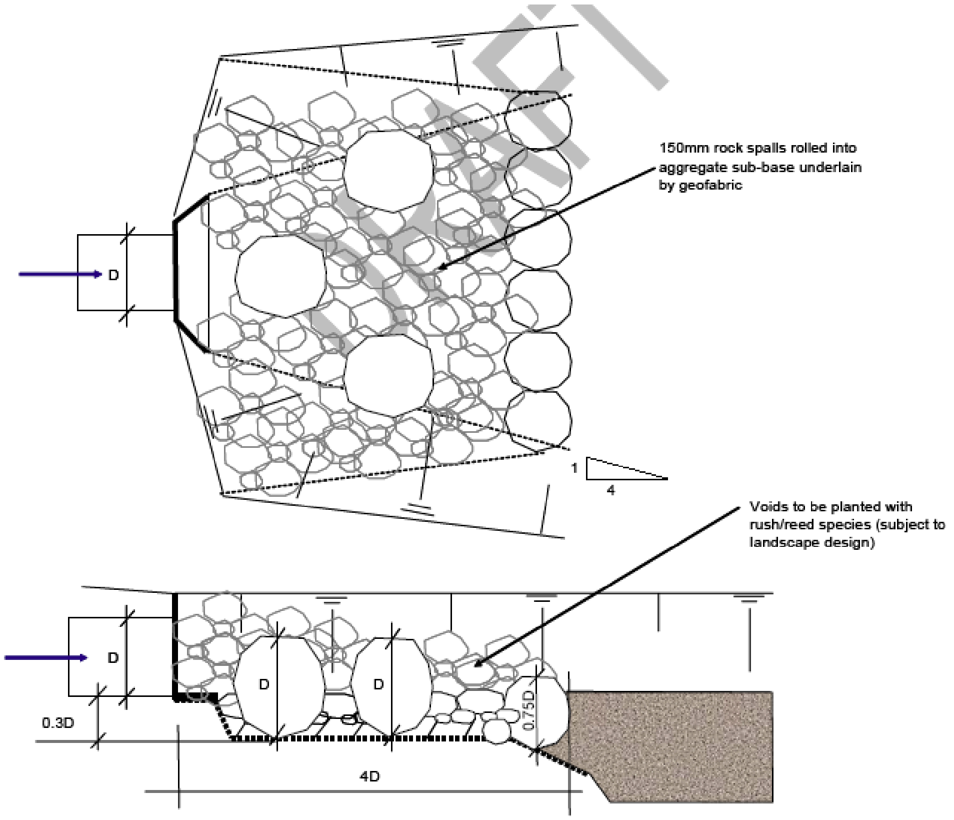


Figure 17. Rock beaching for scour protection in a biofilter receiving piped flows, where D represents the pipe diameter (source: BCC and WBWCP, 2006).

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

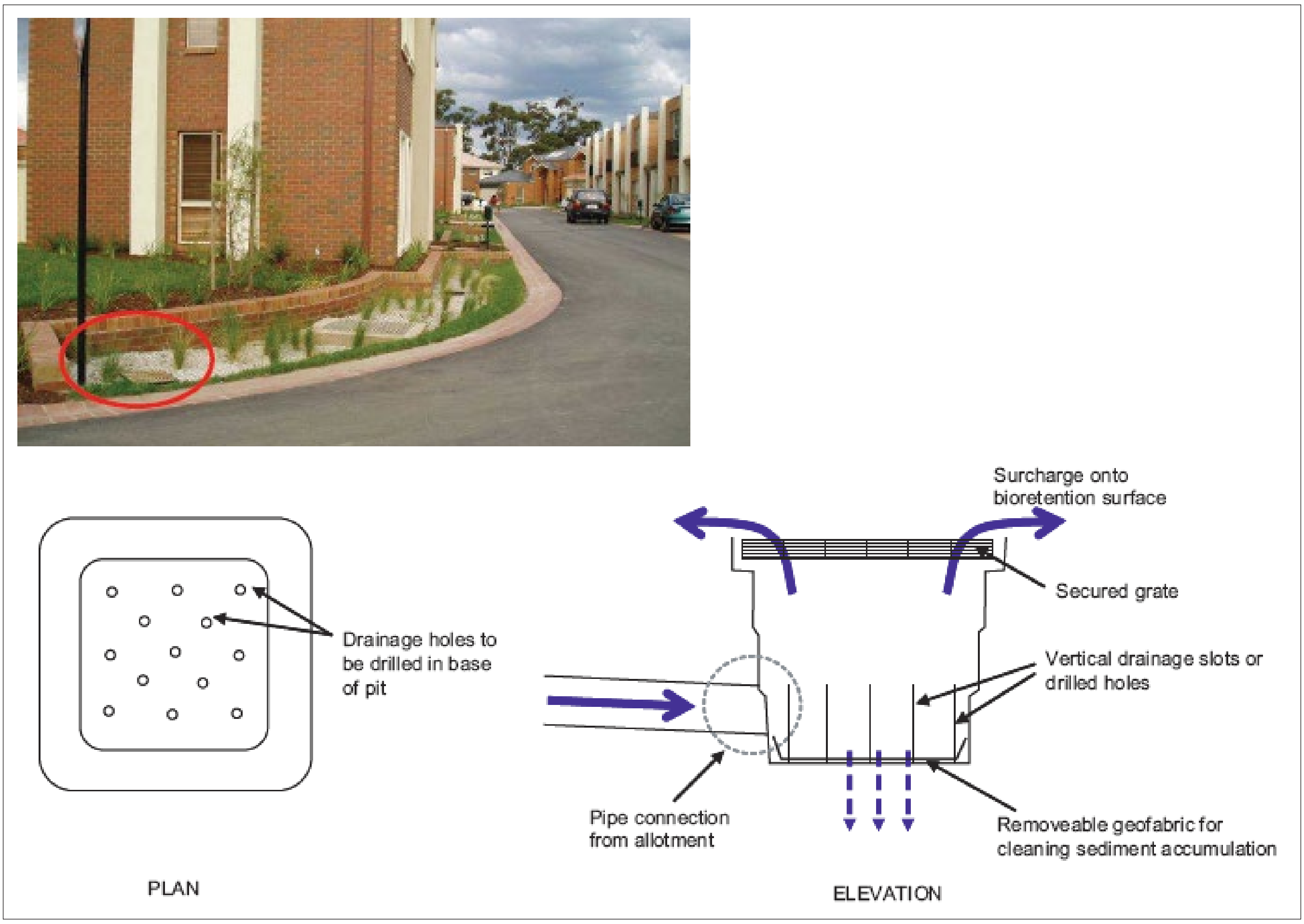


Figure 19. Surcharge inlet pit containing drainage holes at base of pit and removable geotextile layer for cleaning accumulated sediment (source: (Melbourne Water, 2005)).

Important!

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

Overflow or High Flow Bypass

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

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

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

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

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

Design tips

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

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

Important!

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

Raised outlet to create a submerged zone

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

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

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

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

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

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

1. Submerged zone material

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

2. Submerged zone depth

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

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

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

Design tips

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

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

Equation 1. Calculation of estimated rate of submerged zone drawdown

where:

Submerged zone drawdown period – (days)

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

Depth – depth of submerged zone (mm)

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

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

Design tips

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

Underdrain

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

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

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

The following need to be checked:

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

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

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

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

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

f. Design pipe bends to be 450, rather than 900, to facilitate inspection and clearance of blockages (Figure 21)

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

For unlined systems with raised outlet promoting exfiltration:

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

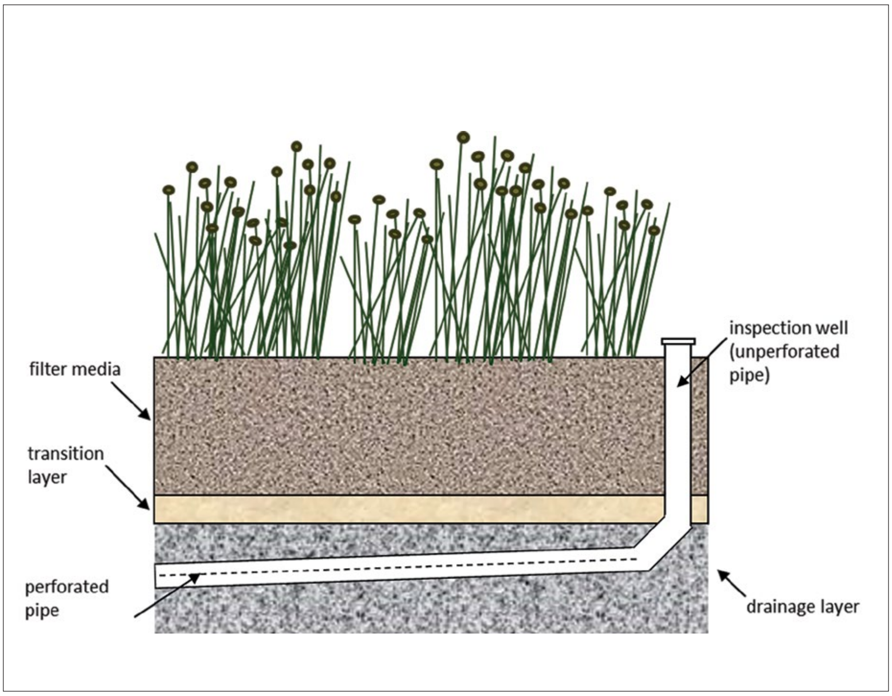


Figure 21. Long section of a biofilter showing collection pipe raise above bottom of drainage layer to promote exfiltration. Note series of 45° elbows rather than 90° elbows, to facilitate entry of maintenance equipment (e.g. pipe snake or water jet). Also note that perforated pipes do not necessarily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

For lined biofilters with longer-lasting submerged zone:

There are two possible configurations:

1. Perforated collection pipe with riser outlet

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

2. Riser outlet only (no collection pipe)

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

The following need to be checked:

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

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

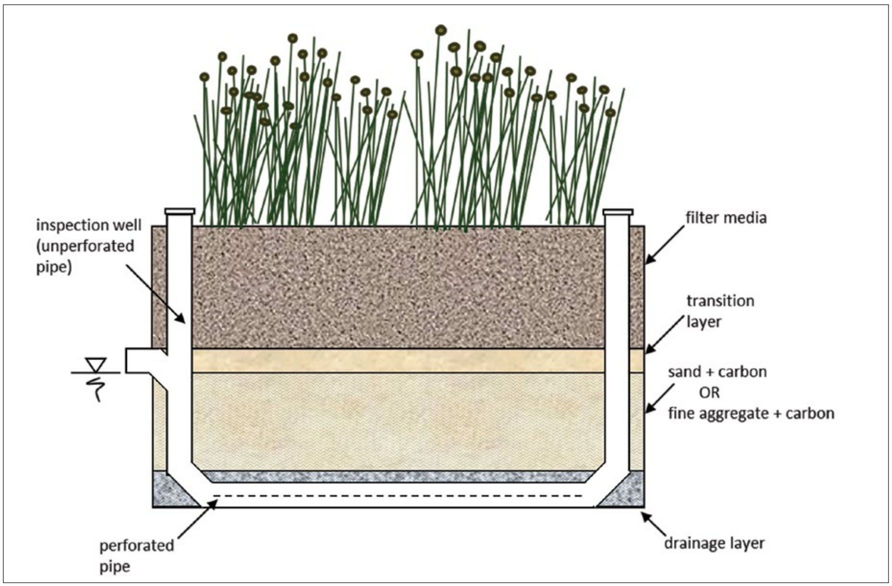


Figure 22. Long section of a biofilter with a submerged zone showing collection pipe and riser outlet (Note that, in this system, the transition layer is between the filter media and submerged zone). Note series of 45° elbows rather than 90° elbows, to facilitate entry of maintenance equipment (e.g.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

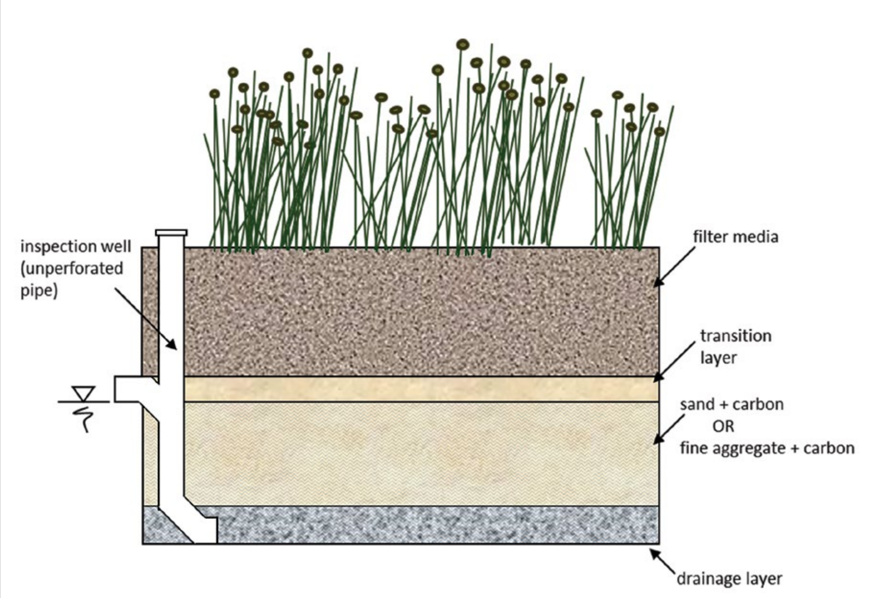


Figure 23. Long section of a biofilter with a submerged zone showing riser outlet (Note that, in this system, the transition layer is between the filter media and submerged zone). An appropriate screen should be placed over the outlet pipe entry in the drainage layer, to prevent ingress of the fine aggregate

Design tips

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

Outlet

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

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

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

Liner

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

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

1. Compacted clay

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

2. Flexible membrane

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

Important!

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

Design tips

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

Biofilter Swales

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

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

Conveyance (Swales only)

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

Design tips

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

Walls and bunds (if present)

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

3.6.4 Media

Filter Media Selection

The filter media is central to biofilter functioning and careful selection is essential. Media must be sourced that does not leach nutrients and has sufficient hydraulic conductivity, but which also supports plant growth, provides filtration capacity for fine sediment and has a stable particle size distribution. Incorrect media specification is a common problem in poorly functioning or failed systems experiencing problems such as nutrient leaching or plant death.

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

Media layers

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

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

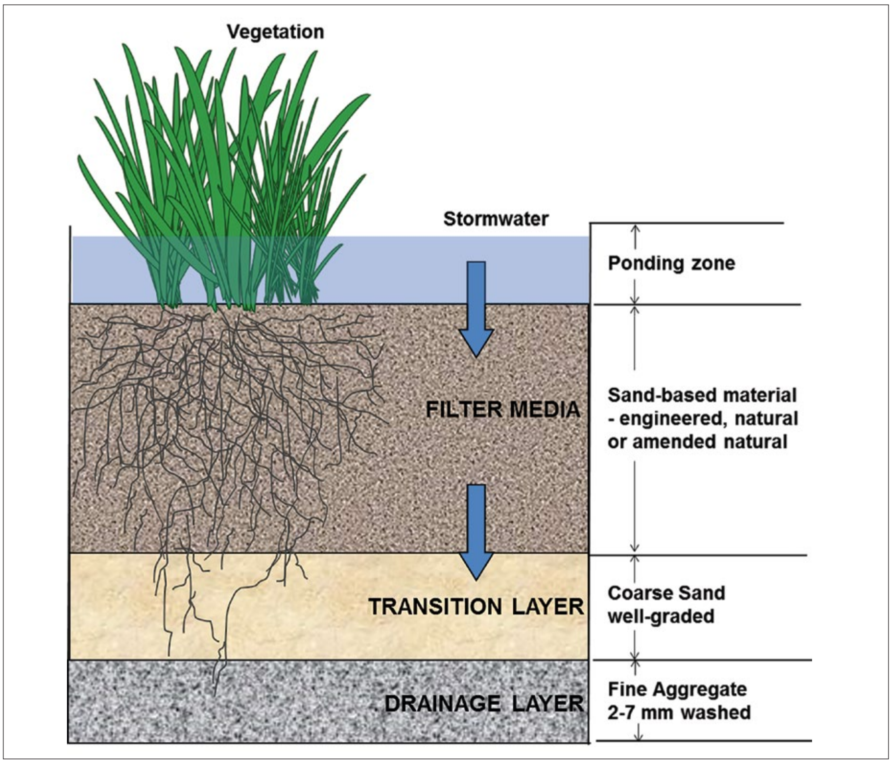


Figure 24. Layers within a biofilter and their function in the treatment of stormwater

Stormwater

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

Vegetation

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

Ponding zone

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

Filter media

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

Transition layer

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

Drainage layer

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

Submerged zone

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

Carbon source (if present with submerged zone)

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

Table 13. Essential and recommended media requirements

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

Cont.

Table 13. Continued

	Property	**Specification to be met**	**Why is this important to biofilter function?**
GUIDANCE	**Particle size distribution (PSD)**	Note that it is most critical for plant survival to ensure the fine fractions are included. **(% w/w) Retained** **Clay & silt < 3% (< 0.05 mm)** **Very fine sand 5-30% (0.05-0.15mm)** Fine sand 10-30% (0.15-0.25 mm) Medium sand 40-60% (0.25-0.5 mm) Coarse sand < 25% (0.5-1.0 mm) Very coarse sand 0-10% (1.0-2.0mm) Fine gravel < 3% (2.0-3.4 mm)	Of secondary importance compared to hydraulic conductivity and grading of particles, but provides a starting point for selecting appropriate material with adequate water-holding capacity to support vegetation. Filter media do not need to comply with this PSD to be suitable for use in biofilters.
	Depth	400-600 mm or deeper	To provide sufficient depth to support vegetation. Shallow systems are at risk of excessive drying.
	Once-off nutrient amelioration	Added manually to top 100 mm once only Particularly important for engineered media	To facilitate plant establishment, but in the longer term incoming stormwater provides nutrients.
	Protective surface layer	Include a surface layer 100-150 mm deep overlying the biofilter media. Use a coarser particle size of higher infiltration rate than the filter media, generally commercially available sands.	Lab studies have demonstrated the potential for this layer to delay clogging and improve treatment performance. Currently being tested in the field.
Transition sand (middle layer)			
ESSENTIAL SPECIFICATIONS	**Material**	Clean well-graded sand e.g. A2 Filter sand	Prevents the filter media washing downwards into the drainage layer
	Hydraulic conductivity	Must be higher than the hydraulic conductivity of the overlying filter media	To allow the system to drain and function as intended
	Fine particle content	< 2%	To prevent leaching of fine particles
	Particle size distribution	Bridging criteria – the smallest 15% of sand particles must bridge with the largest 15% of filter media particles (Water by Design, 2009; VicRoads, 2004): D15 (transition layer) ≤ 5 x D85 (filter media) where: D15 (transition layer) is the 15th percentile particle size in the transition layer material (i.e.,15% of the sand is smaller than D15 mm), and D85 (filter media) is the 85th percentile particle size in the filter media. The best way to compare this is by plotting the particle size distributions for the two materials on the same soil grading graphs and extracting the relevant diameters (Water by Design, 2009).	To avoid migration of the filter media downwards into the transition layer

Cont.

Table 13. Continued

	Property	Specification to be met	Why is this important to biofilter function?
		Bridging criteria only in designs where transition layer is omitted ((Water by Design, 2009); ((VicRoads, 2004): D15 (drainage layer) ≤ 5 x D85 (filter media) D15 (drainage layer) = 5 to 20 x D15 (filter media) D50 (drainage layer < 25 x D50 (filter media) D60 (drainage layer) < 20 x D10 (drainage layer)	To avoid migration of the filter media into the drainage layer only in the case where a transition layer is not possible.
G.	**Depth**	≥ 100 mm	(as per above purpose)
Drainage layer (base)			
ESSENTIAL SPECIFICATIONS	**Material**	Clean, fine aggregate - 2-7 mm washed screenings (not scoria)	To collect and convey treated stormwater, protect and house the underdrain (if present), or provide a storage reserve as part of a submerged zone, or prior to exfiltration (in unlined systems)
	Hydraulic conductivity	Must be higher than the hydraulic conductivity of the overlying transition layer	To allow the system to drain and function as intended
	Particle size distribution	Bridging criteria D15 (drainage layer) ≤ 5 x D85 (transition media) where: D15 (drainage layer) - 15th percentile particle size in the drainage layer material (i.e., 15% of the aggregate is smaller than D15 mm), and D85 (transition layer) - 85th percentile particle size in the transition layer material.	To avoid migration of the transition layer into the drainage layer
	Perforations in underdrain	Perforations must be small enough relative to the drainage layer material. Check: D85 (drainage layer) → diameter underdrain pipe perforation.	To prevent the drainage layer material from entering and clogging the underdrainage pipe (if present)
G.	**Depth**	Minimum 50 mm cover over underdrainage pipe (if present)	To protect the underdrain from clogging

Sustainability tip

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

Design tips

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

1. Drainage layer depth

For biofilters with an underdrain:

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

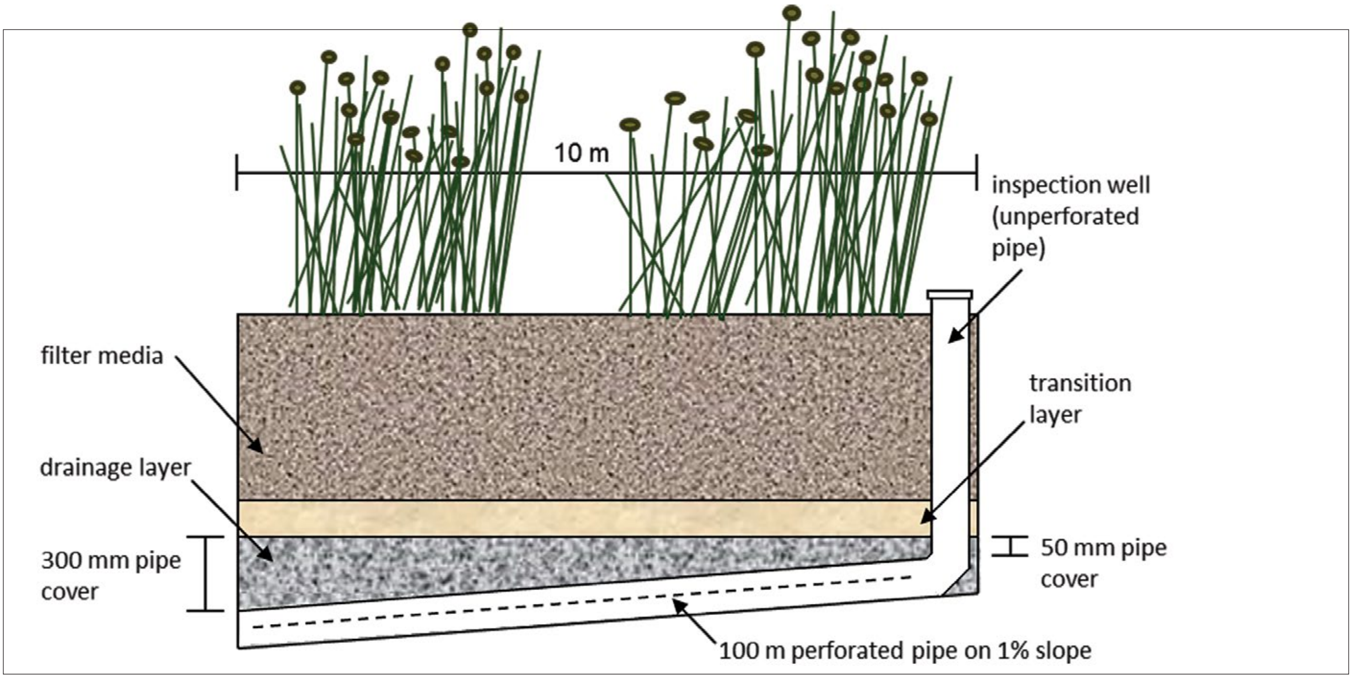


Figure 25. Long-section of a biofilter showing variable drainage layer depth. Also note that perforated pipes can be laid flat.

For biofilters that allow exfiltration (without liner):

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

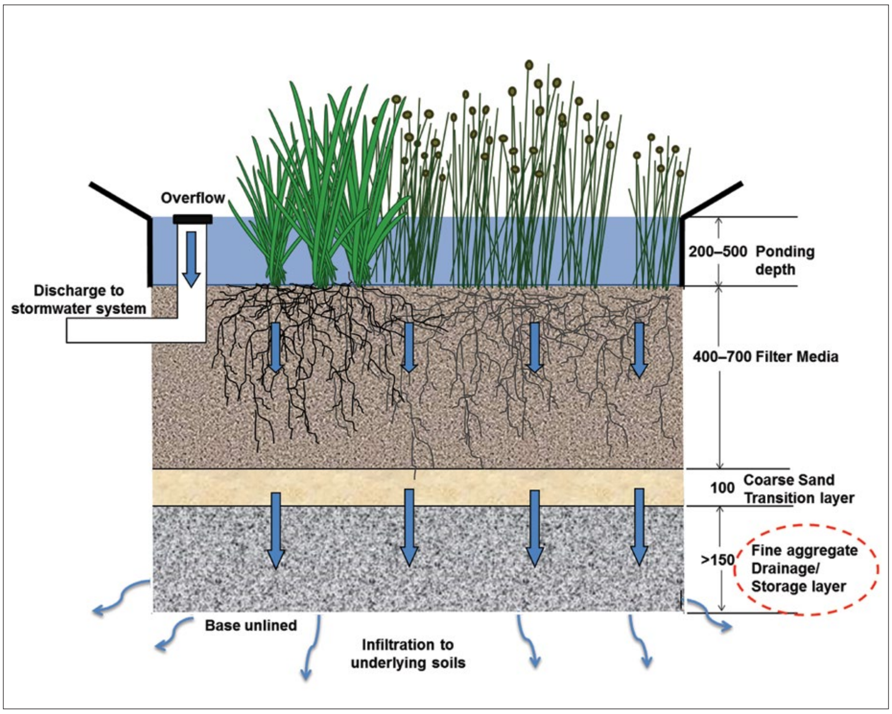
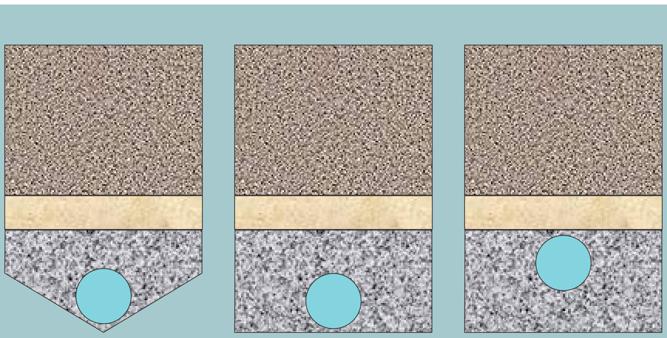


Figure 26. Use of the aggregate drainage layer as a storage zone in a biofiltration system without underdrain.

Design tip

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



Important!

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

Carbon Source

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

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

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

Design tip

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

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

Sustainability tip

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

Designing to prevent clogging

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

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

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

3.6.5 Vegetation

Role of plants

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

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

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

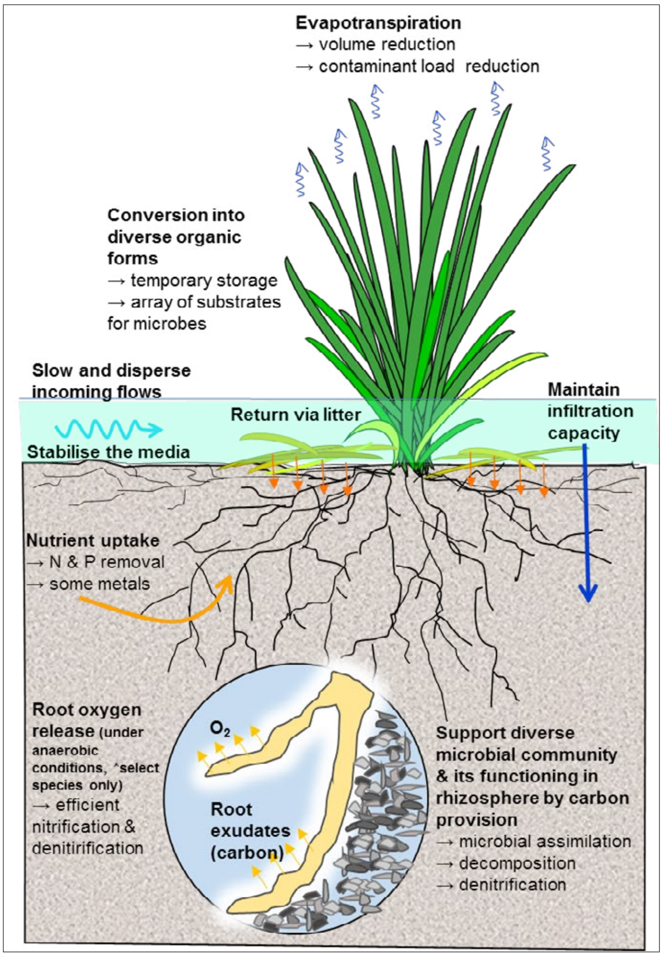


Figure 27. Multiple roles served by plants in water treatment processes within biofilters

Plant species selection

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

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

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

iii. Include a mixture of species to provide resilience;

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Plant selection to meet performance objectives

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

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

Cont.

Table 14. Continued

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

Cont.

Table 14. Continued

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

Cont.

Table 14. Continued

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

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

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

Carex appressa

Melaleuca incana

Juncus kraussii

Carex tereticaulis

Juncus pallidus

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

Design tip

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

Diversity promotes resilience

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

Planting density

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

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

Design tip

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

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

Zoning of planting

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

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

Planting

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

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

Mulch

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

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

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

Harvesting

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

Use of trees

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

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

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

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

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

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

Lawn grasses

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

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

3.6.6 Aesthetics – Biofilters that look good

Introduction

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Figure 38. Context is critical. In this bushy outer suburban setting (above), four different raingarden designs are not equally successful aesthetically. The bottom right-hand option with abundant flowering exotic plants does not relate well to the immediate setting or the nearby gardens. Photos supplied by M. Dobbie, Monash University; photo manipulation by H. Smillie, Seddon.

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

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

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

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

3.6.7 Stormwater harvesting

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Design tip

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

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

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

3.6.8 Other considerations

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

Designing for effective maintenance

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

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

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

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

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

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

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

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

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

Important!

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

Drought resilience

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

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

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

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

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

Edge treatments

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

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

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

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

Interaction with services

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

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

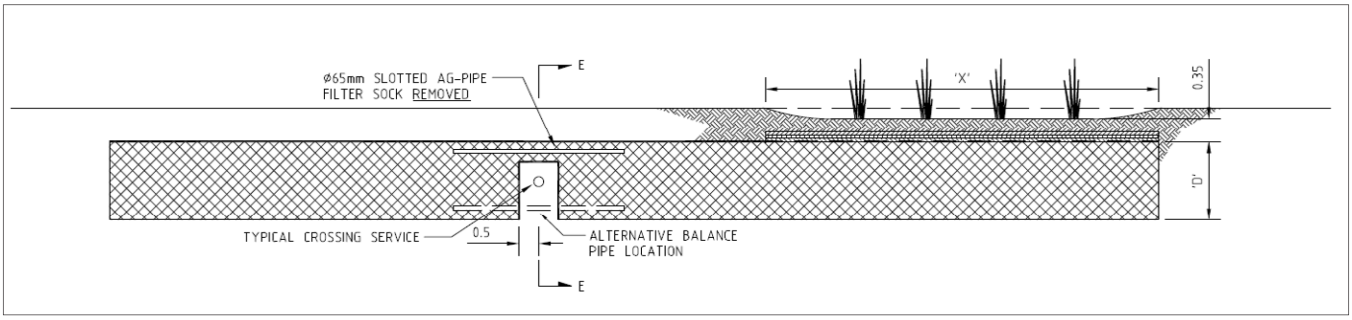

Figure 40. Example of innovative design to overcome interaction with services. In this example, the bio infiltration system is constructed either side of a sewer line, with a connecting pipe in between, avoiding excavation underneath and surrounding the sewer.

Asset protection

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

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

Issues of system size

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

Safety

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

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

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

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

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

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

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

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

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

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

Design tip

Ideas for ensuring both filter integrity and public safety

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

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

Design tip

Provide various crossings to safely direct pedestrians across or around biofilters

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

Design tip

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

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

Geology

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

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

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

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

Climate

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

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

Groundwater

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

Shallow groundwater may:

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

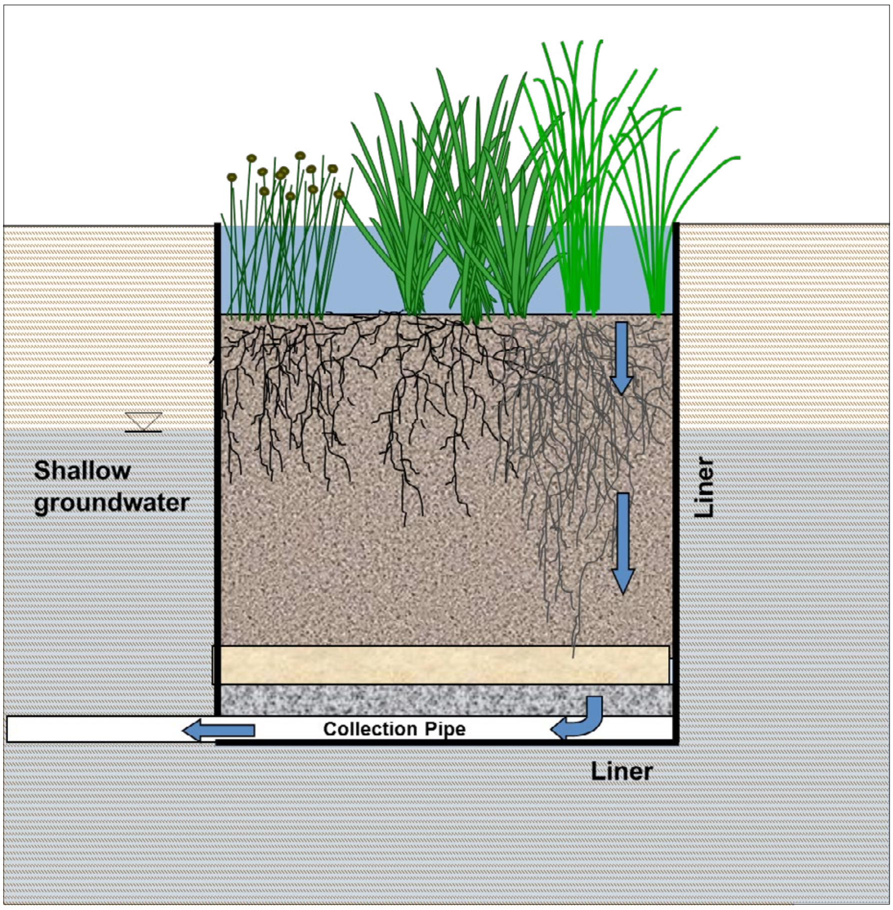

Figure 41. Biofilters can be used successfully in areas of shallow groundwater, with use of a liner if interaction with the groundwater is not desirable

Site gradient and available pipe inverts

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

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

- The depth of the biofilter is likely constrained. A minimum height difference of 900 mm is recommended between the inlet and outlets of a biofilter.
- However, inclusion of a submerged zone allows a deeper system to be used with a reduced head requirement (as a result of the elevated outlet required to create the submerged zone). This option is preferable to shallow systems, which are particularly susceptible to drying.
- Use of above-ground planter boxes (e.g. located below downpipes) is compatible with shallow gradients.
- Consider the use of biofilters alongside other WSUD design elements, such as rain water tanks and harvesting (Burns et al., 2010).

In steep topography, different issues dominate design:

- Inflow velocities will be higher, leading to greater risk of erosion and scour. Energy dissipation is an important consideration and can be achieved using rocks at the inlet, or distribution channels to dissipate low flows and reduce inflow velocities before contact with the filter media.
- The driving head increases the risk of preferential flow pathways or short-circuiting down through the media at the interface with flow control structures, or points where outlet pipes traverse walls or bunds. As a result, sealing the structural components of the biofilter to ensure they are water tight, is vital to avoid failure and wash-out of the media (discussed in the Construction section within Chapter 4).
- There is sufficient head to drive the hydraulic function of the system.
- The use of rock or earthen walls check dams or a terraced system may be necessary for design.
- Biofiltration swales, which also act to convey stormwater, are unlikely to be feasible for stormwater management where slopes exceed 5%.

Small space

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

- Breaking up the catchment by using multiple smaller systems closer to source, including biofilters on private residential blocks (e.g. planter boxes).
- Implementing creative designs that may save space by incorporating systems into novel spaces – for example terraced systems can be incorporated into steeper components of the landscape (refer to Water by Design (2014b) for illustrations of this and other creative ideas).

High sediment loads

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

Coastal / Estuary environments

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

- Salt tolerant plant species (halophytes) should be used
- Estuary environments are particularly sensitive, so it is imperative to ensure filter media with low nutrient content is used to reduce the potential for nutrient leaching.

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

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

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4

Chapter 4: Practical Implementation

4.1 Introduction

This chapter provides general guidance on the construction, establishment, maintenance and monitoring of stormwater biofilters in Australia. It also discusses issues related to biofilter lifespan. The recommendations are based on the experience and observations of ecologists and engineers who have been actively involved in the design, on-site delivery and monitoring of biofilters.

The information presented in this document is intended to provide a broad, national approach to the implementation and management of biofilters, however reference should also be made to locally relevant and more detailed guidelines, where available. Some of these guidelines are listed below. However, contact your local council for the latest requirements and guidelines available:

- Water by Design, 2009. Construction and Establishment Guidelines: Swales, Bioretention systems and Wetlands (Version 1, February 2009). South East Queensland Healthy Waterways Partnership, Brisbane.
- Water by Design, 2014. Bioretention Technical Design Guidelines (Version 1.1, October 2014). Healthy Waterways Ltd, Brisbane.
- Water by Design, 2012. Transferring Ownership of Vegetated Stormwater Assets (Version 1, February 2012).
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- Moreland City Council and GHD, 2013. Streetscape WSUD raingarden & tree pit design package.

4.2 Construction and establishment

In addition to design, the construction and establishment phase is critical for determining the success biofiltration systems. The material specifications and installation criteria must be adhered to during the construction and establishment phase, to ensure that the system will operate effectively. Poor construction or use of inappropriate media can lead to erosion, plant death, ineffective hydraulics, and reduced performance and lifespan. This results in greater long-term costs for maintenance and remedial works, and possibly expensive system re-sets (Water by Design, 2015). As such, careful construction and establishment procedures are vital to ensure long-term performance, and minimise future maintenance requirements.

These guidelines are not intended to provide detailed construction protocols or drawings. Instead, they provide a summary of the key issues identified in other guidelines and reports. The references outlined at the start of this chapter should be referred to directly for a greater level of detail. In particular, the Water by Design *Construction and Establishment Guidelines and Bioretention Technical Design Guidelines (2009)* provide a high level of practical advice, so consulting them is **strongly recommended**.

Key risks during the construction phase, common pitfalls and means to avoid them, are identified and discussed in Table 16, Figure 41 and Table 18

Important!

Significant quantities of sediment can be generated during the construction phase of urban developments, therefore comprehensive erosion and sediment control measures must be implemented to protect receiving waters. Biofiltration systems should not be assumed to provide environmental protection during this phase. Detailed guidance is provided in Water by Design's *Construction and Establishment Guidelines* (2009).

Table 16. Identifying risks, pitfalls and tips during the construction process

Critical stages	Risks / common pitfalls	Useful tips
Pre-construction		
Underground services check	Damage to unexpected **underground services** during excavation can be highly expensive, dangerous and may require costly late-stage design modification.	Use the Dial-Before-You-Dig service during initial design phase (service locations may influence siting and depth). Before construction commission an underground services expert to prove service locations and depth. Mark out services at the site and map locations and depths on site plan. Inform all site personnel at pre-site meeting.
Ordering plant stock	If **plant stock** is not pre-ordered in sufficient time they may not be available at the desired planting time (especially for large projects).	Communicate well ahead of construction with the nursery, ideally during plant selection in the design phase.
Sourcing filter media	**Media composition** is critical to pollutant retention and infiltration rate. Poor media selection can lead to nutrient leaching, clogging, a system that is too dry or wet, and the washout of fine particles.	Ensure the media has been tested to comply with specifications in the Guidelines for Filter Media in Biofiltration Systems (Appendix C). Ensure fine aggregate for drainage layer material has been sufficiently washed to remove fine particles.
Sediment management	**Sediment management** is critical in catchments undergoing development and during construction of the biofilter itself. This is a critical risk to long-term performance. Unless protected, a high sediment load will rapidly overwhelm and clog the biofilter, requiring an expensive re-set. Problematic if the biofilter is commissioned too early in the development process.	During construction activities the system must be protected using temporary measures such as flow diversions, use of bunding and/or geofabric, sediment traps, and planted with a temporary turf layer. Develop a management plan before construction commences and leave measures in place until construction activities cease and soil surfaces are stabilised. Refer to Water by Design (2009) for detailed guidance on sediment management.
Runoff management plans	**Drainage and runoff management plans** are essential during construction when soils are exposed.	To the extent possible, biofilter construction should be conducted in a dry weather period.

Cont.

