STORMWATER BIOFILTRATION SYSTEMS

Adoption Guidelines

Planning, Design and
Practical Implementation

Version 1 June 2009

FAWB
Facility for Advancing
Water Biofiltration

ISBN 978-0-9805831-1-3

Version 1, June 2009

Preferred Referencing for this Report:

FAWB (2009). *Adoption Guidelines for Stormwater Biofiltration Systems*, Facility for Advancing Water Biofiltration, Monash University, June 2009.

DISCLAIMER

ACKNOWLEDGEMENTS

The *Adoption Guidelines for Stormwater Biofiltration Systems* were developed by the Facility for Advancing Water Biofiltration (FAWB), a Victorian Government Science, Technology and Innovation Initiative, and industry funding partners: Adelaide and Mount Lofty Ranges Natural Resources Management Board, SA; Brisbane City Council, Qld; Landcom, NSW; Manningham City Council, Vic; Melbourne Water, Vic; and VicRoads, Vic.

The guidelines were authored by Belinda Hatt (Monash University), Peter Morison (Monash University), Tim Fletcher (Monash University), and Ana Deletic (Monash University), with significant contributions from Sally Boer (EDAW) and Andrew Cook (EDAW).

Our appreciation goes to our industry collaborators, board of management, stakeholder representatives, research review and advisory panels, management, advisory and support staff, and visiting scholars and international collaborators who provided valuable input throughout the development of the guidelines. Our thanks also goes to Alan Hoban (South East Queensland Healthy Waterways Partnership), Shaun Leinster (DesignFlow), Peter Morison (Monash University), Toby Prosser (Melbourne Water), and Marianne Robertson (VicRoads) for their review of the draft document.

These guidelines would not have been possible without the research efforts of the FAWB project researchers and postgraduate students and we extend our thanks to them.

CONTACT DETAILS

The Facility for Advancing Water Biofiltration welcomes feedback on this document, which can be directed to fawb@eng.monash.edu.au

TABLE OF CONTENTS

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.

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)[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 filter medium (usually soil-based) 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.

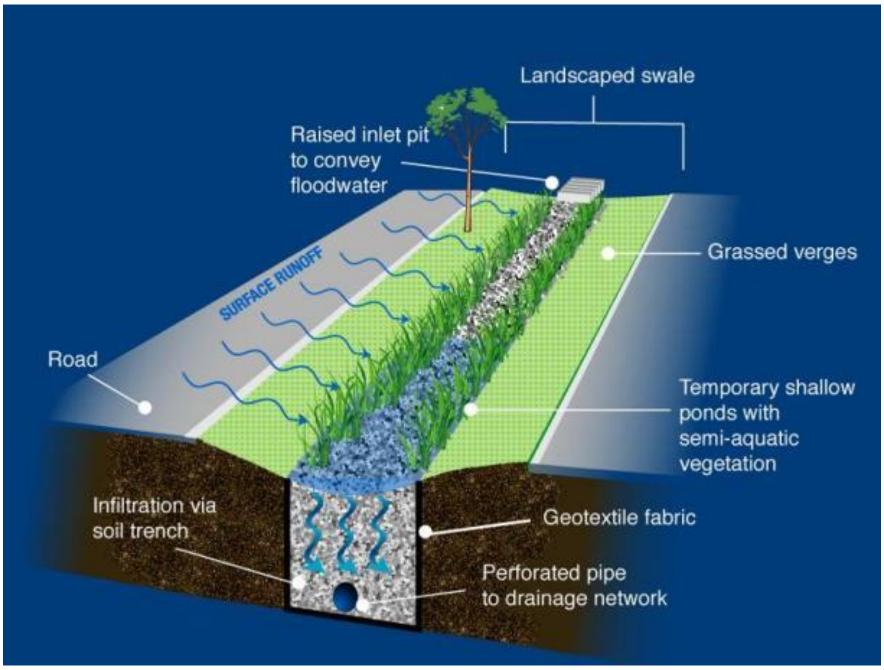


Figure 1. Schematic of a typical biofiltration system.

Small bioretention pods are often referred to as rain gardens, 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. The design configuration of biofilters is flexible, and possible variations include removal of the underdrain (to promote exfiltration into the surrounding soil) and the inclusion of a permanently wet zone at the bottom (to further enhance nitrogen removal). Hybrid systems are also possible, with an underdrain elevated above the base of the biofilter, to promote exfiltration, but allow discharge to the stormwater system during larger events.

[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 *et al.*, 2002).

1.1.1 Hydrologic function

Stormwater runoff from urban areas tends to have 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 biofiltration system and slow filters through the soil media; and
- They reduce runoff volumes by typically around 30%, on average: a portion of every runoff event is retained by the filter media – this will then be lost via evapotranspiration and/or exfiltration, depending on the design of the system. Small runoff events may even be completely absorbed by the biofiltration system (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.

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 basin or trench, 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 (eg., plant and microbial uptake).

1.2 WHY MIGHT WE CHOOSE A BIOFILTRATION SYSTEM?

There have been a number of successful applications of biofiltration, but also many poor outcomes owing to inappropriate utilisation of the technology, and poor construction, operation, and maintenance practices. There has also been insufficient understanding and dissemination of guidance on biofiltration 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. In addition to reducing the impacts of urbanization 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;
- 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 (because evapotranspiration causes cooling of the nearby atmosphere);
- Are not restricted by scale; and
- Can be integrated with the local urban design (streetscape).

1.3 RESEARCH UNDERPINNING THE DESIGN OF BIOFILTRATION SYSTEMS

The Facility for Advancing Water Biofiltration (FAWB) was formed in mid-2005 as an unincorporated joint venture between the Institute for Sustainable Water Resources (ISWR), Monash University and EDAW Australia (previously Ecological Engineering). The following industry collaborators were also involved:

- Adelaide and Mount Lofty Ranges Natural Resources Management Board (succeeding The Torrens and Patawalonga Catchment Water Management Boards) (SA);
- Brisbane City Council (Qld);
- Landcom (NSW);
- Manningham City Council (Vic);
- Melbourne Water (Vic); and
- VicRoads (Vic).

FAWB's mission was to ***provide proof of concept by developing and field-testing a range of biofilter systems that can be applied to specific market-based needs***. This included the needs of catchment managers, environmental regulators, public utilities, local governments, land developers, and design engineers.

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. The total value of the activities within FAWB, including both cash and in-kind contributions, was $4.3 million over three years.

The facility was run by a Board of Management, which was chaired by Professor Russell Mein. The research was carried out by over 25 staff and postgraduate students, and was managed by the following team:

- Chief Executive Officer: Professor Tony Wong, EDAW
- Research Manager: Professor Ana Deletic, Monash University
- Business Manager: Mr John Molloy, Monash University
- Project Leaders: Associate Professor Tim Fletcher, Monash University (*Project 1: Technology*), Associate Professor Rebekah Brown, Monash University (*Project 2: Policy and Organisational Receptivity*), Dr Belinda Hatt, Monash University (*Project 3: Adoption Tools*), and Mr Justin Lewis, Monash University (*Project 4: Demonstration and Testing*).

FAWB also actively collaborated through ongoing joint research projects with INSA Lyon, a leading engineering university in France, and with Luleå University of Technology in Sweden.