Table 16. Continued

Critical stages	Risks / common pitfalls	Useful tips
Runoff management plans (cont.)	Rainfall events during construction can wash substantial volumes of soil into the biofilter excavation or any laid media layers. If left, these sediments will severely compromise the infiltration and pollutant removal performance of the biofilter.	Flow diversions need to be set up, and this will be particularly challenging for online systems (these are not recommended except for small catchments). Any sediment that is washed into the system during construction must be removed (including any media mixed with sediment). Refer to Water by Design (2009) for further guidance on managing runoff during construction.
Timing of construction and commissioning stages	The coordinated **timing of biofilter construction** with development in the catchment is critical for long-term success. Failure to protect the new system from construction works may lead to a complete re-set before its official commissioning.	Stages of works must be carefully planned in coordination with development in the surrounding catchment. Sediment management, temporary protection measures for the biofilter, and delayed planting and commissioning of the biofilter, are all vital. Refer to Water by Design (2009) for step-by-step requirements for each phase of works (including on-site fact sheets).
Construction		
Roles and responsibilities **Communication between stakeholders**	Poor **communication and division of responsibility** between parties can lead to poor oversight of the project and lack of quality control. Projects require cooperation between multiple disciplines and authorities. A common problem is poor coordination between the construction and landscape teams, and a lack of understanding of the system function and objectives.	Ensure **roles and responsibilities** are clearly assigned for each phase, with clear, frequent communication between all parties and across all project stages. Take particular care to ensure communication between designers, the construction team and landscaping/ maintenance teams. All parties should understand the project objectives, function of the system, and key risks to success. Refer to Water by Design (2009) for a discussion of roles, responsibilities for ownership and maintenance, contract requirements and handover.
Excavation & earth works	Traditional **excavation techniques** create a smooth and compacted base, which can reduce infiltration. **Accurate levels and slopes** are critical for effective system function, particularly flow control structures (inflow, overflow) and drainage. Incorrect levels will lead to hydraulic malfunction, plant death and poor treatment, either from flow bypass or flooding. In particular, it is vital that the ponding depth is achieved and the slope of the surface allows even flow and widespread distribution.	If infiltration is an objective (system is unlined) and clay soils are present, excavate using a bucket with 'teeth' to loosen and roughen the base. Levels must be carefully constructed and surveyed once complete. Once commissioned, water levels and flow hydraulics should be checked against the design during significant inflow events.
Liner installation (if present)	Puncture of the liner or ineffective sealing of the system will lead to leakages which may i.) compromise nearby sensitive structures (if present), ii.) reduce yield for stormwater harvesting schemes, and iii.) lead to system failure	Place liner onto surfaces free of rocks, roots or other sharp objects that may cause puncture. Use a reliable and experienced contractor.

Cont.

Table 16. Continued

Critical stages	Risks / common pitfalls	Useful tips
Sealing hydraulic components	Effective **water-tight sealing on hydraulic structures** is essential to prevent short-circuiting, erosion and potential collapse and failure of the system, particularly at steep sites. It also reduces the opportunity for invasion of pipes and structures by plant roots. Problems can arise during sealing and preventing preferential flows at the interfaces of inlet points, inlet/outlet collection pits, sediment forebays, drainage pipes, basin walls and bunds between cells. Points where pipes enter walls/bunds are particularly sensitive failure points. In addition, preferential flow paths can develop down the sides of the inlet pit and sediment forebay, bypassing the surface filter media.	Take great care to water-proof seals at connection points. Use collars on outlet pipes at the point where it traverses the wall. This can be tricky, especially to achieve compaction around the seal. Alternatively it is feasible to use shockcrete to create a large collar extended across the basin surface. (Note techniques developed by Hornsby Shire Council) A filter fabric can be used around the top of inlet pits and underneath inlets and sediment forebays to prevent preferential flows underneath and down the sides, where the structures are embedded below the filter media surface.
Laying down drainage pipe (if present)	Damage to **underdrain** during construction, compromising its function.	Lay pipe above a fine aggregate bed, with sufficient covering with aggregate. Do not use heavy equipment.
Receiving media on-site	Media can be **contaminated with on-site soils** (e.g. clay) upon delivery and earthmoving works. This will significantly reduce infiltration and pollutant removal capacity.	Ensure soils are either delivered straight into the biofilter pit, or tipped onto a hard concrete surface. This prevents the excavator bucket from digging down into in-situ site soils.
Laying down media layers	Appropriate **media layering** (mixing, depth) is a vital characteristic of biofilter function. A high degree of mixing or depths differing from design will compromise pollutant removal.	Lay media sequentially and carefully adhere to the design, including depths of the layers. Conduct quality control checks during media placement. Complete in stages with care to avoid mixing. Additions, such as material providing a carbon source or soil ameliorants, should be thoroughly mixed before placement in the system. When placing layers above the underdrain, avoid dropping large volumes from a height.
	Excessive **compaction** will impede infiltration, thereby severely compromising the treatment capacity of the biofilter	Do not use construction techniques or equipment that leads to high compaction. Light compaction can be applied. Where possible machinery should be located outside and alongside the system, with only lightweight machinery used within the system. Refer to Water by Design (2009) for further details of construction techniques, including specifics for large systems. Where compaction was unavoidable, use scarifying to loosen the media.
Quality control	Ensuring the **construction meets design**, and the **design operates as intended** are vital checks that should be conducted throughout the project. Timely **quality control** will likely allow straightforward rectification, whereas belated discovery of errors will require far greater expense.	A number of hold points should be defined for inspection checks. For example, the drainage system should be checked before it is overlaid with media; checks should be made as the media are laid and also upon completion. Undertake as-constructed cross checks with the design drawings. Confirm levels using survey or measurements. Refer to Water by Design (2009) for survey methods and recommended tolerances.

Cont.

Table 16. Continued

Critical stages	Risks / common pitfalls	Useful tips
Planting and establishment		
Timing of planting	Poor **seasonal timing of planting** can lead to low plant growth, a prolonged establishment period and reduced survival if conditions are challenging. Planting is sometimes dictated by external factors (e.g. need for early landscaping in new developments)	Ideally aim to plant in early spring or autumn for temperate climates, but in tropical and sub-tropical climates there may be a wider planting window, possibly in the cooler season if enough rainfall is available. If non-ideal planting season cannot be avoided, implement careful seedling establishment (see below), including irrigation as required.
Plant establishment	**Establishment of healthy plant cover** across the biofilter is vital for effective long-term function. The period of seedling establishment and early growth is a vulnerable time. Common problem is to 'plant and forget', but careful management during establishment will avoid increased replanting and maintenance costs (e.g. repair of erosion).	Aim to rapidly achieve high plant cover to limit erosion and weed ingress and enhance system performance. Closely monitor vegetation health during seedling establishment. Water frequently as required, particularly immediately following transplant and during long dry periods. More frequent watering will initially be required for smaller seed stock, but can be reduced as plants grow. Plan to provide watering support, particularly during long dry periods, for the first 2-3 years. Some designs allow the temporary raising of the submerged zone and lowering again as plant roots establish. Protect seedlings from erosion - some flow diversions may need to temporarily remain in place from the construction phase if planting occurs during a season of high inflows. Replace dead plants immediately and avoid use of pesticides or herbicides, and fertilisers (beyond an initial once-off). Detailed advice on plant procurement, pre-planting preparations, planting procedures, establishment and assessment are provided in Water by Design (2009).
Maintenance during establishment	**Timely maintenance during establishment** can prevent problems growing into large issues that require costly rectification works (and possible system re-setting). During initial operation, biofilters are particularly vulnerable and errors in construction and design can become apparent. A common problem is insufficient budget to implement the necessary early-life maintenance program, but without this, costs can multiply.	Carefully plan and implement a maintenance schedule specific to the establishment period (initial 2 years of operation). This needs to be conducted at higher frequency with more thorough checks than for mature systems. Ensure adequate budget is available for this maintenance (must be set aside in budget planned during design).
Handover (if relevant)		
Asset handover	**Handover** is a key opportunity for rectification of problems that may compromise long-term system performance e.g. poor plant health, bare zones, inappropriate hydraulics, excessive sediment accumulation.	Inspection is required before handover, and any issues should be rectified before the handover is signed off. Detailed asset handover checks, sign-off documentation and protocols are provided by Water by Design (2009).

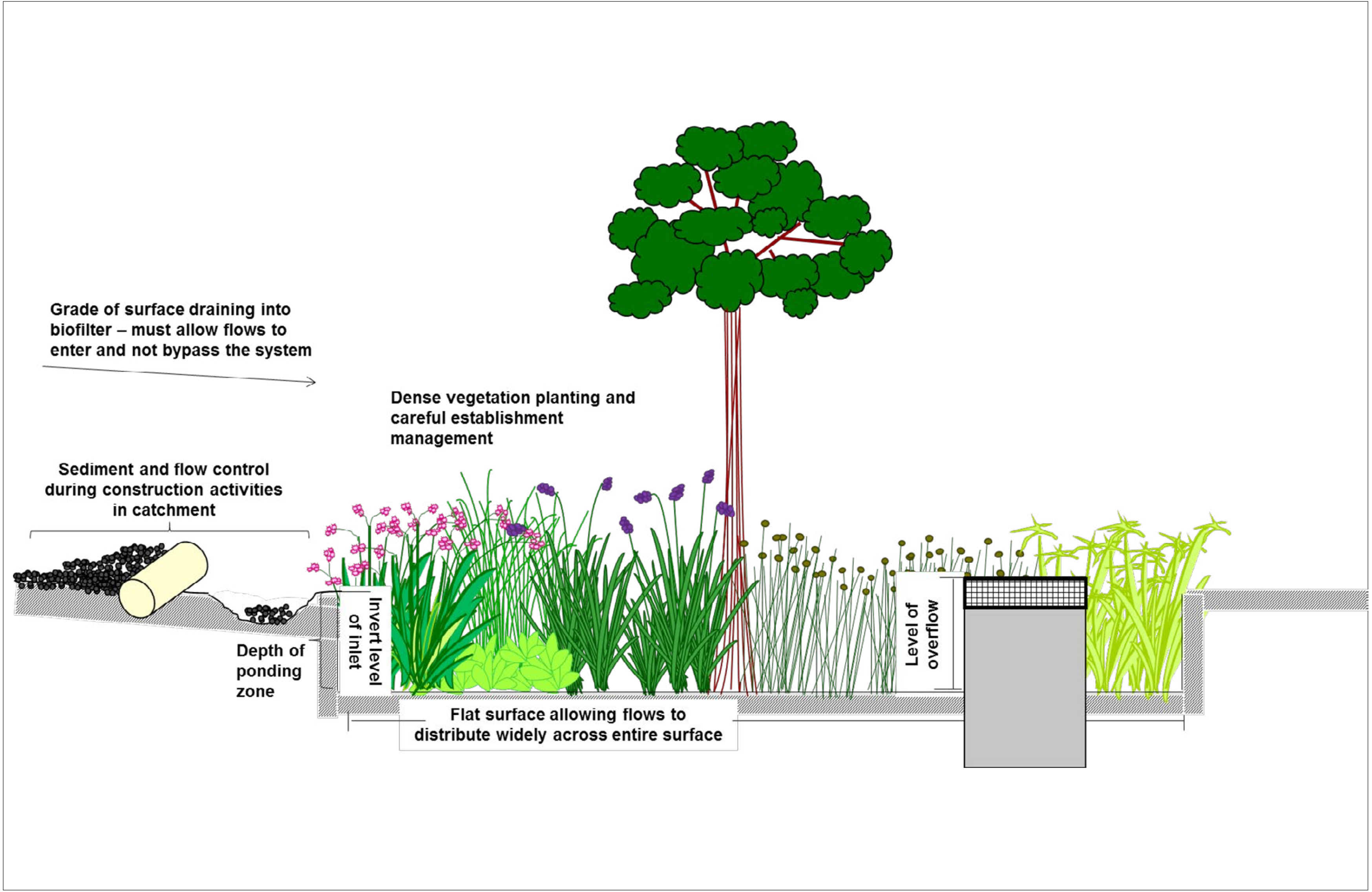


Figure 42. Critical quality control checks during and following construction

Figure 43. Common construction and establishment phase issues

Sediment management – high risk of sediment washing into biofilter during construction activities

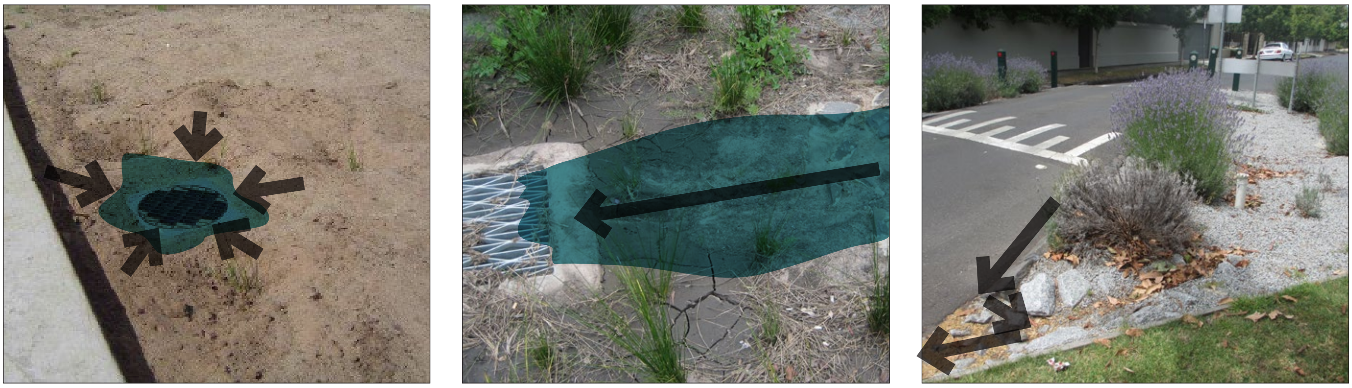
No drop down into biofilter – flow cannot easily enter

Slope follows road
Biofilter surface not flat– uneven flow distribution and poor channelling of flows to top of system

Batter slopes serve a purpose for safety, but need to be factored into design – in this case, the outlet level relative to batter slopes allows only very minimal flow distribution

Good hydraulic design, flow management during construction and establishment, and effective sealing is important to prevent erosion and short-circuiting

Outlet too close to inlet
Outlet level too low – no ponding



Overfilling with media – reduces or prevents ponding in the ponding zone and reduces treatment capacity

Overflow level designed or constructed too low relative to the media and/or inlet level – reduces or prevents ponding, allowing high proportion of untreated flows to bypass

No drop down into biofilter and system overfilled with media and mulch. This prevents flow from both entering and ponding.

4.3 Inspection and maintenance requirements

Routine maintenance is important to ensure that biofilters function effectively in the long term. Regular inspections (or monitoring) are required to continually assess if the system is performing well against its objectives, and to detect issues that may require maintenance attention, before it develops to the point of requiring more significant and costly works to rectify. Both monitoring and maintenance are required for successful operation. The overall purpose is to maintain optimal system functioning to achieve water quality and hydrological performance targets (Section 3.2.1) and other desired benefits (amenity, microclimate, etc.) (Section 2.5).

Maintenance work is distinct from larger rectification works that may be required to fix systems that are functioning poorly. Systems that follow best practice design principles, are well built and carefully established, rarely require these extensive works. In the case of healthy and functional biofilters, maintenance tasks are routine, planned and straightforward. A biofiltration maintenance review conducted in the City of Port Phillip confirmed this, noting that **with good design, construction and establishment practices, maintenance requirements are minimal** (E2DesignLab, 2014b, a). The review also noted the importance of clearly distinguishing between routine maintenance and rectification works. This delineation is important for effective planning, funding and undertaking of maintenance works.

Routine inspection and maintenance requirements are relatively predictable, allowing designers to facilitate maintenance activities from the early stages of design (discussed in Section 3.6.1, and asset managers to plan and budget for the required activities (discussed below in Section 4.3.1). **Effective inspection and maintenance programs can lead to substantial cost savings from the avoidance of expensive rectification works, under-performance and otherwise shortened system lifespan** (Browne et al., 2013). Hence, despite higher upfront costs, maintenance budgets must account for a rate of depreciation, which can be reduced by proactive maintenance (Browne et al., 2013).

Maintenance tip

- To function properly, stormwater biofilters must have a healthy and extensive vegetation cover, flows must be able to enter and pond across the entire surface, stormwater will infiltrate into the media relatively quickly and the system will drain and release outflows as designed.
- In particular, inspections must assess plant health, cover, sediment accumulation or other signs of clogging, and blockages caused by litter and debris (particularly at inlet, outlet or overflow points).
- Systems will also require more frequent monitoring across dry months, and some irrigation or watering may be required to sustain plants through prolonged dry spells.

Asset owners may also wish to undertake a more detailed monitoring program. This can further inform maintenance, future designs and confirm if performance targets are being met. However, monitoring requires careful planning and implementation to achieve the desired outputs (Section 4.3.3 and Appendix G).

The following sections outline a range of issues associated with monitoring and maintenance from i.) organisational planning and record keeping, ii.) project stages and key tasks, iii.) degrees of monitoring and considerations. This guidance is primarily targeted at local government bodies, as they are most commonly the asset owners, but the guidance is also relevant to any other owners and for developers handing over assets.

4.3.1 Enabling successful maintenance systems

Organisational planning

An effective monitoring and maintenance program must be underwritten by capability at the organisational level. This requires a supportive knowledge and culture within the organisation. Processes will necessarily differ between organisations. Examples of organisational planning include the approach adopted by the City of Port Phillip, where planned maintenance is clearly differentiated from renewal works, with each funded separately from different expenditure budgets. In addition, maintenance tasks are allocated to suit contractor skills and other council maintenance tasks; routine maintenance is assigned to traditional civil maintenance crews, and vegetation is looked after by the parks and open spaces contractors.

The key issues and considerations when planning works programs are described below:

- **Capacity and ownership** – although it may appear to be straightforward, in some cases the ownership of assets is not clear. Ensuring the organisation has a clear understanding of its assets and management responsibilities is critical. This requires a culture of willingness and capacity building to develop and constantly update the necessary skills, asset inventory and management systems.

- **Inventory and record keeping** – compiling a list and details of all biofilter assets is a fundamental requirement, but not a trivial task when numerous assets are involved. Keeping these records up-to-date as new assets are handed over or constructed, and recording the outcomes of monitoring and maintenance, is also vital. This background information should also be readily available to managers and field crews undertaking works on individual assets. Resources are available to assist organisations to achieve this – for example, Melbourne Water have undertaken an Asset Inventory project to assist councils in recording and accessing information on WSUD assets and their condtion (Parsons Brinckerhoff, 2013).

- **Clear definition of maintenance (separate from renewal or rectification works)** – routine maintenance activities are relatively straightforward and inexpensive for systems that do not suffer legacy issues from poor design, construction or establishment practices (E2DesignLab, 2014b). Hence, rectification or renewal works should be considered separately to maintenance, and funded accordingly. This allows organisations to plan and budget for maintenance, and separately set aside contingency funds for more substantial rectification works if required.

- **Budget planning and allocation** – sufficient funds for maintenance must be allocated from an early stage, at the outset when the entire project budget is determined. Importantly, additional funds must be available for more frequent monitoring and maintenance during establishment. This vital stage is critical to a successful system as good establishment will significantly reduce long-term maintenance or rectification costs.

- **Contract management** – contract terms must be carefully considered from the outset of the project. Particular care should be given to how the contract terms transition through the different project stages, particularly at handover. Poorly considered contracts can lead to unnecessary challenges for management and may reduce the chances of developing and operating successful biofilters.

- **Differences between assets** – Every biofilter will be unique to some extent, and this can present a challenge to maintenance crews. In particular, systems with highly innovative design may require specific maintenance guidance and training, and there should not be a 'one-size-fits-all' approach to monitoring and maintenance. However, the basic principles of biofilter function and many key risks are common to all systems. Crews must be trained to understand the purpose of biofilters, their basic function, common problems and maintenance activities. Maintenance personnel should also have access to site-specific information when on-site, including detailed plans (showing the flow paths) and maintenance records. When planning activities, it must be recognised that some assets will require more frequent maintenance (such as those in highly visible public places or catchments with high sediment or litter loads) (Parsons Brinckerhoff, 2013). In addition, systems that might be highly innovative in design (i.e., differing from 'standard' configurations) may require greater attention and training of maintenance personnel.

- **Service Levels** – defining the level of service to be provided to biofilter assets is important for maintenance planning (Parsons Brinckerhoff, 2013). In some cases, the community could expect a high level of service that cannot be provided within the available budget. As a result, the level of service provided may differ between assets, with greater service provided to assets in highly visible public places. This challenge can also be addressed through good design, construction and establishment (E2DesignLab, 2014b, a), and in particular by implementing practices that reduce maintenance requirements (Sections 2.7.3 and 3.6.1).

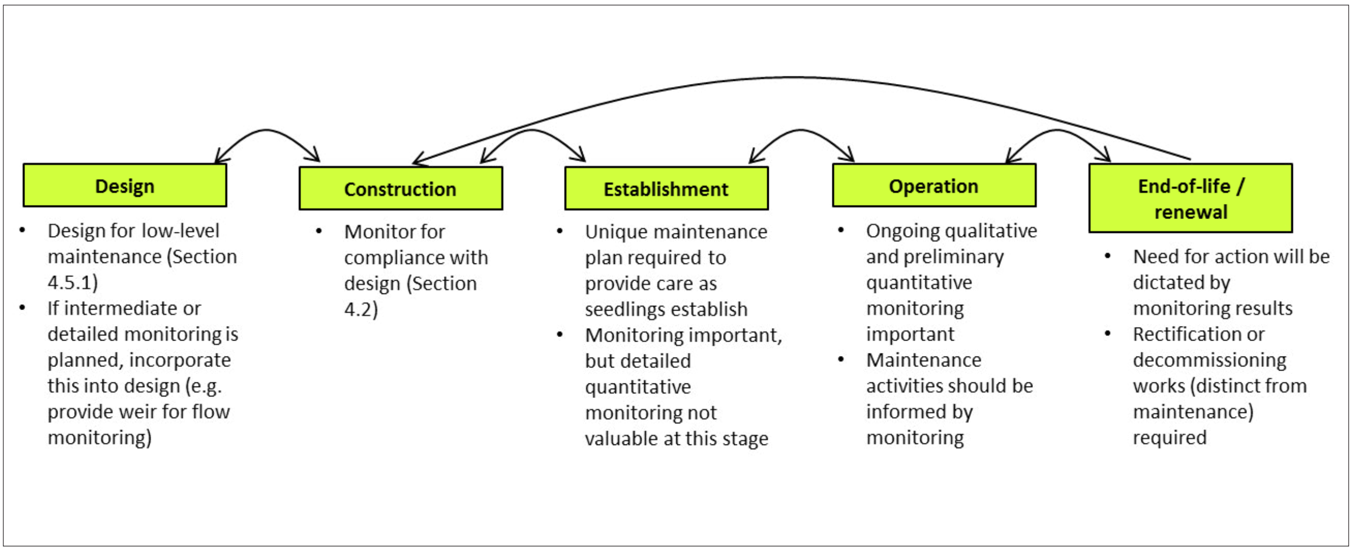
- **Contractor management and training** – Biofilters uniquely combine both landscape and civil components (E2DesignLab, 2014b). This differs from traditional council maintenance requirements and demands a unique skill set. Hence, it is important to train contractors on the function of biofilters and critical components for maintenance (see Maintenance Fact Sheet in Appendix A).

- **Maintenance plan** - All maintenance activities must be specified in an approved Maintenance Plan (and associated maintenance inspection forms) to be documented and submitted to council as part of the Development Approval process (see Appendix D for an example maintenance plan and Appendix J for a maintenance field sheet). Maintenance personnel and asset managers will use this Plan to ensure that the biofilters continue to function as designed. An example operation and maintenance inspection form is included in Appendix K. This form must be developed on a site-specific basis, as the nature and configuration of biofilters varies significantly.

- **Changing requirements through different project stages** - Monitoring and maintenance requirements will change as the project progresses through various stages (Figure 43). In particular, qualitative monitoring is critical following construction and at the time of handover. Further guidance for the handover of assets can be found in Water by Design's *Transferring Ownership of Vegetated Stormwater Assets* (2012).

  Biofilters also require an establishment period of approximately two years to enable the filter media to settle and the vegetation to reach its design conditions. During this phase, careful maintenance is particularly crucial to long-term success, and some preliminary qualitative monitoring may be conducted. For example, the colour and clarity of outflows from a biofilter during the initial operating period should be monitored (to assess whether fines and leaching of organic matter might be problematic), but detailed water quality monitoring during this period would not provide an assessment of the system's optimal treatment performance. Instead, quantitative monitoring is most important within the operational phase. Qualitative and preliminary quantitative monitoring is vital throughout all stages from construction to end-of-life or renewal. Hence, the frequency and tasks undertaken for monitoring and maintenance must be adjusted throughout the project life cycle.

- **Maintenance access** – this must be considered from the outset of the design process, including vehicle and equipment access and any safety requirements with regard to traffic management. In particular, larger biofilters will require a maintenance access track for vehicles (e.g. 4WD ute), including access to the sediment forebay.



Design
- Design for low-level maintenance (Section 4.5.1)
- If intermediate or detailed monitoring is planned, incorporate this into design (e.g. provide weir for flow monitoring)

Construction
- Monitor for compliance with design (Section 4.2)

Establishment
- Unique maintenance plan required to provide care as seedlings establish
- Monitoring important, but detailed quantitative monitoring not valuable at this stage

Operation
- Ongoing qualitative and preliminary quantitative monitoring important
- Maintenance activities should be informed by monitoring

End-of-life / renewal
- Need for action will be dictated by monitoring results
- Rectification or decommissioning works (distinct from maintenance) required

Figure 44. Project phases and interactions between stages

4.3.2 Inspection and maintenance program

Routine maintenance activities aim to support ongoing biofilter function. If conducted effectively and in a timely manner, maintenance will prevent any escalation of problems and avoid the need for costly rectification or system resets.

Typical maintenance tasks and frequencies are outlined in Table 17, while some key aspects are highlighted below:

- **Timing** - Maintenance should occur only after a reasonably rain free period, when the filter media in the biofilter is relatively dry. Inspections are also recommended following large storm events to check for scour and other damage.
- **Frequency** - Recommended frequencies are given in Table 17. However, this will vary throughout the project life, with more frequent inspections required during establishment. It may also differ between systems, depending upon factors such as public visibility or sediment and litter load input from the catchment, or with the level of service to which the asset owner commits.
- **Typical maintenance activities** will focus upon either the vegetation, filter media or hydraulic aspects of the system:
    - **Vegetation** - Vegetation plays a key role in pollutant removal processes and in maintaining the porosity of the filter media. Hence, a strong healthy growth of vegetation is critical to the treatment performance of biofilters. The most intensive period of maintenance is during the plant establishment period (i.e., the first two years), when weed removal and replanting may be required. However, care during this early phase will reduce long-term maintenance requirements and lessen the likelihood that an expensive re-plant of the entire system will be required. Readers are directed to the 'Construction and Establishment Guidelines' by Water by Design (2009) for detailed information on vegetation establishment (also discussed in Section 4.2).
    - **Filter media** – The surface of the biofilter is vulnerable to erosion, scour, damage from pedestrians or vehicles, sediment and litter accumulation, clogging and moss growth. These compromise the function of the system, in terms of the infiltration rate and the capacity to treat stormwater volumes.
    - **Hydraulic components** - Inflow systems and overflow pits require careful monitoring, as these can be prone to scour, sediment accumulation and litter accumulation. Debris can block inlets or outlets and can be unsightly, particularly in high visibility areas. Inspection and removal of debris should be undertaken regularly, and debris should be removed whenever it is observed on a site. Sediment accumulation across the media surface should also be closely monitored and removed when significant. Where sediment forebays or other pre-treatment measures are adopted, regular inspection of the pre-treatment system is required (three monthly) with removal of accumulated sediment undertaken as required (typically once per year).

A range of checking tools to assist designers and local government organisations is provided in Appendix K. These tools include an operation and maintenance inspection form and an asset transfer checklist.

Table 17. Inspection and maintenance - tasks and recommended frequencies.

Filter Media Tasks
Sediment accumulation / clogging Inspect for the accumulation of an impermeable surface layer (such as oily or clayey sediment), ponding of water for more than a few hours following rain (including the first major storm after construction), or widespread moss growth. Repair minor accumulations by scarifying the surface between plants and if feasible, manual removal of accumulated sediment. Investigate the cause of any poor drainage. **Frequency - 3 MONTHLY, AFTER RAIN**
Holes, erosion or scour Check for erosion, scour or preferential flow pathways, particularly near inflow point/s and batter slopes (if present). May indicate poor flow control e.g. excessive inflow velocities or inadequate bypass of high flows. Repair and infill using compatible material. Add features for energy dissipation (e.g. rocks and pebbles at inlet), or reconfigure to improve bypass capacity if necessary. **Frequency - 3 MONTHLY, AFTER RAIN**

Cont.

Table 17. Continued

Filter media surface porosity – sediment accumulation and clogging Inspect for accumulation of an impermeable layer (such as oily or clayey sediment) that may have formed on the surface of the filter media. Check for areas of increased sediment deposition, particularly near inlet/s. A symptom of clogging may be that water remains ponded in the biofilter for more than a few hours after a rain event, or the surface appears 'boggy'. Repair minor accumulations by raking away any mulch on the surface and scarifying the surface of the filter media between plants. Accumulated sediment can be manually removed using rakes and shovels, if the system is not too large, or only certain areas require attention. If excessive loads of sediment, investigate the source and install pre-treatment device if necessary. For biofilter tree pits without understorey vegetation, any accumulation of leaf litter should be removed to help maintain the surface porosity of the filter media. **Frequency - 3 MONTHLY, AFTER RAIN**
Damage Check for damage to the profile from vehicles, particularly streetscape systems alongside parking or street corners. Also check for signs of pedestrian traffic across the filter surface, such as worn pathways. Repair using compatible filter media material. **Frequency – 6 MONTHLY**
Litter control Check for anthropogenic litter and significant accumulations of organic litter, particularly in sediment pits, inlets, outlets and overflows. Remove litter to ensure flow paths and infiltration through the filter media are not hindered. Systems are particularly vulnerable to accumulations of organic litter during establishment, which can smother seedling growth and re-release nutrients as it breaks down. Litter can be removed manually and pre-treatment measures (such as a gross pollutant trap) can be used if it is a significant problem. **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS**
Moss growth Moist systems or those with deep shading of the surface may have excessive moss growth across the surface. This can act to bind the surface, contributing to clogging. Manual scraping can remove the moss, but the underlying cause should be investigated and rectified if possible. **Frequency – 6 MONTHLY, ESPECIALLY DURING WETTEST MONTHS**
Horticultural Tasks
Establishment The initial period after construction (up to the first 2 years) is critical to long-term success or failure of the biofilter. Additional monitoring and maintenance works are required to ensure a healthy and diverse vegetation cover develops, and that stormwater flows move through the system as the design intended (i.e., flows enter freely, covering the entire surface, ponding occurs to the design depth, high flows bypass and the infiltration rate is acceptable). Careful attention can avoid costly replanting and rectification works. New seedlings will require regular watering and irrigation, protection from high sediment loads and high flows. Refer to Water by Design's 'Construction and Establishment Guidelines' (2009). **Frequency – WEEKLY IF ESTABLISHING ACROSS DRY SEASON, HIGH FREQUENCY DURING FIRST 3 MONTHS IN PARTICULAR, INCLUDING AFTER FIRST LARGE RAIN EVENT. AFTER THIS, BIMONTHLY IN WETTER MONTHS AND MORE FREQUENTLY DURING THE COURSE OF ANY LONG DRY AND HOT SPELLS. UP UNTIL 2 YEARS.**
Plant health and cover Lower plant density reduces pollutant removal and infiltration performance. Inspect plants for signs of disease, die-back, pest infection, stunted growth or senescent plants and assess the degree of plant cover across the surface. If manifestations of poor plant health or meagre coverage are widespread, investigate to identify and address the causal factor (e.g. poor species selection, shading, too dry (e.g. oversized, wrong inlet levels or level for ponding zone, dry climate, media with minimal water holding capacity, poor flow distribution, lack of irrigation), too wet (e.g. from clogging, undersizing) or smothering from litter. Treat, prune or remove plants and replace as necessary using appropriate species (species selection may need re-consideration in light of the level of water availability), aiming to maintain the original planting densities (6-10 plants/m^2 recommended). Provide watering or irrigation to support plants through long, dry periods. **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS, BUT ADDITIONALLY CHECK DURING LONG DRY SPELLS**

Cont.

Table 17. Continued

Weeds Weeds should be identified and removed as they emerge. If left, weeds can out-compete the desired species, possibly reducing water treatment function and diminishing aesthetics. Inspect for and manually remove weed species, avoiding the use of herbicides, because biofilters are often directly connected to the stormwater system. If unavoidable, apply in a targeted manner using spot spraying. **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS**
Pruning and harvesting (if feasible) It may be worth considering occasional use of harvesting plants to permanently remove nutrients and heavy metals stored in aboveground plant material, and to promote new plant growth and further nutrient and metal uptake. Pruning may also benefit aesthetics. **Frequency – ONCE or TWICE A YEAR**
Drainage Tasks
Inlet pits/zones, overflow pits, grates and other stormwater junction pits Ensure inflow areas and grates over pits are clear of litter and debris and in good and safe condition. A blocked grate would cause nuisance flooding of streets. Inspect for dislodged or damaged pit covers and ensure general structural integrity. Remove sediment from pits and entry sites, etc. (likely to be an irregular occurrence in a mature catchment). **Frequency - MONTHLY AND OCCASIONALLY AFTER RAIN, BUT 6 MONTHLY IF NO CONSTRUCTION ACTIVITY UNDERWAY IN THE CATCHMENT.**
Underdrain Ensure that underdrain pipes are not blocked, to allow the system to drain as designed and prevent waterlogging of the plants and filter media. A small steady clear flow of water might be observed discharging from the underdrain at its connection into the downstream pit some hours after rainfall. Note that smaller rainfall events after dry weather may be completely absorbed by the filter media and not result in flow. Remote camera (e.g. CCTV) inspection of pipelines for blockage and structural integrity could be useful. **Frequency - 6 MONTHLY, AFTER RAIN**
Sediment forebay/pre-treatment zone Removal of accumulated sediment and debris. **Frequency – TWICE A YEAR (or more frequent if accumulation is particularly rapid)**
Raised outlet Check that the weir/up-turned pipe is clear of debris. **Frequency – 6 MONTHLY, AFTER RAIN**
Submerged zone Although the submerged zone helps to sustain the biofilter through dry periods, if drying persists (e.g. → 3 weeks, but varies with climate) for long enough it will become drawn down and require replenishment (for lined systems), the plants will require irrigation (for unlined systems). **Frequency – MONTHLY THROUGHOUT DRY SEASON (i.e., only when rain is infrequent), or AS REQUIRED (refer to Equation 1 in Section 3.6.3 to estimate the required time for re-filling, but this should also be monitored on-site)**
Other Routine Tasks
Inspection after rainfall Occasionally observe the biofilter after a rainfall event to check infiltration. Identify signs of poor drainage (prolonged ponding on the filter media surface). If poor drainage is identified, check land use and assess whether it has altered from design capacity. For example, unusually high sediment loads may require installation of a sediment forebay. **Frequency – TWICE A YEAR AFTER RAIN**

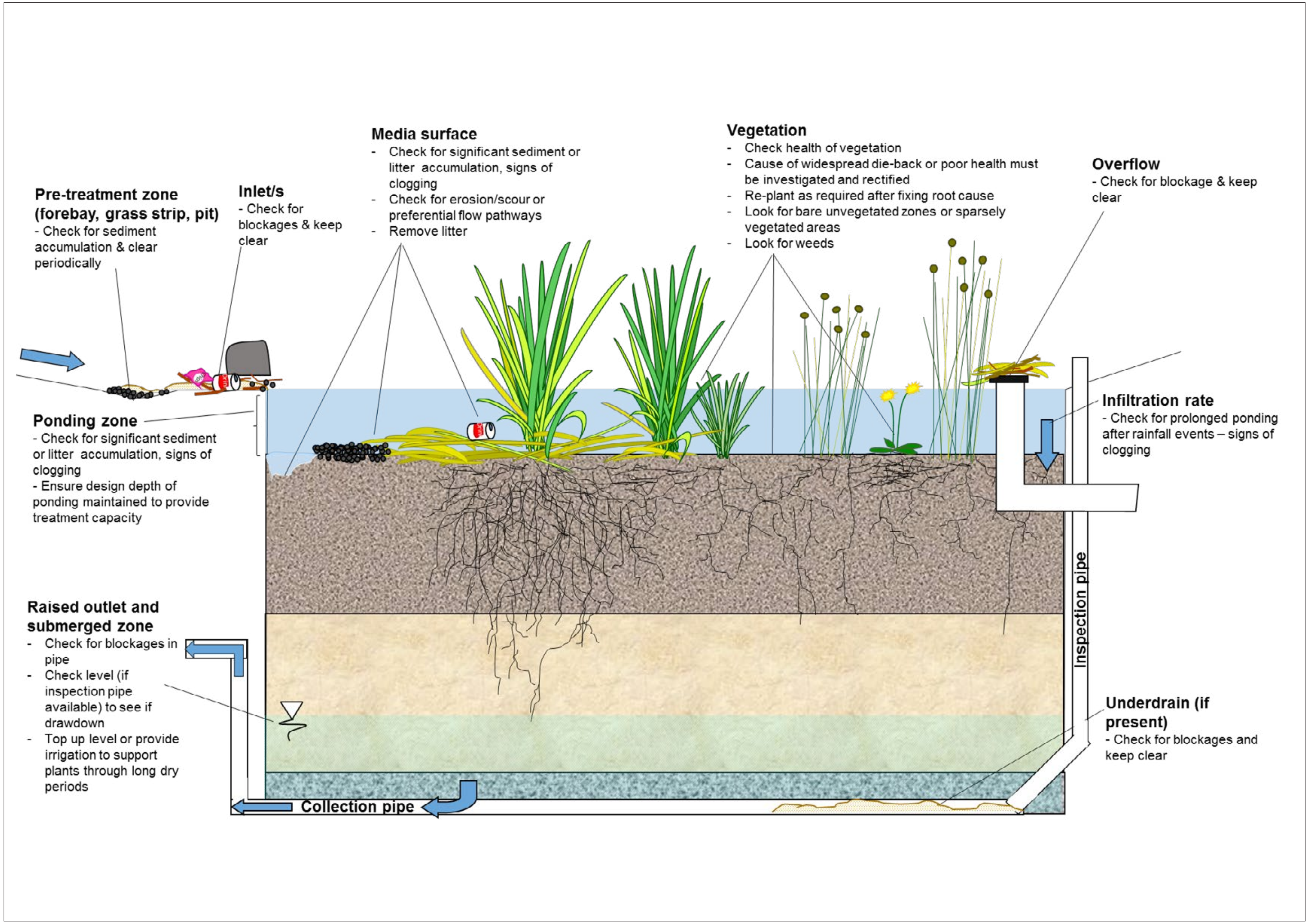


Figure 45. Critical checks and tasks for a monitoring and maintenance program

Maintenance tips

- Delineate biofilter to define areas where maintenance is required
- Include a description and sketch of how the system works in the Maintenance Plan
- Identify maintenance jurisdictions
- Coordinate site inspection and maintenance activities with maintenance of surrounding landscapes (e.g. parks, nature strips)
- Use of pressure jets is not recommended, due to the risk of damaging perforated pipes and opening joints

Important!

Weeds pose a serious problem – in addition to diminishing the appearance of a biofiltration system, they compete with the intended plant community, potentially reducing the treatment capacity. Further, some weeds are "nitrogen fixers" and add nitrogen to the system. Therefore, weed removal is essential to optimal performance.

It is illegal to use some herbicides in aquatic situations. Given that treated water from biofilters often discharges directly to drainage systems and receiving waters, the potential for herbicide contamination of waterways must be considered. For this reason, it is preferable to remove weeds manually. If this is not practicable, then a herbicide that is appropriate for use in and around water should be used.

Table 18. Common maintenance issues

Blocked inlet – restricts flow entry, reducing proportion of flows receiving treatment

Plant die-back – severely reduces treatment efficiency and leaves media vulnerable to erosion: unsightly

Widespread plant loss or die-back – can indicate too much or too little water, or poor filter function

Table 18. Continued

Plant die-back near inlet – may indicate high inflow velocities, sediment accumulation or poor species selection

Poor vegetation spread – may be due to use of rock mulch

Clogging – build up of fine sediments, moss or plant litter on the surface reduces infiltration and treatment capacity

Sediment accumulation – build up of fine sediments reduces infiltration and treatment

Litter accumulation (anthropogenic and organic) – unsightly and can hinder flow paths and infiltration

Blocked overflow grate – can lead to flooding and damage to the filter and vegetation

Vehicle and pedestrian damage – impacts vegetation health and causes compaction

Holes, erosion and scour – compromise even flow distribution and treatment

Weeds – unsightly and can reduce treatment capacity

4.3.3 Monitoring

There are several reasons why monitoring of biofilters might be desirable, including:

- To direct and inform maintenance activities (operational);
- To demonstrate compliance with legislative requirements (e.g. load reduction targets) (see Sections 1.3 and 3.2.1);
- To facilitate handover of the asset;
- To assess overall and/or long term performance (e.g. large scale stormwater quality improvement);
- To help identify the cause/s of any problems with system functioning (trouble-shooting);
- To collect data for model development; and
- To understand detailed processes.

Performance monitoring can quickly become resource intensive, therefore it is crucial that monitoring objectives are clearly developed in order to best harness the available resources. In general, the aim of a monitoring program will be to assess whether the system meets the defined performance objectives, and to provide information to direct maintenance activities. However there may sometimes be additional aims, such as model development or validation, which are more data intensive. An idea of the available budget is also necessary for developing realistic monitoring objectives.

Once the objectives of the monitoring program have been agreed, the type and quality of information required in order to achieve these aims can be determined, that is, the variables to be monitored, the level of uncertainty (accuracy) required and the temporal and spatial scale of the data.

Important!

Qualitative and preliminary quantitative assessment should always be carried out, but detailed monitoring is not required if biofilters are designed according to FAWB guidelines, because this design guidance is based on rigorous testing. However, **deviations from the recommended design** (e.g. alternative filter media, plant species, sizing), and biofilters that are used for stormwater harvesting, **should be carefully monitored**.

Depending upon the objectives, monitoring can be undertaken to varying degrees of detail. There are two main types of monitoring: qualitative and quantitative. There are several levels of quantitative monitoring. Operational monitoring, comprising both qualitative and preliminary quantitative monitoring, should accompany and inform the maintenance program:

- Qualitative (operational inspection) – this should be carried out for **every** system and consists largely of visual assessment formed during routine maintenance (Section 4.3.2). Elements that should be monitored, the problems they indicate and suggested management actions, are outlined within the maintenance discussion in Table 17.; and
- Quantitative –There are three levels of quantitative monitoring: preliminary, intermediate and detailed. These different types of monitoring, the information collected or parameters measured, and benchmarks for comparison of performance indicators, have been outlined in Table 19. The amount of effort, expense and expertise required increases with each level of monitoring:
  - ¬ Preliminary (operational): this should be carried out for **every** system. In general, preliminary quantitative monitoring will be adequate for assessing performance of biofilters designed according to these guidelines. It does not require specialised knowledge in order to be performed correctly.
  - ¬ Intermediate: appropriate for assessing new design configurations where the available budget does not allow for detailed monitoring. Intermediate assessment, through simulated rain events, offers a lower-cost alternative to detailed assessment, although there is a compromise on the amount of information gained; and
  - ¬ Detailed: appropriate for assessing new design configurations, and for model development. This type of monitoring is the most resource intensive and requires a substantial level of expertise. However, it is strongly recommended that this be undertaken for biofilters whose design deviates from tested recommendations and should be undertaken by an organisation experienced in this type of activity.

Monitoring tip

Development of a database of local biofilters that collates information on their catchments, design, maintenance logs and performance assessments would provide an invaluable source of information for design and operation of future systems.

Important!

Qualitative monitoring should **always be carried out and thoroughly documented**; this can be conducted in conjunction with routine maintenance tasks. Photographs are invaluable accompaniments to written documentation.

Table 19. Different types of monitoring, parameters collected and performance assessment

Monitoring type	Information collected or parameters measured	Benchmarks for performance assessment
Background information	The following types of information should be collected, where available: • Catchment characteristics – catchment area, slope, nature and extent of imperviousness, geological characteristics, land-use; • Biofiltration system characteristics – layout (size, slope, elevation), design capacity, materials (filter media, vegetation, liner, submerged zone, underdrain), age and condition, maintenance practices (frequency, cost, etc.); and • Climate – rainfall, temperature, evapotranspiration.	
Preliminary quantitative (operational monitoring & essential)	There are two aspects to preliminary assessment of biofilter performance: • Monitoring of the **hydraulic conductivity of the filter media** - this should be monitored using the method described in Practice Note 1: In situ measurement of hydraulic conductivity (Appendix I). The recommended monitoring frequency is as follows: ¬ At the start of the second year of operation; ¬ Every two years from Year 2 onwards, unless visual assessment indicates that the infiltration capacity might be declining i.e., there is a visible clogging layer, signs of waterlogging, etc.	Target range 100-300 mm/hr. Hydraulic conductivity is expected to decline rapidly initially as the new media consolidates, but partially recover and stabilise once plants have established.

Cont.

Table 19. Continued

Monitoring type	Information collected or parameters measured	Benchmarks for performance assessment
	• **Long-term accumulation of heavy metals** - A field study of more than 18 biofilters showed that, for appropriately sized systems with typical stormwater pollutant concentrations, heavy metal levels are unlikely to accumulate to a level of concern, as compared to the National Environment Protection Council's health and ecological guidelines (NEPC, 1999a) for 10 – 15 years. However, in catchments with past or present industrial land-use heavy metals may accumulate more rapidly. The recommended monitoring protocol is as follows: ¬ Filter media samples should be collected and analysed for heavy metals during Year 5 of operation. ¬ For biofilters with a surface area less than 50 m2, collect filter media samples at three, spatially distributed points (one near the inlet). ¬ For systems with a surface area greater than 50 m2, add an extra monitoring point for every additional 100 m2. ¬ At each monitoring point, collect a sample at the surface and another at a depth of 10 cm to assess whether heavy metals are migrating through the filter media. ¬ To minimise potential for sample contamination and achieve accurate results, collect soil samples according to standard protocol in appropriately prepared containers (see AS 1289.1.2.1 – 1998) and have them analysed by a NATA-accredited laboratory for at least Copper, Cadmium, Lead and Zinc, as well as any other metals that are deemed to be of potential concern. Consult with the analytical laboratory as to the amount of soil required to carry out the analyses. ¬ Note: Accumulated heavy metals will be concentrated at the surface of filter media. Therefore, when heavy metals accumulate to levels of concern, this can be managed by scraping off and replacing the top 100 mm of filter media.	**Accumulation of heavy metals:** Compare test results to both the raw filter media and the National Environment Protection Council's Guideline on the Investigation Levels for Soil and Groundwater; see Health (HIL) and Ecological Investigation Levels (EIL) (Table 5-A). The appropriate HIL will be determined by location of the biofilter. Frequency of further assessment should be based on the results of this first assessment: if the concentration of one or more of the measured heavy metals is half-way to either the HIL or EIL, then heavy metals should be monitored at two-year intervals; if all measured concentrations are well below this, continue to check concentrations at five-year intervals.

Cont.

Table 19. Continued

<table>
<tr><th>Monitoring type</th><th colspan="2">Information collected or parameters measured</th><th>Benchmarks for performance assessment</th></tr>
<tr><td>Intermediate Quantitative</td><td>This involves simulating a rain event using semi-synthetic stormwater. If possible, multiple simulations should be undertaken to give greater insight into biofilter performance. This should include simulated events in different seasons and following different lengths of preceding dry periods. Further details of this procedure appear in Appendix H.</td><td rowspan="2">Guidance for selecting appropriate parameters for different performance objectives is given below:
<table>
<tr><th>Objective</th><th>What to monitor</th></tr>
<tr><td>Pollution control</td><td>Inflow and outflow concentrations (important for flowing waters, e.g. streams) – nutrients, metals
Flow rates at the inflow and outflow – use in conjunction with concentrations to determine pollutant loads (important for standing receiving waters, e.g. lakes, bays)</td></tr>
<tr><td>Flow management</td><td>Flow rates at the inflows and outflow – for determination of:
Runoff frequency reduction
Peak flow reduction
Reduction in runoff volume</td></tr>
<tr><td>Stormwater harvesting</td><td>Peak pollutant concentrations in the treated water (outflows) – metals, pathogens</td></tr>
</table></td><td rowspan="2">A number of state, territories, regions and municipalities stipulate performance targets for WSUD, which often include biofiltration systems (e.g. Clause 56.07 of the Victoria Planning Provisions prescribes target pollutant load reductions of 80, 45, and 45% for TSS, TN, and TP, respectively). Where these exist, monitoring data should be compared against these targets. However, in the absence of mandated performance targets, the primary performance objective should be to maintain or restore runoff volumes to pre-development levels.

In the absence of stipulated performance targets, outflow pollutant concentrations could be compared to the ANZECC Guidelines for Fresh and Marine Water Quality. These guidelines provide water quality targets for protection of aquatic ecosystems; the targets should be selected according to location of the biofilter and the state of the receiving water (e.g. slightly disturbed, etc.). However, the reality is that, even using best practice design, biofilters will not necessarily always be able to comply with these relatively strict guidelines. The local authority may in this instance choose to rely on the national Load Reduction Targets provided in Chapter 7 of <i>Australian Runoff Quality</i> (Wong, 2006).</td></tr>
<tr><td>Detailed Quantitative</td><td>Detailed quantitative assessment involves continuous flow monitoring (of inflows and outflows) and either continuous or discrete water quality monitoring (depending upon the water quality parameter). Further details of procedures are given in Appendix G.</td></tr>
</table>

4.4 Remedial works, re-sets and biofilter lifespan

In general, stormwater biofilters are expected to have a lifespan in the order of 10 – 15 years (Hatt et al., 2011, Parsons Brinckerhoff, 2013, NEPC, 1999b). However, this will vary with catchment characteristics, climate, pollutant and hydraulic loading, design configuration (sizing, vegetation), and construction, establishment and maintenance procedures.

It is important to note that a well-designed, constructed and established biofilter should not require major remedial works until it nears its expected demise (E2DesignLab, 2014b). Hence, upfront investment and care to develop a healthy, resilient and functioning system will yield long-term rewards in terms of greater performance, reduced costs and prolonged lifespan (E2DesignLab, 2014b, Browne et al., 2013).

4.4.1 Pollutant accumulation and lifespan

The lifespan and renewal requirements of biofilters will vary between systems depending upon characteristics of the catchment, local climate and the biofilter itself:

- Sediment sources in the catchment - particularly from a high level of construction activity
- Pollutant sources - such as industrial land use, use of fertilisers, roofing material.
- Litter sources – such as deciduous trees.
- Level of imperviousness and connectivity of the drainage network – are key indicators of the effect of stormwater runoff on stream health, as they represent the degree of shift from natural hydrology (Walsh et al., 2005).
- Rainfall patterns – these generate pollutant transport and loading on biofilters.
- Pre-treatment - acts to remove some of the sediment load, and associated pollutants, before flow enters the biofilter, allowing ease of removal and protecting the biofilter. Pre-treatment is particularly important in catchments with high sediment loads.
- Location of biofilter – if located in headwaters of the catchment, it is less vulnerable, but if located online and/or far downstream, the system will be under greater loading.
- Biofilter design and construction – using good design and construction principles to ensure i.) appropriate sizing, ii.) correct filter media specification, iii.) sufficient media depth, iv.) adequate soil moisture to support vegetation and v.) appropriate invert levels and flow hydraulics to allow stormwater to enter, distribute, pond, infiltrate, drain and overflow as intended. With poor design or construction, lifespan can be significantly reduced, necessitating remedial works and costly resetting.
- Biofilter maintenance – regular and timely maintenance (‘a stitch in time’) is key to achieving an optimal lifespan (Browne et al., 2013).

Biofilters may require renewal for a number of reasons, including pollutant accumulation or poor functionality (e.g. significant erosion, widespread plant loss, severe clogging). Industry data and experience, gathered during interviews, and a review conducted by Parsons Brinckerhoff (2013), collectively suggest the following renewal frequencies for biofilters:

- removal and disposal of accumulated sediments are required every 2-5 years;
- a minor re-set (replacement of plants and the top 100 mm of filter media) is often required after 10 – 15 years of operation.

Without plants, a laboratory study using accelerated dosing estimated 5-10 years before replacement of the surface media with an average loading capacity of 11.2 kg/m^2. This study also found that repeated replacement of the surface media was effective and did not lead to a longer-term deterioration in sediment treatment capacity (Ma et al.).

For tree pits:

- the estimated lifespan before replacement of the cover, filter media and/or tree was generally 5-25 years (Parsons Brinckerhoff, 2013).

It is important to accept that pollutant accumulation is necessary for biofilters to serve its purpose. Biofilters are designed to accumulate pollutants; thus preventing them from dispersing throughout the environment. Hence, pollutant accumulation is desirable and should not be perceived negatively simply because it can pose management and disposal challenges. The accumulation characteristics of key stormwater contaminants are summarised in Table 20.

Table 20. Pollutant accumulation and expected lifespan for various pollutants

Accumulation and Breakthrough/Leaching	Expected lifespan
Sediment	
• Primarily accumulates across surface forming a clogging layer with reduced infiltration rate • Accumulation depends upon sediment delivery from the catchment; particularly high in developing areas with construction. • Course media layered across the surface can delay clogging (Kandra et al., 2014), but field testing still underway • Pre-treatment (e.g. sediment traps, swale, buffer strip) important to capture sediment and prolong lifespan, especially in developing catchments. • Inlet design, with wide flow distribution and multiple inlets to distribute sediment also important (Virahsawmy et al., 2014). • Maintain a high level of vegetation cover as plants help maintain porosity of the clogging layer (Virahsawmy et al., 2014, Le Coustumer et al., 2012, Hatt et al., 2009). • Regular scraping off accumulated sediment, particularly near the inlet, helps prolong lifespan (Hatt et al., 2008).	• Scraping top 2-5 cm approximately 2- 5 years (Parsons Brinckerhoff, 2013). • Replacement of top 100 mm and plants after 10-15 years (Parsons Brinckerhoff, 2013).
Phosphorus	
• Accumulates in media and plant biomass. No permanent removal pathways, except via harvesting plant biomass. • In the media, accumulation can be variable, but generally highest in zones of high sediment accumulation (i.e. near inlets and top 10 cm). • Predominantly adsorbed to iron (Fe) at greater depths for long-term storage under aerobic (oxygenated) conditions (Glaister et al., 2013)	• Expect removal in long-term to be maintained in the long-term without breakthrough using current, best-practice design. • Enhance long-term retention if filter media is augmented with iron- and aluminium-oxide rich sand (Glaister et al., 2013)
Nitrogen	
• May accumulate in media and plant biomass, and permanently removed via denitrification (which requires anaerobic (low oxygen) conditions). • Plant uptake can form the primary removal pathway in early biofilter life (Payne et al., 2014). • Recommend low-nutrient content media, careful plant species selection and inclusion of a submerged zone for long-term removal. • If feasible, harvesting (pruning) and removing above-ground biomass may help prolong lifespan, but this remains to be tested.	• In field biofilters have shown consistently good nitrogen removal, even under high nitrate loading (Zinger and Deletic, 2012). • Contribution of plant uptake, re-release and denitrification loss in mature systems, are relatively unknown.

Cont.

Table 20. Continued

Accumulation and Breakthrough/Leaching	Expected lifespan
Metals	
• Progressively saturate the media from the surface downwards (Hatt et al., 2008). • Will vary with catchment sources - catchments with current or past industrial uses more likely to have limited lifespan and require regular removal of surface sediment • Plant uptake and storage in biomass may help prolong lifespan, as shown in phytoremediation applications (Rascio and Navari-Izzo, 2011, Dahmani-Muller et al., 2000). If biomass accumulation is significant, harvesting and removal of biomass provides a permanent removal pathway, but the potential remains largely unknown in stormwater biofilters.	• Test filter media for metals accumulation after 5 years. Accumulation is unlikely to be of concern for 10-15 years if biofilter adequately sized and inflow concentrations typical. For industrial or past-industrial catchments, accumulation will be more rapid. • See Monitoring Section 4.3.3 for protocols. - Removal of the surface layer in a timely manner can lead to lower disposal costs before accumulation exceeds certain thresholds (as per state regulations or National Environment Protection Council, 1999). • Zinc prone to accumulation and saturation, due to typically higher stormwater concentration (Hatt et al., 2011) – may leach after 10-15 years • Lifespan of 12-15 years expected for Cd, Cu and Pb[1] (Hatt et al., 2011) • Prolong lifespan by increasing biofilter size, using deeper filter media with high cation exchange capacity (Hatt et al., 2011)
Micropollutants	
• Breakthrough point variable between micropollutants. • Breakthrough more likely for those with long half-lives and/or low tendency to adsorb (e.g. herbicides, chloroform, phenol; Table 1, Zhang et al. 2014). • Breakthrough point sensitive to amount of organic matter, inflow concentrations and occurrence of back-to-back storm events (detrimental to removal) (Zhang et al., 2014b).	• Limited data • Theoretical maximum mass adsorbed before breakthrough estimated by Zhang et al. 2014b (Table 3), but difficult to quantify lifespan, given sensitivity to organic matter, inflow concentration, chemical properties of pollutant and inflow hydrology.

Notes: 1 – assuming sized to 2% of catchment area, with typical Melbourne rainfall

4.4.2 Management, renewal and re-sets

The following considerations are involved with the management of biofilter lifespan and renewal:

- **Monitor for indicators that require action** - Resetting (i.e., complete reconstruction) or remedial works (renewing only certain aspects) may be required if:
    - the system fails to drain adequately (clogging);
    - it is determined that the filter media has reached its maximum pollutant retention capacity;
    - widespread vegetation die-back, disease or death occurs;
    - there is significant erosion, scour or preferential flow pathways;
    - there is significant sediment, litter, or moss accumulation across large areas of the biofilter surface;
- **Investigate the cause** – Before any large-scale works are undertaken it is vital to investigate and understand the cause of the problem. If the underlying cause is not also addressed, resources spent on remedial works may be wasted if the problem recurs. Causes may vary widely between systems, or even be unique to individual systems. However, reasons for remediation or re-sets may include:
    - Plants receiving insufficient water, i.e. low soil moisture levels, falling below wilting point < 0.1% v/v (Daly et al. 2012), possibly due to poor plant species selection, over-sizing biofilter area, poor hydraulics that do not allow ponding across the entire surface, media with very low water holding capacity (e.g. too sandy), shallow system, or lack of a submerged zone.

  - Incorrect invert level or lack of ponding depth – may be due to over-filling with media, poor design or construction, accumulation of high levels of sediment or litter.

  - Plants receiving too much water – outlet may be blocked, system undersized, or filter media clogged.

  - Preferential flow-paths move across surface or down through media – erosion or scour may result from poor plant cover, an undersized system, poor inlet design with insufficient velocity attenuation, failure to bypass high flows from the system, or failure to adequately seal the system, particularly in steep terrain with rock or soil walls.

- **Actions** – A re-set will only be required at end-of-life. In other cases, remedial works may be required to restore function. These activities may include (E2DesignLab, 2014b):

  - removal and replacement of the top layer of filter media,
  - widespread re-planting,
  - media removal to achieved the desired ponding depth,
  - modifications to hydraulic structures to improve function (e.g. invert levels, grate design),
  - retrofitting a submerged zone,
  - removal of gravel mulch,
  - large-scale sediment removal and disposal; and,
  - significant repairs from damage to the system.

- **Timely intervention** – Problems should be addressed as soon as they become evident. Ensure routine maintenance checks look for early indications of problems, and further monitoring is implemented if required to confirm this. This timely, or proactive, approach will generate cost savings as the problem can be addressed before it escalates and requires more substantial works (Browne et al., 2013).

- **Regular testing of metals accumulation in the filter media** - Allows timely replacement and disposal of the top layer, before metal levels exceed the National Environment Protection Council's Guidelines on Investigation Levels for Soil (Health and Ecological Investigation Levels). This is particularly important for biofilters with industrial or past-industrial land uses in their catchment. Monitoring protocols for heavy metal accumulation are detailed in Table 19 and testing is recommended after five years. Depending upon state soil disposal regulations (which do vary significantly between states (MacMahon, 2013a)), costs can be minimised if disposal occurs before the soil reaches prescribed waste classification, or a higher level of prescribed waste (if applicable to the state). This has been studied in the context of constructed wetlands and sediment ponds (MacMahon, 2013a, b).

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EXISTING TWIN SIDE ENTRY PIT IL2.20
ABLISHMENT OF N, DECOMMISION IDE ENTRY PITS REAKOUT KERB.
IL 1.70
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0.50m MIN PED ZONE REFER TO DRG 1432-08 FOR DETAILS
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EXISTING POWER POLE
ERBERT PLACE
E DETAIL A

Appendix A:
Fact Sheets

CRC for Water Sensitive Cities

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Fact Sheet: Why choose stormwater biofiltration?

Today's cities, and cities of the future, face mounting challenges from increasing population, housing density and climatic variability. Without careful planning, these changes greatly reduce the liveability of the urban area. The built environment in its traditional form exacerbates hot temperatures, severely restricts green spaces and distorts the hydrological cycle (Figure 1).

However, the potential of Water Sensitive Urban Design (WSUD) to help alleviate these problems is increasingly being recognised and quantified. Biofiltration of stormwater runoff is amongst a suite of WSUD tools. Biofilters provide improvements in water quality, downstream hydrology, biodiversity, microclimate, aesthetics, urban greenery, human health and an alternative water supply (Table 1). The costs of WSUD should be compared against the costs of implementing traditional stormwater management, which is accompanied by waterway degradation, flood control, water pollution, asset maintenance, upkeep of civic garden beds, loss of revenue to businesses dependent upon healthy aquatic environments, and loss of amenity to the community. Not all of these aspects can be readily quantified, but evidence of the economic benefits of biofiltration, or more broadly, WSUD, includes:

- The **amenity value of streetscape raingardens** in Sydney is realised in residential house prices, **increasing property values by around 6% ($54,000 AUD) for houses within 50 m and 4% ($36,000 AUD) up to 100 m away** (Polyakov et al., 2015).

- **A business case analysis of WSUD technology found the benefits do surpass the costs.** Even on a standalone basis, the value of nitrogen reduction was predicted to exceed the project lifecycle cost; increased property values were estimated at approximately 90% of the capital costs of WSUD; and the saved cost of waterway restoration works equate to approximately 70% of the project life cycle cost (Water by Design, 2010).

- From a waterway protection and restoration perspective, **WSUD technologies cost less to implement than the economic cost of traditional stormwater drainage** (i.e. taking into consideration the avoided costs of restoration works etc.; Vietz et al., 2014).

- A **reduction in nitrogen load** in stormwater runoff is currently **valued at $6,645/kg N in Victoria**, valued on the basis of past stormwater treatment works (Melbourne Water website, 2015)

Figure 1. Traditional urban design with impervious surfaces brings challenges for water management, climate control, human wellbeing and waterway health

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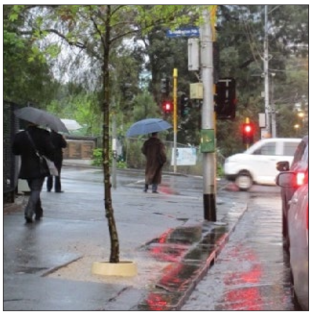
Table 1. The multiple and wide-ranging benefits of stormwater biofilters

Outcome delivered by biofilter	Resulting benefits
Improvement in quality of stormwater runoff	Improved water quality in local creeks, rivers, bays or lakes downstream. The improved health of riparian and aquatic environments: • Supports greater diversity and numbers of flora and fauna • Provides enhanced amenity for the local community & visitors • Improves community engagement and satisfaction with the local environment, • Increases the potential for use and enjoyment, which in turn delivers health benefits • Increases local property values • Reduces the need for expenditure on maintenance, management and works to restore degraded waterways and waterbodies • Increases commercial opportunities for fishing, tourism, sport and other activities associated with downstream waterbodies
Pollutant collection	The concentration of pollutants at a central point allows: • Capture before pollutants are distributed widely throughout receiving environment • Appropriate management, including potential reuse or safe disposal
Conversion of some pollutants into inert or stabilised forms	This transformation provides: • Permanent removal from the system (e.g. N into N_2 gas (denitrification), organic compounds into CO_2 and H_2O)
Reduction in runoff volume and peak flow	Alteration of the hydrological regime towards pre-development conditions delivers: • Reduced erosion and scouring in downstream creeks and streams • Flow regime that better supports healthy macrophyte and aquatic invertebrate communities, and diverse and healthy in-stream and riparian vegetation • Reduces the need to maintain or construct traditional stormwater drainage (e.g. piped underground networks) • Helps to mitigate localised flooding risk
Adds to neighbourhood aesthetics	Improves the landscape and attractiveness of streetscapes, parking lots, median strips and other public or private spaces, which generates: • Increased local property values • Community satisfaction and sense of pride
Provides a green space, cooling and enhanced amenity in the urban environment	In the urban environment green spaces provide: • Microclimate benefits with significant cooling of the urban environment from evapotranspiration and shading – this reduces energy demand and benefits human health significantly • Improvements to human health with increased mental wellbeing, exercise areas and socialising areas – providing a place 'people want to spend time in' • Public amenity as cities move towards higher density, with limited or no backyard environments • Avoids the landscaping cost otherwise required for a garden bed or lawn occupying the space



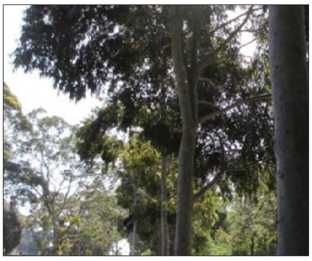


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Table 1. Continued

Outcome delivered by biofilter	Resulting benefits
Visible water management	The treatment of stormwater above ground, where it is visible and available to provide additional benefits, creates: • Community engagement and education • Allows stormwater to be embraced as a valuable resource and part of the urban environment • Potential for unique and functional landscaped elements – a possible 'selling point' or increased brand for the development
Habitat and biodiversity	Provision of habitat for flora and some fauna generates: • Greater diversity and distribution of local indigenous plant species • Habitat for insects and birds in the urban environment
Supplies alternative and local water source (stormwater harvesting schemes)	In the case of stormwater harvesting projects, the recycled water supply allows: • A viable alternative water supply • Greener public spaces - supports larger irrigated areas and green spaces throughout the summer • Reduced demand for potable water • Reduced demand for water pumping across long distances • Increased security of supply • Increases amenity for use (e.g. sports field) - delivering social and human health benefits
Passive and localised water treatment technology	Small-scale, distributed treatment of stormwater: • Has low energy requirements and no operational costs • Does not require large pipe collection/distribution networks • Reduces need to invest in large centralised and heavily engineered infrastructure for water treatment plant • Reduces the need for irrigated garden beds and landscaping, instead providing 'self-irrigation'
Provides shelter and screening	As a landscape element biofilters can be applied to provide: • Shelter from wind • Shading from the sun • A screen to improve the visual aesthetics (e.g. to conceal structures considered ugly) or provide a visual barrier

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Fact Sheet: How does stormwater biofiltration work?

What is biofiltration?

Compared to undeveloped catchments, urban areas generate stormwater runoff that is magnified in flow volume, peak and pollutant load. The poor water quality and altered hydrology are both highly detrimental to the health of receiving waters (e.g. streams, estuaries, bays). Water biofiltration is the process of improving water quality by filtering water through biologically influenced media (Figure 1). Stormwater biofiltration systems (also known as biofilters, bioretention systems and rain gardens) are just one of a range of accepted Water Sensitive Urban Design (WSUD) elements. They are a low energy treatment technology with the potential to provide both water quality and quantity benefits. The technology can be applied to various catchment sizes and landscape settings, from street trees and private backyards to street-scale applications and car parks, up to larger regional stormwater treatment systems, including in public parks and forested reserves (Figure 2). Further, biofilter design can be tailored to optimise performance for local conditions and specific treatment objectives.

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

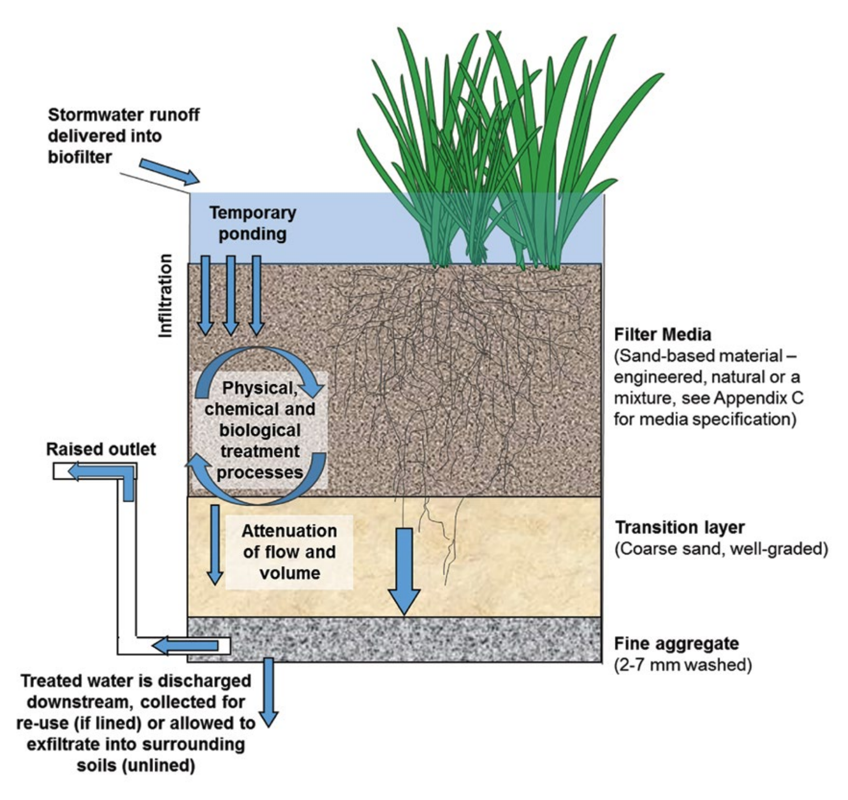

Figure 1. Key principles of stormwater biofiltration

For full details please refer to the Adoption Guidelines for Stormwater Biofiltration, CRC for Water Sensitive Cities (2015)

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Figure 2. Examples of stormwater biofilters, which can vary widely in their scale, appearance and design to suit treatment objectives and local site conditions. Photos supplied by Krish Seewraj and Antonietta Torre, Department of Water and Emily Payne, Monash University

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Key components

All biofilters operate using the same basic principles and some features are essential and common to all biofilters (Figure 3). Each component contributes to system functioning (Table 1). Configurations are flexible though and some characteristics will be tailored (Figure 4), allowing each system to be adapted for optimised performance, depending upon performance objectives and local site conditions.

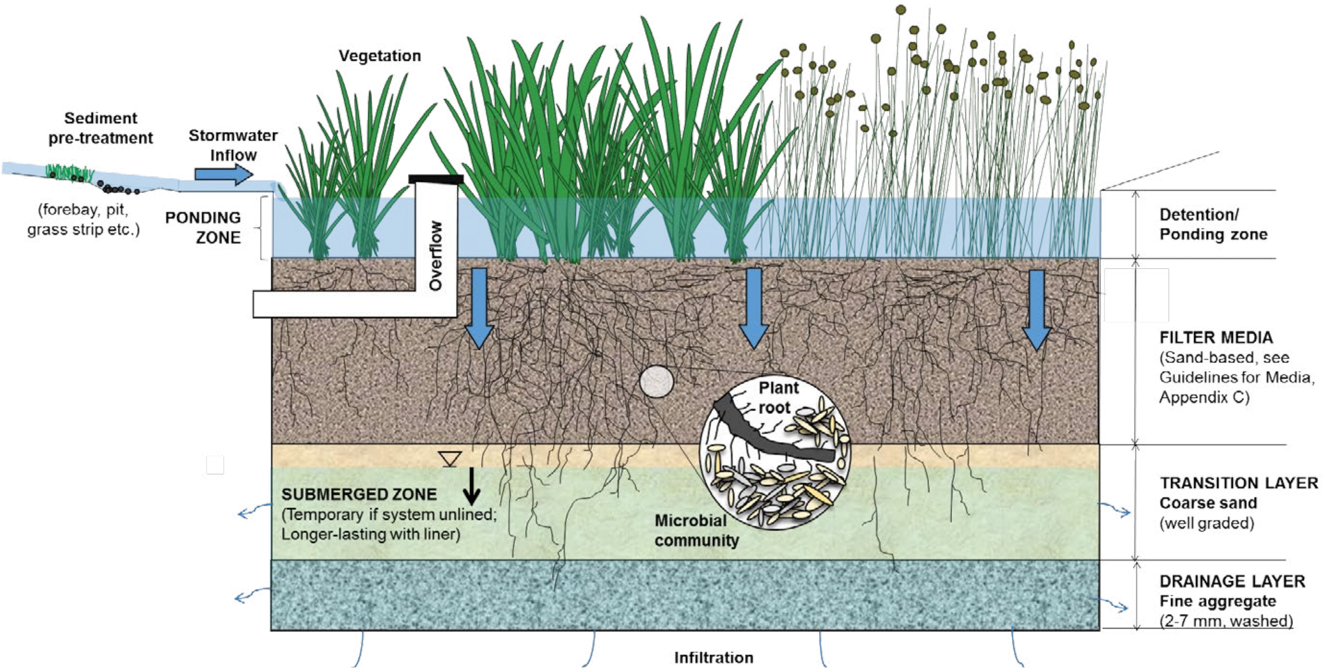

Figure 3. Essential components for stormwater biofilters (although their configuration can vary from the illustration shown above)

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

Essential components and function	**Key information can be found within Biofilter Adoption Guidelines (CRC for Water Sensitive Cities, 2015), Section...**	
Inflow	Delivers stormwater into biofilter	3.6.3
Overflow	Allows high flows to bypass to avoid damage to system	3.6.3
Ponding	(or detention zone) Increases treatment capacity by allowing stormwater to pond before infiltration	3.6.2
Vegetation	Serves multiple roles in water treatment via uptake, transformation to organic forms, carbon provision to microbes, transpiration reducing stormwater volume, stabilising media surface, helping to maintaining infiltration rates, provides cooling to surrounding environment, amenity and aesthetics. The microbial community associated with plant roots facilitates uptake, decomposition and transformation of stormwater pollutants and plant litter.	3.6.5
Filter media	Provides physical filtration of particulates, physiochemical pollutant removal processes such as adsorption, fixation, precipitation, supports vegetation growth and the infiltration of stormwater attenuates and reduces the magnitude of the outflow hydrograph (providing stream health benefits)	3.6.4
Transition layer	Coarse sand. Provides a bridging layer to prevent migration of fine particles from the upper filter media to the gravel drainage layer	3.6.4
Drainage layer	Gravel. Allows the system to drain, either into a collection pipe and outflow point or infiltration into surrounding soils, also provides higher porosity to temporarily store stormwater between pores	3.6.4
Unlined	Allows infiltration into surrounding soils, either for the entire or only part of the system	3.6.3
Pre-treatment	Collects coarse sediment and litter, helping to protect the biofilter itself from premature clogging and blockages, and facilitating maintenance. Recommended for all systems except those < 2ha in size without identifiable sediment sources, or systems only receiving roof runoff (Water by Design, 2014).	3.6.3
Additional components (depending upon treatment objectives and site conditions)		
Collection pipe	Underdrain formed with slotted pipe and used to drain and collect effluent from the system. May not be needed for small systems, nor for those with only exfiltration and no outflow pipe.	3.6.3
Raised outlet; creates temporary submerged zone	Strongly recommended, providing multiple benefits for water treatment and plant survival. Allows ponding in the lower portion of the biofilter, increasing moisture availability for plants and providing larger retention capacity for the temporary storage of stormwater. If the system is unlined, the raised outlet promotes exfiltration and creates a temporary submerged zone. Alternatively, if combined with an impermeable liner, it provides a longer-lasting submerged zone which benefits nitrogen removal via denitrification.	3.6.3
Submerged zone (or Saturated zone)	Created using a raised outlet, but may be temporary (if system unlined) or longer-lasting (if lined). Serves multiple roles: i.) provides a water supply to support plant and microbial survival across dry periods; ii.) benefits N removal, particularly following dry periods; iii.) provides anaerobic conditions for denitrification; iv.) provides prolonged retention for a volume of stormwater – which allows longer processing time.	3.6.3
Liner; creates long-lasting submerged zone	Prevents infiltration and may fully or only partially line the system	3.6.3
Carbon source	(wood chips) Mixed throughout the submerged zone when a liner is present. As the carbon source decomposes, it provides electrons to drive denitrification	3.6.4

Key components

All biofilters operate using the same basic principles and some features are essential and common to all biofilters (Figure 3). Each component contributes to system functioning (Table 1). Configurations are flexible though and some characteristics will be tailored (Figure 4), allowing each system to be adapted for optimised performance, depending upon performance objectives and local site conditions.

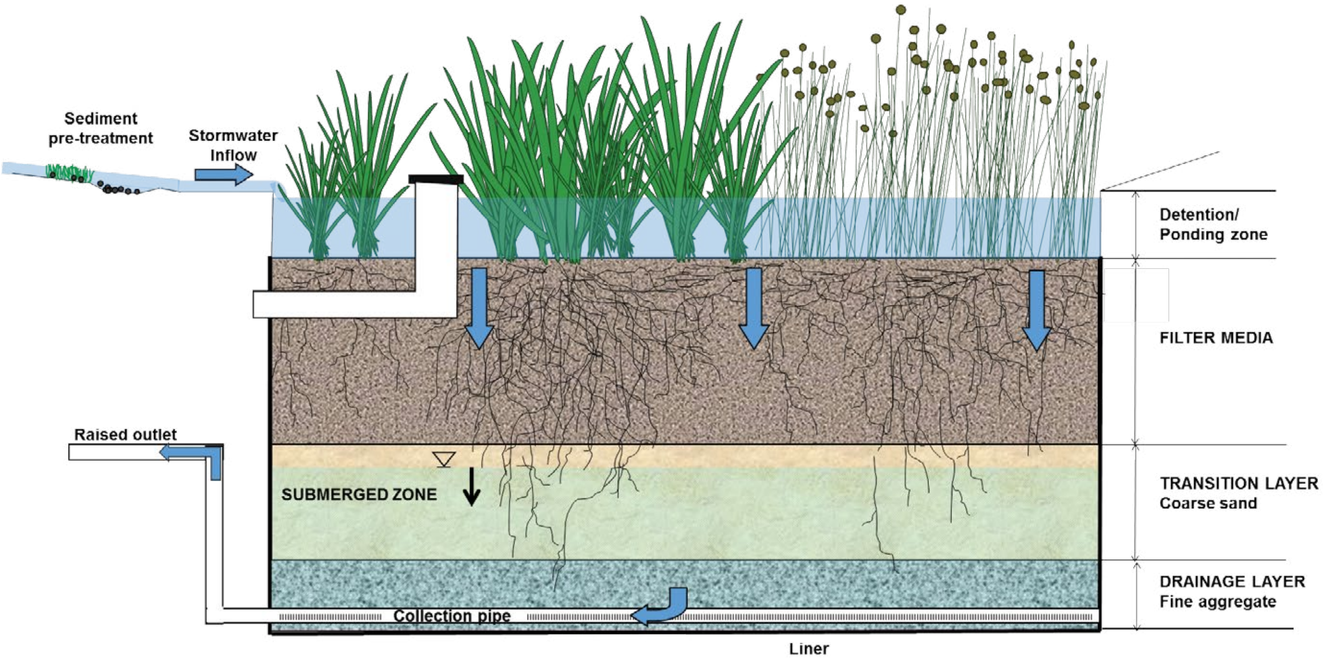

Figure 4. Typical biofilter configuration recommended for dense urban areas and/or where prolonged dry spells are experienced

Pollutant processing in biofilters

A wide range of processes act to retain or transform incoming stormwater pollutants. The plants, filter media and microbial community all play important roles in pollutant processing as stormwater enters the biofilter, infiltrates through the filter media and comes into contact with plant roots and the microbes (Table 2 and Figure 4):

Table 2. Key processes involved in the removal or transformation of stormwater pollutants

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

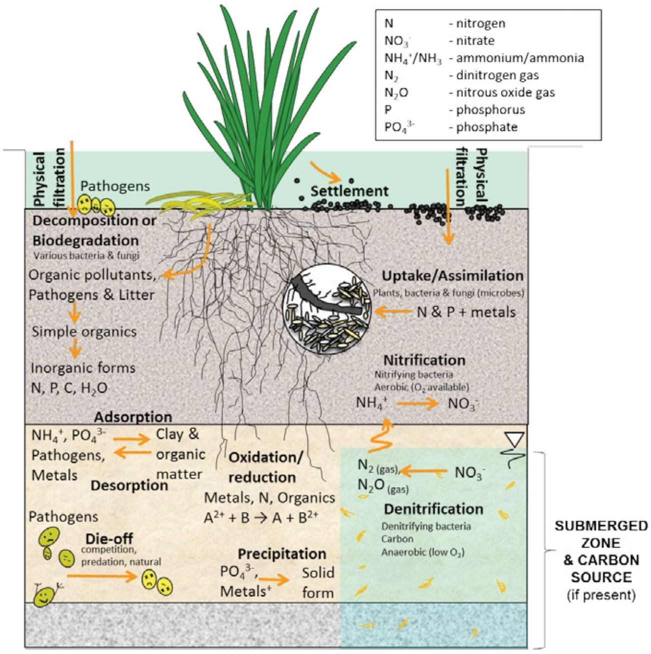

Figure 4. Key processes involved in pollutant attenuation, removal or transformation in stormwater biofilters

Fact Sheet: Stormwater biofiltration – What are the ingredients for successful systems?

Key design tips

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

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Construction and establishment tips

- **Protect the system from sediment** when construction activities are occurring within the catchment, and during biofilter construction itself.
- **Conduct quality checks** throughout construction and landscaping works to ensure the design intent is represented. Critical checks include:
    - flow hydraulics (invert level of inlet/s, invert level of the outlet and overflow structures, the ponding depth and slope of the biofilter surface);
    - filter media (material, layering, depths, potential contamination with site soils, minimal compaction and avoidance of mulch); and
    - vegetation (plant density, seedling size and establishment).

  Common problems include incorrect surface gradients for streetscape systems (sloping towards the kerb) and inadequate (or no) ponding capacity (if the system is overfilled with media or invert levels are wrong).
- Establishment of healthy plant cover across the biofilter is vital for effective function. The period of seedling establishment and early growth is a vulnerable time and long-term success can hinge on its management. Plant death or stunted growth will compromise long-term hydraulic operation and pollutant removal. A common problem is to ‘plant and forget’, but **careful and timely management during establishment** will avoid increased replanting and maintenance costs (e.g. repair of erosion).

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

No step down into biofilter: flow cannot easily enter

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

Common sediment and hydraulic problems in biofilters

Monitoring and maintenance tips

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

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

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

- **Establish a dense and healthy cover of vegetation** – this will develop a system that is more resilient to erosion, requires less long-term maintenance or remediation, and is more effective.

- **Ensure sufficient soil moisture is available** – Systems that are too shallow, sandy or small are particularly vulnerable to drying out. Inclusion of a raised outlet is essential to help maintain moisture for plants.

- **Design pits, pipes and culverts to facilitate inspection** – pit lids should not be difficult or require heavy lifting by maintenance personnel, but should instead be designed with safety and ease of removal in mind. Pipes should be designed to facilitate inspection and cleaning.