1.3.1 Structure of the Research Program

To refine the design of biofilters and facilitate widespread adoption of these systems, the following research questions were posed:

1. Technology questions:
   - How do biofilters work?
   - How should we design biofilters to work efficiently in a wide range of applications (eg. pollution control, flow management, stormwater harvesting) and site characteristics (eg. different climates, pollutant loading rates)?
2. Adoption questions:
   - What are the factors (policy, regulation, risk, etc.) that advance their widespread implementation?
   - How do we quantify these factors and their relative significance?
3. To test the technology and enable its uptake, FAWB also committed to:
   - Develop adoption tools, such as design methods and adoption guidelines; and
   - Demonstrate and test the technology, by supporting construction of a number of full-scale systems.

The entire Research Program was divided into four highly interlinked Projects:

- *Project 1: Technology*, which aimed to overcome technical barriers to widespread adoption of the technologies, and to optimise the performance and lifespan of biofiltration systems;
- *Project 2: Policy and Organisational Receptivity*, which aimed to develop methodologies and strategies to overcome institutional and social barriers to widespread adoption of the technologies;
- *Project 3: Adoption Tools*, which aimed to develop design and implementation tools for practitioners; and
- *Project 4: Demonstration and Testing*, which aimed to demonstrate and monitor the wide capability of novel, multi-functional biofilter designs.

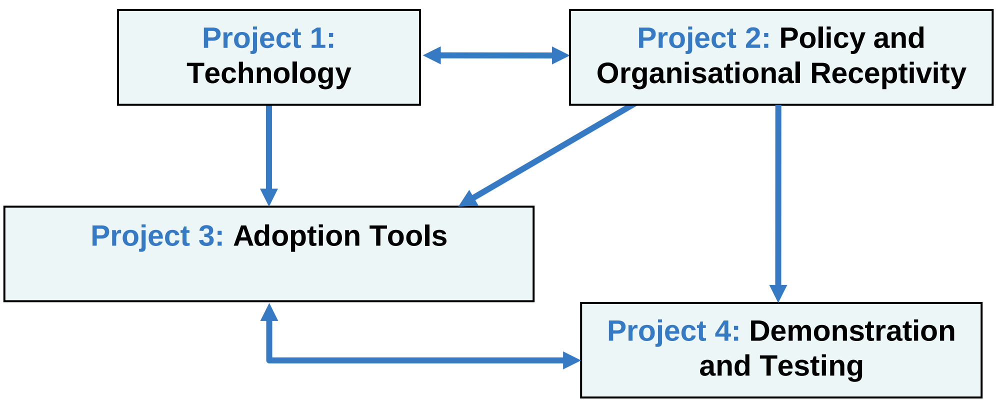


Figure 2. Structure of FAWB's Research Program.

The aims and activities of each of the projects are described in detail elsewhere (FAWB, 2008). The research outcomes have been extensively peer-reviewed by both the Australian and international scientific community; a list of publications that report on the details on the various research activities can be found in Appendix A. This gives confidence that these guidelines are based on sound science.

1.4 HOW TO USE THESE GUIDELINES

The purpose of this document is to provide guidance on how to apply FAWB's 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 presented as a series of chapters, each addressing a different aspect of implementation of biofiltration systems, as follows:

- Chapter 2 (*Planning for Biofiltration*) outlines the planning aspects associated with implementing biofiltration systems, and reviews the planning instruments and initiatives to facilitate biofiltration in each state and territory of Australia. After identifying the gaps in the policy frameworks across the nation and highlighting the successful initiatives to endorse the implementation of biofiltration, interim performance measures for the technology that may be used in the absence of state or territory policy are presented;
- Chapter 3 (*Technical Considerations*) provides guidance on conceptual design considerations 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 biofiltration systems, as well as five fundamental design configurations. The design considerations for the overall configuration and each component are identified and, finally, specific site and application considerations are discussed; and
- Chapter 4 (*Practical Implementation*) provides general 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 at-source and end-of-line biofiltration systems. In addition, it provides example checklists and sign-off forms for designers and local government development assessment officers as well as practice notes for monitoring the performance of biofiltration systems.

In preparing these guidelines, we have attempted to be concise and avoid repetition, however, given that the chapters are required to be stand-alone to some extent, some overlap between chapters is necessary; this reiteration should be interpreted as an emphasis of the importance of these issues.

Note: Like all other WSUD elements, biofiltration technologies 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. Therefore, in the case of greenfield and infill developments, these guidelines should be considered ***before*** any detailed planning and design occurs.

1.5 OTHER RELEVANT DOCUMENTS

These guidelines are intended to be relevant at the national scale and therefore cannot be a stand-alone document, as the final detailed design of biofiltration systems will be dictated by local site conditions (eg. soil type, rainfall intensity) and stormwater management requirements.

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

- Local planning policies and regulations
- Local development guidelines
- Local stormwater management guidelines
- Local construction guidelines
- MUSIC modelling documentation (see www.toolkit.net.au/music)
- Australian Runoff Quality (see http://www.engaust.com.au/bookshop/arq.html)
- ANZECC Water Quality Guidelines

  (see http://www.environment.gov.au/water/publications/quality/index.html#nwqmsguidelines)

Examples of successful and not-so-successful (which are, in some ways, more valuable) implementation and operation of biofiltration systems are a valuable source of information. 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 (http://wsud.melbournewater.com.au/)
- Water by Design (www.waterbydesign.com.au)
- Water Sensitive Urban Design in the Sydney region (http://www.wsud.org/)
- urbanwater.info (www.urbanwater.info)

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

1.6 REFERENCES

FAWB (2008). *2007 – 2008 Annual Report*. Facility for Advancing Water Biofiltration, www.monash.edu.au/fawb/publications.

Lloyd, S. D., T. H. F. Wong and C. J. Chesterfield (2002). *Water Sensitive Urban Design: A Stormwater Management Perspective*. Cooperative Research Centre for Catchment Hydrology.

Wong, T. H. F. (Ed.) (2006). *Australian Runoff Quality: A Guide to Water Sensitive Urban Design*. Sydney, Engineers Australia.

CHAPTER 2: PLANNING FOR BIOFILTRATION

2.1 INTRODUCTION

These guidelines address the practical issues of implementing water biofiltration schemes. Given that biofiltration systems are a relatively new addition to the set of technologies associated with integrated urban water management, there are a number of common challenges faced by implementers of the technology. These issues can be classified into the following three types:

- Limits to planning and regulation;
- Construction faults; and
- Maintenance problems.

While construction and maintenance issues are considered in Chapter 4 (*Practical Implementation*), this chapter outlines the planning aspects associated with implementing biofiltration systems and reviews the planning instruments and initiatives to facilitate biofiltration in each state and territory of Australia. After identifying the gaps in the policy frameworks across the nation and highlighting the successful initiatives to endorse the implementation of biofiltration (Section 2.2), we offer interim performance measures for the technology that may be used in the absence of state or territory policy (Section 2.3).

Policy Officers and Strategic Planners will most benefit from the guidance in this chapter. However, engineers, scientists, and environmental managers who are developing policy in the area of WSUD will also find this chapter helpful. Whilst this document does not provide definitive guidance on which planning instruments to use, it does provide a very useful link to initiatives currently in place and default measures that can be used in the absence of existing local regulatory requirements.

2.2 PLANNING FOR STORMWATER BIOFILTRATION

In planning for stormwater biofiltration, it is useful to consider two separate modes of implementation:

- The private domain (residential, commercial and industrial development); and
- The public domain (eg. parks, town squares, and road reserves).