- **Provide safe and easy maintenance access with minimum need for traffic management** – when locating and designing the system consider access requirements for maintenance crews.

For full details please refer to the Adoption Guidelines for Stormwater Biofiltration, CRC for Water Sensitive Cities (2015)

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Fact Sheet: Biofilter design to meet objectives and adapt to local site conditions

One of the greatest benefits of biofiltration is the adaptability and flexibility of the technology. As a result, the design process is essential. Successful systems are designed to meet various stormwater treatment and additional objectives, suit the specific application and take advantage of opportunities presented by the site (e.g. high potential for infiltration), while managing any constraints (e.g. nearby sensitive assets). Biofilter designs can vary widely as a result of different target pollutants, applications or conditions. While the basic principles are the same, the design should be adapted to suit the specific site conditions and performance objectives.

The way in which system design can be influenced by objectives and site conditions is illustrated using a flow chart in Figure 1. First of all the objectives must be clearly defined, and must reflect the purpose of the biofilter (e.g. downstream waterway protection and/or stormwater harvesting for a given re-use application). The critical pollutants should be identified and targets determined for their reduction (e.g. set concentration or load thresholds for treated water – if available, these may reflect local regulations), and flow management objectives should be defined (e.g. reduce volume, peak or frequency of flows to improve downstream waterway health or, in harvesting schemes, to maximise the volume collected for reuse).

The design also needs to consider conditions at the site and within its catchment including:

- Local climate
- Geology of surrounding soils
- Groundwater characteristics
- Catchment characteristics (size, land-use, level of development (imperviousness), hydraulic connectivity of impervious areas, degree of construction activities or other sediment sources, prevalence of deciduous trees)
- Nearby sensitive infrastructure
- Surrounding landscape and vegetation
- Safety
- Maintenance access and efficiency

Tips to adapt biofilter design to these various considerations are provided in Table 1. Importantly, these objectives, site opportunities and constraints should be identified in an initial site inspection and through consultation with all stakeholders throughout the life of the biofilter. In particular, representatives from the design, construction, establishment, maintenance and operational phases of the biofilter must be involved and communicate with each other from the outset of the project.

For full details please refer to the Adoption Guidelines for Stormwater Biofiltration, CRC for Water Sensitive Cities (2015)

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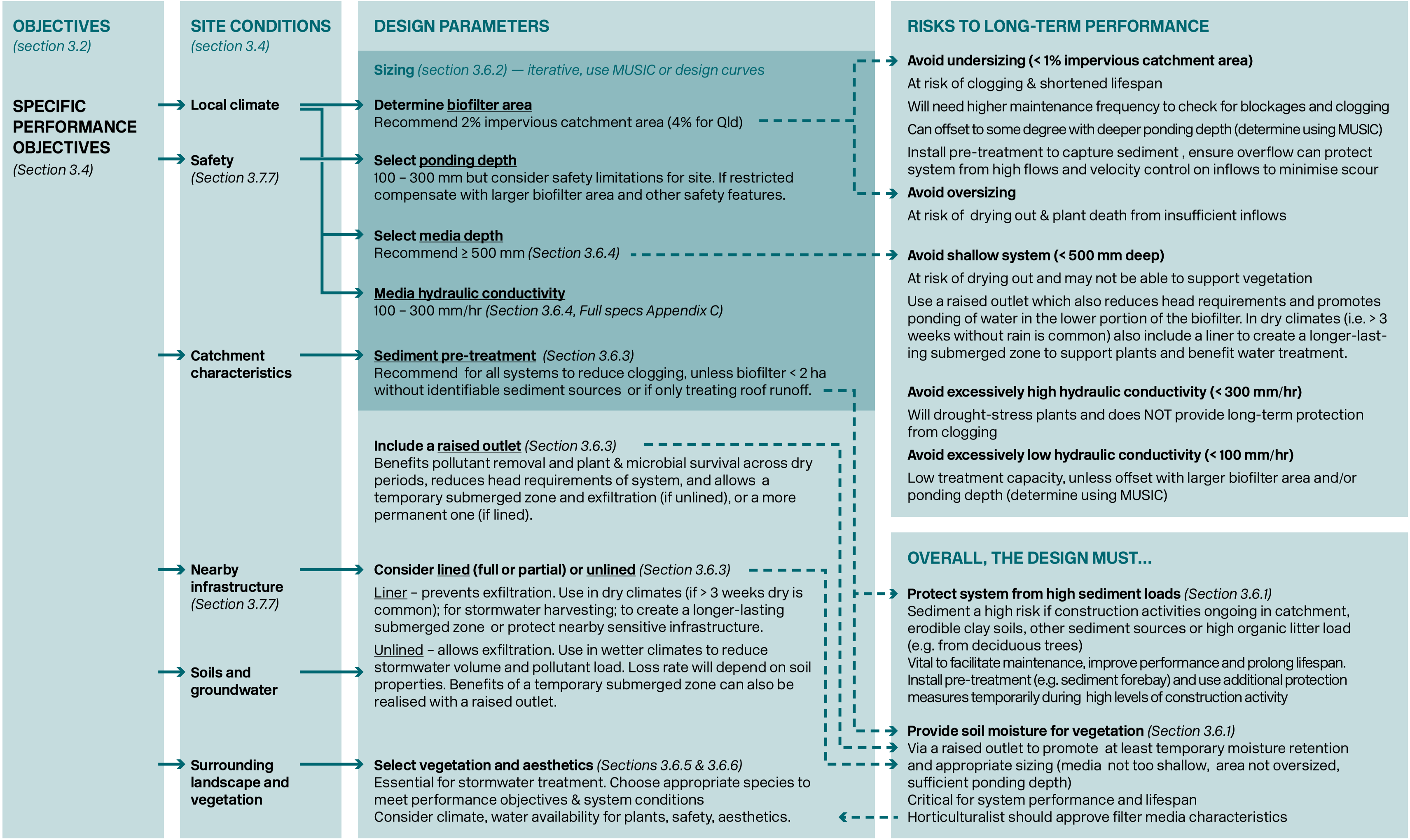

OBJECTIVES

(section 3.2)

SPECIFIC PERFORMANCE OBJECTIVES

(Section 3.4)

SITE CONDITIONS

(section 3.4)

Local climate

Safety
(Section 3.7.7)

Catchment characteristics

Nearby infrastructure
(Section 3.7.7)

Soils and groundwater

Surrounding landscape and vegetation

DESIGN PARAMETERS

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

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

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

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

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

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

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

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

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

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

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

RISKS TO LONG-TERM PERFORMANCE

Avoid undersizing (< 1% impervious catchment area)

At risk of clogging & shortened lifespan

Will need higher maintenance frequency to check for blockages and clogging

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

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

Avoid oversizing

At risk of drying out & plant death from insufficient inflows

Avoid shallow system (< 500 mm deep)

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

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

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

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

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

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

OVERALL, THE DESIGN MUST…

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

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

Figure 1. Decision flow-chart illustrating the design process across a range of biofilter components, with references to Sections of the Biofilter Adoption Guidelines (CRC for Water Sensitive Cities, 2015) for further details .

Table 1. Summary table relating biofilter applications and performance objectives with design tips

Waterways Protection	
Nutrients	• Plants are essential – plant densely, include a diversity of species, and select at least 50% of species with characteristics for effective removal (particularly for nitrogen – see below for further guidance) • Minimise N & P content in filter media to avoid leaching • Include a raised outlet and liner to create a submerged zone, particularly in dry climates (> 3 weeks dry is common) and if N removal is a key objective • Minimise desiccation by watering across dry periods and using species that cover or shade the surface • To enhance P retention, select media rich in iron- or aluminium-oxides
Sediment	• Primarily captured in surface layer. Remove by scraping once treatment is compromised by clogging. • Protect biofilter from high sediment loads from catchment (e.g. during construction) using temporary or permanent measures (e.g. pre-treatment) • Size the system appropriately to avoid a shortened lifespan from clogging (area – 2% of impervious catchment (Melbourne climate) or 4% (Brisbane) and sufficient ponding depth)
Heavy metals	• High fraction bound to sediment (see above)\ • Incoming load may be higher in industrial catchments. Zinc accumulation can be problematic. • Organic matter binds metals, but note high content compromises nutrient removal and infiltration • Iron removal optimal with a larger biofilter area (≥4%) and use of effective species (e.g. *Carex appressa*)
Organic micro-pollutants	• For example: hydrocarbons, pesticides, herbicides, PAHs, phthalates and phenols • Similarly as for heavy metals, organic matter assists removal but content must not be excessive • Prolonged drying benefits removal
Pathogens	• Use known effective plant species (e.g. *Leptospermum continentale, Melaleuca incana, Carex appressa*) • Include a raised outlet and liner to create a submerged zone which provides prolonged retention for die-off and adsorption to occur • Some drying is beneficial, but beyond 2 weeks drying performance is adversely affected. Successive inflow events (back-to-back) also lead to poor treatment. • Top-up the level of the submerged zone during extended dry periods • (Subject to further testing), consider use of a novel antimicrobial media (heat-treated copper-coated Zeolite) to enhance pathogen removal (see Biofilter Guidelines)
Flow Management	• Objectives may include reduction in volume, peak flow and frequency of flows • Maximise biofilter treatment capacity via increased area, media depth or hydraulic conductivity of media (but within recommended range) • Consider including a submerged zone to retain a proportion of runoff • Promote infiltration if conditions are suitable (e.g. unlined, partially lined or bioinfiltration design) • Maximise evapotranspiration loss by maximising the biofilter area and using a dense planting
Stormwater harvesting	
Pathogen, sediment, heavy metals and organic micro-pollutants may be key objectives (see above, and further below for more details) Nutrient removal may not be important if re-use for irrigation purposes	
Maximise pathogen removal & yield	• Design to co-optimise for yield and to meet ecosystem protection objectives – generally line the system but balance with stormwater storage and demand patterns to achieve desired discharge reduction. • Use good species for pathogen removal. • Use media that are good for the removal of pathogens (see Appendix D, but note that the use of
Additional	
Biodiversity	• Use a diverse mixture of local native species
Microclimate	• Include trees to provide shading and cooling via evapotranspiration • Local in urban zones lacking green spaces e.g. streets and car parks
Amenity, aesthetics & community engagement	• Use species and landscaping with compatibility with local surrounds (see below for further guidance) • Include a raised outlet to retain more moisture to support green and lush plant growth\ • Engage with the community and communicate the function of the system through the design (e.g. signage), and encourage the public to view and walk alongside the biofilter • As far as practical keep biofilter looking neat, well-kept and green – design for low-level maintenance
Habitat	• Use flowering species to promote birds and insects, and native plants from nearby habitat patches

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Fact Sheet: Vegetation selection for stormwater biofilters

Plants are an essential component of biofilters. Without plants, the performance of stormwater biofilters is much poorer. Both plants and microbes serve multiple roles in biofilter function (Figure 1). Importantly, plants and microbes are inseparable, as most microbes are supported in the zone around plant roots.

Plants also provide additional benefits within the urban environment, including improving amenity, creating green spaces, enhancing biodiversity and habitat, and providing microclimate benefits, which are associated with considerable human health and economic benefits.

However, not all plant species will perform the same in stormwater biofilters, particularly for nitrogen removal. Research has identified the characteristics of effective and poorer performing plant species (Table 1 and Figure 2). Species must be capable of survival in the biofilter environment (sandy substrate, prolonged drying and intermittent inundation). It is recommended that a mixture of plant species including various plant types are selected, including at least 50% of species with desirable traits for effective removal of the target pollutants (Table 1). Other considerations for plant selection also include aesthetics and amenity within the local environment, diversity and habitat objectives, microclimate benefits and safety requirements (Table 1).

Plants should be densely planted and carefully established to develop an effective and low-maintenance biofilters in the long-term.

Further guidance is provided in the full Biofilter Guidelines and 'Vegetation guidelines for stormwater biofilters in the South West of Western Australia' (Monash Water for Liveability, 2014).

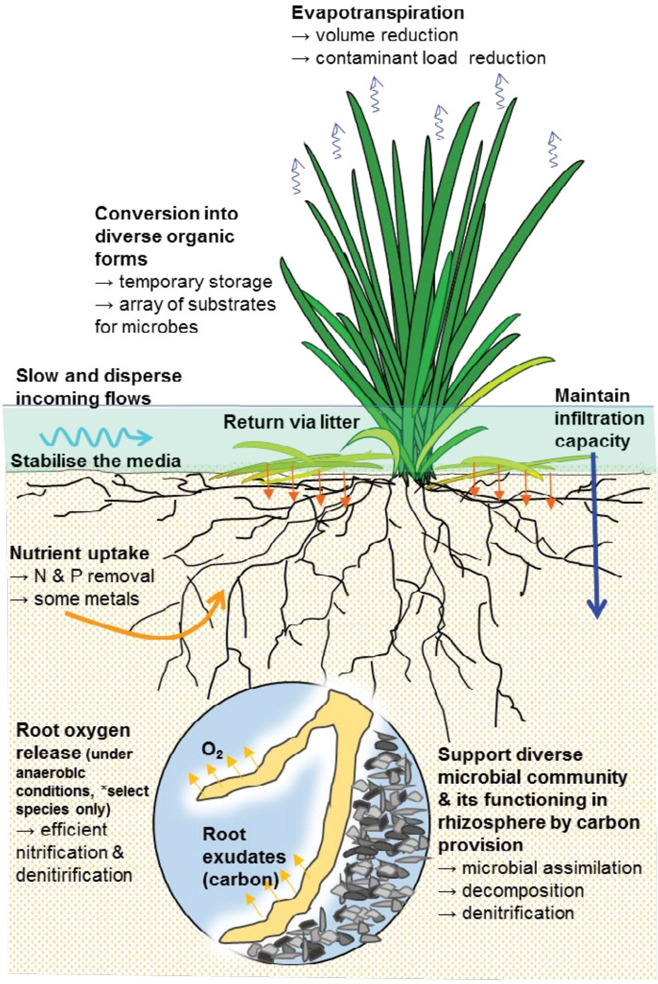

Figure 1. Traditional urban design with impervious surfaces brings challenges for water management, climate control, human wellbeing and waterway health

For full details please refer to the Adoption Guidelines for Stormwater Biofiltration (CRC for Water Sensitive Cities, 2015)

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Table 1. Desirable plant traits for stormwater biofilters

Objectives	Desirable species traits and plant selection tips
FUNCTIONAL OBJECTIVES (stormwater treatment)	• Include at least 50% plant species with effective traits that meet water treatment objectives • Distribute these across the biofilter area as much as possible
Nitrogen (N) removal	• Effective species have extensive and fine root systems which maximise uptake capacity, contact with the stormwater and supports a vast microbial community alongside the root: - High total root length - High root surface area - High root mass - High root shoot ratio - High proportion fine roots • Relatively rapid growth but ability to survive and conserve (or 'down regulate') water across dry periods • High total plant biomass often accompanies an extensive root system • Do not select species based on similarity in above-ground appearance or plant type – this is a poor indicator of performance for N • Exclude species with limited root systems (i.e. minimal total root length and mass) or dominated by thick roots which are less effective • In particular, avoid trees or shrubs with limited root systems as these tend to be consistently poor performers • Use a diversity of plant species and types, as species can vary in their relative performance between wet and dry conditions • Avoid nitrogen-fixing species which can input additional N to the system (e.g. wattles (Acacia species), clover and peas; all legumes from the Fabaceae family, and members of the Casuarinaceae family (e.g. Allocasurina). • Use a high planting density to maximise root and microbial contact with the media and stormwater • If feasible, consider harvesting the plant biomass to permanently remove N and possibly stimulate new growth and uptake
Phosphorus (P) removal	Although plant selection is less critical, select species with extensive root systems, similar to characteristics effective for N removal – these will also effectively take up P.
Heavy metal removal	Select effective species with extensive root systems (e.g. *Carex appressa*)
Pathogen removal	Select effective species with extensive root systems (e.g. *Leptospermum continentale, Melaleuca incana, Carex appressa*) Select species associated with lower infiltration rates
Hydrological treatment - Volume reduction	Select species with high transpiration (such as trees) but also able to conserve water in dry periods Use multiple layers of vegetation and various plant types to increase transpiration (i.e. trees and shrubs with understorey species)
Infiltration capacity	• It is recommended to: - Include species with a proportion of thick roots (e.g. Melaleuca ericifolia), - Include species with robust stems able to disturb the surface layer - Avoid species with predominantly fine roots (i.e. no thick roots) - Avoid species with shallow or minimal root systems (e.g. Microleana stipoides) - Plant relatively densely

Cont.

Table 1 Cont.

Objectives	Desirable species traits and plant selection tips
Effective maintenance	• Plant densely across the entire biofilter • Select robust species for edges and plant densely to deter pedestrian access • Similarly, near inflow points carefully select robust species and offset planting rows to help widely distribute inflows • Include a diversity of species to provide resilience and allow plants to 'self-select' and expand if other species die out. • Do not select short-lived or annual species • Avoid species that require regular pruning or those that produce large volumes of litter at senescence • Avoid the use of deciduous trees in or near biofilters • If possible, include trees to shade understorey layers and the media surface. • Plant sedges or grasses along biofilter edges adjacent to lawn to provide shade and reduce the need for edge trimming
ADDITIONAL OBJECTIVES	• Plants with attributes that only suit these objectives (i.e. do not overlap with effective traits for functional objectives) should comprise ← 50% of biofilter vegetation
Biodiversity	• Select local indigenous species, compatible with nearby remnant vegetation • Include a diversity of species and plant types to provide structural diversity • Include flowering plant species, species used by local birds and insects • Never use invasive species in biofilters – not only known invasive species, but beware of species that can rapidly and easily spread by rhizomes or seeds
Aesthetics and Amenity	• Understand the site context - match species, layout and materials to surrounding landscape and neighbourhood character (conduct a site visit) • Consider land use, architecture, other landscaping and plantings in the area • Balance unity and variety in design • Include some complexity but the design should be orderly (i.e. avoid 'messy' and 'unkempt' appearance) • Consider long-term appearance and form as plants grow • Consider use of colours, textures, patterns, and use of light and shade • Include trees as features (if possible), consider use of colours and textures • Include seasonal variety with various flowering plants
Habitat	• Use a diversity of plant species and plant types • Incorporate woody plants and some woody debris if possible
Microclimate	• Include trees with a sizeable canopy and depth of shade (broad-leaved)
Safety	• Always consider plant species size at maturity and any tendency to collapse during senescence, drop limbs, fruit or significant volumes of leaf litter • Consider line-of-sight requirements for vehicles and pedestrians • Avoid planting species in border plantings that may protrude or collapse onto adjacent pathways

Carex appressa

Melaleuca incana

Juncus kraussii

Carex tereticaulis

Juncus pallidus

Figure 2. Examples of effective species for nitrogen removal in stormwater biofilters

Fact Sheet: Stormwater biofilter monitoring and maintenance

Why monitor and maintain systems?

Routine maintenance is important to ensure the biofilter functions effectively across its entire, intended lifespan. Monitoring is required to assess if the system is performing well against its objectives, and to detect issues that may require maintenance attention, before it develops to require more significant and costly rectification works.

Maintenance work is distinct from larger renewal or resetting works that may be required to fix systems that are functioning poorly. Systems that follow good design principles, are well built and carefully established are not expected to require these extensive works. Instead, only relatively straightforward and regular tasks are required for ongoing maintenance. However, biofilters require additional monitoring and maintenance care during their establishment. Investment in this early establishment, and conducting monitoring and maintenance checks regularly can lead to long-term savings from avoided rectification works, prolonged biofilter life and more effective performance.

To function properly, stormwater biofilters must have a healthy and extensive vegetation cover, flows must be able to enter and pond across the entire surface, stormwater will infiltrate into the media relatively quickly and the system will drain and release outflows as designed. In particular, inspections must assess plant health, plant cover, sediment accumulation or other signs of clogging (e.g. waterlogging), and blockages caused by litter and debris (particularly at inlet, outlet or overflow points). Systems will also require more frequent monitoring across dry months, and some irrigation or watering may be required to sustain plants through prolonged dry spells.

How to plan an effective maintenance program

- Consider maintenance requirements as part of early design and seek feedback from maintenance personnel from the outset of the project, including ways to reduce maintenance by design, and facilitate maintenance ease, access and safety.
- Develop capacity building in the organisation and amongst contractors to undertake effective biofilter maintenance, including investment in skills and training – all personnel should understand the key objectives and functions provided by stormwater biofilters
- Clearly define asset ownership and responsibilities, and carefully draw contract arrangements to facilitate transition of the project at handover
- Develop an effective system to provide an inventory and record of all assets, their design and construction and up-to-date maintenance details
- When planning and budgeting, clearly distinguish between maintenance and extensive remediation or re-setting works
- Allocate sufficient budget for maintenance from the outset of the project, including additional resources during the critical establishment phase
- Provide maintenance crews with a diagram or plan of each system, with intended flow hydraulics clearly marked with arrows, and key aspects of the design labelled
- Clearly define the level of service to be provided for maintenance of each system, and accept this may vary with the complexity or visibility of systems to the public
- Plan for and provide additional maintenance during establishment and dry periods

For full details please refer to the Adoption Guidelines for Stormwater Biofiltration (CRC for Water Sensitive Cities, 2015)

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Monitoring and maintenance tasks

Many of the key tasks are illustrated in Figures 1 and 2.

Filter media

- **Holes, erosion or scour** – Check for erosion, scour or preferential flow pathways, particularly near inflow point/s and batter slopes (if present). Repair and infill using compatible filter media material. Add features for energy dissipation (eg. rocks and pebbles at inlet) if necessary.

- **Sediment accumulation / clogging** – Inspect for the accumulation of an impermeable surface layer (such as clayey sediment), ponding of water for more than a few hours following rain (including the first major storm after construction), or widespread moss growth. Repair minor accumulations by scarifying the surface between plants and if feasible, manual removal of accumulated sediment. Investigate the cause of any poor drainage.

- **Damage** - Check for damage to the profile from vehicles, particularly streetscape systems alongside parking or street corners. Also check for signs of pedestrian traffic across the filter surface, such as worn pathways. Repair using compatible filter media material.

- **Litter** - Check for anthropogenic litter and significant accumulations of organic litter, particularly in sediment pits, inlets, outlets and overflows. Remove litter to ensure flow paths and infiltration are not hindered.

Vegetation

- **Establishment** – The initial period after construction (up to the first 2 years) is critical to long-term success or failure of the biofilter. Additional monitoring and maintenance works are required to ensure a healthy and diverse vegetation cover develops, and that stormwater flows move through the system as the design intended (i.e. flows enter freely, covering the entire surface, ponding occurs to the design depth, high flows bypass and the infiltration rate is acceptable). Careful attention can avoid costly replanting and rectification works. New seedlings will require regular watering and irrigation, protection from high sediment loads and high flows. Refer to Water by Design's 'Construction and Establishment Guidelines'.

- **Plant health and cover** - Inspect plants for signs of disease, die-back, pest infection, stunted growth or senescent plants and assess the degree of plant cover across the surface. If poor plant health or cover is widespread, investigate to identify and address the causal factor (e.g. poor species selection, shading, too dry (e.g. oversized, dry climate, media with minimal water holding capacity, poor flow distribution, lack of irrigation), too wet (e.g. from clogging, undersizing) or smothering from litter. Treat, prune or remove plants and replace as necessary using appropriate species, aiming to maintain the original planting densities (6-10 plants/m^2 recommended). Provide watering or irrigation to support plants through long dry periods.

- **Weeds** – Weeds should be identified and removed as they occur. If left, weeds can out-compete the desired species, possibly reducing water treatment function and diminishing aesthetics. Manually remove weed species, avoiding the use of herbicide (if unavoidable use targeted spot spraying).

- **Pruning and harvesting** (if feasible) - It may be worth considering occasionally harvesting plants to permanently remove nutrients and heavy metals stored in aboveground plant material, and to promote new plant growth and further nutrient and metal uptake. Pruning may also benefit aesthetics.

Drainage

- **Inlet pits/zones, overflow pits, grates and other stormwater junction pits** - Ensure these are clear of litter, sediment and debris and remain structurally sound. More frequent inspection and removal will be required for systems with construction works in their catchment.

- **Underdrain** - Ensure that underdrain pipes are not blocked to allow the system to drain as designed.

- **Raised outlet** - Check that the weir/up-turned pipe is clear of debris.

- **Submerged zone** – Although the submerged zone helps to sustain the biofilter through dry periods, if drying persists for long enough (e.g. beyond 3 weeks) it will become drawn down and require replenishment. Check that the water level in the submerged zone is at the design level and top this up as required.

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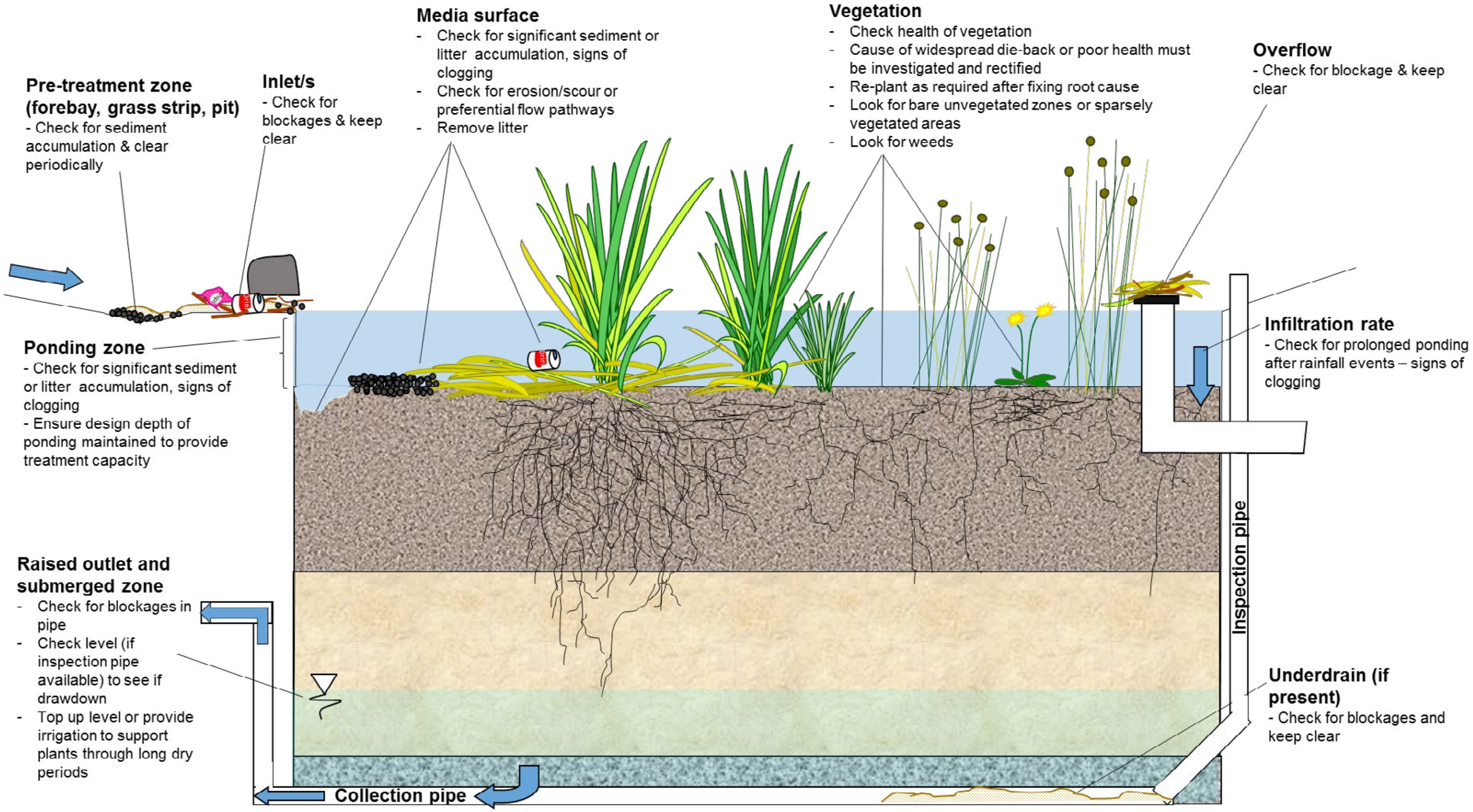
Renewal

- **Monitor** for signs of clogging, widespread plant death or die-back, significant erosion or extensive sediment, litter or moss across the surface
- **Investigate and address the cause** to avoid a recurrence
- Take **action to restore system functionality** (e.g. retrofitting a submerged zone, modifying invert levels of flow control structures, replanting, scraping off and replacing top layer of filter media, media removal to restore desired ponding depth, erosion repairs, removal of gravel mulch)
- **Timely intervention** to address problems as soon as they become evident and before worsening.
- **Test metal accumulation in the filter media** to allow timely disposal before concentrations reach levels that require more costly disposal (depending upon state soil classification regulations). Recommend testing in year 5 and comparison against National Environment Protection Council (NEPC, 1999) Health and Ecological Investigation Levels. If sized appropriately with typical inflow concentrations, accumulation to levels of concern unlikely for 10-15 years. However, industrial and past-industrial catchments likely to accumulate metals more rapidly.
- **Typical renewal frequencies** (Water Sensitive Urban Design Life Cycle Costing – Data Analysis Report, April 2013. Parsons Brinckerhoff, prepared for Melbourne Water):
- **Remove and dispose of accumulated sediments** – every 2-5 years
- **Minor re-set** (replace plants and top 100 mm media) – after 10-15 years



Pre-treatment zone (forebay, grass strip, pit)
- Check for sediment accumulation & clear periodically

Inlet/s
- Check for blockages & keep clear

Media surface
- Check for significant sediment or litter accumulation, signs of clogging
- Check for erosion/scour or preferential flow pathways
- Remove litter

Vegetation
- Check health of vegetation
- Cause of widespread die-back or poor health must be investigated and rectified
- Re-plant as required after fixing root cause
- Look for bare unvegetated zones or sparsely vegetated areas
- Look for weeds

Overflow
- Check for blockage & keep clear

Ponding zone
- Check for significant sediment or litter accumulation, signs of clogging
- Ensure design depth of ponding maintained to provide treatment capacity

Infiltration rate
- Check for prolonged ponding after rainfall events – signs of clogging

Raised outlet and submerged zone
- Check for blockages in pipe
- Check level (if inspection pipe available) to see if drawdown
- Top up level or provide irrigation to support plants through long dry periods

Underdrain (if present)
- Check for blockages and keep clear

Figure 1. Critical checks and tasks for a monitoring and maintenance program

Blocked inlet – restricts flow entry, reducing proportion of flows receiving treatment

Plant die-back – severely reduces treatment efficiency and leaves media vulnerable to erosion

Poor vegetation spread – may be due to use of rock mulch

Clogging – build up of fine sediments, moss or plant litter on the surface reduces infiltration and treatment

Blocked overflow grate – can lead to flooding and damage to the filter and vegetation

Vehicle and pedestrian damage – impacts vegetation health and causes compaction

Figure 2. Common maintenance tasks

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Widespread plant loss or die-back – can indicate too much or too little water, or poor filter function

Plant die-back near inlet – may indicate high inflow velocities, sediment accumulation or poor species selection

Sediment accumulation – build up of fine sediments reduces infiltration and treatment

Litter accumulation (anthropogenic and organic) – unsightly and can hinder flow paths and infiltration

Holes, erosion and scour – compromise even flow distribution and treatment

Weeds – unsightly and can reduce treatment capacity

Fact Sheet: Biofilter Construction Checks

Table 2. Identifying risks, pitfalls and tips during the construction process

Critical stages	Risks / common pitfalls	Useful tips
Pre-construction		
Underground services check	Damage to unexpected **underground services** during excavation can be highly expensive, dangerous and may require costly late-stage design modification.	Use the Dial-Before-You-Dig service during initial design phase (service locations may influence siting and depth). Before construction commission an underground services expert to prove service locations and depth. Mark out services at the site and map locations and depths on site plan. Inform all site personnel at pre-site meeting.
Ordering plant stock	If **plant stock** is not pre-ordered in sufficient time they may not be available at the desired planting time (especially for large projects).	Communicate well ahead of construction with the nursery, ideally during plant selection in the design phase.
Sourcing filter media	**Media composition** is critical to pollutant retention and infiltration rate. Poor media selection can lead to nutrient leaching, clogging, a system that is too dry or wet, and the washout of fine particles.	Ensure the media has been tested to comply with specifications in the Guidelines for Filter Media in Biofiltration Systems (Appendix C). Ensure fine aggregate for drainage layer material has been sufficiently washed to remove fine particles.
Sediment management	**Sediment management** is critical in catchments undergoing development and during construction of the biofilter itself. This is a critical risk to long-term performance. Unless protected, a high sediment load will rapidly overwhelm and clog the biofilter, requiring an expensive re-set. Problematic if the biofilter is commissioned too early in the development process.	During construction activities the system must be protected using temporary measures such as flow diversions, use of bunding and/or geofabric, sediment traps, and planted with a temporary turf layer. Develop a management plan before construction commences and leave measures in place until construction activities cease and soil surfaces are stabilised. Refer to Water by Design (2009) for detailed guidance on sediment management.
Runoff management plans	**Drainage and runoff management plans** are essential during construction when soils are exposed. Rainfall events during construction can wash substantial volumes of soil into the biofilter excavation or any laid media layers. If left, these sediments will severely compromise the infiltration and pollutant removal performance of the biofilter.	To the extent possible, biofilter construction should be conducted in a dry weather period. Flow diversions need to be set up, and this will be particularly challenging for online systems (these are not recommended except for small catchments). Any sediment that is washed into the system during construction must be removed (including any media mixed with sediment). Refer to Water by Design (2009) for further guidance on managing runoff during construction.

For full details please refer to the Adoption Guidelines for Stormwater Biofiltration (CRC for Water Sensitive Cities, 2015)

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Table 2. Continued

Critical stages	Risks / common pitfalls	Useful tips
Timing of construction and commissioning stages	The coordinated **timing of biofilter construction** with development in the catchment is critical for long-term success. Failure to protect the new system from construction works may lead to a complete re-set before its official commissioning.	Stages of works must be carefully planned in coordination with development in the surrounding catchment. Sediment management, temporary protection measures for the biofilter, and delayed planting and commissioning of the biofilter, are all vital. Refer to Water by Design (2009) for step-by-step requirements for each phase of works (including on-site fact sheets).
Construction		
Roles and responsibilities	Poor **communication and division of responsibility** between parties can lead to poor oversight of the project and lack of quality control. Projects require cooperation between multiple disciplines and authorities. A common problem is poor coordination between the construction and landscape teams, and a lack of understanding of the system function and objectives.	Ensure **roles and responsibilities** are clearly assigned for each phase, with clear, frequent communication between all parties and across all project stages. Take particular care to ensure communication between designers, the construction team and landscaping/maintenance teams. All parties should understand the project objectives, function of the system, and key risks to success. Refer to Water by Design (2009) for a discussion of roles, responsibilities for ownership and maintenance, contract requirements and handover.
Communication between Stakeholders		
Excavation & earth works	Traditional **excavation techniques** create a smooth and compacted base, which can reduce infiltration. **Accurate levels and slopes** are critical for effective system function, particularly flow control structures (inflow, overflow) and drainage. Incorrect levels will lead to hydraulic malfunction, plant death and poor treatment, either from flow bypass or flooding. In particular, it is vital that the ponding depth is achieved and the slope of the surface allows even flow and widespread distribution.	If infiltration is an objective (system is unlined) and clay soils are present, excavate using a bucket with 'teeth' to loosen and roughen the base. Levels must be carefully constructed and surveyed once complete. Once commissioned, water levels and flow hydraulics should be checked against the design during significant inflow events.
Liner installation (if present)	Puncture of the liner or ineffective sealing of the system will lead to leakages which may i.) compromise nearby sensitive structures (if present), ii.) reduce yield for stormwater harvesting schemes, and iii.) lead to system failure	Place liner onto surfaces free of rocks, roots or other sharp objects that may cause puncture. Use a reliable and experienced contractor.

Cont.

Table 2. Continued

Critical stages	Risks / common pitfalls	Useful tips
Sealing hydraulic components	Effective **water-tight sealing on hydraulic structures** is essential to prevent short-circuiting, erosion and potential collapse and failure of the system, particularly at steep sites. It also reduces the opportunity for invasion of pipes and structures by plant roots. Problems can arise during sealing and preventing preferential flows at the interfaces of inlet points, inlet/outlet collection pits, sediment forebays, drainage pipes, basin walls and bunds between cells. Points where pipes enter walls/bunds are particularly sensitive failure points. In addition, preferential flow paths can develop down the sides of the inlet pit and sediment forebay, bypassing the surface filter media.	Take great care to water-proof seals at connection points. Use collars on outlet pipes at the point where it traverses the wall. This can be tricky, especially to achieve compaction around the seal. Alternatively it is feasible to use shockcrete to create a large collar extended across the basin surface. (Note techniques developed by Hornsby Shire Council) A filter fabric can be used around the top of inlet pits and underneath inlets and sediment forebays to prevent preferential flows underneath and down the sides, where the structures are embedded below the filter media surface.
Laying down drainage pipe (if present)	Damage to **underdrain** during construction, compromising its function.	Lay pipe above a fine aggregate bed, with sufficient covering with aggregate. Do not use heavy equipment.
Receiving media on-site	Media can be **contaminated with on-site soils** (e.g. clay) upon delivery and earthmoving works. This will significantly reduce infiltration and pollutant removal capacity.	Ensure soils are either delivered straight into the biofilter pit, or tipped onto a hard concrete surface. This prevents the excavator bucket from digging down into in-situ site soils.
Laying down media layers	Appropriate **media layering** (mixing, depth) is a vital characteristic of biofilter function. A high degree of mixing or depths differing from design will compromise pollutant removal.	Lay media sequentially and carefully adhere to the design, including depths of the layers. Conduct quality control checks during media placement. Complete in stages with care to avoid mixing. Additions, such as material providing a carbon source or soil ameliorants, should be thoroughly mixed before placement in the system. When placing layers above the underdrain, avoid dropping large volumes from a height.
	Excessive **compaction** will impede infiltration, thereby severely compromising the treatment capacity of the biofilter	Do not use construction techniques or equipment that leads to high compaction. Light compaction can be applied. Where possible machinery should be located outside and alongside the system, with only lightweight machinery used within the system. Refer to Water by Design (2009) for further details of construction techniques, including specifics for large systems. Where compaction was unavoidable, use scarifying to loosen the media.
Quality control	Ensuring the **construction meets design**, and the **design operates as intended** are vital checks that should be conducted throughout the project. Timely **quality control** will likely allow straightforward rectification, whereas belated discovery of errors will require far greater expense.	A number of hold points should be defined for inspection checks. For example, the drainage system should be checked before it is overlaid with media; checks should be made as the media are laid and also upon completion. Undertake as-constructed cross checks with the design drawings. Confirm levels using survey or measurements. Refer to Water by Design (2009) for survey methods and recommended tolerances.

Table 2. Continued

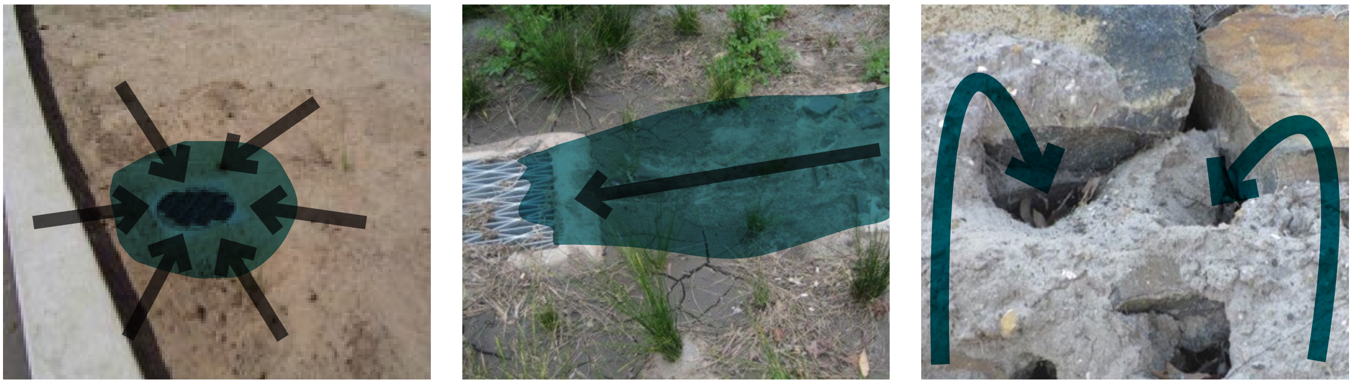
Critical stages	Risks / common pitfalls	Useful tips
Planting and establishment		
Timing of planting	Poor **seasonal timing of planting** can lead to low plant growth, a prolonged establishment period and reduced survival if conditions are challenging. Planting is sometimes dictated by external factors (e.g. need for early landscaping in new developments)	Ideally aim to plant in early spring or autumn for temperate climates, but in tropical and sub-tropical climates there may be a wider planting window, possibly in the cooler season if enough rainfall is available. If non-ideal planting season cannot be avoided, implement careful seedling establishment (see below), including irrigation as required.
Plant establishment	**Establishment of healthy plant cover** across the biofilter is vital for effective long-term function. The period of seedling establishment and early growth is a vulnerable time. Common problem is to 'plant and forget', but careful management during establishment will avoid increased replanting and maintenance costs (e.g. repair of erosion).	Aim to rapidly achieve high plant cover to limit erosion and weed ingress and enhance system performance. Closely monitor vegetation health during seedling establishment. Water frequently as required, particularly immediately following transplant and during long dry periods. More frequent watering will initially be required for smaller seed stock, but can be reduced as plants grow. Plan to provide watering support, particularly during long dry periods, for the first 2-3 years. Some designs allow the temporary raising of the submerged zone and lowering again as plant roots establish. Protect seedlings from erosion - some flow diversions may need to temporarily remain in place from the construction phase if planting occurs during a season of high inflows. Replace dead plants immediately and avoid use of pesticides or herbicides, and fertilisers (beyond an initial once-off). Detailed advice on plant procurement, pre-planting preparations, planting procedures, establishment and assessment are provided in Water by Design (2009).
Maintenance during establishment	**Timely maintenance during establishment** can prevent problems growing into large issues that require costly rectification works (and possible system re-setting). During initial operation, biofilters are particularly vulnerable and errors in construction and design can become apparent. A common problem is insufficient budget to implement the necessary early-life maintenance program, but without this, costs can multiply.	Carefully plan and implement a maintenance schedule specific to the establishment period (initial 2 years of operation). This needs to be conducted at higher frequency with more thorough checks than for mature systems. Ensure adequate budget is available for this maintenance (must be set aside in budget planned during design).
Handover (if relevant)		
Asset handover	**Handover** is a key opportunity for rectification of problems that may compromise long-term system performance e.g. poor plant health, bare zones, inappropriate hydraulics, excessive sediment accumulation.	Inspection is required before handover, and any issues should be rectified before the handover is signed off. Detailed asset handover checks, sign-off documentation and protocols are provided by Water by Design (2009).