Each mode follows a separate planning process. Planning for the private domain is particularly important, given that the great majority of development in Australia occurs on private land. While biofiltration has largely been implemented within the public domain as part of demonstration projects throughout Australia, recently, with the amendment to planning regulations in Victoria, an emerging suite of biofiltration technologies can be seen in greenfield residential developments around Melbourne. It is anticipated that, as planning regulations across the Australian states and territories acquire more indicative and prescriptive elements for WSUD, biofiltration will become standard practice and thus will eventually dominate the urban landscape in the private domain. Accordingly, the private domain is the area which requires greater planning emphasis and thus we deal with this matter first.

2.2.1 The Private Domain

Each of the states and territories in Australia operate different planning legislation which affects the uniform implementation of stormwater biofiltration. In some states, the planning regulations may facilitate the inclusion of biofiltration within the developed landscape, while others may inhibit it. We have selected all the states and territories of Australia to review the relevant aspects of the planning legislations and provide guidance on what may enhance the implementation of biofiltration through planning schemes.

IMPORTANT!

- These guidelines are not designed to provide a detailed analysis of the legislative frameworks but to practically advise on what policy opportunities exist to implement biofiltration systems.

The planning legislation in all of the six states and the Northern Territory do not currently privilege biofiltration systems, or more generally, the practice of WSUD. This is recognised by the industry as potentially inhibiting the advancement of the technology (Hatt *et al.*, 2006; Mitchell, 2006; Wong, 2006a). It is argued that part of the problem is the lack of clear direction and mandatory prescription of WSUD in the planning regulations (Potter & RossRakesh, 2007). At the time of publication, Victoria was the only state to require WSUD in its totality but this is restricted to residential subdivisions. In the Australian Capital Territory (ACT), requirements for WSUD were mandated in 2008 for a large proportion of new urban development. This is the most advanced of the states and territories for implementing WSUD. Further details of the requirements for WSUD across the states and territories are provided below.

While the Queensland Integrated Planning Act provides general support and direction for WSUD, which is followed by local councils in preparing their local planning schemes across the state, the South East Queensland Regional Plan acknowledges WSUD as best-practice for urban development and specifically requires its adoption (HWP, 2006). A number of local councils have prepared local planning schemes that include provisions for WSUD; noteworthy are the councils of the Sunshine Coast region (formerly Maroochy Shire), Gold Coast City and Ipswich City (A. Hoban, pers. comm.). While municipal officers in the south-east region do not believe the current provisions are satisfactory to achieving WSUD on new developments (HWP, 2007), the state government plans to release revisions of the Environmental Protection Policy (Water) and State Planning Policy (Water). It is expected that these reforms will consistently apply load-based pollutant reduction targets for stormwater runoff to urban development across the state and hence, remove the need for councils to individually produce local policies of this nature (A. Hoban, pers. comm.).

The introduction of the *Building Sustainability Index* (BASIX) in New South Wales by the state government has stimulated the inclusion of rainwater tanks and water conservation measures in new housing (DoP, 2007), but does not currently prescribe exclusive stormwater treatment facilities. The state government's land development corporation, Landcom, has led a number of WSUD ventures, including Victoria Park in southern Sydney and Second Ponds Creek in the outer north-west of the metropolitan area. These projects, combined with a number of local government and private development initiatives, have provided a variety of showcases to build upon. However, current planning legislation at the state level is vague on WSUD requirements and therefore the onus is on local councils to provide the mandate. The government has included in its direction to local government under Section 117 of the Environmental Planning and Assessment Act the requirement to consider the impact of stormwater discharges on waterways when preparing *Local*

Environmental Plans (LEPs), although it was uncertain at the time of writing whether this consideration would translate into WSUD.

In Victoria, Clause 56.07 (Integrated Water Management) of the *Victoria Planning Provisions* (DPCD, 2008) prescribes Water Sensitive Urban Design for residential subdivisions. Loopholes do exist for so-called 'procedural subdivisions' under Clause 56, i.e., subdivisions of land containing an existing dwelling. These types of development are common in the suburban areas of Melbourne and regional townships in Victoria where, for example, a classic quarter-acre block with home is subdivided for multiple, freestanding dwellings. In these cases, the applicant can seek approval under Clause 55 of the Victoria Planning Provisions to construct multiple dwellings on the lot prior to obtaining a subdivision planning permit, which in practical terms means that WSUD is not pursued (Potter & RossRakesh, 2007). In developments other than residential subdivisions, the planning provisions do not mandate WSUD and as a consequence, biofilters are not generally features of these developments. Melbourne Water is working with the Department of Sustainability and Environment to amend the 5-star building regulations with requirements for WSUD (Potter & RossRakesh, 2007). These will enhance the current requirements for either a rainwater tank or solar hot water system associated with a dwelling. However, it is expected the regulatory amendments will take some years to materialise.

With the injection of federal funds through the Natural Heritage Trust, the Derwent Estuary Program in Tasmania has prepared WSUD engineering procedures (DPE, 2005) and worked with the Royal Botanic Gardens in Hobart to showcase a biofilter with visitor interpretive signage and information in the gardens. While there are a number of protagonists within state and local governments, the implementation of WSUD is in its infancy in Tasmania.

Planning SA (the Government of South Australia's planning agency) is currently pursuing a consistent WSUD planning framework and associated guidelines and industry capacity building to 'institutionalise' WSUD across the Adelaide metropolitan area. The work was scheduled to be completed by the end of 2008 (Planning SA, 2008).

Western Australia is the birthplace of WSUD, going back fifteen years with the publication of a discussion paper entitled *Planning and Management Guidelines for Water Sensitive Urban (Residential) Design* (Whelans, 1993). While developments such as Ascot Waters, Beachridge, and Brookdale/Wungong situated around Perth demonstrate WSUD, the initiative has not translated into wholesale application throughout the state. The WA Planning Commission has developed the *Statement of Planning Policy 2.9 'Water Resources'* which requires that developers take into account WSUD principles and ensure that development is consistent with current best management and planning practices for the sustainable use of water resources, particularly stormwater. However, WSUD will only be practically achieved once the principles are translated into "local planning strategies, structure plans and town planning schemes and the day-to-day consideration of zoning, subdivision, strata subdivision and development proposals and applications, together with the actions and advice of agencies in carrying out their responsibilities" (Planning Commission WA, 2006). To date, there is little evidence to suggest WSUD has been extensively incorporated into these systems.

In the Australian Capital Territory, WSUD is promoted in the government's draft policy – *Water ACT* (ACT, 2003) and the strategy *Think water, act water* (ACT, 2004). One of the six objectives of the strategy is to "facilitate the incorporation of water sensitive urban design principles into the urban, commercial, and industrial development". The Planning and Land Authority of ACT has since included in its principal planning document, – the *Territory Plan* – a "general code" for WSUD, known as *Waterways* (PLA, 2008). The code sets out the stormwater management requirements for new urban development, which are mandatory for all new residential estates, all residential development including three or more residential units and any non-residential development where the total site is greater than 5,000 m^2. Biofiltration is one of the suggested best-practice techniques for achieving the mandatory requirements.

WSUD is new to the Northern Territory, with relatively little implementation to date. However, the Australian Government's Coastal Catchments Initiative is funding a project in NT that considers WSUD policy and implementation with a trial underway in a new greenfield subdivision (R. McManus, pers. comm.). The Bellamack residential subdivision in Palmerston (21 km south of Darwin) is a new suburb under development that is intended to combine the principles of affordable housing and WSUD. The project is being managed by the NT Lands Group, an arm of the NT government.

Taken together, the situation across Australia indicates that the current planning frameworks for WSUD are somewhat fragmented and need to be consistently applied and mandated at the state and territory level, particularly for those developments outside of the large residential estates (Kay *et al.*, 2004).

2.2.1.1 Local Policy Leadership

At this point in time, biofiltration systems as an element of WSUD are being pursued mainly at the municipal level through the planning system. There are many examples of good practice stimulated by local councils seeking more sustainable urban development and protecting the ecological health of local waterways. Municipal Development Control Plans (DCPs) in select NSW local councils include WSUD terminology and promote WSUD solutions for new developments and redevelopments (Dahlenburg, 2005). In a number of cases, these have been guided by model planning provisions created by coalitions of local councils, such as the Lower Hunter and Central Coast Regional Environmental Management Strategy (REMS), the Southern Councils Group, the Clarence Valley Councils, and the WSUD in Sydney Region project. Following these initiatives, councils such as Newcastle City, Richmond Valley, Sutherland Shire, Ku-ring-gai, and Hunters Hill have developed DCPs that promote the implementation of WSUD[2].

> ☝ **PLANNING TIP**
>
> - There is currently no consistent national planning approach for achieving WSUD. In the interim, practitioners may resort to local municipal planning instruments to implement biofiltration systems and draw from the various examples provided here.

Two Sydney councils, Kogarah Council and Parramatta City Council, have implemented "deemed-to-comply" requirements that establish WSUD objectives for development proposals. Both schemes are complementary to the NSW Government's BASIX scheme and balance WSUD and On-site Detention requirements for flood control at the lot scale.

Kogarah Council has prepared a *Water Management Policy* that stipulates generally that development proposals on land less than 3000 m^2 in area include stormwater treatment measures in accordance with the on-line calculator (see Kogarah Council, 2006a for specific requirements). Development proposals on sites of 3000 m^2 or greater shall be comprehensively assessed by the council. In either case, the council prescribes biofiltration as a solution for water quality

[2] The website of the WSUD in the Sydney Region project provides the policies of these councils for download: www.wsud.org/Exchange.htm

management and provides media specifications and performance data in a practice note for development applicants (Kogarah Council, 2006b).

Modelled on the Stormwater Management Manual of the City of Portland, Oregon in the United States, the *Deemed to Comply Stormwater Management Requirements* of Parramatta City Council are separated into two parts: a simple calculator method that utilises standard drawings for construction; and submissions requirements for developments of a more complex nature that are assessed using recognised water quality modelling software, such as MUSIC (Collins *et al.*, 2008). The requirements are established under both the City's Local Environmental Plan and comprehensive Development Control Plan. The council is currently evaluating incentives for development applicants who exceed the minimum WSUD requirements.

Within Queensland, the Healthy Waterways Partnership in the south-east region has fostered the implementation of WSUD through capacity-building initiatives under the banner of "Water by Design". The majority of the eighteen local councils in the region possess local planning schemes that include provisions for WSUD (Gaskell, 2008). A subset of these councils have well-developed, in-house technical expertise to approve and advise on the inclusion of WSUD in development proposals. Within the region, proposed design objectives for urban stormwater management have been prepared and placed within the *Regional Implementation Guideline 7 for Water Sensitive Urban Design*. The objectives include criteria to address both the hydrologic and ecological impacts of stormwater runoff from urban developments.

In Victoria, the Association of Bayside Municipalities (ABM), a group of councils that fringes Port Phillip Bay, released a planning framework – *Clean Stormwater* – to incorporate WSUD in municipal planning schemes (Kay *et al.*, 2004). The framework includes a model planning policy and provisions for state and local planning schemes. An amendment to the local planning scheme by Bayside City Council incorporates the framework. However, after three years, the amendment was recently approved in a modified form by the Minister for Planning and the councils are now in the process of applying the amendments to their local planning schemes. Kingston City Council, a member of the ABM, has successfully adopted principles for treating industrial developments, which involve the structural isolation of developments that are assessed through the local planning scheme (Pfitzner, 2006; Potter & RossRakesh, 2007; Walsh & Wong, 2006). Moreover, the council has pursued WSUD for infill developments and has been successful in getting a commitment from applicants to WSUD treatments despite the lack of mandatory controls under the Victoria Planning Provisions. This has been achieved by the combined use of standard conditions and negotiations with developers (P. Jumeau, pers. comm.). The City of Port Phillip and Moreland City Council are leading a group of councils committed to the sustainability assessment of development proposals, of which WSUD is a consideration. The tools, known as STEPS and SDS for residential and non-residential developments respectively, incorporate a simplified stormwater quality assessment tool (known as STORM) that is supported by Melbourne Water[3]. At this stage, the sustainability assessment tools are only voluntary for developers to use. Knox City Council is in the process of developing a WSUD policy document; in the meantime, the council has issued an interim policy requiring that all new council projects and substantial rehabilitation, renewal and upgrade projects maintain pre-development stormwater runoff levels.

[3] See www.morelandsteps.com.au and http://www.portphillip.vic.gov.au/sds.html for details on the STEPS and SDS tools, respectively.

2.2.1.2 Summary of the National Policy Landscape

It is clear that the current planning frameworks do not provide consistent nor mandatory prescriptions for WSUD. Table 1 summarises the existing frameworks for each state and territory and identifies the current gaps in the planning instruments for WSUD.

2.2.2 The Public Domain

While biofiltration has been showcased in a number of public areas throughout Australian cities, the examples can generally be attributed to innovative public-private partnerships for design and construction. In the industry focus group convened by FAWB in February 2008, a common concern raised by the participants was that there is little guidance in the form of standard drawings, specifications, and quality assurance documentation (such as inspection and testing plans) for stormwater biofiltration.

The design documentation for biofiltration systems is evolving and, perhaps in time, suitably qualified professionals will be accredited to certify the designs and constructed elements. However, in the interim, within Chapter 4 (*Practical Implementation*) of these guidelines, relevant recommendations are provided for organisations calling tenders for design and/or construction of biofiltration schemes.

2.3 PERFORMANCE TARGETS FOR BIOFILTRATION

Prescribing stormwater biofiltration in both the private and public domains requires the inclusion of suitable performance targets to ensure the reliability of the design and installation of the technology and relate to the ecology of the receiving waters.

A number of states, territories, regions and municipalities stipulate 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 mandated targets, the primary performance objective should be to ***maintain or restore runoff volumes and frequency to pre-development levels***, provided the standard of design for a biofiltration system is in accordance with Chapter 3 (*Technical Considerations*) of these guidelines. 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 (MWC, 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, 2006b), are recommended alternatives, particularly for the 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, but are 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).

Table 1. Current planning instuments addressing WSUD at the State and local scales.