Cont.

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

Surface of biofilter not flat, slope follows fall of road – poor distribution of flow

No step down into biofilter: flow cannot easily enter



Overfilling with media or mulch – reduces or prevents ponding, reducing treatment capacity

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

Good hydraulic design and flow management during construction & establishment required to prevent erosion and short-circuiting

Figure 2. Hydraulic and sediment management issues

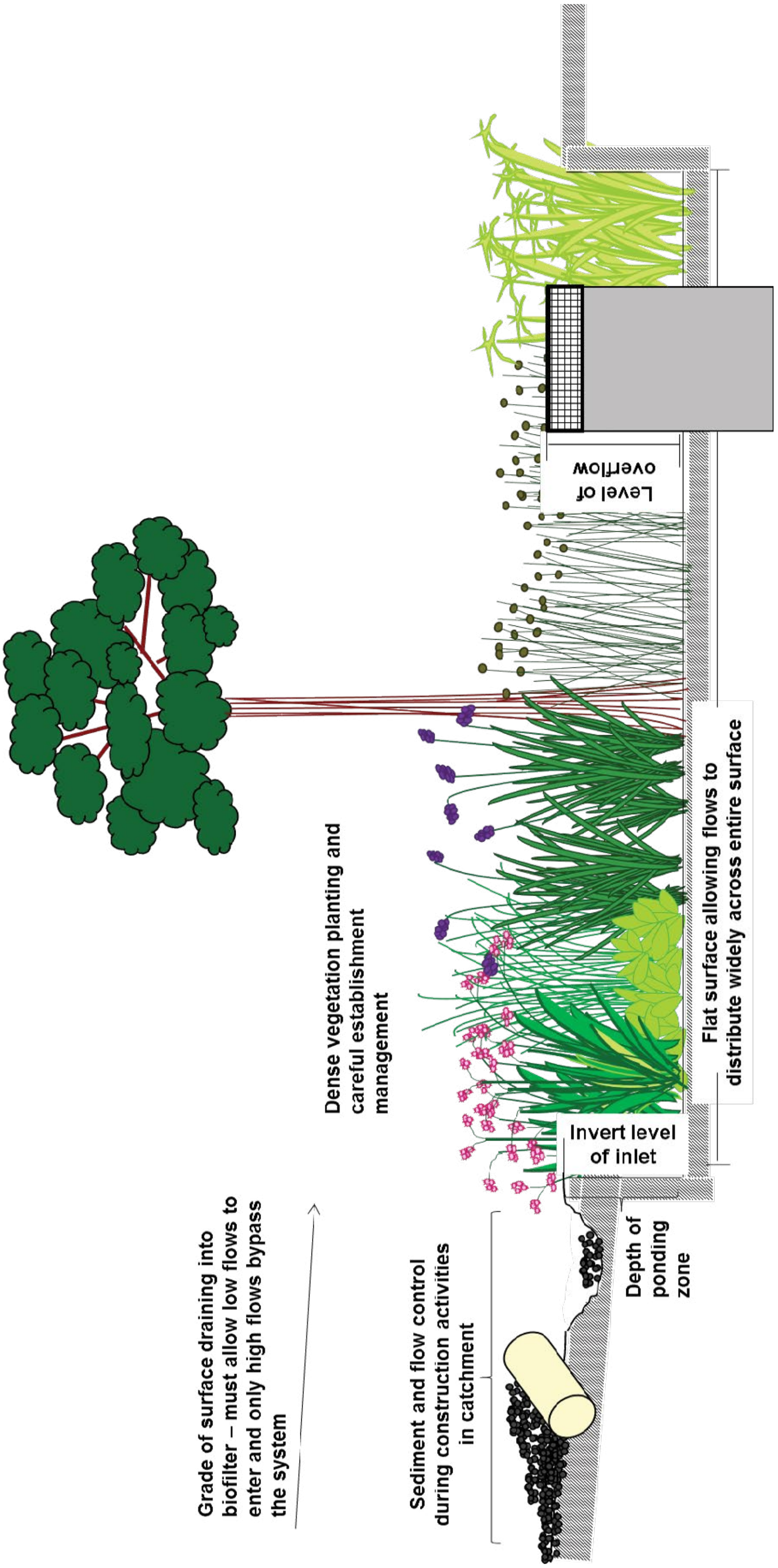
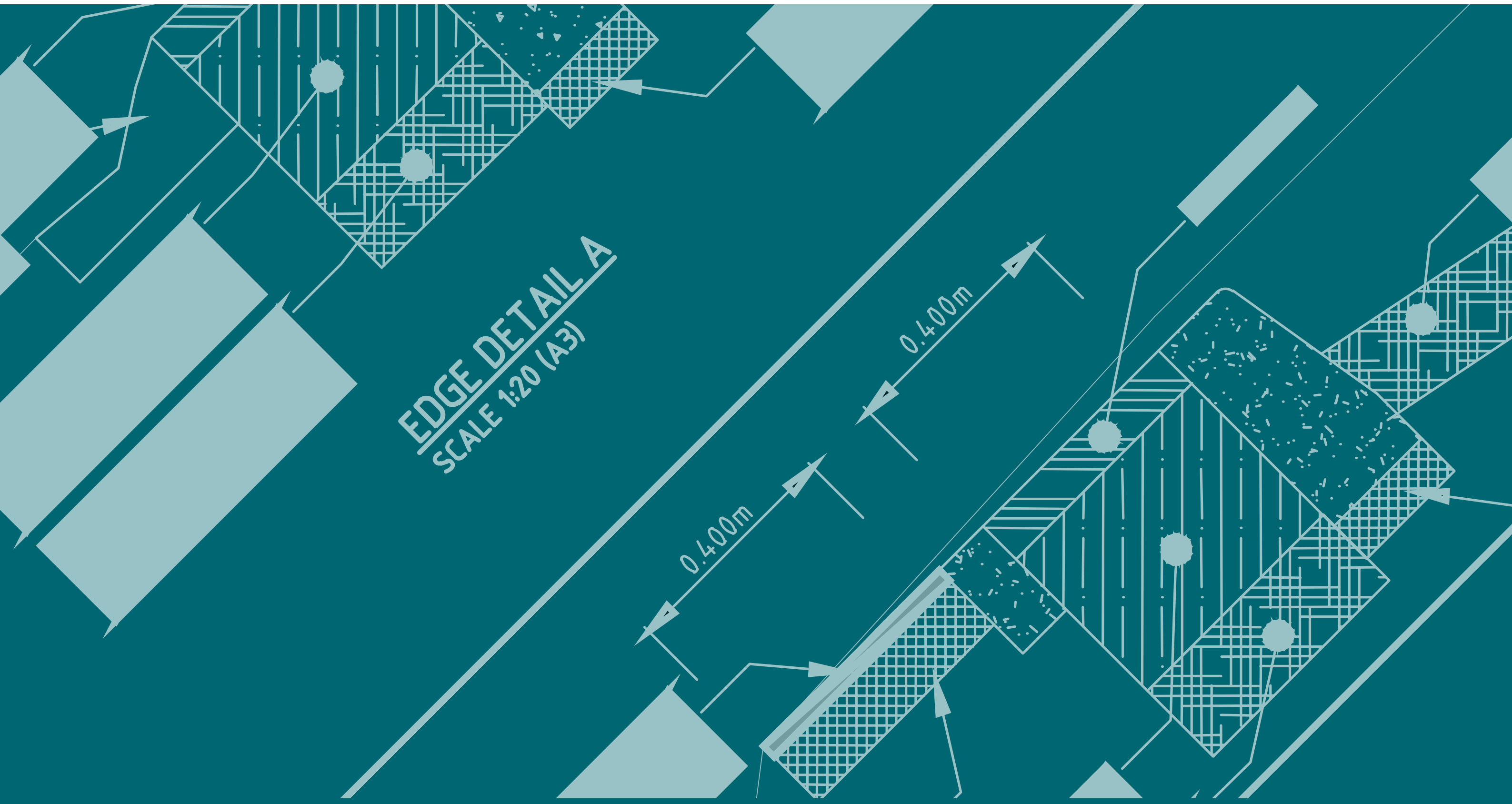


Figure 1. Critical quality control checks during and following construction


EDGE DETAIL A
SCALE 1:20 (A3)
0.400m
0.400m

Appendix B:
Research underpinning the biofilter adoption guidelines

CRC for Water Sensitive Cities

Australian Government
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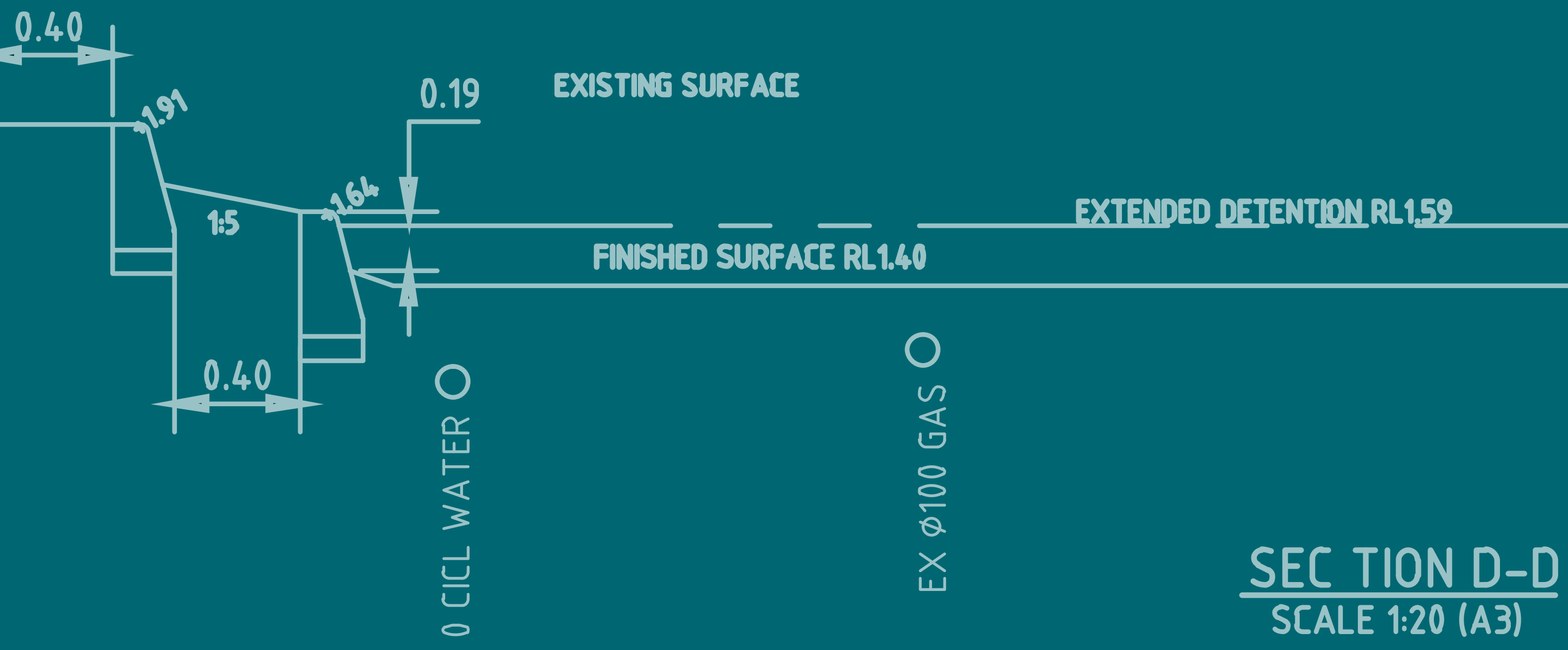
0.40
1.91
0.19
EXISTING SURFACE
1.64
1:5
EXTENDED DETENTION RL1.59
FINISHED SURFACE RL1.40
0.40
0 CICL WATER
EX Ø100 GAS
SEC TION D-D
SCALE 1:20 (A3)

Appendix C: Guidelines for filter media in stormwater biofiltration systems

(Version 4.01) - July 2015

CRC for
Water Sensitive Cities

Australian Government
Department of Industry and Science

Business
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The following guidelines for filter media in stormwater biofilters have been prepared on behalf of the Cooperative Research Centre for Water Sensitive Cities (CRC WSC) to assist in the development of biofiltration systems, including the planning, design, construction and operation of those systems.

Note: This is a revision of the previous Facility for Advanced Water Biofiltration (FAWB) filter media guidelines (published in 2006 (Version 1.01), 2008 (Version 2.01) and 2009 (Version 3.01)). It attempts to provide a simpler and more robust guideline for both sand-based and engineered filter media. In the development of these guidelines across four versions, the CRC WSC acknowledges the contribution of Terry Woodcock and Michael Robinson (Sportsturf Consultants), Greg Fitzgerald and Shane Howes (Daisy's Garden Supplies), EDAW Inc., Melbourne Water Corporation, Dr Nicholas Somes (Ecodynamics), Alan Hoban (South East Queensland Healthy Waterways Partnership), Shaun Leinster (DesignFlow) and STORM Consulting to the preparation of the revised guidelines.

Disclaimer

The Guidelines for Filter Media in Stormwater Biofiltration Systems are made available and distributed solely on an "as is" basis without express or implied warranty. The entire risk as to the quality, adaptability and performance is assumed by the user.

It is the responsibility of the user to make an assessment of the suitability of the guidelines for its own purposes and the guidelines are supplied on the understanding that the user will not hold the CRCWSC or parties to the CRCWSC ("the Licensor") liable for any loss or damage resulting from their use.

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1 Introduction and summary of the media specifications

Each component of a biofilter, including the various layers of media, serve important roles in the treatment of stormwater runoff. Key components and layers within a biofilter, and the purpose they serve, are illustrated in Figure 1. Selecting appropriate material for the biofilter is crucial to the performance of the biofilter, and use of the wrong materials can lead to system failure, leaching of pollutants to the environment and expensive rectification costs. These guidelines have been developed to help avoid this and instead ensure reliable and effective stormwater treatment.

A summary of the key specifications for each layer of material is given in Table 1. Some requirements are essential specifications (highlighted in blue), while other characteristics are only recommended to provide guidance for the selection of appropriate materials (highlighted in grey). The rationale(s) for each requirement are also given in the table. Readers are referred to the subsequent sections in these guidelines for further discussion and clarification of the media requirements.

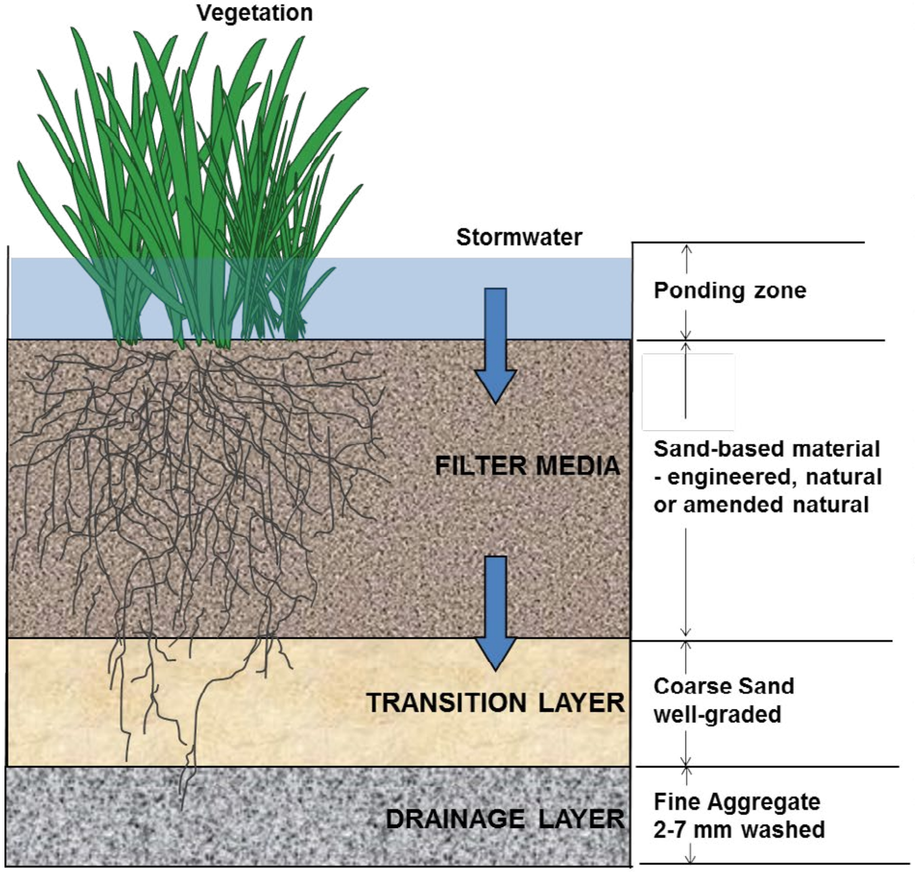

Figure 1. Layers within a biofilter and their function in the treatment of stormwater

STORMWATER

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

VEGETATION

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

PONDING ZONE

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

FILTER MEDIA

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

TRANSITION LAYER

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

DRAINAGE LAYER

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

SUBMERGED ZONE

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

CARBON SOURCE (if present with submerged zone)

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

Table 1. Essential and recommended media requirements

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

Table 1 Cont.

	Property	Specification to be met	Why is this important to biofilter function?
GUIDANCE	**Particle size distribution (PSD)**	Note that it is most critical for plant survival to ensure that the fine fractions are included (% w/w) Retained **Clay & silt < 3% (< 0.05 mm)** **Very fine sand 5-30% (0.05-0.15mm)** Fine sand 10-30% (0.15-0.25 mm) Medium sand 40-60% (0.25-0.5 mm) Coarse sand < 25% (0.5-1.0 mm) Very coarse sand 0-10% (1.0-2.0mm) Fine gravel < 3% (2.0-3.4 mm)	Of secondary importance compared with hydraulic conductivity and grading of particles, but provides a starting point for selecting appropriate material with adequate water-holding capacity to support vegetation. **Filter media do not need to comply with this particle size distribution to be suitable for use in biofilters**
	Depth	400-600 mm or deeper	To provide sufficient depth to support vegetation Shallow systems are at risk of excessive drying
	Once-off nutrient amelioration	Added manually to top 100 mm **once only** Particularly important for engineered media	To facilitate plant establishment, but in the longer term incoming stormwater provides nutrients
	Protective surface layer	Include a surface layer 100-150 mm deep overlying the biofilter media. Use a coarser particle size than the media, generally commercially available sands.	Lab studies have successfully demonstrated the potential for this layer to delay clogging and improve treatment performance. Currently being tested in the field.
Transition sand (middle layer)			
ESSENTIAL SPECIFICATIONS	**Material**	**Clean well-graded sand e.g. A2 Filter sand**	Prevents the filter media washing downwards into the drainage layer
	Hydraulic conductivity	**Must be higher than the hydraulic conductivity of the overlying filter media**	To allow the system to drain and function as intended
	Fine particle content	**< 2%**	To prevent leaching of fine particles
	Particle size distribution	Bridging criteria – the smallest 15% of sand particles must bridge with the largest 15% of filter media particles (Water by Design, 2009) (VicRoads, 2004): **D_{15} (transition layer) ≤ 5 x D_{85} (filter media)** *<u>where</u>: D_{15} (transition layer) is the 15th percentile particle size in the transition layer material (i.e.,15% of the sand is smaller than D_{15} mm), and D_{85} (filter media) is the 85th percentile particle size in the filter media* The best way to compare this is by plotting the particle size distributions for the two materials on the same soil grading graphs and extracting the relevant diameters (Water by Design, 2009)	To avoid migration of the filter media downwards into the transition layer
		Bridging criteria **only in designs where transition layer is omitted** (Water by Design, 2009; VicRoads, 2004): D_{15} (drainage layer) ≤ 5 x D_{85} (filter media) D_{15} (drainage layer) = 5 to 20 x D_{15} (filter media) D_{50} (drainage layer < 25 x D_{50} (filter media) D_{60} (drainage layer) < 20 x D_{10} (drainage layer)	To avoid migration of the filter media into the drainage layer only in the case where a transition layer is not possible.

Table 1. Continued

	Property	**Specification to be met**	**Why is this important to biofilter function?**
G.	**Depth**	≥ 100 mm	(as per above purpose)
Drainage layer (base)			
ESSENTIAL SPECIFICATIONS	**Material**	**Clean, fine aggregate - 2-7 mm washed screenings (not scoria)**	To collect and convey treated stormwater, protect and house the underdrain (if present), or provide a storage reserve as part of a submerged zone, or prior to exfiltration (in unlined systems).
	Hydraulic conductivity	**Must be higher than the hydraulic conductivity of the overlying transition layer**	To allow the system to drain and function as intended
	Particle size distribution	Bridging criteria D_{15} (drainage layer) ≤ 5 x D_{85} (transition media) *<u>where</u>: D_{15} (drainage layer) - 15th percentile particle size in the drainage layer material (i.e., 15% of the aggregate is smaller than D_{15} mm), and D_{85} (transition layer) - 85th percentile particle size in the transition layer material*	To avoid migration of the transition layer into the drainage layer
	Perforations in underdrain	Perforations must be small enough relative to the drainage layer material Check: **D_{85} (drainage layer) > diameter underdrain pipe perforation**	To prevent the drainage layer material from entering and clogging the underdrainage pipe (if present)
G.	**Depth**	Minimum 50 mm cover over underdrainage pipe (if present)	To protect the underdrain from clogging

2 General Description

3.1 Media layers

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

3.2 Filter media properties

The filter media is required to support a range of vegetation types (from groundcovers to trees) that are adapted to freely draining soils with occasional wetting. This horticultural purpose is essential – without vegetation, the biofilter cannot serve its proper function for stormwater treatment. The material should be based on **natural or amended natural sands** or it can be **entirely engineered**; in either case, it can be of siliceous or calcareous origin.

Where there is not a locally available, natural sand-based material that complies with the properties outlined in Table 1, it is possible to construct an appropriate filter medium. A washed, well-graded sand with an appropriate hydraulic conductivity should be used as the filter medium. A mixture of engineered and natural materials may also be used. The engineered media should meet the same essential specifications given in Table 1. Suitable materials include those used for the construction of turf profiles (e.g. golf greens); these materials are processed by washing to remove clay and silt fractions. In large quantities (→20 m^3), they can be obtained directly from sand suppliers, while smaller quantities can be purchased from local garden yards.

Laboratory testing has shown that biofilters that contain an engineered filter medium will achieve essentially the same hydraulic and treatment performance as those containing a natural filter medium (Bratieres et al., 2009). However, it is recommended that a submerged zone be included in biofilters that utilise such a free draining filter medium to provide a water source for vegetation between rainfall events (Section 5). Biofilter media is deliberately designed to be a barren media as incoming stormwater provides a steady supply of nutrients to support plant growth. It is vital that **no additional soil-based materials are added outside of these specifications**, as this will compromise system function. The only acceptable amendment is a once-off application of ameliorant to aid initial plant establishment (Table 2). In general, the media will have an appropriately high permeability under compaction and be free of rubbish, deleterious material, toxicants, declared plants and local weeds (as listed in local guidelines/Acts), and must not be hydrophobic. The filter media will contain some organic matter for increased water holding capacity. Potential filter media can be assessed by a horticulturalist to ensure that they are capable of supporting a healthy vegetation community.

3.3 Infiltration capacity

Maintaining an adequate infiltration capacity is crucial in ensuring the long-term treatment efficiency of the system. The ability of a biofilter to detain and infiltrate incoming stormwater is a function of the filter surface area, ponding depth, and the hydraulic conductivity of the filter media (Figure 2). Most importantly, design of a biofilter must optimise the combination of these three design elements.

For a biofilter in a temperate climate with a ponding depth of 100 – 300 mm and whose surface area is approximately 2% of the connected impervious area of the contributing catchment, the prescribed hydraulic conductivity will generally be between 100 – 300 mm/hr in order to meet best practice targets (Figure 3). This configuration supports plant growth without requiring too much land space. In warm, humid (sub- and dry- tropical) regions the hydraulic conductivity may need to be higher and/or the surface area may need to be larger (approximately 4%) in order to achieve the required treatment performance (i.e., ensuring that the proportion of water treated through the media meets requirements). However, high hydraulic conductivities (→ 300 mm/hr) present challenging conditions for plant survival which need to be addressed by other aspects of the design (Table 2). It is important to also note that high hydraulic conductivity does not ensure protection against clogging in the long-term, but instead depends upon sediment inputs and the inclusion of pre-treatment devices for protection.

Where one of the design elements falls just outside the recommended range, the desired infiltration capacity of a biofilter can still be achieved by offsetting another of the design elements (Table 2). owever, problems can arise if properties deviate too far outside the recommended range – the likelihood of drought conditions, clogging and sediment accumulation, or a risk to public safety may increase. Some of the different design possibilities have been summarised in Table 2 and, if considered, should be investigated using a model such as MUSIC.

Table 2. Biofilter design – benefits, offsets and risks if designs stray outside the range of recommended specifications

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

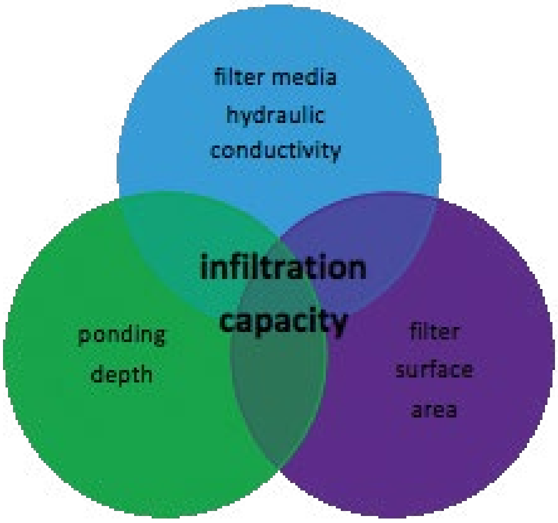

Figure 2. Design elements that influence infiltration capacity.

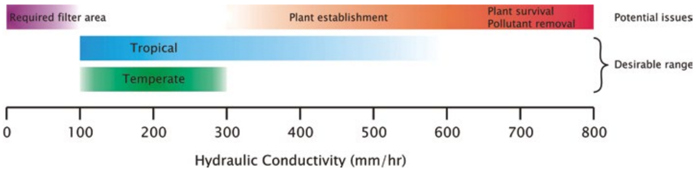

Figure 3. Recommended filter media hydraulic conductivity range and potential issues

The infiltration capacity of a biofilter will decline during the early part of the establishment phase (first 6 - 12 months of operation) as the filter media settles and compacts, but this will level out and then start to increase as the plant community establishes itself and the rooting depth increases. In order to ensure that the biofilter functions adequately at its eventual (minimum) hydraulic conductivity, a safety co efficient of 2 should be used: i.e., **designs should be modelled using half the prescribed hydraulic conductivity.** If a system does not perform adequately with this hydraulic conductivity, then the area and/or ponding depth should be increased. It may also be desirable to report sensitivity to infiltration rate, rather than simply having one expected rate. This is important when assessing compliance of constructed systems as systems should ideally meet best practice across a range of infiltration rates.

2.4 Designing to prevent clogging

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

However, good design can also help to delay the onset of clogging, prolonging biofilter lifespan and improving stormwater treatment performance. Clogging is closely related to particle sizes within the biofilter media. Laboratory studies have found that **clogging can be significantly reduced by including two distinctly different layers of particle sizes, either in separate layers (with a coarse upper layer overlying media with finer particles) or a mixture of different size categories** (Kandra et al., 2014). Including this overlying layer with a coarser particle size leads to better performance, in terms of the volume of stormwater treated and sediment removed, compared to a single layer of media.

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

3 Testing requirements

3.1 Determination of hydraulic conductivity

The hydraulic conductivity of potential filter media should be measured using the ASTM F1815-11 method. This test method uses a compaction method that best represents field conditions and so provides a more realistic assessment of hydraulic conductivity than other test methods. **Do not use AS4419-2003** as this generally leads to overestimation of the in situ hydraulic conductivity.

Note: if a hydraulic conductivity lower than 100 mm/hr is prescribed, the level of compaction associated with the ASTM F1815-11 method may be too severe and so underestimate the actual hydraulic conductivity of the filter media under field conditions. However, this test method is considered to be an appropriately conservative test, and it is therefore recommended even for low conductivity media.

3.2 Particle size distribution

An appropriate PSD is required to provide a stable media (i.e. does not migrate downwards through the biofilter profile), enough water holding capacity to support healthy vegetation, while also allowing a sufficient infiltration rate. The filter media should be well-graded i.e., it should have all particle size ranges present from the 0.05 mm to the 3.4 mm sieve (as defined by (ASTM F1632-03(2010)).

Clay and silt are important for water retention and sorption of dissolved pollutants, however they substantially reduce the hydraulic conductivity of the filter media. This size fraction also influences the structural stability of the material (through migration of particles to block small pores and/or slump). It is essential that the total clay and silt mix is **less than 3% (w/w)**.

Particle size distribution (PSD) is of secondary importance compared with hydraulic conductivity. Further, a material whose PSD falls within the following recommended range does not preclude the need for hydraulic conductivity testing i.e., it does not guarantee that the material will have a suitable hydraulic conductivity. The PSD should be assessed by a horticultural expert for its suitability as a growing medium. **If a material cannot be sourced that meets both the hydraulic conductivity requirement and the suggested PSD below, it may still be suitable**, provided the hydraulic conductivity range is met, it is structurally stable and a horticulturalist deems the media as appropriate to support vegetation. The following composition range (percentage w/w) provides **a useful guide** for selecting an appropriate material:

Clay & Silt	< 3%	(<0.05 mm)
Very Fine Sand	5-30%	(0.05-0.15 mm)
Fine Sand	10-30%	(0.15-0.25 mm)
Medium Sand	40-60%	(0.25-0.5 mm)
Coarse Sand	< 25%	(0.5-1.0 mm)
Very Coarse Sand	0-10%	(1.0mm-2.0mm)
Fine Gravel	< 3%	(2.0-3.4 mm)

4 Once-off initial amelioration

The filter media is designed to be low in nutrient content, as over time incoming stormwater and the turnover of plant roots will provide nutrients and organic matter to support plant growth. However, at the very beginning, the **top 100 mm of the filter medium** needs be ameliorated with appropriate organic matter, fertiliser and trace elements (Table 3). This amelioration is a once-off application to aid initial plant establishment and is designed to last four weeks. Beyond this point, the plants receive adequate nutrients via incoming stormwater and no further fertilisation is generally necessary. The ameliorants will be supplied separately to the media and applied to the surface layer on-site (e.g. using a rotary-hoe).

Testing of the media for its nutrient content and advice from a horticulturalist will indicate the required amendment to support initial plant establishment. However, a general guide for amelioration of the top 100 mm is provided in Table 3.

Table 3. Recipe for ameliorating the top 100 mm of sand filter media

Constituent	**Quantity (kg/100 m^2 filter area)**
Granulated poultry manure fines	50
Superphosphate	2
Magnesium sulphate	3
Potassium sulphate	2
Trace Element Mix	1
Fertilizer NPK (16.4.14)	4
Lime	20

5 Submerged zone and carbon source

The submerged zone (also referred to as a saturated zone) is created using an upturned outlet and use of a liner, which allows ponding in the lower layers of the biofilter (within the transition and drainage layers). Its inclusion is strongly recommended using an upturned outlet, with the moisture retention providing benefits in both unlined (creates a temporary submerged zone) and lined systems (longer-lasting submerged zone). It is particularly beneficial for systems that are unavoidably shallow or over-sized, when nitrogen or pathogen removal is a key objective, or in low rainfall areas. A submerged zone serves multiple roles in biofilter function, including provision of i.) a water supply to support plant and microbial survival across dry periods, ii.) benefits to nitrogen removal, particularly following extended dry periods, iii.) potential for anaerobic (low oxygen) conditions which allow denitrification (which removes nitrogen),and i.) prolonged retention for a volume of stormwater, which provides a longer processing time. For possible design configurations that include a submerged zone please see Section 3.5 of the 'Adoption Guidelines for Stormwater Biofiltration Systems' (Version 2; CRC WSC, 2015).

In lined systems the submerged zone often includes a carbon source mixed throughout the submerged layers. This provides electrons to drive denitrification (a key nitrogen removal process). The carbon source should decompose in the first one to two years of operation, while plant roots develop (which provide carbon over the longer term). The carbon source should comprise approximately 5% (v/v) and include a mixture of mulch and hardwood chips (approximately 6 mm grading), by volume. The **carbon source material needs to be low in nutrients;** appropriate materials include sugar cane mulch, pine chips (without bark) and pine flour ('sawdust'). High nutrient sources such as pea straw (derived from nitrogen-fixing plants) should be avoided as these are likely to leach nitrogen and phosphorus, negating the benefits of including a submerged zone. In addition, straw should not be used as a carbon source, due to reports of odours from some systems using straw. The carbon source is commonly provided separately to the media in bags, and it can be mixed in on site (e.g. using a rotary hoe).

6 Testing the media

In sourcing media for biofilters, test results for the specifications outlined in these guidelines should be sought from suppliers. If possible, it is best to source from experienced and trusted suppliers. This precludes the need for on-site testing; with the condition that a supplier must be able to provide recent test results from the specified source stockpile in their yard. It is important to note all media testing should be conducted in accordance with soil testing standards in this document, Careful consideration must be given to of the number of samples, their collection and the analytical testing method. Test results are only as reliable as the data collection and methodology; it should be recognised that there will be some variation in the stockpile thus collecting one sample from the surface of a stockpile will not provide representative nor useful results. In addition, once media has been delivered to site there is potential for cross-contamination with on-site soils if care is not taken (see Installation Section below), and if this has occurred then on-site testing of the media can place unreasonable liability on the supplier if the media properties no longer meet the specification.

7 Installation

It is vital that when media is delivered to site it is either stockpiled on a hard surface or tipped directly into the biofilter trench/basin (taking care not to damage any underdrain pipes and ensuring the correct layering and compaction as described below). Otherwise, there is high potential for contamination with on-site soils during earthmoving works. Even a small amount of clay or silt can be severely detrimental to the long-term function of the biofilter and is likely to require expensive reinstatement works.

It is recommended that filter media be lightly compacted during installation to prevent migration of fine particles. In small systems, a single pass with a vibrating plate should be used to compact the filter media, while in large systems, a single pass with roller machinery (e.g. a drum lawn roller) should be performed. Under no circumstance should heavy compaction or multiple-passes be made. Filter media should be installed in two lifts unless the depth is less than 500 mm.

Following construction the plant establishment period is a crucial stage, with long-term success of the biofilter hinging on the development of healthy vegetation cover. It is vital to closely monitor the health of the seedlings and functioning of the new biofilter, and to provide additional watering to plants during this vulnerable stage. Further details can be found in the 'Adoption Guidelines for Stormwater Biofiltration Systems' (Version 2; CRC for Water Sensitive Cities, 2015) or Water by Design (2009).

8 Field testing

It is recommended that field testing, or sampling for laboratory testing, of hydraulic conductivity be carried out 1. in the second year of operation to assess the impact of inflow sediment and vegetation on hydraulic conductivity, 2. in mature systems (e.g. 8+ years) or 3. to investigate and diagnose problems in systems suffering from poor infiltration.

The hydraulic conductivity of the filter media should be checked at a minimum of three points within the system. The single ring, constant head infiltration test method (shallow test), as described by Le Coustumer et al. (2007), should be used for field testing. Alternatively, depending upon the resources and expertise available, samples of media can be collected (either in cores or grab samples). Samples may be combined (or composited) across the entire system or between zones in large systems (e.g. near inlet). The surface layer can be selectively sampled, as can deeper layers, to diagnose any problems within the profile. Further details on testing methodology can be found in Appendix I of the Biofilter Adoption Guidelines (CRC for Water Sensitive Cities, 2015).

Given the inherent variability in hydraulic conductivity testing and the heterogeneity of the filter media, the laboratory and field results are considered comparable if they are within 50% of each other. However, even if they differ by more than 50%, the system will still function if both the field and laboratory results are within the relevant recommended range of hydraulic conductivities.

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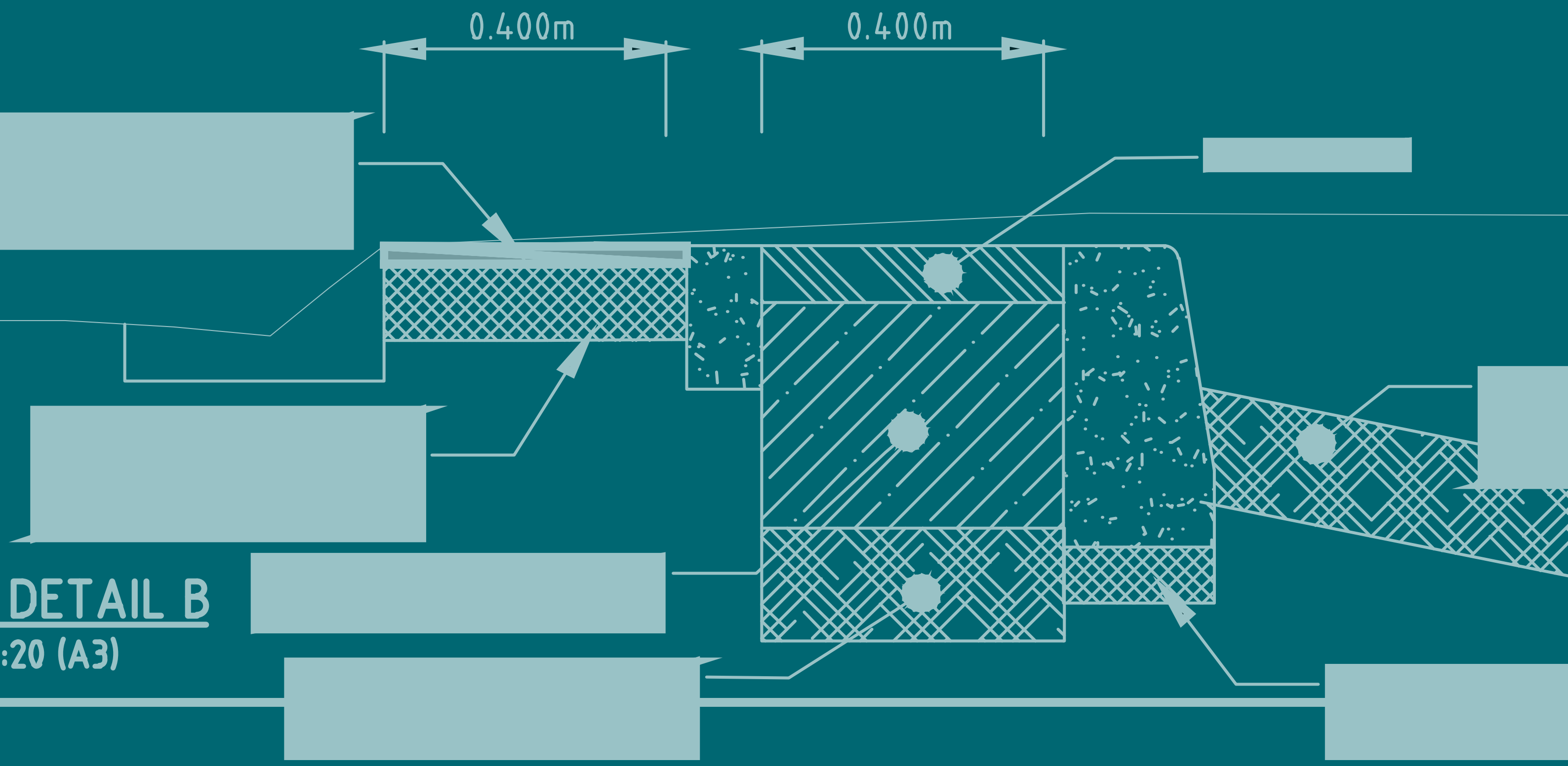
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Appendix D: Enhancing pathogen removal using novel antimicrobial media

CRC for Water Sensitive Cities

Australian Government
Department of Industry and Science

Business
Cooperative Research
Centres Programme

Recent research has demonstrated the potential to enhance pathogen removal from stormwater in biofilters using layers of a specially modified media. To date, this novel design approach has only been tested under laboratory conditions. However, field-scale systems trialling this media are currently under construction and performance results will be assessed from these systems. This section summarises the use of antimicrobial media in laboratory trials, and further details can be found in:

> Li, Y. L., Deletic, A., Henry, R., Schang, C. & McCarthy, D. T. in preparation. *Pollutant removal from urban stormwater by copper-zeolite integrated biofilters.*
>
> Li, Y. L., Deletic, A. & McCarthy, D. T. 2014a. Removal of E. coli from urban stormwater using antimicrobial-modified filter media. *Journal of Hazardous Materials*, 271, 73-81.
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> Li, Y. L., McCarthy, D. & Deletic, A. submitted. The removal of E. coli from urban stormwater by biofilters using copper-treated media. *Water Research*.
>
> Li, Y. L., McCarthy, D. T. & Deletic, A. 2014b. Stable copper-zeolite filter media for bacteria removal in stormwater. *Journal of Hazardous Materials*, 273, 222-230.

Detailed laboratory testing has been conducted to develop an antibacterial media that is stable under wide-ranging conditions, and does not contribute to pollutant leaching. While zeolite coated with exchangeable copper (Cu^{2+}) (known as 'ZCu') is effective for the removal of bacteria from stormwater, it is not stable under very saline conditions and copper leaching can be problematic. However, further testing revealed that calcination (a thermal treatment process) and application of a $Cu(OH)_2$ coating significantly reduces copper leaching (Cu leaching of 20mg/L was reduced by 97%, when using a test solution of salinity 250 μS/cm).

Two media designs were identified for optimal bacterial removal. The first uses ZCu coated with $Cu(OH)_2$ and treated at 180°C, which shows effective E. coli removal (1.7-2.7 log reduction in concentration) from various test solutions under a contact time of 22 minutes (known as 'ZuCuCuO180'). The second type of media uses ZCu calcined at 400°C (known as 'ZCu400'), which effectively inactivates retained bacteria across a 24 hour drying period. As a result, layers of both media are recommended in biofilters seeking optimal removal of bacteria, and copper leaching was minimised to 9 μg/L.

A further consideration is the potential for copper toxicity effects on plants within the biofilter. High levels of copper can lead to poor plant growth, possibly death, which will severely restrict biofilter functioning. To prevent this, it is recommended the antimicrobial layers are restricted to relatively thin layers near the surface of the biofilter, laid down a month or two after planting (to allow establishment). In addition, pipe collars can be used to protect plant stems from the antimicrobial media if necessary to further protect plants (Figure 1). However, in publicly accessible areas it may not be deemed safe to have the ZCu layer exposed. While mulch is not recommended in biofilters, in this case a thin layer (e.g. 50 mm) of granite mulch (14 mm diameter) may be laid above the ZCu layers to prevent the risk of contact with the public.

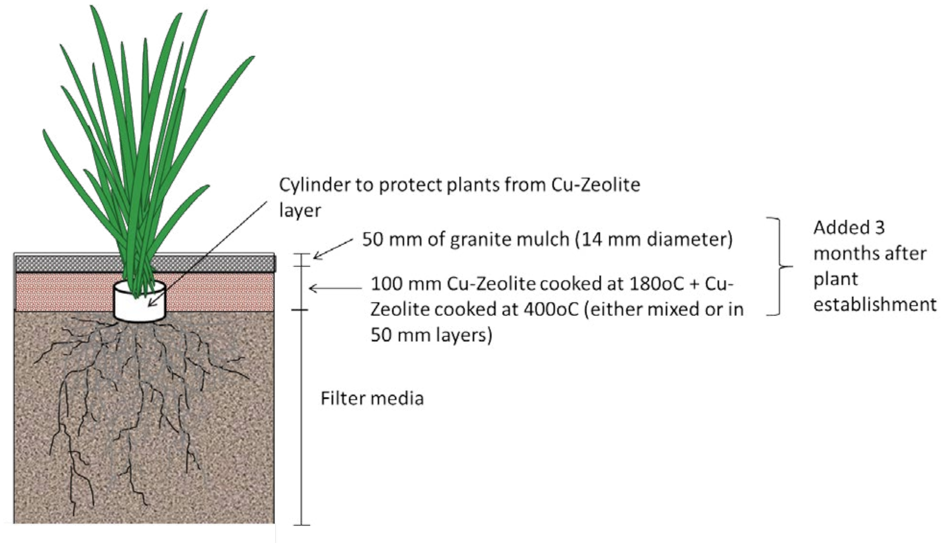
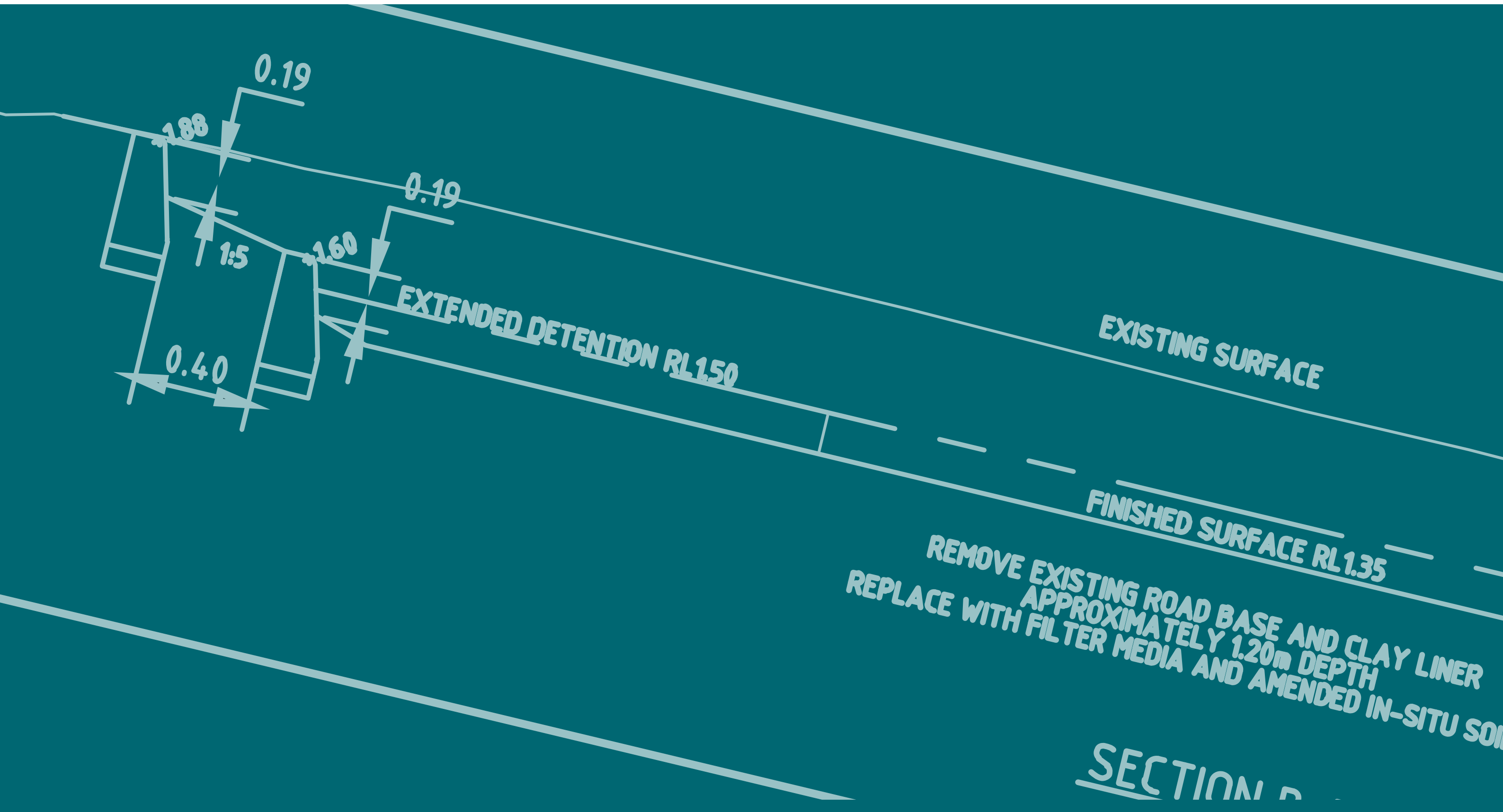


Figure 1. Example layering of Cu-Zeolite antibacterial layers using pipe collar to prevent contact with plant stems and roots

Summary

- It is important to note that, while novel antimicrobial media has been thoroughly tested under laboratory conditions, it is currently undergoing field testing. Hence, it is not as yet recommended for widespread adoption, but guidance will be updated as performance results from the field become available.
- Biofilter designs using antimicrobial media should incorporate:
    - A layer of ZCu400 at the top of the biofilter to inactivate bacteria during dry periods
    - A layer of ZCuCuO180 below the ZCu400 to retain and inactivate bacteria that pass through the upper layer during storm events
    - Plant roots should be protected from potential Cu toxicity but restricting the ZCu layers to the surface of biofilter, with seedlings planted directly into traditional biofilter media and allowed to establish for a month or two before the ZCu layers are placed above. A cut piece of pipe can be used to reduce contact between the plant stem and the ZCu layers. A topping layer of granite mulch (14 mm diameter) may be added above to prevent the risk of contact between the public and the ZCu.


0.19
1.88
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EXTENDED DETENTION RL1.50
EXISTING SURFACE
FINISHED SURFACE RL1.35
REMOVE EXISTING ROAD BASE AND CLAY LINER
APPROXIMATELY 1.20m DEPTH
REPLACE WITH FILTER MEDIA AND AMENDED IN-SITU SOI
SECTION

Appendix E:
Case studies

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Monash University stormwater harvesting system

This project was undertaken by FAWB and Monash University's Water Conservation Committee to capture and treat stormwater runoff from a multi-level carpark (4500 m^2) on the Clayton campus of Monash University. The treated water is then used to irrigate an adjacent sports ground and there is an existing ornamental pond to store the treated water.

The system is small relative to its catchment area and as a result overflow occurs frequently. This is not particularly problematic for harvesting (because the water is always pre-treated in two sedimentation tanks, where heavy metal concentrations are reduced, and high nutrient levels are not detrimental for this irrigation application) and, since overflows discharge to the storage pond, load reductions will still be achieved, provided overflow from the pond to the conventional stormwater drainage system is minimised. This can be achieved by keeping the pond slightly drawn down. The system has the following elements:

- Surface area 45 m2, ponding depth 25 cm and filter depth of 70 cm.
- 50 cm loamy sand above a 10 cm transition and 10 cm drainage layer Fully lined to prevent exfiltration
- Densely planted with indigenous plants to a.) maximise the volume of treated water (plants help to maintain infiltration capacity) and b.) maximise pollutant removal.

The system is currently being renewed with new media compositions, different plant species selection and layout.

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Little Stringybark Creek biofiltration project

This project was undertaken as part of a large-scale catchment retrofit project to restore the Little Stringybark Creek by reducing the impacts from stormwater runoff. A study of this catchment had demonstrated that the frequency of urban runoff was a key driver of degradation.

The system is built to treat a house (265 m^2) and surrounding paved area (200 m^2). The site has the benefits of a large available area and a large lawn below the proposed biofilter location for infiltration of overflows before runoff reaches the street drainage. As it is a private property safety considerations are important and the ponding depth must be kept shallow. In addition, a nearby swimming pool necessitated lining the system on the closest side.

At this site reducing the runoff frequency to the desired level was more challenging than reducing the pollutant load to meet the set targets. The design had the following characteristics:

- Surface area 11 m2, ponding depth 20cm and filter depth of 80 cm.
- Bottom 35 cm of media comprised scoria to maximise the available storage, with loamy sand and two transition layers (a fine gravel and a medium sand) overlying this.
- System unlined except for the side closest to the swimming pool, with no underdrain – designed entirely for infiltration in order to minimise runoff frequency.
- System was densely planted with indigenous plants to
  a. maximise evapotranspiration and
  b. meet biodiversity objectives.

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

Two biofilters have been installed along Kelvin Road in the City of Gosnells. 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. However, three deep waterings were required over the very long summer drought in 2013/14, which replenished the saturated zone. Gingin Loam was used for the filter media.

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

Biofilter integrated into public open space, Meadow Springs, Mandurah (Source: Department of Water, WA)

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

The Barlee Street biofilter was built in June 2009 in the Busselton light industrial area of Western Australia. 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 management of the design inflows to improve the runoff water quality before entry into the Lower Vasse River. Due to shallow winter groundwater levels the biofilter was constructed with a liner. A 150 mm deep saturated zone was created in the biofilter using a raised slotted pipe outlet that is connected to the piped stormwater network. Spearwood red sand/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.

Biofilter on Stephen Street in the central business district of the City of Bunbury, Western Australia (Source: Department of Water, WA)

The stormwater drainage system on Stephen Street in the City of Bunbury, in Western Australia was retrofitted in 2009. This included a series of biofilters designed to fit in with the required parking bays and existing side entry pits. The piped conveyance system was also modified to include StormTech cells to enhance local infiltration. The biofilters were sized at approximately 2% of the impervious catchment area, providing management of the design inflows to improve the runoff water quality before entry into the Leschenault Inlet. They incorporated both groundcover and upper storey planting, with the inclusion of a 580 mm deep, open based root director around trees to protect adjacent infrastructure. Filter media was placed to a depth of 600mm, underlain by 600mm of clean sand allowing infiltrated runoff to enter the underlying groundwater system.

Biofilter on Queens Street roundabout in the town centre of the City of Busselton, Western Australia (Source: Department of Water, WA)

The roundabout on the junction of Queens Street and Prince Street in the City of Busselton, Western Australia was upgraded in July 2009 to include treatment of small events using biofilter, prior to entry into the existing piped stormwater system. The upgrade enhanced the street landscaping and also included artwork incorporated into required infrastructure). The unlined biofilters were sized at approximately 4% of the impervious catchment area, providing management of the design inflows to improve the runoff water quality before entry into the Geographe Bay. Due to constraints of the existing stormwater system a filter media depth of 200 mm was viable. The systems were initially planted with Ficinia nodosa, which was later replaced by City of Busselton with Lomandra species. Due to the requirement for kerbs at a junction, breaks in the kerb were used as entry points.

Large scale biofilter in Margaret River, Western Australia (Source: Cape to Cape Catchments Group, WA)

The Margaret River Rain Garden was completed in July 2008 and comprised a large scale multi-layered biofilter system. The system receives untreated runoff, via a piped stormwater system, from the Margaret River central business district that includes commercial areas, roads, carparks and pavements. Due to limited space within the urban area the end of line biofilter system was constructed within an 'A Class' reserve, with the support of the reserve manager and community of Margaret River. As the system receives flows from a large catchment on a steep slope a bypass channel takes larger flows while low flows are passed through a gross pollutant trap and sediment settlement basin prior to entry into the biofilter. The biofilter has been sized at approximately 2% of the impervious catchment area, providing management of the design inflows to improve the runoff water quality before entry into the Margaret River. It comprises an upper and lower biofilter of 750 m² and 340 m² respectively, with an option of an additional future biofilter of 1025 m². Due to the clayey nature of the soils the 600 mm deep filter media is underlain with a sub-soil system that directs treated water back into the bypass channel.

How does the Rain Garden work?

1 Pipe outlets have net type litter traps.
2 Controlled inlet to Rain Garden is lower than the bypass channel to direct water in to Rain Garden.
3 Sediment zone settles out sand and gravel. It is placed for easy access for regular cleaning.
4 Rain Garden filter media.
5 Outlet from upper to lower Rain Garden distributes flow when the upper basin fills.
6 Inlet to lower basin from upper basin.
7 Overflow outlet and inspection pit.
8 Bypass channel diverts excess water after a heavy rain storm when the Rain Garden basins are full.
9 Riffles slow down and break up bypass flows to control erosion.
10 Treated water outlets.

A Long Section through the Water Outlet

Biofilter in the Cultural Precinct on Queens Street in the town centre of the City of Busselton, Western Australia

The stormwater drainage system on Queens Street was retrofitted during a major upgrade and facelift of the streetscape in the area of the Cultural Precinct in City of Busselton, Western Australia. This included inclusion of biofilters sized at approximately 2% of the impervious catchment area, providing management of the design inflows to improve the runoff water quality before entry into the Geographe Bay. The biofilters were specifically designed to mould into and add aesthetic value to the streetscape with consideration of shape, location, vegetation and shade being considered. The biofilters included trees, with the inclusion of a 580 mm deep, open based root director around trees to protect adjacent infrastructure. These trees provide a more relaxing environment and also shade for strategically placed benches. The street is completely kerb less and as such bollards have been installed, making use of timber to ensure provide less of a visual impact. The biofilter includes filter media to a depth of 1000mm, underlain by 600mm of clean sand allowing infiltrated runoff to enter the underlying groundwater system.

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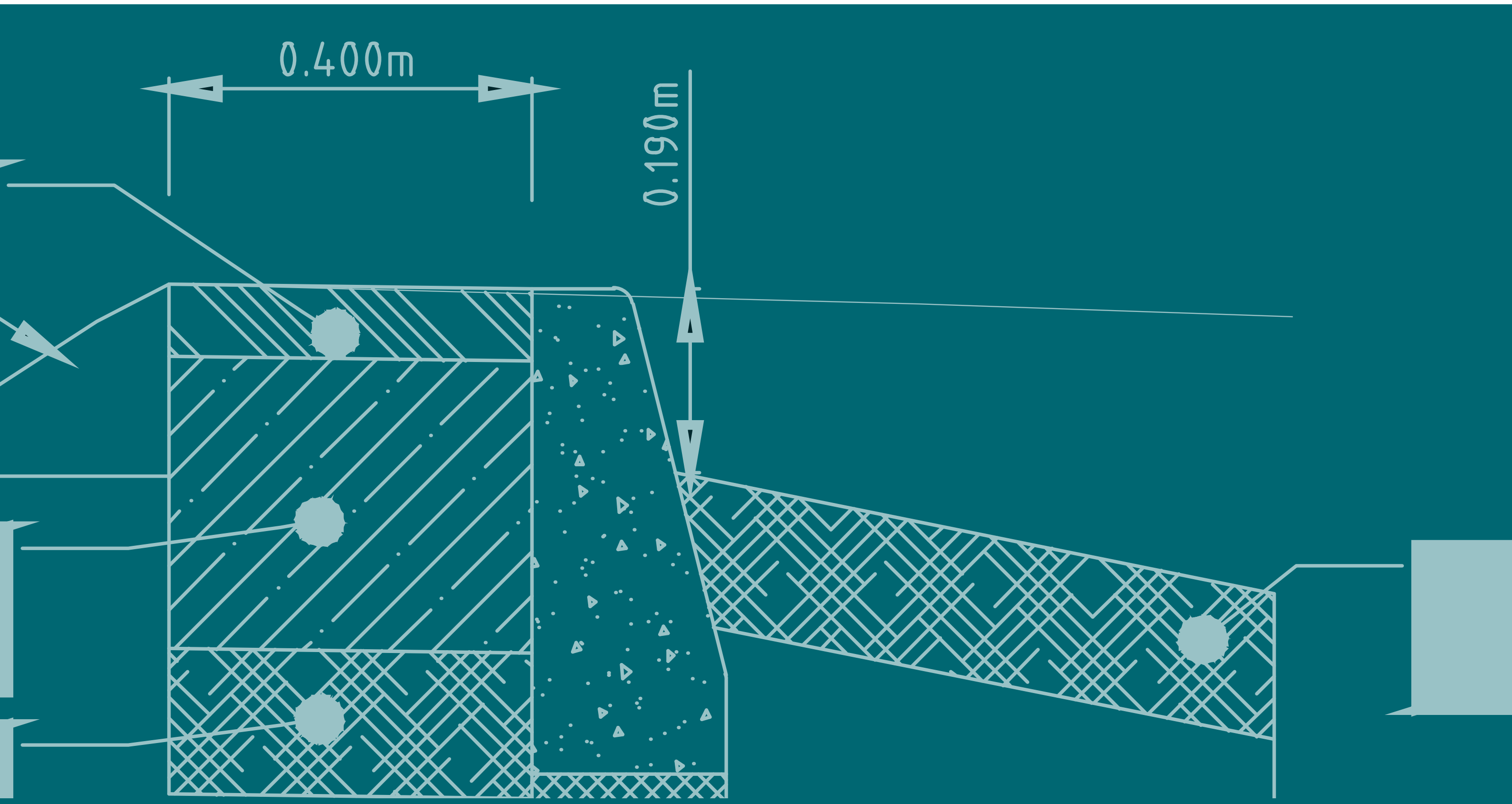
Biofilter with information board in carpark in the town centre of the City of Busselton, Western Australia (Source: Department of Water, WA)

Two existing raised garden beds in a carpark in in the town centre of the City of Busselton, Western Australia were retrofitted as biofilters as part of a demonstration project in April 2011. The biofilter sizes were pre-set by the existing garden footprint, which resulted in the size of the biofilters being approximately 2% and 1% of the impervious catchment area. They provide management of the design inflows to improve the runoff water quality before entry into the Geographe Bay. Filter media was placed to a depth of 500 mm, underlain with a 100 mm thick clay layer. The purpose of the clay layer below filter media was to assist in capturing pollutants and retaining water for absorption by the plants. The systems were initially planted with Ficinia nodosa, Melaleuca incana and Beaufortia sparsa.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Appendix F: Biofilters that look good – Enhancing aesthetics, community appreciation and acceptance

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Introduction

Urban landscapes must be designed for everyone. Yet not everyone will look at a landscape in the same way: what some people will like, others might not. Nevertheless, studies have shown that most people like urban landscapes with trees, smooth ground surfaces, curving lines, the presence of water, and a hint of mystery. Landscapes that appear healthy, with lush green vegetation, are preferred to landscapes that do not. Similarly, natural urban landscapes that are manicured are preferred to those that appear messy (Kaplan and Kaplan, 1989).

Similar landscape elements were important in preferences for constructed wetlands (Dobbie and Green, 2013, Dobbie, 2013, Cottet et al., 2013), a common feature in water sensitive urban design:

- The inclusion of trees
- The presence of vegetation rather than bare soils
- Water visible in the landscape
- Systems that appear healthy (i.e. lush, green vegetation and clear water)
- Characteristics that are generally compatible with ecological function

These same principles might usefully be applied in the design of biofilters. However, more than attention to these is required to ensure that biofilters will achieve community acceptance. The way in which these landscape elements are combined and arranged and the selection of plant species are also important. Specifically, the design of biofilters that are visually appreciated and accepted in our urban landscapes requires:

- an understanding of the site context,
- the application of good design principles, and
- careful selection of materials, both hard and soft.

Context

A biofilter is not an isolated landscape element but is ‘read’ with all the other elements within a landscape or streetscape. Any design must be site-specific, taking into consideration the appearance of the surrounding area, which may vary from dense urban environments, to leafy suburban streets or parks, to semi-urban areas fringing natural bushland. The character of suburban streets and neighbourhoods can also vary widely. An appealing landscape design for one environment might not be suitable for another.

Context is critical. Different contexts can apply to a project, depending on the landscape scale. Landscape scale can vary from a regional scale, to a city scale, to a neighbourhood scale, to a street scale, down to a lot scale. In designing biofilters, the relevant scale is likely to be neighbourhood scale for biofilters in parks, or street scale for raingardens incorporated into road reserves, car parks, etc.

Context informs many design decisions. Context must be understood and generally it requires a visit to the site. A site visit will reveal the neighbourhood character, related to the land use, building scale, form and density, and predominant vegetation. For understanding at a finer scale, details of the specific street in which one or more raingardens are to be sited are required. A site visit provides insight into the community for which you are designing the biofilter, and its landscape preferences.

It reveals the physical context of the site. The design of biofilters should generally respect both neighbourhood and streetscape characters.

Things to look out for on a site visit are:

1. Land use
2. Predominant period of architecture, e.g. Edwardian, post-World War 2, contemporary
3. Predominant hard landscaping materials
4. Predominant planting style, i.e. formal or informal
5. Predominant plant selection, i.e. native, exotic, or mixed

Land use is an important factor in designing biofilters. It influences the physical context of the biofilter and so, too, its design. This is especially the case in residential streets. In residential streets, the residents are likely to consider the street as an extension of their domestic domain. Therefore, it is very important that the design process considers the landscape preferences of residents so that the biofilter 'fits in' visually to their street. It is essential that the residents appreciate, accept and value the biofilter in order that it can deliver the intended stormwater management service. This acceptance is less critical in commercial or industrial locations, where the property occupants are likely to be less critical of changes in the streetscape. Every opportunity should be taken to adopt innovative biofilter designs in these locations. They offer an opportunity to make biofilters accessible to the public, capture their attention and engage with them and demonstrate the function of biofilters.

Design of a raingarden should reflect its context, including land use, predominant style of architecture, and plant selection in existing streetscape. A suitable design for a raingarden in one context might not be suitable in another. Photos: M. Dobbie

Good design principles

Principles of good design apply to landscape projects at any scale. The design of even the simplest biofilter will benefit from an understanding of good design principles.

Commonly adopted design principles are:

Unity and variety: There should be a balance of unity and variety within the design. Unity creates wholeness to the design, a sense of order and cohesion. On the other hand, variety creates interest, holding the viewer's attention. Another way of thinking about this is to aim for coherence, legibility, complexity and order in your design. These are thought to be important when people 'read' a landscape (Kaplan and Kaplan 1989). The same principles can be applied to biofilters. The design should be coherent: it should hang together. It should also be legible, i.e., it should be able to be 'read' as an entity. There should be some complexity so that the landscape is interesting, but within this complexity, there should be order.

Much research has shown that orderly urban landscapes are generally preferred to disorderly, or messy, landscapes (Kaplan and Kaplan, 1989, Nassauer, 1995). This applies even to the smallest biofilter. Messy biofilters are unlikely to be appreciated and accepted in an urban setting. If the design of the biofilter must appear 'messy' because of the choice of plant, e.g. sedges, grasses, reeds, consider including 'cues to care' (Nassauer 1995). 'Cues to care' are such things as regular maintenance, mown edges, street furniture, signage and flowering plants. These indicate that the apparent messiness of the biofilter is intended and that the area more generally is cared for and valued. 'Cues to care' provide an 'orderly frame' to a 'messy ecosystem' (Nassauer 1995).

Raingardens should sit comfortably within the urban setting, contributing positively to the streetscape. Multiple raingardens within a street should be designed to be read together, creating coherence in the streetscape. Raingardens with strappy plants can appear messy. 'Cues to care', such as good maintenance, are important to communicate that the 'messy' plants are intended. Photos: M. Dobbie.

Form: The three-dimensional shape of the design should be carefully considered. The location and form of the various landscape elements should be chosen with an appreciation of how they relate to each other and how that relationship might change over time as the plants grow. All landscapes, including biofilters, are dynamic. A biofilter will change in form with time. The challenge is to design a biofilter that not only looks good when first constructed but that continues to look good as it matures. In situations where naturalistic plantings are desired and maintenance is intentionally less, an understanding of plant succession is necessary to anticipate likely changes in form of the plants and so, too, of the whole biofilter. Undesirable changes can be avoided by appropriate plant selections.

Scale: Scale relates to proportions of the different elements within the biofilter and of the biofilter in relation to the broader landscape. The elements within the biofilter should be in proportion to each other. In turn, the biofilter should be in proportion to its setting. This can be a subjective assessment. Nevertheless, scale should be considered in developing the design.

Seasonal variation: A biofilter can be designed to provide seasonal variation through the thoughtful choice of appropriate vegetation. The easiest seasonal variation is provided through flowering. Generally, deciduous plants are unsuitable in a biofilter so the seasonal variation of change in leaf colour in Autumn, leaf loss in Winter, to reveal the sculptural form of the plant, and new colour of Spring is not possible. Choice of flowering plants can be guided by the planting in nearby private gardens.

Inclusion of flowering plants adds interest through seasonal variation throughout the year. Choice of species or flower colour can be guided by existing vegetation in private gardens nearby. The results can be dramatic or more sedate; it is up to the designer to decide.
Photo: M. Dobbie; photo manipulation: H. Smillie.

Patterns: Landscape perception operates at the level of landscape patterns (Gobster et al. 2007). Landscape patterns are what people notice in the landscape, i.e. the perceptible realm. Patterns can be created within a biofilter through the placement of plants with contrasting form, foliage and flowers, and the use of hard landscaping materials. Patterns can also be created by playing with solid masses of vegetation and areas of open space. Water can also be used. Formal patterns tend to be geometric whereas informal patterns tend to be random or curvilinear. However, this is not a clear-cut distinction: it is possible to have curvilinear formal patterns. When creating formal patterns, it is important to understand the growth of the plants within the biofilter and implement a suitable maintenance regime. With growth, the various plants might obscure the original pattern. Maintenance might involve regular pruning to retain the design intent.

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

The pattern of the raingarden outside the Victorian College of the Arts, in St Kilda Road, Melbourne, is very strong, formal and geometric, creating interest. Photo: Spiire; http://www.spiire.com.au/case-studies/victorian-college-arts-forecourt

Selection of vegetation with contrasting colours can simulate light and shade for visual interest. Photo: M. Dobbie

Texture: Texture can be both physical and visual. Physical texture can be used in the design of biofilters to create visual texture and thus visual interest. Texture is especially important when the choice of colour within a biofilter is limited. Texture can be provided by any of the materials used to construct the biofilter, including plant material and hard landscaping materials, e.g. concrete, stone, timber, etc. Texture can be fine or coarse. Small-leaved plants provide fine texture; large-leaved plants provide coarse texture.

Colour and tone: There is colour (or hue) in every biofilter. Green should always be present in the vegetation. Additional or different colours can also be provided by the vegetation, for example by the flowers or foliage. Colour can also be provided by hard surfaces, such as paving, edging and grilles. Tone relates to colour. A tone is a hue to which some black and white have been added. In a biofilter with foliage of a single colour, visual interest can be created through selection of a mix of vegetation with different tones of that colour.

Texture provided by different types of vegetation can create interest in a raingarden. Photo: M. Dobbie

Green comes in many tones, which can add interest in a raingarden, even without the addition of another colour. Paving can also contribute visual interest. Photo: M. Dobbie

Material selection

Hard landscaping materials: Context, budget, and maintenance requirements will determine the choice of hard landscaping materials. There is a wide range of proprietary products on the market for such things as grilles, paving, bollards, etc. If the budget allows, bespoke structures can be designed and manufactured.

Fixtures can be designed and manufactured specifically for a raingarden. An example is the outlet of the stormwater downpipes, collecting and diverting water to the raingarden outside the Victorian College of the Arts. Photo: Spiire; http://www.spiire.com.au/case-studies/victorian-college-arts-forecourt

Plant material: Careful plant selection for biofilters is critical to ensure their technical function and their visual appreciation and acceptance by the local and broader communities. Plant selection to meet performance objectives is discussed in Section 3.6.14. This section provides guidance on selection for appearance. In this case, context is all-important.

Plant selection in residential locations is more constrained than elsewhere. In commercial, industrial, and public open space, the designer has more freedom to create a biofilter that is eye-catching and perhaps even provocative. However, to enhance the visual appreciation and acceptance of biofilters retrofitted into existing streetscapes, the biofilters' design should reflect the predominant garden preferences of the residents. Predominant garden style is more important than predominant style of architecture. For example, in a street with predominantly informal gardens with native vegetation, raingardens should have an informal design with native plants. Conversely, in a street with predominantly formal gardens with exotic vegetation, raingardens should have a formal design with an emphasis on exotic plants. Sufficient plants proven to function in stormwater treatment should always be included. At least 50% of all vegetation should be proven to improve stormwater quality (Section 4.4.14). However, these plants should be supplemented with a selection of plants reflecting the street's residents' preferences, which is expressed in their own gardens. These preferences will influence the planting style, structure and composition, plant selection and maintenance regime for the biofilters.

Both exotic and native species can be used, depending on the surrounding neighbourhood:

- Exclusively native species might be appropriate in bushland, semi-urban or urban areas with native gardens. Look to combinations found occurring naturally together (Water by Design, 2014). A guide to plant selection and arrangement can be found in nature. Plants that occur together in nature are likely to survive well together in a constructed landscape such as a biofilter. Alternatively, plant selection could be based on what is used in nearby gardens. When considering native species, it might be important to use endemic plants of local provenance, depending on the setting. Include ornamental native plant species, e.g. kangaroo paw or Gymea lilies, where appropriate. Also consider biodiversity: plants can be selected to attract insects and birds and to discourage predators, e.g. cats.

- Exotic species might be most appropriate in heritage or older suburban landscapes. Again, take your cue from the context and popular garden plant combinations.

Incorporate structural complexity. If trees are planted, this might include a canopy layer with an understorey of multiple layers below. If trees are not to be planted, structural complexity might derive from vegetation of different heights, including groundcovers, sedges, rushes and shrubs.

Within any mix of plant types, consider using a mix of:

- different sized and shaped foliage, e.g. Leucophyta, to create different textures,

- different foliage colour,

- plants that flower across different seasons, with contrasting or complementary flower colour.

Plant selection in this raingarden reflects the choice of plants made by owners of adjacent properties, contributing to a sense of place in the streetscape. If the raingarden includes plants used in neighbouring gardens, it is more likely to be appreciated (and perhaps maintained) by residents of the street. Photo: M. Dobbie

Context is all-important. In this bushy outer suburban setting, different raingarden designs are possible but not all are equally successful in respecting the context. The bottom right-hand option, with the abundant exotic flowering plants, does not relate well to the setting or the planting of the nearby gardens, with which the raingarden will be 'read'. Photo: M. Dobbie; photo manipulation: H. Smillie.

Trees as landscape features

Trees are a popular feature in our urban landscapes. They contribute greatly to the visual amenity of a streetscape or broader landscape. Studies have shown that landscapes with trees are preferred to treeless landscapes (Kaplan and Kaplan 1989; Dobbie 2013). Trees provide structural complexity to a design, a permanent framework for other plantings in understorey layers.

The tree canopy contributes to the form of the biofilter itself and also to the wider landscape. The canopy provides important shade, which can help mitigate the urban heat island effect. It is important to know the canopy density of selected trees. Canopy density will influence selection of plants for the understorey. Trees with an open canopy support a greater range of species in the understorey than trees with a closed canopy. Shade-tolerant species, i.e. those adapted to forests or rainforests, must be used under trees with a dense canopy (Water by Design, 2014).

A single tree can be used as a feature in a small biofilter. Clumps or groups of trees are suitable in larger systems. Odd-numbered groups of trees are more visually pleasing than even-numbered groups. Trees can be arranged formally or informally. For informal plantings, inspiration can be found in naturally occurring groups of trees. Placement and spacing of trees should be chosen with the size of the mature tree in mind.

Evergreen trees, not deciduous ones, should be selected for planting in the biofilter. Evergreen trees will have less leaf litter, which can foul the biofilter. They will also provide foliage, and hence colour, over winter.

Trees in bioretention pits or vegetated raingardens in urban areas contribute multiple benefits to the community. Photos: M. Dobbie

Plant layout

Plant layout can be formal or informal, using native plants only or a mix of native and exotic plants. If exotic plants are known to function in improving water quality, it might be possible to use exotic plants only.

Choice of plant layout will be influenced by site context. Potential layouts are:

- Random
- Geometric, e.g. bands, zig zags (chevron)
- Curvilinear, waves, concentric

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

Keeping it green

Green, lush vegetation is preferred by most people to brown, dry vegetation. Thus, it is important to keep the biofilters green.

Design and maintain the biofilter for moisture retention. This can be done by:

- shading the surface,
- including a submerged zone,
- watering the plants as required in dry season spells (particularly during establishment).

Select species with minimal seasonal die-back (or senescence), or use a mixture of species with different timings of senescence. For this reason, it is best to avoid the use of annuals.

Community engagement and landscape design

To further foster community understanding and engagement with the system, designers should consider:

- Public accessibility to the biofilter: Where safety permits, allowing members of the community to get close and peer into the system will foster curiosity and engagement. Consider accessibility in the design of barriers (if any), edges, seating, the proximity of pathways, system shape and crossings, walkways and bridges traversing the system.
- Visibility of the biofilter will help the community to understand biofilter function and add to its appeal. This can be achieved through:
    - The movement of water through the system. Designs may include channels delivering inflow, structures distributing flows across the system, grated coverings on those traversing pedestrian pathways, or the visible movement of flow between biofilter cells. The latter may be best achieved on sites with a sufficient gradient and terraced design.
    - Labels or signage. These can be creatively designed, such as labelling drains with their source (e.g. catchment) or destination (e.g. local creek or bay).

The dynamism of water adds interest to the landscape, as demonstrated in this raingarden in Were Street, Montmorency, and helps to tell a story about the function of the raingarden. Photo: Spiire; http://www.spiire.com.au/case-studies/were-street-raingarden

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GAS - LOW PRESSURE
EXISTING BITUMEN FOOTPATH
BITUMEN FOOTPATH

Appendix G: Detailed scientific monitoring

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Intermediate monitoring

Intermediate quantitative assessment of biofilters involves simulating a rain event using semi synthetic stormwater. This should be carried out using the methods described in Practice Note 2: Preparation of semi-synthetic stormwater (Appendix F) and Practice Note 3: Performance assessment of biofiltration systems using simulated rain events (Appendix G). The number of simulations that should be undertaken is flexible however more simulations give greater insights into the performance of the biofiltration system. Simulations in different seasons and after different lengths of preceding dry periods should also be considered.

Box 1. Quality control considerations.

Soil

- Sampling – bottles (cleanliness, appropriate material), sampling equipment (cleanliness, appropriate method), storage and preservation, labelling and identification of samples
- QC samples – bottle blanks, field blanks, replicates, spikes
- Analysis – NATA-accredited laboratory, close to sampling location, experienced in analysis, timely in reporting

Water Quality

- Sampling – bottles (cleanliness, appropriate material), sampling equipment (cleanliness, appropriate method), storage and preservation, labelling and identification of samples
- Field instruments – condition, calibration
- QC samples – bottle blanks, field blanks, replicates, spikes
- Analysis – NATA-accredited laboratory, close to sampling location, experienced in analysis, timely in reporting

Water Quantity

- Instruments – condition, calibration

Quality Assurance

- Sampling – careful documentation of time of collection, sampling person, location, storage temperature; identify each sample with a unique number
- Document training of staff, QC checks, equipment calibration and maintenance, sample storage and transport

In order to minimise the potential for sample contamination and achieve accurate results, water quality samples should be collected according to standard protocol in appropriately prepared bottles (see AS/NZS 5667:1 1998 and Box 1) and analysed by a NATA-accredited analytical laboratory. The pollutants that should be monitored will be determined by the system objectives and the type of receiving water. In general, the following parameters should be measured as a minimum:

- Total suspended solids (TSS);
- Total nitrogen (TN);
- Total phosphorus (TP); and
- Heavy metals – copper, cadmium, lead and zinc.

Physical parameters such as pH, electrical conductivity (EC, as a measure of salinity), temperature, and dissolved oxygen (DO) are relatively cheap and easy to measure using a field probe and could also be considered. The following water quality parameters might also be required:

- Nutrient species – ammonium (NH4+), oxidised nitrogen (NOx), organic nitrogen (ON), and orthophosphate (PO43-, commonly referred to as dissolved reactive phosphorus, FRP); and
- Other metals – aluminium, chromium, iron, manganese, and nickel.

Consult with the analytical laboratory as to the sample volume required to carry out the analyses.

See Section 4.4.7 for guidance on interpreting test results.

Detailed monitoring

Detailed quantitative assessment involves continuous flow monitoring (of inflows and outflows) and either continous or discrete water quality monitoring (depending on the water quality parameter). This type of monitoring is the most resource intensive and requires a substantial level of expertise, however it is strongly recommended that this be undertaken for biofilters whose design deviates from FAWB (i.e., tested) recommendations or where biofilters are used to treat stormwater for harvesting purposes.

This type of monitoring would need to be implemented and managed by an organisation with the capacity to undertake such a program. Further, the installation, calibration and maintenance of instrumentation requires a high level of expertise and should be undertaken by an organisation experienced in this type of activity.

The following are suggested approaches to this type of monitoring:

- Flow
    - Appropriate infrastructure for flow measurement includes weirs, flumes, and pipes in combination with water level or area/velocity meters.
- Water quality (see Section 4.4.6.2 for guidance on selection of water quality parameters)
    - Continuous – sensors; and
    - Collection of discrete samples – this is usually

undertaken by automatic samplers during rain events, but occasional grab samples should also be collected in baseflow, as well as during rain events to verify samples collected by automatic samplers. The entire hydrograph should be sampled, regardless of whether each sample is analysed or all samples are combined to assess the Event Mean Concentration.

Selection of monitoring equipment should be done in consultation with experienced operators, who should also be responsible for installing and maintaining the equipment. The following considerations should be made during the selection process:

- Environmental parameters need to be within the operational range for certain variables;
- Easy of calibration of instrumentation; and
- Instrumentation should not interfere with the hydraulic operation of the system (eg. it should not create backwatering problems) and must be able to cope with the full range of hydraulic conditions.

For guidance on selection of appropriate water quality parameters, see Section 4.4.6.1 (Treatment Performance).

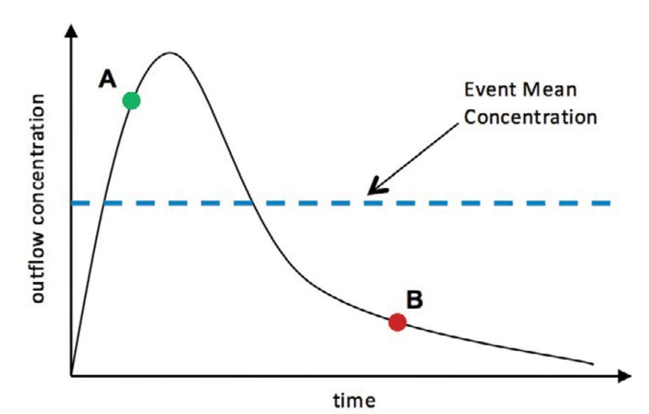
See Section 4.4.7 for guidance on interpreting test results.

Validation of biofilter performance under challenging conditions

The validation of biofilter performance is critical to the widespread adoption of the technology. Evidence of stormwater biofilter efficiency is provided in the many laboratory and field studies conducted (see chapter References and Appendix B Publications list). However, some studies have sought further confirmation of performance by testing biofilters under challenging operating conditions. This validation is particularly important for stormwater harvesting applications, when water re-use for a given purpose needs to ensure water quality targets are consistently met. Validation testing is commonly undertaken for traditional and highly engineered water treatment facilities (e.g. for drinking water or water recycling purposes). However, the adaptation of a validation framework developed for pathogen removal from wastewater (for non-potable reuse), to micropollutant removal by stormwater biofilters was undertaken by Zhang et al. (2013, 2014). The methodology and outcomes of challenge tests, as detailed by Zhang et al. (2014), has been summarised below:

Important!