Planning Instruments	Queensland	New South Wales	Victoria	Tasmania	South Australia	Western Australia	Australian Capital Territory	Northern Territory
State planning legislation	WSUD encouraged in SEQ Regional Plan. Policy reform underway.	WSUD not prescribed in legislation. Section 117 direction requires stormwater discharge considerations in LEPs.	WSUD specified only for residential subdivisions. Initiative in motion to include WSUD in 5-star building regulations.	WSUD not prescribed in legislation. WSUD guidelines prepared under the state government's Derwent Estuary Program.	WSUD not identified in planning legislation; project currently underway to create planning framework.	Statement of Planning Policy 2.9 'Water Resources' promotes WSUD in new development but not mandatory.	General Code within the Territory Plan requires WSUD within new residential development including three units or more, commercial and industrial above 5000 m^2	Policy under development with the provision of a new WSUD suburb.
Local	Various local council policies with ranging requirements (see Gaskell, 2008 for comprehensive review in SEQ).	Various Development Control Plans (see www.wsud.org for complete list); deemed-to-comply requirements at Kogarah and Parramatta Councils.	'Clean Stormwater' local planning scheme framework (ABM); Kingston City Council planning for industrial precincts and standard conditions for medium density residential developments; STEPS and SDS sustainability planning assessment tools.	Limited policy development	Limited policy development	Limited policy development	N/A	Limited policy development

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).

2.4 REFERENCES

ACT (2003). *Water ACT*. Retrieved 22 October 2008. Available at: http://www.thinkwater.act.gov.au/PDFs/water_policy.pdf.

ACT (2004). *Think water, act water*. Retrieved 22 October 2008. Available at: http://www.thinkwater.act.gov.au/permanent_measures/the_act_water_strategy.shtml#strategy_documents.

Collins, A., P. Morison and S. Beecham (2008). *Deemed to comply stormwater management requirements for Parramatta City Council*. Paper presented at the 2008 Joint Annual Conference of the NSW and Queensland Stormwater Industry Associations.

Dahlenburg, J (2005). *An overview of resources available to facilitate the planning, design and uptake of Water Sensitive Urban Design (WSUD)*. Paper presented at the NSW Stormwater Industry Association 2005 Regional Conference. Retrieved 10 June 2008, from http://www.wsud.org/literature.htm#second

DoP (2007). *BASIX Ongoing Monitoring Program: 2004–2005 Outcomes*. Sydney: NSW Department of Planning.

DPCD (2008, 17 September 2007). Victoria Planning Provisions.   Retrieved 10 June, 2008, from http://www.dse.vic.gov.au/planningschemes/VPPs/index.html

DPE (2005). Water Sensitive Urban Design: Engineering Procedures for Stormwater Management in Southern Tasmania 2005, Available at: http://www.derwentestuary.org.au/folder.php?id=208

Gaskell, J (2008). *Implementation of stormwater management design objectives in planning schemes: Assistance to local governments*. Brisbane: South East Queensland Healthy Waterways Partnership.

Hatt, B. E., A. Deletic and T. D. Fletcher (2006). Integrated treatment and recycling of stormwater: a review of Australian practice. *Journal of Environmental Management, 79*(1), 102-113.

HWP (2006). Water Sensitive Urban Design Technical Design Guidelines for South East Queensland, Available at: www.healthywaterways.org/wsud_technical_design_guidelines.html

HWP (2007). *Water sensitive urban design: Barriers to adoption and opportunities in SEQ*. Brisbane: Healthy Waterways Partnership.

Kay, E., G. Walsh, T. Wong, C. Chesterfield and P. Johnstone (2004). Delivering water sensitive urban design: Final report of clean stormwater – a planning framework, Available at: http://www.abmonline.asn.au/reports/12_1.Clean%20Stormwater%20Report.pdf

Kay, E., T. Wong, P. Johnstone and G. Walsh (2004). *Delivering Water Sensitive Urban Design through the Planning System.* Paper presented at the 2004 International Conference on Water Sensitive Urban Design, Adelaide.

Kogarah Council (2006a). Water Management Policy, Available at: http://www.kogarah.nsw.gov.au/resources/documents/part_13.pdf

Kogarah Council (2006b). Water Management Policy: Water Quality Systems Practice Note # 2 - Filtration, Infiltration, Extended detention, Permeable Pavement, Available at: http://www.kogarah.nsw.gov.au/resources/documents/Practice_note_21.pdf

Mitchell, V. G (2006). Applying Integrated Urban Water Management concepts: a review of Australian experience. *Environmental Management, 37*(5), 589-605.

MWC (2008). Water Sensitive Urban Design: Selecting a Treatment. Retrieved 19 November 2008, from http://www.wsud.melbournewater.com.au/content/selecting_a_treatment/selecting_a_treatment.asp

Pfitzner, M (2006). Stormwater Quality Precinct Planning & WSUD for Industrial Areas: Final Project Report, Available at: http://www.kingston.vic.gov.au/Files/VSAP_WSUD_Final_Report.pdf

PLA (2008). *Waterways: Water Sensitive Urban Design general code*. Retrieved 22 October 2008, from http://www.legislation.act.gov.au/ni/2008-27/current/default.asp?identifier=General+CodesWaterWays%3A+Water+Sensitive+Urban+Design+General+Code

Planning Commission WA. (2006). *State Planning Policy 2.9: Water Resources*. Retrieved 10 June 2008, from http://www.wapc.wa.gov.au/Publications/1281.aspx

Planning SA. (2008). Water Sensitive Urban Design project: Institutionalising Water Sensitive Urban Design in the Greater Adelaide Region. Retrieved 22 October 2008, from http://www.planning.sa.gov.au/go/strategy/water-sensitive-urban-design-project

Potter, M. and S. RossRakesh (2007). *Implementing water sensitive urban design through regulation.* Paper presented at the 13th International Rainwater Catchment Systems Conference and 5th International Water Sensitive Urban Design Conference, Sydney, Australia.

UPRCT (2004). Water Sensitive Urban Design Technical Guidelines for Western Sydney, Available at: http://www.wsud.org/tech.htm

Walsh, G. M. and T. H. F. Wong (2006). *Water sensitive urban design for industrial sites and precincts.* Paper presented at the 7th International Conference on Urban Drainage Modelling and the 4th International Conference on Water Sensitive Urban Design, Melbourne.

Whelans (1993). *Water sensitive urban (residential) design guidelines for the Perth Metropolitan Region: discussion paper* (No. 0646154680). Perth: Prepared by Whelans Consultants for the Department of Planning and Urban Development, the Water Authority of Western Australia and the Environmental Protection Authority.

Wong, T. H. F. (2006a). Water sensitive urban design – the journey thus far. *Australian Journal of Water Resources, 10*(3), 213-222.

Wong, T. H. F. (Ed.) (2006b). *Australian Runoff Quality: A Guide to Water Sensitive Urban Design*. Sydney, Engineers Australia.

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 begins with a brief discussion of considerations in the conceptual design stage, including guidance for linking management objectives to design, a key step in biofilter design that is often overlooked. The main components of biofiltration systems and five fundamental design configurations are presented in Section 3.4. This is followed by a discussion of the design considerations for each component as well as the overall configuration (Section 3.5). Finally, specific site and application considerations are discussed (Section 3.6).

3.2 CONCEPTUAL DESIGN

It is very 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 a number of existing useful conceptual design guidance documents and we refer the reader to these documents, in particular, the South East Queensland Healthy Waterways Partnership's Concept Design Guidelines for Water Sensitive Urban Design (Water by Design, 2009a). 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? For example, the State of Victoria requires 80, 45 and 45% load reductions of TSS, TP and TN, respectively, for new developments, while other states, such as Queensland, have treatment goals.
  - What are the local water demands?
  - What are the catchment properties? eg. size, flow rates, land use.
  - Are there any obvious sources of high pollutant loads? eg. high numbers of deciduous trees.
  - Is the site sloped? Flat? Both very sloped and very flat slopes can be challenging.
  - 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?
  - What is the space availability?
  - What are the *in situ* soil properties? eg. salinity, acidity, infiltration capacity
  - How is the urban design arranged? eg. 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 other elements of the urban environment (eg. 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.

3.2.1 Linking management objectives to design

The design of a biofilter should be governed by the objectives for the particular catchment or site. Whilst this seems like an all-too-obvious statement, there is often very little thought given to the management objectives. As a result, systems are often designed in a way that is sub-optimal for the particular requirements of the site, even if it performs well for other (perhaps less important) objectives.

For example, possible objectives 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.

The optimal design of a biofilter will be very different, depending on which objective(s) are to be met. Table 2 outlines (i) design processes and the (ii) likely design attributes for each of these objectives.

There may be other objectives that also need to be considered, such as biodiversity and public amenity. These should be identified, along with site opportunities and constraints, in an initial site inspection, with ***all stakeholders*** in attendance.

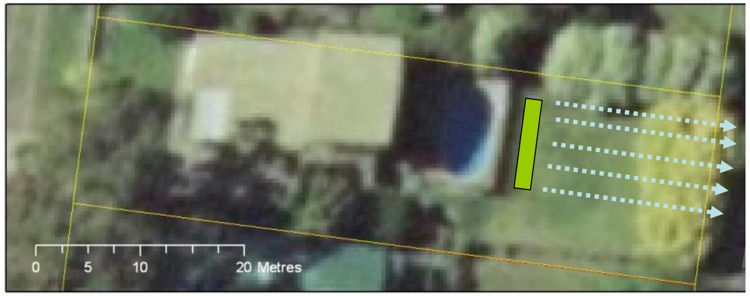
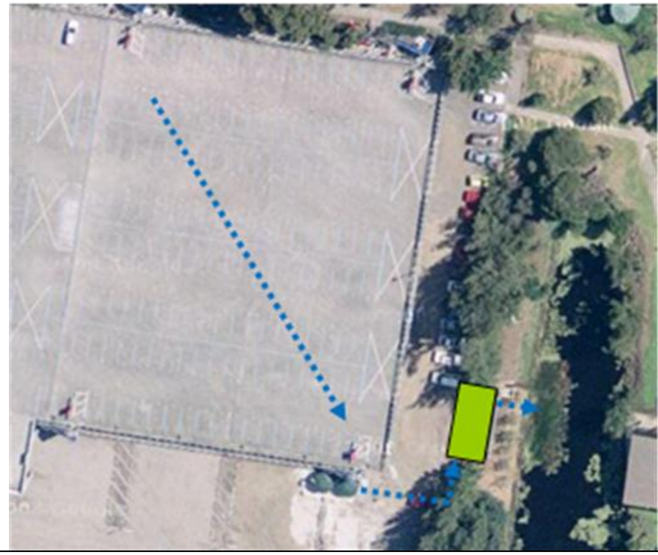
Table 2. Design procedures and design attributes of a biofilter, relative to design objectives.

Objective	Typical design procedure	Key attributes of biofilter
Water quality		
Concentrations	1. (Optionally) start with simple lookup charts for basic dimensions. 2. Model in MUSIC or similar; use Statistics or Cumulative Frequency Graphs to examine results in MUSIC. 3. Finalise design details.	1. Filter depth (enough to achieve optimal treatment) and filter type (low P index, appropriate organic matter, hydraulic conductivity, etc.) (Section 3.5.3). 2. May be lined or unlined, subject to constraints of nearby infrastructure (Section 3.5.11). 3. Submerged zone best for N removal (no significant effects for TSS, TP, metals) (Section 3.5.4). 4. Must be vegetated with optimal species for N removal (Section 3.5.12). 5. Adequate detention volume and filter area to reduce frequency of overflow (of untreated water) (Section 3.5.2).
Loads	1. (Optionally) start with simple lookup charts for basic dimensions. 2. Model in MUSIC or similar; use *Mean Annual Loads* or *Treatment Train Effectiveness*: use Mean Annual Loads or Treatment Train Effectiveness to examine results in MUSIC. 3. Finalise design details.	1. Filter depth (enough to achieve optimal treatment) and filter type (low P index, appropriate organic matter, hydraulic conductivity, etc.) (Section 3.5.3). 2. Should be unlined wherever possible, to maximise exfiltration, subject to constraints of nearby infrastructure (Section 3.5.11). 3. Must be vegetated with optimal species for N removal. (Section 3.5.4) Maximise vegetation density to maximise evapotranspiration losses. 4. Adequate detention volume and filter area to reduce frequency of overflow (of untreated water) (Section 3.5.2). Maximise filter area to maximise exfiltration.
Hydrology		
Runoff frequency reduction	1. Runoff frequency can be modelled in MUSIC (with post-analysis of the model results done in a simple spreadsheet): see Appendix B. Model is run at 6 minute timestep with results exported to Excel at daily timestep. 2. Finalise design details.	1. Must be unlined wherever possible, to maximise exfiltration, subject to constraints of nearby infrastructure (Section 3.5.11). Lining can be on one side only if necessary. 2. Must be densely vegetated to maximise evapotranspiration losses. 3. Maximise filter area to maximise exfiltration. Adequate detention volume and filter area to reduce frequency of overflow (of untreated water) (Section 3.5.2). 4. Maximise storage volume in filter; for example, consider having a deep base layer of high-porosity material (eg. scoria) to act as a 'buffer-store', particularly in the case of underlying soils with low hydraulic conductivity.

Table 2 cont...

Objective	Typical design procedure	Key attributes of biofilter
Hydrology cont...		
Peak flow reduction	1. Model in MUSIC; use <u>Statistics or Cumulative Frequency Graph</u> for flow to assess results (may choose to use Flow Threshold to remove zero or low flow periods). 2. Finalise design details.	1. Maximise <u>detention volume</u> and filter area to reduce rate of overflow (Section 3.5.2). 2. Maximise <u>storage volume</u> in filter; for example, consider having a deep base layer of high-porosity material (eg. scoria) to act as a 'buffer-store', particularly in the case of underlying soils with low hydraulic conductivity. 3. Preferably <u>unlined</u> wherever possible, to maximise exfiltration, subject to constraints of nearby infrastructure (Section 3.5.11). Lining can be on one side only if necessary.
Stormwater harvesting	1. Modelling may be undertaken in MUSIC, as for water quality (concentrations or loads), but also using <u>Mean Annual Loads</u> or <u>Treatment Train Effectiveness</u> to determine what proportion of inflow is passed to the stormwater harvesting store. To determine the proportion which is treated and untreated a flux file can be used in MUSIC. 2. Finalise design details.	1. System must be <u>lined</u> to minimise exfiltration losses (thus maximising harvested yield). 2. <u>Vegetation density should be reduced</u> in order to reduce evapotranspiration losses. Shallow-rooted plants will result in less losses (but this will need to be traded off against the reduced nitrogen treatment; the optimal solution will depend on the end-use of the water and when nitrogen removal is important). 3. The proportion of water treated should be maximised (to maximise harvested yield) by <u>maximising detention volume and filter area</u>. Where the end-use is sensitive to changes in water quality, overflows from the biofilter should not be allowed to enter the harvesting store.