- Water quality results obtained by collecting the occasional grab can only be used as a general indicator of treatment performance. Outflow concentrations of some pollutants have been shown to vary with flow rate or time, therefore collecting only one water quality sample during a rain event will not necessarily give a true measurement of the average outflow concentration for that event (Event Mean Concentration, EMC). An example of how the outflow concentration of a pollutant might vary with time is shown below, and the EMC is indicated by the dashed line. If a grab sample was collected at point A, where the pollutant concentration is higher than the EMC, this would under-estimate the treatment performance of the biofilter. On the other hand, a grab sample collected at point B would over-estimate the treatment performance of the biofilter. While neither of these sampling points give an accurate assessment of the treatment performance, they do provide a useful rough indication of the pollutant removal capacity.



Three steps are involved: i.) the identification of target pollutants, challenge conditions and performance objectives in the pre-validation phase, ii.) validation monitoring testing, conducted under defined environmental conditions, and iii.) ongoing monitoring of the system in operation to confirm long-term performance. Zhang et al. (2014) investigated the removal of total petroleum hydrocarbons (TPHs), polycyclic aromatic hydrocarbons (PAHs), glyphosate, triazines, phthalates, trihalomethanes and phenols. The study aimed to quantify hydraulic performance, micropollutant removal and the hypothetical potential for re-use of the water in a drinking water treatment scheme, all under challenging operational conditions.

Test site: The experiment was conducted on a well-monitored field system treating stormwater runoff from a car park at Monash University, Melbourne. The system contains separate cells with differing characteristics, and for this study two cells were used: 1.) a free-draining cell with media with relatively high nutrient and organic content, and 2.) a sandy low nutrient media and a submerged zone; both of which were vegetated.

Pre-validation preparation: Before the challenge tests were conducted it was necessary to characterise i. target concentrations of micropollutants in the inflows, ii. their removal dynamics and iii. hydraulic conditions within the system. These define the 'boundaries' for acceptance of the validation and the following information was gathered:

i. A literature review was conducted to gather data on micropolluta nt concentrations (using event mean concentrations (EMC) where possible and gathering at least 15 EMC values) and the 95th percentile concentrations were selected as the challenge concentrations. In some cases, these values already lay below the Australian Drinking Water Guidelines (ADWG), so to add further certainty stormwater inflows with micropollutant concentrations approximately twice the ADWG limits were tested; conditions which may eventuate from a spill or other extreme conditions.

ii. Knowledge of micropollutant removal in similar vegetated systems was reviewed (given the lack of information specific to stormwater biofilters) e.g. constructed wetlands. Adsorption and biodegradation were found to be the most likely removal processes. The review also suggested micropollutant removal is likely to be sensitive to the infiltration rate, the length of drying between inflow events, hydraulic loading (i.e. volume of water treated per event) and temperature. These formed the key operational variables.

iii. An understanding of the operational conditions of stormwater biofilters, as noted in the literature.

Next, a MUSIC model was used to determine challenging conditions for the identified operational variables i.e. the duration of dry weather, storm inflow volume in wet weather and the frequency of wet weather events (based on local climate).

Two wet weather challenge scenarios were selected and characterised using the MUSIC model:

i. The volume of a single wet weather event – the 95th percentile cumulative volume for a single event was adopted (and this was equivalent to 4 pore volumes – i.e. water holding capacity within the biofilter)

ii. The volume of two consecutive events, occurring within 12 hours of each other – the 95th percentile of two such events was adopted (equivalent to 3 pore volumes).

Challenge tests: In total six challenge tests were undertaken in two series of experiments; with three undertaken in winter and three in summer. Semi-synthetic stormwater was used for the tests (see Appendix X). Inflow and outflow samples were collected across the inflow and outflow hydrographs. The results allowed calculation of a water balance for each series of challenge tests.

Data analysis and interpretation

It is very easy for data to be defective, therefore it is essential that data is checked for errors prior to evaluating results. Possible problems include noise, missing values, outliers.

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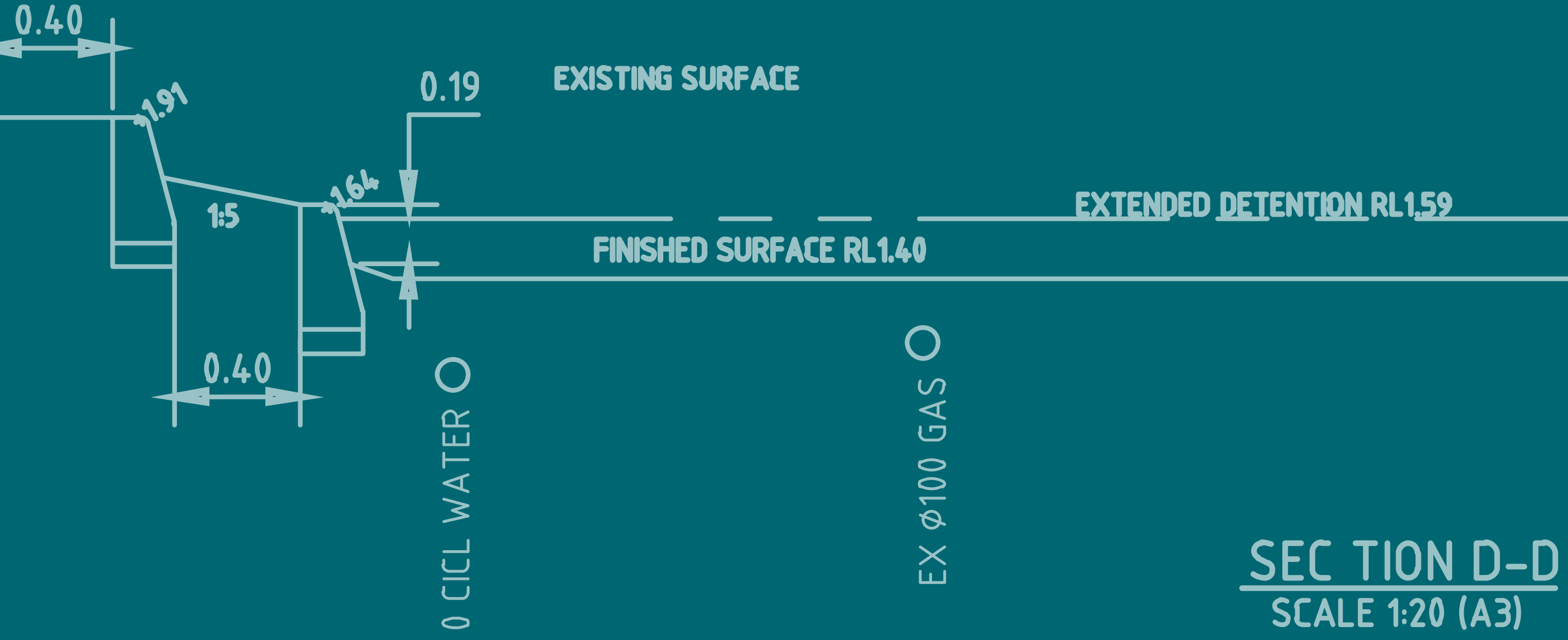

SECTION D-D
SCALE 1:20 (A3)

Appendix H:
Performance assessment of biofiltration systems using simulated rain events

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Condition assessment and performance evaluation of biofiltration systems

Practice note 2: Performance assessment of biofiltration systems using simulated rain events

Belinda Hatt
March 2009

The Facility for Advancing Water Biofiltration (FAWB) aims to deliver its research findings in a variety of forms in order to facilitate widespread and successful implementation of biofiltration technologies. This Practice Note for Performance Assessment of Biofiltration Systems using Simulated Rain Events is part of a series of Practice Notes being developed to assist practitioners with the assessment of construction and operation of biofiltration systems.

Disclaimer: Information contained in this Practice Note is believed to be correct at the time of publication, however neither the Facility for Advancing Water Bioifltration nor its industry partners accept liability for any loss or damage resulting from its use.

1. Scope of document

This Practice Note for Performance Assessment of Biofiltration Systems using Simulated Rain Events is designed to provide practitioners with a hydrologic and treatment performance assessment tool where a more detailed assessment than collecting the occasional water quality sample is required, but where continuous flow and water quality monitoring is not feasible. From a practical viewpoint, this approach is limited to small-scale systems as the volume of stormwater required to evaluate large-scale systems is too onerous. This approach is also limited to sites where the outlet can be easily accessed in order to measure flow and collect water quality samples.

2. Rain event simulation

The hydrologic and treatment performance of biofiltration systems can be assessed by simulating a rain event. A pre-determined volume of semi-synthetic water (usually equivalent to that of the design storm) is prepared and delivered to the biofiltration system. Normally this is done via a tanker truck and a mixing tank. The outflow rate is measured and water quality samples are collected at regular intervals until outflow ceases.

Simulating a rain event is a full-day exercise and initially requires a minimum number of four people; the busiest stage is preparing and delivering the semi-synthetic stormwater to the biofilter. Once this stage has finished, two people can manage the flow monitoring and water quality sample collection at the outflow.

Caution: Appropriate safety protocols and precautions should be followed. For example, if the biofiltration system to be monitored is beside a road, traffic control may be required. While the risk of microbiological and virological hazards in stormwater is likely to be low, gloves should be worn. Personnel should also have received necessary vaccinations; consult a general practitioner or health advisor for further information.

Note: A rain event simulation cannot be carried out in wet weather as any unquantified inflows will interfere with mass balance calculations with respect to runoff volumes and pollutant loads. Further, there must also be no residual outflow from a previous rain event. The simulation should be carried out on a day when it is not predicted to rain before outflows from the simulation cease (i.e., at least 24 hours after the beginning of the simulation), and when there is no outflow from an existing event.

2.1 Determination of rain event simulation volume

In general, a rain event simulation should be based on the design storm for that biofiltration system, as this will enable evaluation of the upper performance limit. For example, if a biofiltration system was designed to treat up to a 15-minute rain event with an average recurrence interval (ARI) of three months, the simulation volume should be equivalent to the volume of runoff produced during this rain event, and over a time as close as possible to the design storm duration (see further commentary on this in Section 2.5).

2.2 Determination of water quality sampling intervals

Outflow concentrations of some pollutants have been shown to vary dramatically with flow rate or time, therefore water quality samples need to be collected at regular intervals in order to obtain a representative water quality assessment of the entire rain event. These water quality samples can then be analysed individually or combined; the latter option will cost significantly less, but will give less information about the performance of the system. 12 – 15 water quality samples collected over the entire duration of outflow will suffice. Calculate the sampling interval by dividing the event volume by the number of samples to be collected:

$$\text{interval} = \frac{\text{event volume} \times 0.7}{\text{no. samples}}$$

e.g. $$\text{interval} = \frac{3000\ \text{L} \times 0.7}{14} = 150\text{L}$$

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The 0.7 multiplier allows for a fraction of the inflow to be retained by the system, which has been demonstrated to be in the order of 30% (Hatt et al., 2009). The total number of samples collected would be 15, including at the start of outflow.

2.3 Selection of water quality parameters

The pollutants that should be monitored will be determined by the system objectives and the type of receiving water. In general, the following parameters should be measured as a minimum:

- Total suspended solids (TSS);
- Total nitrogen (TN);
- Total phosphorus (TP); and
- Heavy metals – copper (Cu), cadmium (Cd), lead (Pb) and zinc (Zn).

Physical parameters such as pH, electrical conductivity (EC, as a measure of salinity), temperature, and dissolved oxygen (DO) are relatively cheap and easy to measure using a field probe and chould also be considered. The following water quality parameters might also be required:

- Nutrient species – ammonium (NH4+), oxidised nitrogen (NOx), organic nitrogen (ON), and orthophosphate (PO43-, commonly referred to as dissolved reactive phosphorus, FRP); and
- Other metals – aluminium (Al), chromium (Cr), iron (Fe), manganese (Mn), and nickel (Ni).

Consult with the analytical laboratory as to the sample volume required to carry out the analyses.

2.4 Apparatus

The following is required:

- Semi-synthetic stormwater – volume as determined in Section 2.1 and prepared according to Practice Note 2: Preparation of Semi-Synthetic Stormwater (available at http://www.monash.edu.au/fawb/products/index.html) – Note: This will most likely need to be prepared on-site
- Stirrer
- Means of delivering the water (e.g. tanker truck)
- Tank with removable lid and off-take point (with tap) at bottom of tank
- Stopwatch x 2
- 10 L bucket x 2
- Scales –battery operated, capacity to weigh 5+ kg, precision to 2 decimal places, water resistant
- Water quality sample bottles as required (see Table 1)
- 0.45 µm quick-fit filters (allow at least two filters per sample)
- 2 x 25 mL syringes
- Gloves
- 2 x permanent marker pens
- Rubber boots
- Cool box and ice
- Portable computer and long-life battery (or several standard batteries)

Table 1. Handling and preservation procedures for typical water quality parameters (Australian/New Zealand Standard, 1998).

Pollutant	Container	Filter	Preservation
Total Suspended Solids	plastic bottle, general washed	n/a	refrigerate
Total Nitrogen/Total Phosphorus	plastic bottle, general washed	n/a	refrigerate or freeze
Nutrient species • Dissolved Organic Nitrogen • Nitrate/Nitrite • Ammonia • Filterable Reactive Phosphorus	plastic bottle, general washed	0.2 µm	filter on site (0.45 µm cellulose acetate membrane filter) and refrigerate or freeze
Metals	plastic bottle, acid washed	n/a	acidify with nitric acid to pH 1 to 2

2.5 Procedure

a. Place tank just upstream of the inlet to the biofiltration system.

b. Prepare semi-synthetic stormwater in tank, continuously stirring.

Note: Depending on the size of the tank, it may not be possible to prepare the entire volume of semi-synthetic stormwater required in one batch. If this is the case, it is entirely fine to prepare the stormwater in batches, however the total number of batches should be minimised to reduce variability and maximise repeatability of the experiment.

c. Collect water quality samples from the tank into the appropriate containers, process and store as required.

Note: To avoid sample contamination, rinse sample collection vessels and bottles with a small amount of sample before filling and ensure hands do not contact the sample, filters, inside of bottles, lids, etc. Samples that require filtering should be filtered as soon as possible, preferably immediately, and samples that require refrigeration should be stored on ice.

Note: If the semi-synthetic stormwater is prepared in batches, water quality samples should be collected from each batch and equal volumes from each batch combined for an average inflow concentration.

d. Continue stirring, open tap to allow semi-synthetic stormwater to flow into biofilter, start one stopwatch.

Note: This stopwatch is the timer for the whole simulation and should not be stopped until the final flow and water quality measurements are taken.

e. If preparing semi-synthetic stormwater in batches, begin preparing next batch as soon as the tank is empty. Repeat Steps b - d (except for starting the stopwatch) until all the semi-synthetic stormwater has been delivered to the biofilter.

Note: It is not possible to replicate a typical hydrograph using this approach, however the aim is to deliver the entire volume in the same timeframe as the design storm. For example, for a 15-minute design storm, the stormwater should be prepared and delivered to the biofilter in approximately 25 minutes (allowing for some flow attenuation in the catchment).

f. Check the outlet at regular intervals. At the first appearance of flow, measure the flow rate using a bucket and the other stopwatch and collect a water quality sample.

g. Measure the flow rate at two-minute intervals. Enter this data into a spreadsheet to keep track of the cumulative outflow volume (an example spreadsheet is provided with the case study described in Section 4).

h. Continue to monitor the flow rate and cumulative outflow volume, collecting water quality samples at the appropriate intervals. The flow rate will change rapidly at first and reach a peak before decreasing.
The rate of change will also decrease, at which point flow measurements intervals can be increased to every five minutes, and even longer as flow slows.

i. Flow monitoring and water quality sample collection should continue until the time between samples is deemed too high (see case study as a guide); this is the end point, however consider also taking a final flow measurement and water quality sample the following day (i.e., 24 hours after the start of the simulation).

j. Water quality samples should be analysed by a NATA-accredited laboratory.

2.5.1 Quality control

It is important to collect quality control samples to validate results and eliminate the possibility of sample contamination. At least one of each of the following should be collected per simulation:

- Field blank
- Transport blank
- Replicate sample

For further details, see the Australian standard for design of water quality sampling programs (Australian/New Zealand Standard, 1998).

3. Interpretation of results

It is very easy for data to be defective, therefore it is essential that data is checked for errors prior to evaluating results. Possible problems include noise, missing values, outliers. However, outliers should not be removed without reason or justification.

3.1 Pollutant load calculations

Pollutant loads can be calculated by combining the flow and water quality data.

$$l_{in} = v_{in} c_{in}$$

where: lin = inflow load (mg)

vin = total inflow volume (L)

cin = inflow pollutant concentration (mg/L)

$$l_{out} = \sum_{i=1}^{N} v_{i,out} c_{i,out}$$

where: lout = outflow load (mg)

vi,out = volume between samples i and i-1

ci,out = pollutant concentration at sampling interval i

N = total number of samples taken during simulation

The load reduction is simply the difference between the inflow and outflow load expressed as a percentage of the inflow load.

3.2 Performance targets

A number of state, territories, regions and municipalities stipulate performance targets for WSUD, which often include biofiltration systems (e.g. Clause 56.07 of the Victoria Planning Provisions prescribes target pollutant load reductions of 80, 45, and 45% for TSS, TN, and TP, respectively). Where these exist, monitoring data should be compared against these targets.

In the absence of stipulated performance targets, outflow pollutant concentrations could be compared to the ANZECC Guidelines for Fresh and Marine Water Quality; these guidelines provide water quality targets for protection of aquatic ecosystems – the targets to use should be selected according to the location of the biofilter and the state of the receiving water (e.g. slightly disturbed, etc.). However, the reality is that, even using the best available technology, biofiltration systems will not necessarily always be able to comply with these relatively strict guidelines. The local authority may in this instance choose to rely on the national Load Reduction Targets provided in Chapter 7 of Australian Runoff Quality (Wong, 2006).

Note: Comparison of simulation results to performance should be treated with caution. While this methodology enables a more detailed assessment than occasional grab samples, it still provides only a "snapshot" and doesn't give detailed information about the overall performance of the biofiltration system for the whole range of rain events it is subjected to.

4. Case study: Saturn cresent, Brisbane

The methodology for simulating a rain event was originally developed in order to monitor the performance of a small biofiltration basin in McDowall, Queensland (Figure 1). This system was retrofitted into the streetscape of a residential area in 2006 to treat road and roof runoff. The 20 m^2 treatment area (2% of the impervious catchment area) contains a 400 mm deep sandy loam filter media and a dense growth of Carex appressa and various Dianella species. The system has a maximum ponding depth of 200 mm. Two perforated 100 mm diameter PVC underdrain pipes in the underlying drainage layer (100 mm sand plus 200 mm gravel) convey the treated water to a side-entry pit, which is connected to the existing storm drainage system.

This design storm for this system is a 3-month ARI with a duration of 15 minutes, which equates to a volume of 3000 L. Semi-synthetic stormwater is prepared in five 600 L batches using mains water supplied by a tanker, slurry and chemicals (Figure 2a, b and c, and see Practice Note 2 for further details on semi-synthetic stormwater preparation). The target pollutant concentrations match typical stormwater quality for Brisbane (Table 2). The semi-synthetic stormwater is stirred in the tank using a kayak paddle during preparation and as the water is discharged to the biofilter (Figure 2d and e). It takes approximately 25 minutes to prepare and discharge the five batches to the biofilter (Figure 2f and g). Outflow appears 20 – 25 minutes after the beginning of the simulation (i.e., when the first batch of semi-synthetic stormwater is discharged to the biofilter). Flow is measured every two minutes until the peak has passed (Figure 3). Water quality samples are collected every 150 L (Figure 3). This equates to samples being collected every five minutes or so at the peak of the hydrograph, and extending to 50 minutes between samples by the 14th sample. At this point, the simulation is finished for the day, however the stopwatch is left running as one final flow measurement and water quality sample is collected on the following day (approximately 24 hours after the start of the simulation, Figure 3).

Figure 1. Biofiltration basin at Saturn Crescent, October 2006.

Water quality samples are collected from each of the five batches of semi-synthetic stormwater and combined in equal portions to create a composite sample. The 15 outflow water quality samples are analysed individually. Parameters that are analysed for include: TSS, TN, NOx, NH3, DON, PON, TP, FRP, Cu, Cd, Pb and Zn. The following volumes are collected for each sample: 1 L for TSS, 250 mL for TN/TP, 100 mL filtered for nutrient species and 100 mL for metals. The samples for nutrient species are filtered immediately, and all samples are stored on ice until they can be delivered to the analytical laboratory.

Table 2. Target pollutant concentrations for Saturn Crescent rain event simulations.

Pollutant	Concentration (mg/L)
Total Suspended Solids (TSS)	150
Total Nitrogen (TN)	1.69
Nitrate/Nitrite (NOx)	0.59
Ammonia (NH3)	0.24
Dissolved Organic Nitrogen (DON)	0.47
Particulate Organic Nitrogen (PON)	0.39
Total Phosphorus (TP)	0.31
Copper (Cu)	0.05
Lead (Pb)	0.14
Zinc (Zn)	0.25
Cadmium (Cd)	0.0045

Figure 2. Conducting a rain event simulation at the Saturn Crescent biofiltration system.

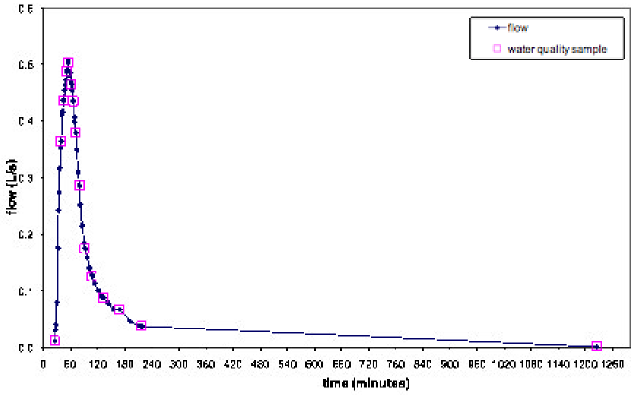

Figure 3. Typical hydrograph for a rain event simulation at the Saturn Crescent biofiltration system showing water quality sample collection times.

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EXISTING TWIN SIDE
ENTRY PIT
IL2.20
IL 1.70
EDGE DETAIL B
1
1
Ø300
IL 1.59
Ø375
EXISTING JUNCTION
PIT TO REMAIN
Ø525
1:5
1:5
FSL2.05m AHD
EXISTING POWER
POLE
m MIN PED ZONE
TO DRG 1432-08
DETAILS

Appendix I:
Measurement of hydraulic conductivity – Using in situ and ex situ (laboratory) sampling methods

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Condition assessment and performance evaluation of biofiltration systems

Practice note 1: measurement of hydraulic conductivity

Belinda Hatt, Sebastien Le Coustumer
June 2009 (updated April 2015)

This Practice Note for *In Situ* Measurement of Hydraulic Conductivity is the first in a series of Practice Notes being developed to assist practitioners with the assessment of construction and operation of biofiltration systems.

Disclaimer: Information contained in this Practice Note is believed to be correct at the time of publication, however neither the CRC for Water Sensitive Cities nor its industry partners accept liability for any loss or damage resulting from its use.

1. Scope of document

This Practice Note for In Situ Measurement of Hydraulic Conductivity is designed to complement the Guidelines for Filter Media in Biofiltration Systems (Appendix A) (visit http://www.monash.edu.au/fawb/publications/index.html for a copy of these guidelines). However, the recommendations contained within this document are more widely applicable to assessing the hydraulic conductivity of filter media in existing biofiltration systems.

For new systems, this Practice Note does not remove the need to conduct laboratory testing of filter media prior to installation.

2. Determination of hydraulic conductivity - In Situ

The recommended method for determining in situ hydraulic conductivity uses a single ring infiltrometer under constant head. The single ring infiltrometer consists of a small plastic or metal ring that is driven 50 mm into the filter media. It is a constant head test that is conducted for two different pressure heads (50 mm and 150 mm). The head is kept constant during all the experiments by pouring water into the ring. The frequency of readings of the volume poured depends on the filter media, but typically varies from 30 seconds to 5 minutes. The experiment is stopped when the infiltration rate is considered steady (i.e., when the volume poured per time interval remains constant for at least 30 minutes). This method has been used extensively (eg. Reynolds and Elrick, 1990; Youngs *et al.*, 1993).

Note: This method measures the hydraulic conductivity at the surface of the filter media. In most cases, it is this top layer which controls the hydraulic conductivity of the system as a whole (i.e., the underlying drainage layer has a flow capacity several orders of magnitude higher than the filter media), as it is this layer where fine sediment will generally be deposited to form a “clogging layer”. However this shallow test would not be appropriate for systems where the controlling layer is not the surface layer (eg. where migration of fine material down through the filter media has caused clogging within the media). In this case, a ‘deep ring’ method is required; for further information on this method, see Le Coustumer et al. (2008).

2.1 Selection of monitoring points

For biofiltration systems with a surface area less than 50 m2, in situ hydraulic conductivity testing should be conducted at three points that are spatially distributed (Figure 1). For systems with a surface area greater than 50 m2,an extra monitoring point should be added for every additional 100 m2. It is essential that the monitoring point is flat and level. Vegetation should not be included in monitoring points.

Figure 1. Spatially distributed monitoring points.

2.2 Apparatus

The following is required:

- 100 mm diameter PVC rings with a height of at least 220 mm – the bottom edge of the ring should be bevelled and the inside of the ring should be marked to indicate 50 mm and 150 mm above the filter media surface (Figure 2)
- 40 L water
- 100 mL, 250 mL and 1000 mL measuring cylinders
- Stopwatch
- Thermometer
- Measuring tape
- Spirit level
- Hammer
- Block of wood, approximately 200 x 200 mm

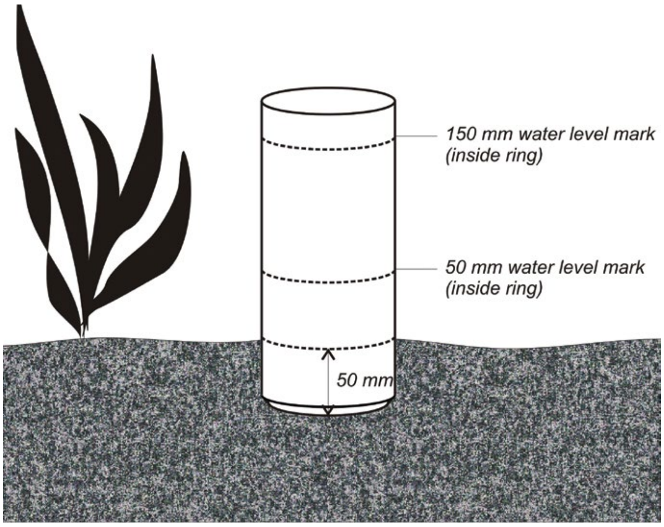


Figure 2. Diagram of single ring infiltrometer.

2.3 Procedure

a. Carefully scrape away any surface covering (eg. mulch, gravel, leaves) without disturbing the soil filter media surface (Figure 3b).

b. Place the ring on the surface of the soil (Figure 3c), and then place the block of wood on top of the ring. Gently tap with the hammer to drive the ring 50 mm into the filter media (Figure 3d). Use the spirit level to check that the ring is level.

   Note: It is essential that this the ring is driven in slowly and carefully to minimise disturbance of the filter media profile.

c. Record the initial water temperature.

d. Fill the 1000 mL measuring cylinder.

e. Using a different pouring apparatus, slowly fill the ring to a ponding depth of 50 mm, taking care to minimise disturbance of the soil surface (Figure 3f). Start the stopwatch when the water level reaches 50 mm.

f. Using the 1000 mL measuring cylinder, maintain the water level at 50 mm (Figure 3g). After 30 seconds, record the volume poured.

g. Maintain the water level at 50 mm, recording the time interval and volume required to do so.

   Note: The time interval between recordings will be determined by the infiltration capacity of the filter media. For fast draining media, the time interval should not be greater than one minute however, for slow draining media, the time between recordings may be up to five minutes.

   Note: The smallest measuring cylinder that can pour the volume required to maintain a constant water level for the measured time interval should be used for greater accuracy. For example, if the volume poured over one minute is 750 mL, then the 1000 mL measuring cylinder should be used. Similarly, if the volume poured is 50 mL, then the 100 mL measuring cylinder should be used.

h. Continue to repeat Step f until the infiltration rate is steady i.e., the volume poured per time interval remains constant for at least 30 minutes.

i. Fill the ring to a ponding depth of 150 mm (Figure 3h). Restart the stopwatch. Repeat steps e – g for this ponding depth.

   Note: Since the filter media is already saturated, the time required to reach steady infiltration should be less than for the first ponding depth.

j. Record the final water temperature.

k. Enter the temperature, time, and volume data into a calculation spreadsheet (see “Practice Note 1_Single Ring Infiltration Test_Example Calculations.xls”, available at www.monash.edu.au/fawb/publications/index.html, as an example).

2.4 Calculations

In order to calculate K_{fs} a ‘Gardner’s’ behaviour for the soil should be assumed (Gardner, 1958 in Youngs *et al.*, 1993)

$$K(h) = K_{fs} e^{\alpha h} \quad : \quad \text{Eqn. 1}$$

where *K* is the hydraulic conductivity, α is a soil pore structure parameter (large for sands and small for clay), and h is the negative pressure head. K_{fs} is then found using the following analytical expression (for a steady flow) (Reynolds and Elrick, 1990):

$$K_{fs} = \frac{G}{a}\left(\frac{Q_2 - Q_1}{H_2 - H_1}\right) \qquad \text{Eqn. 2}$$

where *a* is the ring radius, H_1 and H_2 are the first (50 mm) and second (150 mm) pressure heads, respectively, Q_1 and Q_2 are the steady flows for the first and second pressure heads, respectively, and G is a shape factor estimated as:

$$G = 0.316\frac{d}{a} + 0.184 \qquad \text{Eqn. 3}$$

where *d* is the depth of insertion of the ring and *a* is the ring radius.

G is nearly independent of soil hydraulic conductivity (i.e., K_{fs} and α) and ponding, if the ponding is greater than 50 mm.

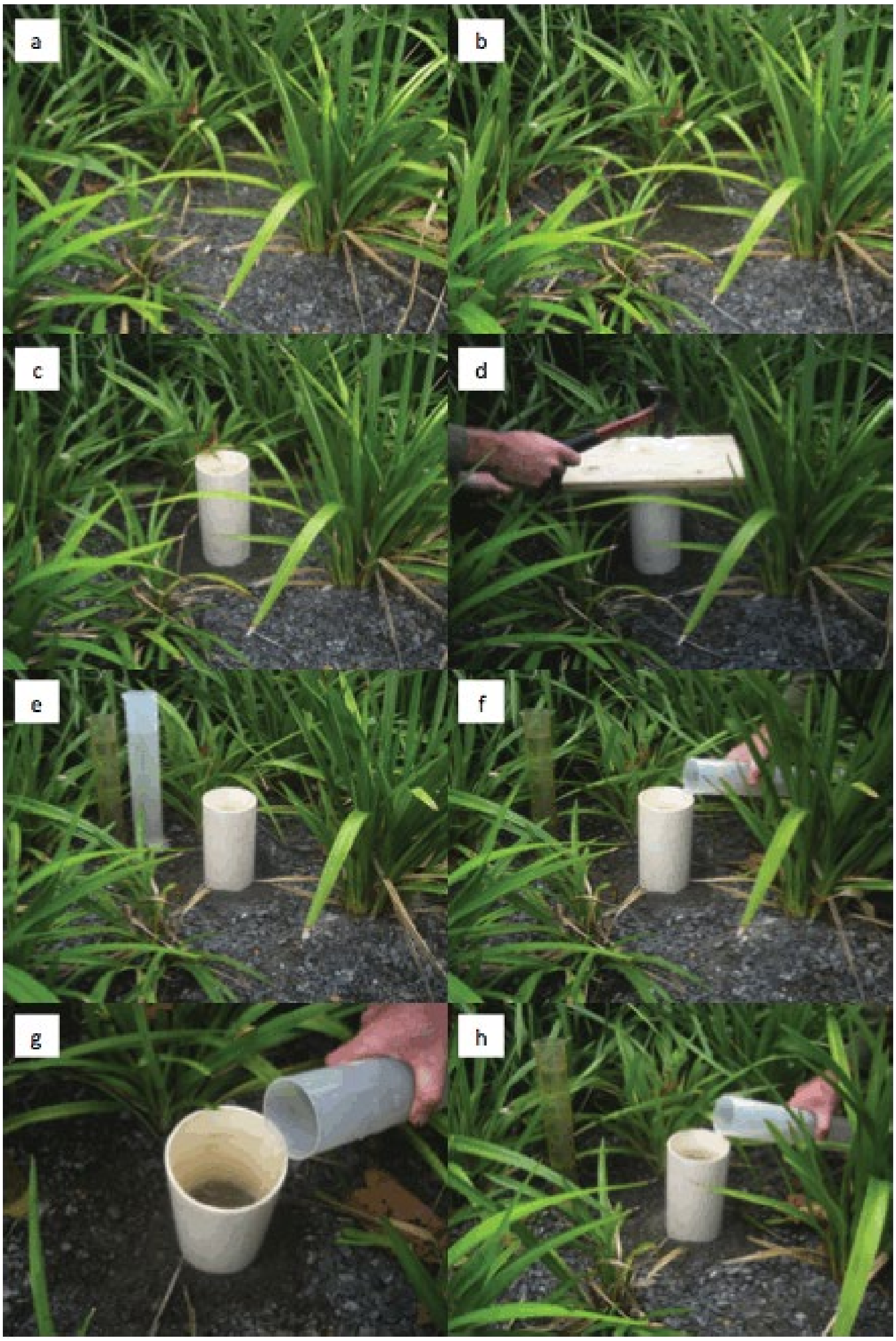


Figure 3. Measuring hydraulic conductivity.

The possible limitations of the test are (Reynolds et al., 2000): (1) the relatively small sample size due to the size of the ring, (2) soil disturbance during installation of the ring (compaction of the soil), and (3) possible edge flow during the experiments.

2.5 Interpretation of results

This test method has been shown to be relatively comparable to laboratory test methods (Le Coustumer et al., 2008), taking into account the inherent variability in hydraulic conductivity testing and the heterogeneity of natural soil-based filter media. While correlation between the two test methods is low, results are not statistically different. In light of this, laboratory and field results are deemed comparable if they are within 50% of each other. In the same way, replicate field results are considered comparable if they differ by less than 50%. Where this is not the case, this is likely to be due to a localised inconsistency in the filter media, therefore additional measurements should be conducted at different monitoring points until comparable results are achieved. If this is not achieved, then an area-weighted average value may need to be calculated.

2.6 Monitoring frequency

Field testing of hydraulic conductivity should be carried out at least twice: (1) One month following commencement of operation, and (2) In the second year of operation to assess the impact of vegetation on hydraulic conductivity. Following this, hydraulic conductivity testing should be conducted every two years or when there has been a significant change in catchment characteristics (eg. construction without appropriate sediment control).

3. Determination of hydraulic conductivity – Ex Situ (Laboratory testing)

In situ testing is valuable as it allows testing of the media under (as close as possible to) undisturbed conditions, in terms of compaction, soil structure and the critical surface clogging layer. However, it is not always feasible to undertake in situ testing of the hydraulic conductivity, either due to resource constraints, such as time and costs, a lack of available water supply near the site or the potential for high spatial variability in hydraulic conductivity. If this is the case then useful information can still be determined by collecting samples from the field for laboratory analysis.

Samples can be collected from cores or as bagged samples, and these may then be composited with multiple samples across the site to gain some overall understanding of soil properties across the filter surface. Samples can be collected across a range of depths and care should be taken to observe the thickness of any clogging layer when determining the thickness of the surface sample. In larger systems, samples may be collected from distinct zones, such as near the inlet versus areas closer to the outlet.

This approach will not be nearly as accurate as the in situ test for hydraulic conductivity, but it is a useful approach for diagnosing problems such as clogging. For example, the upper 0-50 mm or 0-100 mm may be sampled and the hydraulic conductivity compared to samples from lower in the profile. The laboratory testing is also more straightforward and cost effective. However, as discussed, it is best applied for investigating problems and not to determine an accurate hydraulic conductivity.

References

Gardner, W. R. (1958). Some steady-state solutions of the unsaturated moisture flow equation with application to evaporation from a water table. *Soil Science* 85: 228-232.

Le Coustumer, S., T. D. Fletcher, A. Deletic and M. Potter (2008). *Hydraulic performance of biofilter systems for stormwater management: lessons from a field study,* Melbourne Water Corporation, available at: www.monash.edu.au/fawb/publications

Reynolds, W. D., B. T. Bowman, R. R. Brunke, C. F. Drury and C. S. Tan (2000). Comparison of tension infiltrometer, pressure infiltrometer, and soil core estimates of saturated hydraulic conductivity. *Soil Science Society of America journal* 64(2): 478-484.

Reynolds, W. D. and D. E. Elrick (1990). Ponded infiltration from a single ring: Analysis of steady flow. *Soil Science Society of America journal* 54: 1233-1241.

Youngs, E. G., D. E. Elrick and W. D. Reynolds (1993). Comparison of steady flows from infiltration rings in “Green and Ampt” and “Gardner” soils. *Water Resources Research* 29(6): 1647-1650.

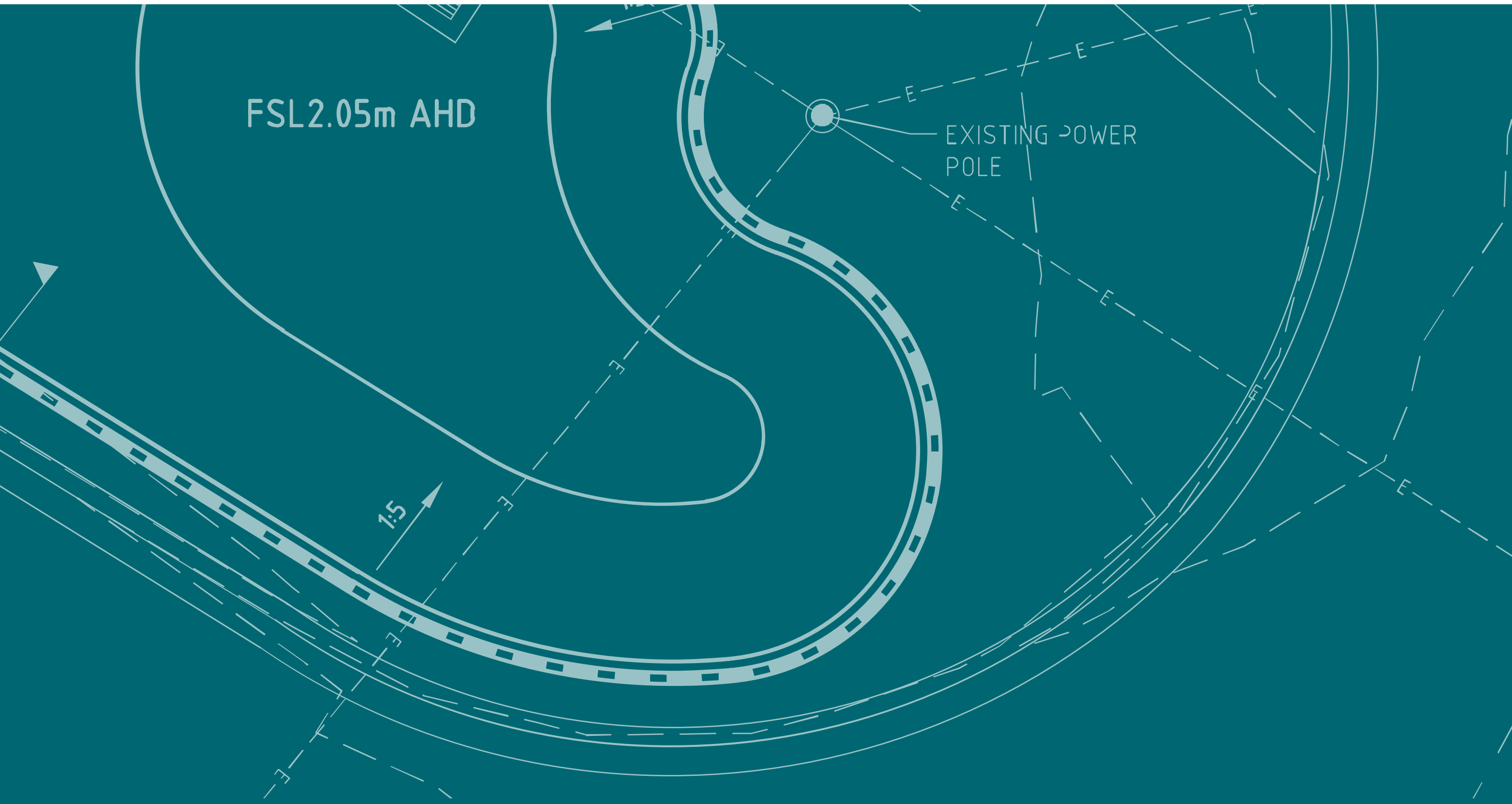
Single Ring Infiltration Test

Site: ____

Date: ____

Constant water level = 50 mm		
Time (min)	Volume (mL)	Q (mL/s)

Constant water level = 50 mm		
Time (min)	Volume (mL)	Q (mL/s)


FSL2.05m AHD
EXISTING POWER
POLE
1:5
E

Appendix J:
Maintenance: field sheet

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Maintenance requirements for biofiltration systems

Biofiltration systems (also known as biofilters, bioretention systems and rain gardens) are designed with the primary intent of removing pollutants from stormwater before the water is discharged to the local waterway, infiltrated into surrounding soils or reused for other applications (e.g. irrigation). They are typically constructed as basins, trenches or tree pits (Figure 1). Stormwater runoff generally enters the biofiltration system through a break in a standard road kerb where it temporarily ponds on the surface before slowly filtering through the soil media. Treated stormwater is then collected at the base of the biofiltration system via perforated pipes located within a gravel drainage layer before being discharged to conventional stormwater pipes, infiltrated or collected for reuse. Note that, it is recommended that the outlet pipe is upturned to create a pool of water, or submerged zone, in the bottom of the biofiltration system. If unlined, this pool will be temporary, but will be longer-lasting in lined systems. Conventional stormwater pipes also act as an overflow in most designs, taking flows that exceed the design capacity of the biofiltration system.