3.2.2 Case Study

	Little Stringybark Creek biofiltration project		Monash stormwater harvesting system
Context:	Project undertaken as part of a large-scale catchment retrofit project to restore Little Stringybark Creek by reducing the impacts from stormwater runoff. A study of this catchment had showed that the frequency of urban runoff was a key driver of degradation.	Context:	Project undertaken by FAWB and Monash University's Water Conservation Committee to capture and treat stormwater runoff from a multi-level carpark on the Clayton campus of Monash University. The treated water would then be used irrigate an adjacent sports ground.
Objectives:	1. Reduce runoff frequency to pre-development level of 15 days per year. 2. Reduce annual loads of TSS, TP and TN loads by 80, 45 and 45% respectively. 3. Maximise biodiversity benefits.	Objectives:	1. Maximise volume of treated water available for irrigation. 2. Reduce annual loads of TSS, TP and TN loads by 80, 45 and 45% respectively.
Catchment:	System is to be built to treat a house ($265 m^2$) and surrounding paved area ($200 m^2$). Hence catchment area = $465 m^2$.	Catchment:	System is to be built to treat a paved carpark ($4500 m^2$).
			
Opportunities:	1. There is a large area available (although the property owners would prefer to minimise the amount of space lost). 2. A large lawn area below the proposed biofilter location could be used for infiltration of overflows, before it reaches the street drainage.	Opportunities:	1. There is an existing ornamental pond that can act as a store for the treated water.

	Little Stringybark Creek biofiltration project		Monash stormwater harvesting system
Constraints:	1. The underlying soils in the area have a hydraulic conductivity of around 0.1mm/hr 2. Being a private property, safety considerations must be foremost and so the extended detention depth must be kept shallow. 3. Nearby infrastructure (a swimming pool) required lining of the system on the closest side.	Constraints:	1. Available space for the biofiltration system is limited as existing tress cannot be removed. 2. Half of the carpark drains to the south; this drainage system cannot be accessed due to the slope of the site (i.e., this system is lower than the biofilter inlet).
Design process:	MUSIC was used to model the runoff frequency. A 6-minute timestep was used, and the results exported to Excel at a daily timestep. The number of days runoff was thus counted, using the Excel function "=countif(A1:A365,"0")". Designs were trialled until the target of 15 days runoff per year was achieved.	Design process:	MUSIC was used to model the pollutant removal efficiency and treated volume using a 6-minute timestep. The reduction in loads discharged to the drainage system was assessed using the Treatment Train Effectiveness at the pond, the reduction in pollutant concentrations in the irrigation water was assessed using Statistics, and the volume available for use was assessed using Mean Annual Loads.
Chosen elements:	Meeting the runoff frequency objective was much more difficult than meeting the pollutant load reduction target. Thus the design was driven by the need to reduce runoff frequency. The resulting system had the following elements: 1. An area of 11m^2, with a ponding depth of 20cm and filter depth of 80 cm. 2. The bottom 35cm of the filter was made up of scoria, to maximise the available storage in the filter. The remaining filter was made up of a loamy sand (with two transition layers – a fine gravel and a medium sand – in between the loamy sand and the scoria layer. 3. The system was <u>unlined</u>, except for the side closest to the swimming pool. 4. No underdrain was used – the system operates entirely by infiltration, since runoff frequency needed to be minimised. 5. The system was densely planted with indigenous plants to (a) maximise evapotranspiration and (b) meet biodiversity objectives.	Chosen design solution:	The system is small relative to its catchment area and therefore 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 slight drawn down. The resulting system had the following elements: 1. A surface area of 45 m^2, with a ponding depth of 25 cm and filter depth of 70 cm. 2. The filter was made up of 50 cm of loamy sand with a 10 cm transition and 10 cm drainage layer. 3. The system was fully lined to prevent exfiltration. 4. The system was densely planted with indigenous plants to (a) maximise the volume of treated water (maintain infiltration capacity) and (b) maximise pollutant removal.

Little Stringybark Creek biofiltration project	Monash stormwater harvesting system
 	

3.3 KEY DESIGN ELEMENTS

The key components that need to be specified in the technical design are (Figure 3):

1. ***Inflow 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 – controls the volume of water that is treated; and
    c. 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). They also contribute to the reduction of outflow volumes via evapotranspiration, which in turn can 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 filter media has two layers:
    a. Soil- or sand-based media , where most treatment occurs; and
    b. Transition layer, which serves to prevent washout of filter media.

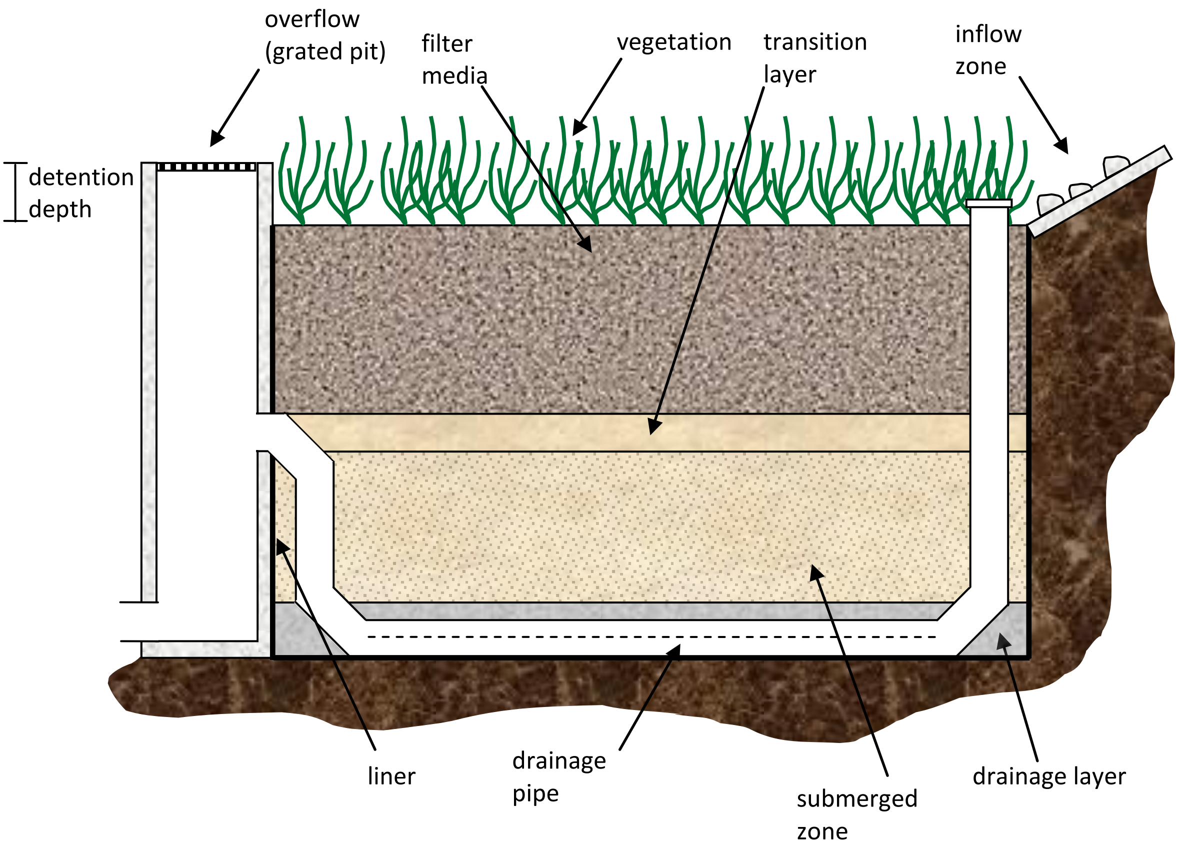


Figure 3. Main components of biofiltration systems that have to be specified.