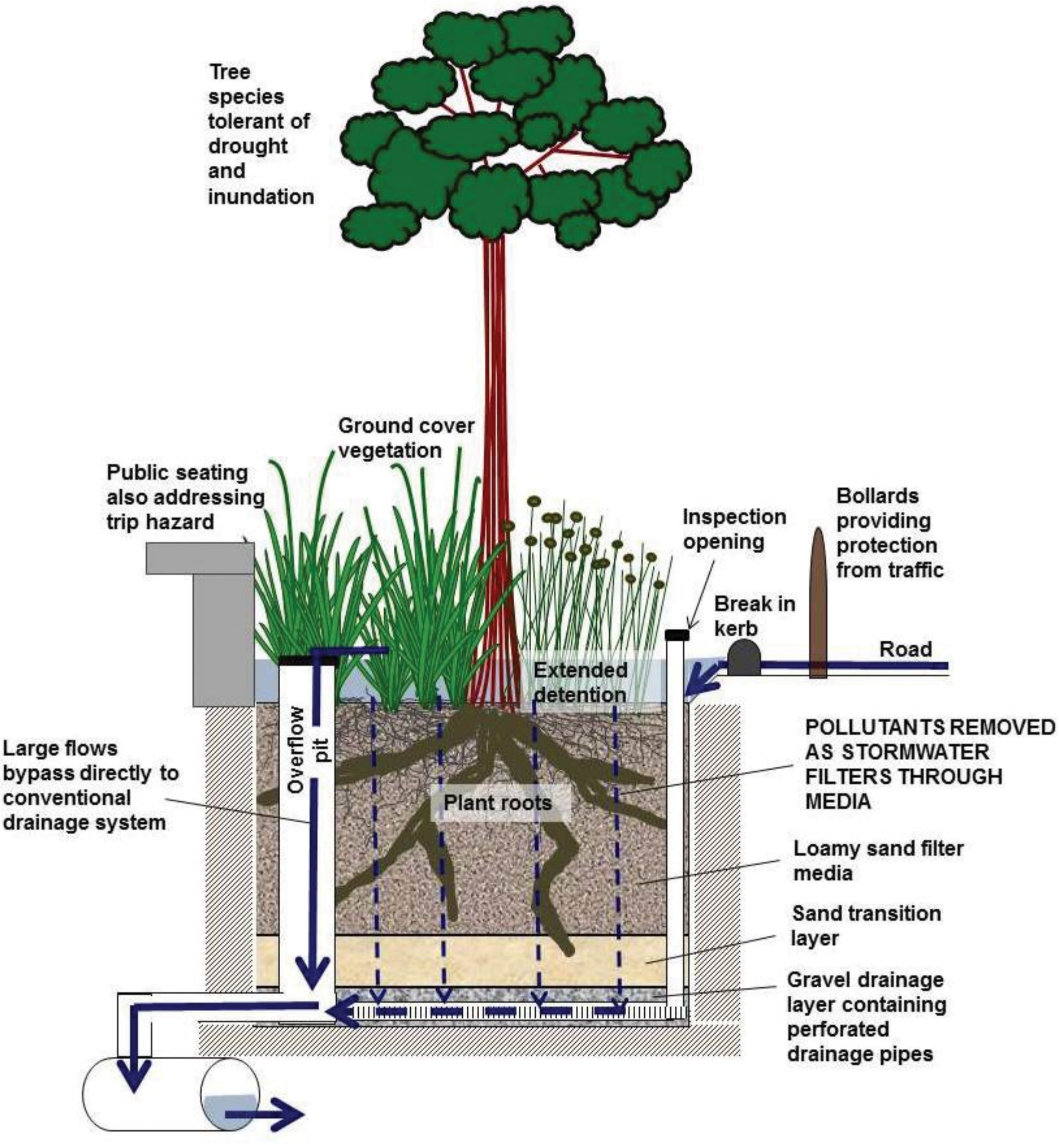

Figure 1. Conceptual drawing of a biofiltration system illustrating stormwater flow pathways and subsurface infrastructure.

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There are a number of maintenance activities that need to be carried out to ensure effective long-term function of biofiltration systems. Table 1 provides example illustrations of maintenance issues while Table 2 outlines inspection tasks, recommended frequencies and associated maintenance actions.

Table 1. Examples of issues requiring maintenance.

Build-up of fine sediments on the surface of the filter media reduces surface porosity and treatment capacity.		Holes, erosion and scour should be repaired and inflow controls provided or augmented.	
Anthropogenic and organic litter build-up is unsightly and can hinder flow paths and infiltration.		Anthropogenic and organic litter build-up is unsightly and can hinder flow paths and infiltration.	
Poor plant growth can be a sign of too much or too little water, or of poor filter function.		Vegetation die off can be a sign of too much or too little water, or of poor filter function.	
Weeds are unsightly and can reduce treatment capacity.		Blocked overflow grates can result in nuisance flooding.	
Overfilling of filters reduces the extended detention storage and treatment capacity.		Overflow levels that are set too low reduces the extended detention storage and treatment capacity.	

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Inspection Task	Frequency	Comment	Maintenance Action
Filter media			
Check for sediment deposition	3 monthly, after rain	Blocking of inlets and filter media reduces treatment capacity.	Remove sediment from inlets, forebays and other pre-treatment measures, and the surface of biofiltration street trees
Check for holes, erosion or scour	3 monthly, after rain	Holes, erosion and scour can be a sign of excessive inflow velocities due to poor inflow control or inadequate provision for bypass of high flows.	Infill any holes, repair erosion and scour Provide/augment energy dissipation (e.g. rocks and pebbles at inlet) Reconfigure inlet to bypass high flows Relocate inlet
Inspect for the build-up of oily or clayey sediment on the surface of the filter media, excessive moss growth, or evidence of prolonged ponding (i.e. clogging)	3 monthly, after rain	Reduced surface porosity reduces treatment capacity.	Clear away any mulch on the surface and lightly rake over the surface of the filter media between plants
Check for litter in and around treatment areas	3 monthly, after rain or as desired for aesthetics	Flow paths and infiltration through the filter media may be hindered.	Remove both litter/rubbish and excessive build-ups of plant litter
Damage	6 monthly	Check for damage to the surface from vehicles or pedestrians.	Repair using compatible filter media material.
Horticultural			
Additional checks of system health and function required during establishment	As required – weekly during initial establishment if during dry periods. May reduce to bimonthly later and in wetter periods.	The initial period after construction (up to the first 2 years) requires additional monitoring and maintenance works are required. Ensure a healthy and diverse vegetation cover is developing and that stormwater moves through the system as the design intended.	New seedlings will require regular watering and irrigation, protection from high sediment loads and high flows. If flows do not move through the system as intended, this requires further investigation. Works may be required to remedy the hydraulics (e.g. changing the invert level of the overflow, the surface gradient or removing mulch to reinstate the desired ponding depth). Refer to Water by Design's 'Construction and Establishment Guidelines' (2009).

Inspection Task	Frequency	Comment	Maintenance Action
Horticultural			
Assess plants for disease or pest infection	3 monthly, or as desired for aesthetics		• Treat or replace as necessary
Check plants for signs of stunted growth or die off	3 monthly, but more frequently during long dry spells	Poor plant health can be a sign of too much or too little water, or poor flow control.	• Check inlet and overflow levels are correct and reset as required • For too much water: • Replace plants with species more tolerant of wet conditions OR • Replace filter media with that of a higher infiltration capacity • For too little water: • Consider installing a choke on the outlet or retrofitting a submerged zone (i.e. raised outlet) OR • Replant with species more tolerant of dry conditions
Check that original plant densities are maintained	3 monthly, or as desired for aesthetics	Plants are essential for pollutant removal and maintaining drainage capacity. Plants should be close enough that their roots touch each other; 6 – 10 plants/m² is generally adequate. A high plant density also helps prevent ingress of weeds.	• Carry out infill planting as required – plants should be evenly spaced to help prevent scouring due to a concentration of flow
Check for presence of weeds	3 monthly, or as desired for aesthetics	Weeds can reduce aesthetics and treatment capacity because some plants are more effective at pollutant removal than others.	• Manually remove weeds where possible – where this is not feasible, spot spray weeds with a herbicide appropriate for use near waterways
Pruning and harvesting (if feasible)	Once or twice a year	It may be worth considering occasionally harvesting plants to permanently remove nutrients and heavy metals stored in aboveground tissues, and to promote new plant growth and further nutrient and metal uptake.	• If practical, cut back and remove above-ground biomass (but do not cut back so severely that plant health and survival is compromised) • Prune plants back as required to enhance aesthetics, but remove cuttings from the system.

Inspection Task	Frequency	Comment	Maintenance Action
Drainage			
Check that inflow areas, weirs and grates over pits are clear of litter and debris and in good and safe condition.	Monthly, and occasionally after rain, but 6 monthly if no construction activity in the catchment	A blocked grate or inlet would cause nuisance flooding and may lead to plant death within the biofilter.	• Replace dislodged or damaged pit covers as required • Remove sediment from pits and entry sites (likely to be an irregular occurrence in mature catchments)
Check that the underdrain is not blocked with sediment or roots	6 monthly, after rain	Filter media and plants can become waterlogged if the underdrain is choked or blocked. Remote camera (CCTV) inspection of pipelines could be useful.	• Clear underdrain as required using a pipe snake or water jet • Water jets should be used with care in perforated pipes
Check the sediment forebay or pre-treatment zone (if present) is clear of high accumulations of sediment and debris	Twice a year (more frequently if accumulation is rapid)	Pre-treatment device may become full of sediment or debris, which stops it serving its function of protecting the biofilter. The biofilter will then be impacted by sediment and rectification will be more costly.	• Remove accumulated sediment and debris before it builds up to excessive levels
Check the water level within the submerged zone (if lined)	Monthly throughout the dry season or as required	Although the submerged zone helps to sustain the biofilter through dry periods and drawdown is expected, if drying persists for long enough it will become drawn down and require replenishment.	• Check that the water level in the submerged zone is at the design level and top this up as required.
Check that the elevated outlet for the submerged zone	6 monthly, after rain	Debris may block the outlet or the level of the raised pipe may not match the design, producing a different depth for the submerged zone.	• Check outflow level is correct and reset as required

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Other			
Observe biofiltration system after a rainfall event to check drainage	Twice a year, after rain	Ponding on the filter media surface for more than a few hours after rain is a sign of poor drainage	• Check catchment land use and assess whether it has altered from design capacity (e.g. unusually high sediment loads may require installation of a sediment forebay)

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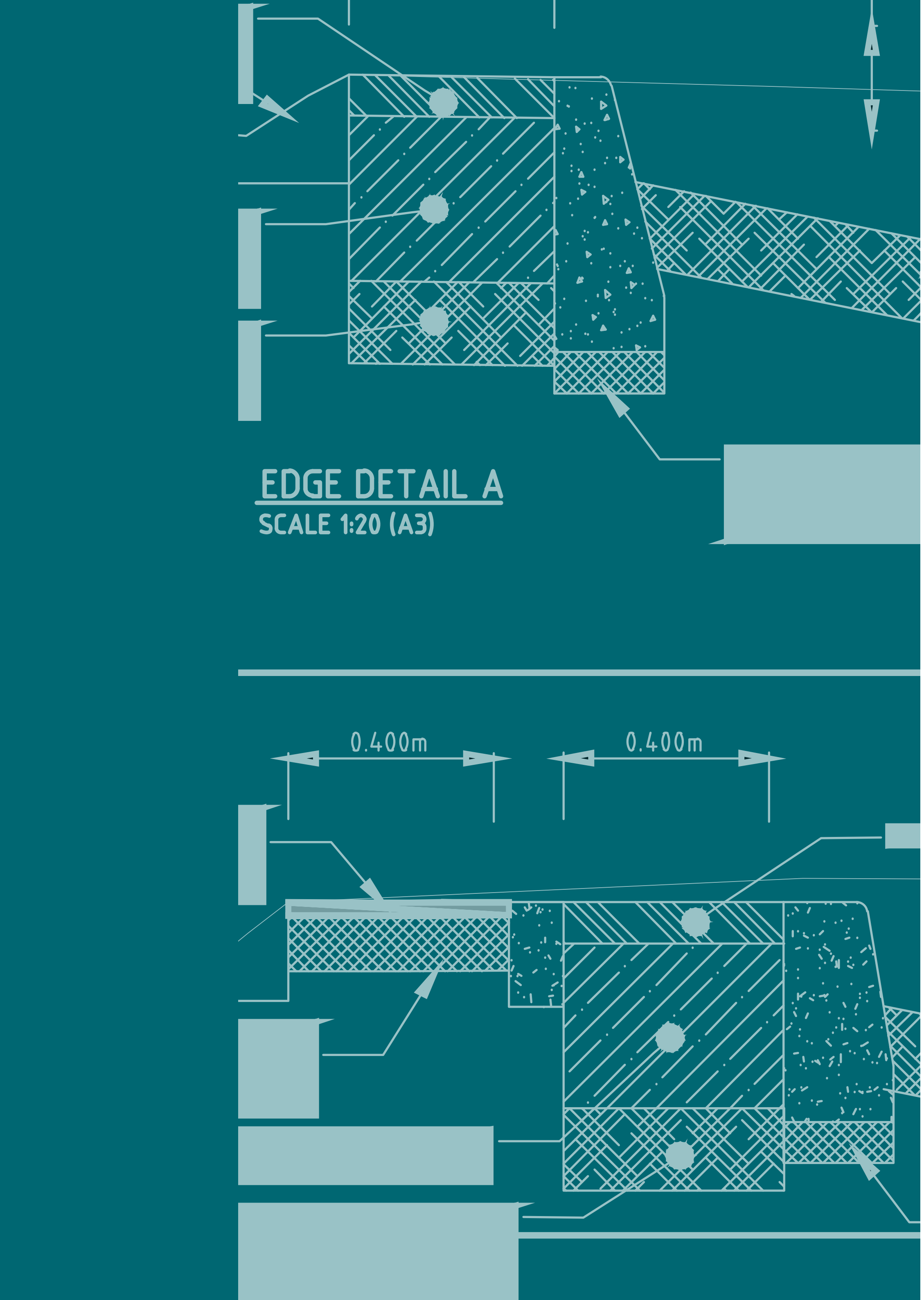
EDGE DETAIL A
SCALE 1:20 (A3)
0.400m
0.400m

Appendix K: Maintenance requirements for biofiltration systems: plan and checking tools

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Biofiltration systems maintenance plan

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Table of Contents

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1 Biofilter functions

This is a sample maintenance plan only. When preparing a maintenance plan for a specific site, consideration should be given to the individual site requirements to ensure all the elements within a particular design are incorporated in to the plan.

A sketch or drawing should be provided (as seen in Figure 1) to help maintenance personnel and asset managers understand the function and features of a particular asset. The drawing should provide enough information about the function of a system to enable appropriate management/maintenance decisions to be made.

Biofiltration systems (also known as biofilters, bioretention systems and rain gardens) are designed with the primary intent of removing pollutants from stormwater before the water is discharged to the local waterway or reused for other applications (e.g. irrigation). They are typically constructed as basins, trenches or tree pits (Figure 1). Stormwater runoff generally enters the biofiltration system through a break in a standard road kerb where it temporarily ponds on the surface before slowly filtering through the soil media. Treated stormwater is then collected at the base of the biofiltration system via perforated pipes located within a gravel drainage layer before being discharged to conventional stormwater pipes or collected for reuse. Note that, in some cases, the drainage pipe is up-turned to create a permanent pool of water, or submerged zone, in the bottom of the biofiltration system. Conventional stormwater pipes also act as an overflow in most designs, taking flows that exceed the design capacity of the biofiltration system.

The inclusion of biofiltration systems into the stormwater drainage system does not affect other conventional drainage elements. Stormwater discharge that exceeds the capacity of the biofiltration system may continue down the kerb to be collected in a conventional side entry pit or may overflow into a pit located within the biofiltration system that is directly connected to the conventional drainage system.

Biofiltration systems provide stormwater treatment as well as landscape amenity. An additional benefit is that the passive irrigation from stormwater reduces the demand for irrigation from other sources, such as potable water.

The tree and/or understorey species need to be relatively hardy, and tolerant of both freely draining sandy soils and regular inundation. The soil filter media into which the trees are planted generally has a specified hydraulic conductivity of 100 – 300 mm/hr, depending on the local climate and the configuration of the system. Healthy vegetation cover across the biofilter is vital to the system function, helping to i.) significantly improve stormwater treatment, ii.) reduce the likelihood of clogging at the surface of the media, and iii.) reduce erosion..

Figure 1 illustrates the intended flow pathways for stormwater through a typical biofiltration system (a tree pit, in this case) and shows some of the subsurface infrastructure that requires consideration for maintenance. It should be noted that stormwater biofilters share many common design features, although their configurations will vary to suit site conditions and the performance objectives.

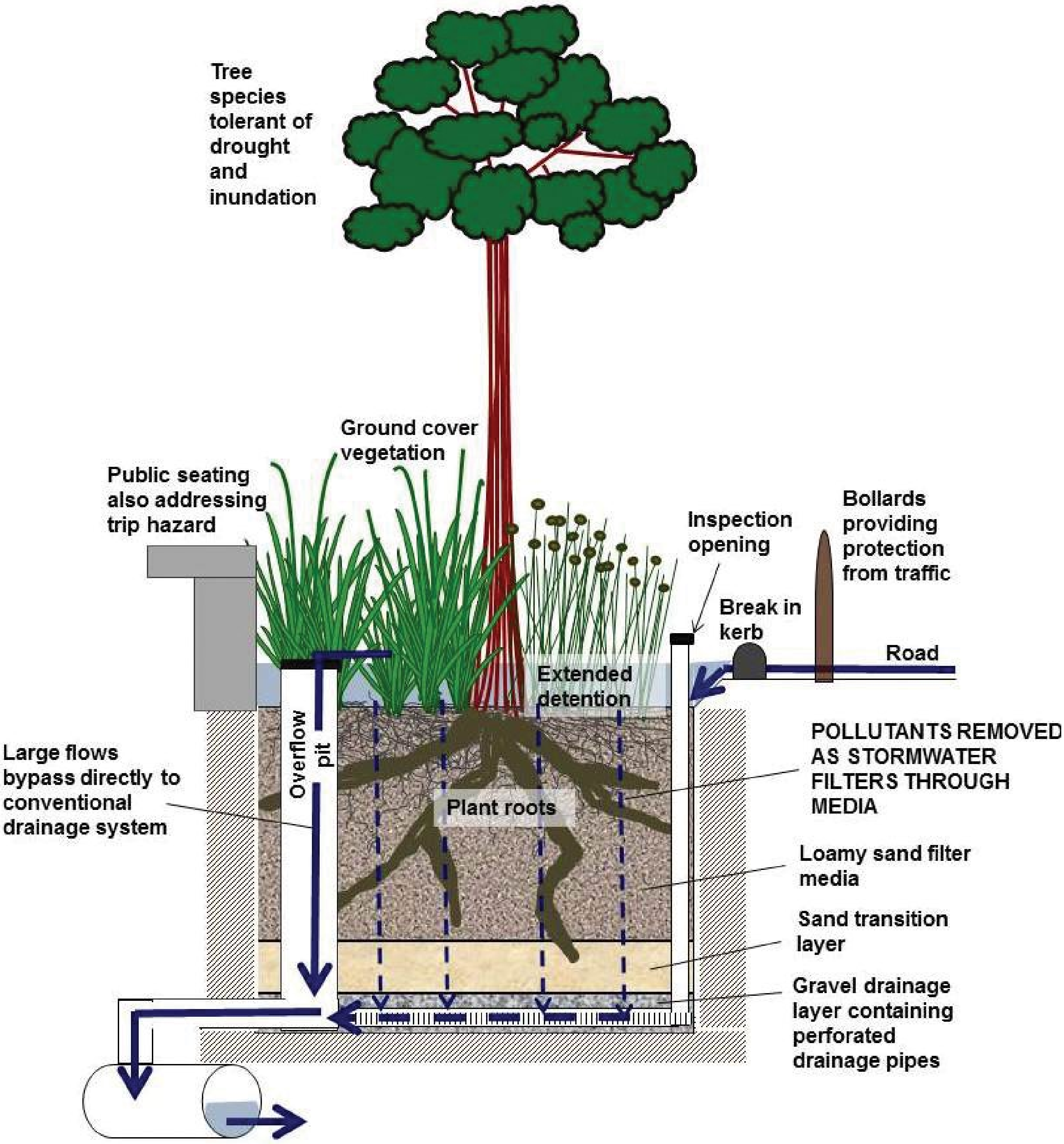

Figure 1. Conceptual drawing of a biofiltration system illustrating stormwater flow pathways and subsurface infrastructure requiring maintenance. Note that biofilters share many features but configurations can vary from the design above to suit site conditions and objectives.

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2 Minimising the long term maintenance

Four key elements in the design and construction of raingardens and biofiltration tree pits have been identified that strongly influence the amount of long-term maintenance that is required. Adequately addressing these key elements ensures that the long-term maintenance of these systems is predictable, and therefore minimal. The elements are:

- Correct filter media specification and installation;
- Dense vegetation cover;
- Correct design and construction of the hydraulic components (i.e. components that channel, direct, pond or drain flow within the biofilter), and keeping these free from blockages; and
- Protection during construction phases.

The importance of these key elements is described in more detail below.

2.1 Filter media

The filter media for the biofiltration system must meet certain specifications. It is crucial that the filter media maintains its hydraulic conductivity (i.e., it's ability to pass water through the media) in the long term. When an inappropriate filter media is installed (eg. it contains high levels of fine silt and/or clay materials), it may result in compaction or even structural collapse of the media. This leads to a substantial reduction in the treatment capacity of the system because water will not filter through the media; instead it will pond on the surface and spill out through the overflow. A symptom of this compaction is often the loss of vegetation within the biofiltration system.

Similarly, filter media must be correctly installed with an appropriate level of compaction during installation. Guidelines currently recommend that filter media be lightly compacted during installation to prevent migration of fine particles. It is important to avoid heavy compaction with machinery as this will reduce the infiltration capacity and reduce the volume of stormwater treated.In small systems, a single pass with a vibrating plate should be used to compact the filter media, while in large systems, a single pass with roller machinery (e.g. a drum lawn roller) should be performed (FAWB, 2009).

2.2 Vegetation cover

Nutrients have been identified as a key pollutant in stormwater, particularly nitrogen and phosphorus. The nutrient removal efficiency of biofiltration systems is related to the root characteristics and density of the plants within the system. Further, as plants mature and their roots penetrate the filter media, they play a role in maintaining the hydraulic conductivity of the media because root growth helps to maintain the surface porosity and the infiltration capacity of the filter media. As a result, it is important that dense vegetation cover is established at an early stage to prevent compaction or surface sealing. Some biofiltration tree pits are designed without understorey vegetation. In these instances, it is likely that additional maintenance will be required to maintain the porosity of the surface of the filter media (e.g. physical removal of any fine sediments that accumulate on the surface).

2.3 Hydraulic components

The function of a biofilter is dependent upon appropriate hydraulics. This requires good design and construction of the components (inlet/s overflow pits, outlets, depth of ponding zone, underdrains and surface gradient). It is most important to ensure invert levels are correct and to design to minimise the risk of blockages of key flow structures. Regular inspection and maintenance of these components is critical to allow stormwater flows to continue to enter the biofilter, distribute across the surface, temporarily pond, infiltrate downwards and drain from the base (either into surrounding soils or collected in underdrainage pipes), or for high flows to overflow/bypass the biofilter.

The hydraulic components are prone to blockage from sediment accumulation or litter, and the surrounding media can suffer from erosion or scour. Blockage of the inlet, outlet or overflow will compromise stormwater treatment, and may lead to widespread plant death either due to drought conditions (if the inlet is blocked) or prolonged flooding (if the outlet or overflow is blocked).

2.4 Protection during construction phases

Protection of biofiltration systems during construction allows for good plant establishment and prevents disturbance or scour of the filter media surface. It is also important to protect the biofiltration system from heavy sediment loads (including contamination of the biofilter media with on-site soils), or other wash off (e.g. cement washings), during any construction in the catchment to prevent clogging of the surface of the filter media (see Section 3 for more detail).

3 Construction and establishment phase maintenance

A number of maintenance activities have been identified that are, in most cases, only required during the establishment phase of a biofiltration system. The end of the establishment phase can be defined by the completion of both of the following:

(i) The plant establishment – where plants are suitably established to no longer require irrigation and are close to their mature height and/or when larger trees no longer require tree stakes for support. This period is typically 18 to 24 months; and

(ii) The biofiltration system is completely connected to its intended catchment and the catchment is no longer under construction (therefore there is less risk of high sediment loads or other contaminants, such as cement washings or fine clay sediments, being washed onto the surface of the filter media and causing clogging). It is also important that the entire catchment is connected to ensure adequate water availability for plants under normal climatic conditions.

This section contains considerations that are important during construction and establishment. Sign-Off forms for these phases are included in Water by Design's Construction and Establishment Guidelines. For more detailed information on the risks, common pitfalls and tips for the construction phase see Section 4.2 of the Biofilter Guidelines.

3.1 Protection of filter media during construction

Construction sites usually generate very high loads of sediment in stormwater runoff. These exceptionally high loads can cause the filter media within a biofiltration system to become clogged or blocked. Blockage may occur as a result of the accumulation of fine sediment on the surface; this can sometimes be manually removed. Accumulation of fine sediment may also occur in a layer deeper within the filter media, usually resulting in the need to remove and replace the filter media.

During construction of the biofilter itself, it is vital to protect the filter media from sediment in the surrounding area that can be washed into the pit, or from cross-contamination with on-site soils if the media is stockpiled before it is laid. This can be avoided by:

1. Protecting the biofilter construction pit from runoff using flow diversions, sediment traps or bunding;
2. If possible, timing construction of the biofilter to avoid the highest rainfall months; and,
3. Ensuring materials for the biofilter media layers are either tipped directly into the pit or deposited on a hard surface for stockpiling (thus preventing possible contamination with on-site soils).

To protect the filter media while construction activities are occurring in the catchment, at least one of the following precautions should be taken:

1. Keep the biofiltration system off-line during this period to prevent any stormwater entering – Note: adequate alternative sediment control measures must also be installed during construction to prevent heavy sediment loads being discharged directly to the stormwater system while the biofiltration system is off-line;
2. Delay final landscaping and protect the system by covering the entire biofiltration surface with geotextile (and turf or gravel if desired for aesthetic purposes) as shown in Figure 2 (left); or
3. Temporarily partition the biofiltration system, creating a sacrificial sediment forebay. This allows the vegetation to establish in the rest of the system while the sacrificial sediment forebay at the inlet is protected using textile and turf, as described above and shown in Figure 2 (right). This approach is best suited when the overflow pit is located close to the inlet zone.

Figure 3. Concept illustration showing how Ag pipes installed for tree watering can result in short circuiting and reduced stormwater treatment.

3.3 Tree stake removal

Tree stakes are often used to support young trees planted into the filter media of biofiltration systems. The stakes should be removed once the trees are adequately established and the holes filled in with filter media. Failure to fill in the holes will result in the creation of a short-circuit pathway, or preferential flow path, for stormwater. Instead of ponding on the surface of the raingarden, the holes left behind after the stakes are removed allow water to bypass the filter media and drain directly into the drainage layer at the base of the cell, effectively bypassing any pollutant removal processes.

4 Asset handover

4.1 Asset Transfer

Land ownership and asset ownership are key considerations prior to construction of a stormwater treatment device. A proposed design should clearly identify the asset owner and who is responsible for its maintenance.

If ownership of the asset is to be transferred (commonly from a developer to local council or government authority), the proposed owner should be responsible for performing the asset transfer checklist. Handover is a key opportunity for the identification and rectification of problems that may compromise long-term system performance (e.g. poor plant health, bare zones, inappropriate hydraulics, excessive sediment accumulation). For details on asset transfer specific to each council, contact the relevant local authority to obtain their specific requirements for asset transfer.
The example below provides an indicative asset transfer checklist.

4.2 Asset Transfer Checklist

BIOFILTRATION SYSTEM ASSET TRANSFER CHECKLIST		
Asset ID:		
Asset Location:		
Constructed by:		
'On-maintenance' period:		
TREATMENT	Y	N
System visually appears to be working as designed?		
No obvious signs of under-performance?		
MAINTENANCE	Y	N
Maintenace plans and indicative maintenance costs provided for each asset?		
Vegetation establishment period (two years) completed?		
Inspection and maintenance undertaken as per maintenance plan?		
Inspection and maintenance forms provided?		
ASSET INSPECTED FOR DEFECTS AND/OR MAINTENANCE ISSUES AT TIME OF ASSET TRANSFER	Y	N
Sediment accumulation at inflow points?		
Litter within system?		

Erosion at inlet or other key structures?		
Traffic damage present?		
Evidence of dumping (eg. building waste)?		
Vegetation condition satisfactory (density, weeds, etc.)?		
Water of vegetation required?		
Replanting required?		
Mowing/slashing required?		
Clogging of drainage points (sediment or debris)?		
Evidence of overly long periods of ponding?		
Damage/vandalism to structures present?		
Surface clogging visible?		
Drainage system inspected?		
Weir/up-turned pipe is clear of debris (if applicable)?		
Water level in saturated zone as designed (if applicable)?		
COMMENTS/ACTION REQUIRED FOR ASSET TRANSFER		
ASSET INFORMATION	Y	N
Design Assessment Checklist provided?		
As constructed plans provided?		
Copies of all required permits (both construction and operational) submitted?		
Proprietary information provided (if applicable)?		
Digital files (eg. drawings, surveys, models) provided?		
Asset listed on asset register or database?		

5 OPERATIONAL MAINTENANCE TASKS

5.1 Schedule of visits

5.1.1 Schedule of Site Visits (Regular Inspection & Maintenance)	
Purpose of visit	**Frequency**
Inspection	Regular inspection and maintenance should be carried out to ensure the system functions as designed. It is recommended that these checks be undertaken on a three monthly basis during the initial period of operating the system. A less frequent schedule (e.g. 6 monthly) might be determined after the system has established.
Maintenance	

5.2 Tasks

The scope of maintenance tasks should include verifying the function and condition of the following elements:

- Filter media
- Horticultural
- Drainage infrastructure
- Other routine tasks

Further discussion of monitoring and maintenance of biofilters is provided in Section 4.3 of the biofilter guidelines.

5.2.1 Filter media tasks	
Sediment accumulation / clogging	Inspect for the accumulation of an impermeable surface layer (such as oily or clayey sediment), ponding of water for more than a few hours following rain (including the first major storm after construction), or widespread moss growth. Repair minor accumulations by scarifying the surface between plants and if feasible, manual removal of accumulated sediment. Investigate the cause of any poor drainage. **Frequency - 3 MONTHLY, AFTER RAIN**
Holes, erosion or scour	Check for erosion, scour or preferential flow pathways, particularly near inflow point/s and batter slopes (if present). May indicate poor flow control e.g. excessive inflow velocities or inadequate bypass of high flows. Repair and infill using compatible material. Add features for energy dissipation (e.g. rocks and pebbles at inlet), or reconfigure to improve bypass capacity if necessary. **Frequency - 3 MONTHLY, AFTER RAIN**
Filter media surface porosity – sediment accumulation and clogging	Inspect for the accumulation of an impermeable layer (such as oily or clayey sediment) that may have formed on the surface of the filter media. Check for areas of increased sediment deposition, particularly near inlet/s. A symptom of clogging may be that water remains ponded in the biofilter for more than a few hours after a rain event, or the surface appears 'boggy'. Repair minor accumulations by raking away any mulch on the surface and scarifying the surface of the filter media between plants. Accumulated sediment can be manually removed using rakes and shovels, if the system is not too large or only certain areas require attention. If excessive loads of sediment, investigate the source and install pre-treatment device if necessary. For biofilter tree pits without understorey vegetation, any accumulation of leaf litter should be removed to help maintain the surface porosity of the filter media. **Frequency - 3 MONTHLY, AFTER RAIN**
Damage	Check for damage to the profile from vehicles, particularly streetscape systems alongside parking or street corners. Also check for signs of pedestrian traffic across the filter surface, such as worn pathways. Repair using compatible filter media material. **Frequency – 6 MONTHLY**

Litter control	Check for anthropogenic litter and significant accumulations of organic litter, particularly in sediment pits, inlets, outlets and overflows. Remove litter to ensure flow paths and infiltration through the filter media are not hindered. Systems are particularly vulnerable to accumulations of organic litter during establishment, which can smother seedling growth and re-release nutrients as it breaks down. Litter can be removed manually and pre-treatment measures (such as a gross pollutant trap) can be used if it is a significant problem. **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS**
Moss growth	Moist systems or those with deep shading of the surface may have excessive moss growth across the surface. This can act to bind the surface, contributing to clogging. Manual scraping can remove the moss, but the underlying cause should be investigated and rectified if possible. **Frequency – 6 MONTHLY, ESPECIALLY DURING WETTEST MONTHS**
5.2.2 Horticultural tasks	
Establishment	The initial period after construction (up to the first 2 years) is critical to long-term success or failure of the biofilter. Additional monitoring and maintenance works are required to ensure a healthy and diverse vegetation cover develops, and that stormwater flows move through the system as the design intended (i.e., flows enter freely, covering the entire surface, ponding occurs to the design depth, high flows bypass and the infiltration rate is acceptable). Careful attention can avoid costly replanting and rectification works. New seedlings will require regular watering and irrigation, protection from high sediment loads and high flows. Refer to Water by Design's 'Construction and Establishment Guidelines'.**Frequency – WEEKLY IF ESTABLISHING ACROSS DRY SEASON, HIGH FREQUENCY DURING FIRST 3 MONTHS IN PARTICULAR, INCLUDING AFTER FIRST LARGE RAIN EVENT. AFTER THIS, BIMONTHLY IN WETTER MONTHS AND MORE FREQUENTLY DURING THE COURSE OF ANY LONG DRY AND HOT SPELLS. UP UNTIL 2 YEARS.**
Plant health and cover	Reduced plant density reduces pollutant removal and infiltration performance. Inspect plants for signs of disease, die-back, pest infection, stunted growth or senescent plants and assess the degree of plant cover across the surface. If poor plant health or cover is widespread, investigate to identify and address the causal factor (e.g. poor species selection, shading, too dry (e.g. oversized, wrong inlet levels or level for ponding zone, dry climate, media with minimal water holding capacity, poor flow distribution, lack of irrigation), too wet (e.g. from clogging, undersizing) or smothering from litter. Treat, prune or remove plants and replace as necessary using appropriate species (species selection may need re-consideration in light of the level of water availability), aiming to maintain the original planting densities (6-10 plants/m^2 recommended). Provide watering or irrigation to support plants through long dry periods. **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS, BUT ADDITIONALLY CHECK DURING LONG DRY SPELLS**
Weeds	Weeds should be identified and removed as they occur. If left, weeds can out-compete the desired species, possibly reducing water treatment function and diminishing aesthetics. Inspect for and manually remove weed species, avoiding the use of herbicides because biofilters are often directly connected to the stormwater system (if unavoidable apply in a targeted manner using spot spraying). **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS**
Pruning and harvesting (if feasible)	It may be worth considering occasionally harvesting plants to permanently remove nutrients and heavy metals stored in aboveground tissues, and to promote new plant growth and further nutrient and metal uptake. Pruning may also benefit aesthetics.**Frequency – ONCE or TWICE A YEAR**
5.2.3 Drainage tasks	
Inlet pits/zones, overflow pits, grates and other stormwater junction pits	Ensure inflow areas and grates over pits are clear of litter and debris and in good and safe condition. A blocked grate would cause nuisance flooding of streets. Inspect for dislodged or damaged pit covers and ensure general structural integrity. Remove sediment from pits and entry sites, etc. (likely to be an irregular occurrence in a mature catchment). **Frequency - MONTHLY AND OCCASIONALLY AFTER RAIN , BUT 6 MONTHLY IF NO CONSTRUCTION ACTIVITY UNDERWAY IN THE CATCHMENT.**

Underdrain	Ensure that underdrain pipes are not blocked to allow the system to drain as designed and prevent waterlogging of the plants and filter media. A small steady clear flow of water may be observed discharging from the underdrain at its connection into the downstream pit some hours after rainfall. Note that smaller rainfall events after dry weather may be completely absorbed by the filter media and not result in flow. Remote camera (eg. CCTV) inspection of pipelines for blockage and structural integrity could be useful. **Frequency - 6 MONTHLY, AFTER RAIN**
Sediment forebay/pre-treatment zone **(if present)**	Removal of accumulated sediment and debris. **Frequency – TWICE A YEAR (or more frequent if accumulation is particularly rapid)**
Elevated outlet **(if submerged zone present)**	Check that the weir/up-turned pipe is clear of debris. **Frequency – 6 MONTHLY, AFTER RAIN**
Submerged zone **(if present)**	Although the submerged zone helps to sustain the biofilter through dry periods, if drying persists for long enough it will become drawn down and require replenishment. Check that the water level in the submerged zone is at the design level and top this up as required. **Frequency – MONTHLY THROUGHOUT DRY SEASON (i.e., only when rain is infrequent), or AS REQUIRED (refer to Equation 1 in Section 3.6.7 to estimate the required time for re-filling)**
5.2.4 Other routine tasks	
Inspection after rainfall	Occasionally observe biofiltration system after a rainfall event to check infiltration. Identify signs of poor drainage (extended ponding on the filter media surface). If poor drainage is identified, check land use and assess whether it has altered from the design capacity (eg. unusually high sediment loads may require installation of a sediment forebay). **Frequency – TWICE A YEAR, AFTER RAIN**

The following example form should be developed and used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time. Inspections should occur every 1 – 6 months depending on the size, complexity and location of the system. For example systems will require more frequent inspection if they are located in a highly visible place, or if the catchment contributes high sediment or litter loads. More detailed site specific maintenance schedules should be developed for major biofiltration systems and include a brief overview of the operation of the system as well as key aspects to be checked during each inspection.

5.2.5 FORM (REGULAR INSPECTION & MAINTENANCE)

Location	Raingarden/Tree Pit		
Site Visit Date:		Site Visit By:	
Weather:			
Purpose of the Site Visit	Routine Inspection	☐	Complete section 1 (below)
	Routine Maintenance	☐	Complete sections 1 and 2 (below)

NOTE: Where maintenance is required ('yes' in Section 2), details should be recorded in the 'Additional Comments' section at the end of this document.

1. Filter media				
*In addition to regular inspections, it is recommended that inspection for damage and blockage is made after significant rainfall events that might occur once or twice a year.	Section 1		Section 2	
	Maintenance Required?		Maintenance Performed	
	Yes	No	Yes	No
Filter media (CIRCLE – pooling water or evidence of overly long water ponding/ accumulation of silt & clay layer/scour/holes/sediment build up/traffic damage)	☐	☐	☐	☐
Litter (CIRCLE - large debris/accumulated vegetation/anthropogenic/dumping of building waste or rubbish)	☐	☐	☐	☐
2. Vegetation				
Vegetation health (CIRCLE - signs of disease/pests/poor growth - watering required – mowing/trimming required)	☐	☐	☐	☐
Vegetation densities (CIRCLE – low densities- infill planting required)	☐	☐	☐	☐
Build up of organic matter, leaf litter (CIRCLE - requires removal)	☐	☐	☐	☐
Weeds (CIRCLE - isolated plants/infestation) (SPECIES - ……………………………………………………………..)	☐	☐	☐	☐

3. Pits, pipes and inflow areas				
*In addition to regular inspections, it is recommended that inspection for damage and blockage is made after significant rainfall events that might occur once or twice a year.	Section 1		Section 2	
	Maintenance Required?		Maintenance Performed	
	Yes	No	Yes	No
Perforated pipes (CIRCLE – full blockage/partial blockage/damage)	☐	☐	☐	☐
Inflow areas (CIRCLE – erosion/excessive sediment deposition/litter blockage)	☐	☐	☐	☐
Overflow grates (CIRCLE – damage/scour/blockage)	☐	☐	☐	☐
Pits (CIRCLE – poor general integrity/sediment build-up/litter/blockage)	☐	☐	☐	☐
Other stormwater pipes and junction pits (CIRCLE – poor general integrity/ sediment build-up/litter/blockage)	☐	☐	☐	☐
4. Submerged zone (if present)				
*In addition to regular inspections, it is recommended that inspection for damage and blockage is made after significant rainfall events that might occur once or twice a year.	Section 1		Section 2	
	Maintenance Required?		Maintenance Performed	
	Yes	No	Yes	No
Weir/up-turned pipe (CIRCLE – full blockage/partial blockage/damage)	☐	☐	☐	☐
Water level (CIRCLE – at design level/drawn down) **SOME DRAWDOWN DURING DRY PERIODS IS EXPECTED**	☐	☐	☐	☐
5. Additional Comments				
Details of routine maintenance, renewal or resetting works required:				

REFERENCES

FAWB (2009). Guidelines for Filter Media in Biofiltration Systems (Version 3.01), Facility for Advancing Water Biofiltration, available at http://www.monash.edu.au/fawb/publications

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