4. ***Submerged zone***: This is comprised of a mix of medium-to-coarse sand and a carbon source, or gravel and a carbon source, and contains a permanent pool of water to support the plants and microbial community during extended dry spells, as well as to enhance nitrogen removal (because it promotes denitrification). This design element is highly recommended, however it is optional and its inclusion depends on the objectives of the system, as discussed in Section 3.2.1.

5. ***Outflow controls:*** These are structures that control how much water leaves the system, both through exfiltration (i.e., infiltration into surrounding soils) as well as direct outflow of through a drainage pipe. They incorporate the following:

    a. Liner – optional component, depending on site opportunities and constraints, which controls exfiltration of treated water into surrounding soils and/or intrusion of unwanted inflows from surrounding soils;

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

    c. Drainage pipes – quickly convey treated flows 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 3.2 and 3.2.1). The next section outlines possible system configurations, while details on how each component is designed are presented in Section 3.5.

3.4 KEY DESIGN CONFIGURATIONS

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.

IMPORTANT!

- We ***strongly*** recommend the use of biofiltration systems that have a submerged zone ***wherever possible***. It has been shown that the treatment performance of biofiltration systems without submerged zones is significantly reduced after extended dry periods. However, the presence of a permanent pool of water, or submerged zone, at the bottom of the system helps to buffer against drying as well as maintain a healthy plant community throughout long dry spells.

3.4.1 Lined biofiltration system with submerged zone

This type of biofilter is optimal for the following cases:

- Sites where exfiltration is not possible (eg. where this is a need to protect built infrastructure, or interaction with a shallow groundwater table is undesirable);
- Climates that have very long dry spells (because the submerged zone will act as a water source to support the plants and microbial community for over five weeks with no rainfall); and
- If systems are designed for NO_x removal or if receiving waters are highly sensitive to Cu or Zn.

Two possible configurations of this type of the system are given in Figure 4. The top biofiltration system contains a submerged zone created in a sand layer while the bottom system contains a submerged zone created in a gravel layer.

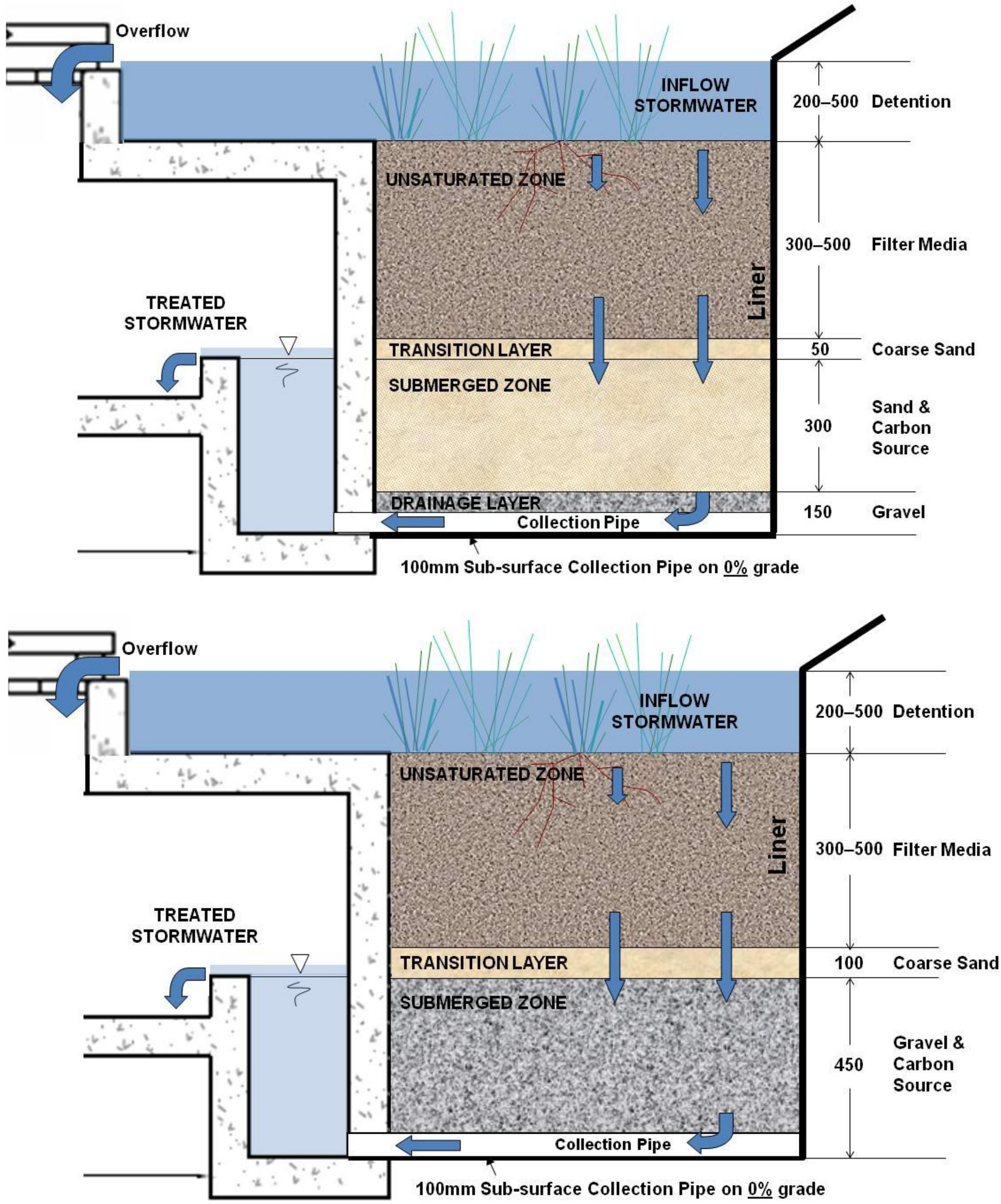


Figure 4. Lined biofiltration system with submerged zone comprised of sand (top) and gravel (bottom).

It should be noted that, in small systems, the outflow structure for treated water should be made using a simple pipe with two elbows (designed as a raised outlet), while overflow structures could be simple raised pits located within the detention pond (as in Figure 3). Only large systems require more complex outflow structures, as presented in Figure 4.

These systems can be shaped to fit into the available space and therefore can 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 needs 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.

3.4.2 Lined standard biofiltration system

This type of biofilter, whose possible configuration is illustrated in Figure 5, should be used for the following situations:

- Sites where exfiltration is not possible (eg. where this is a need to protect built infrastructure or avoid interactions with groundwater);
- 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); and
- If systems are designed for stormwater harvesting where nitrogen removal is not critical (eg. for irrigation applications).

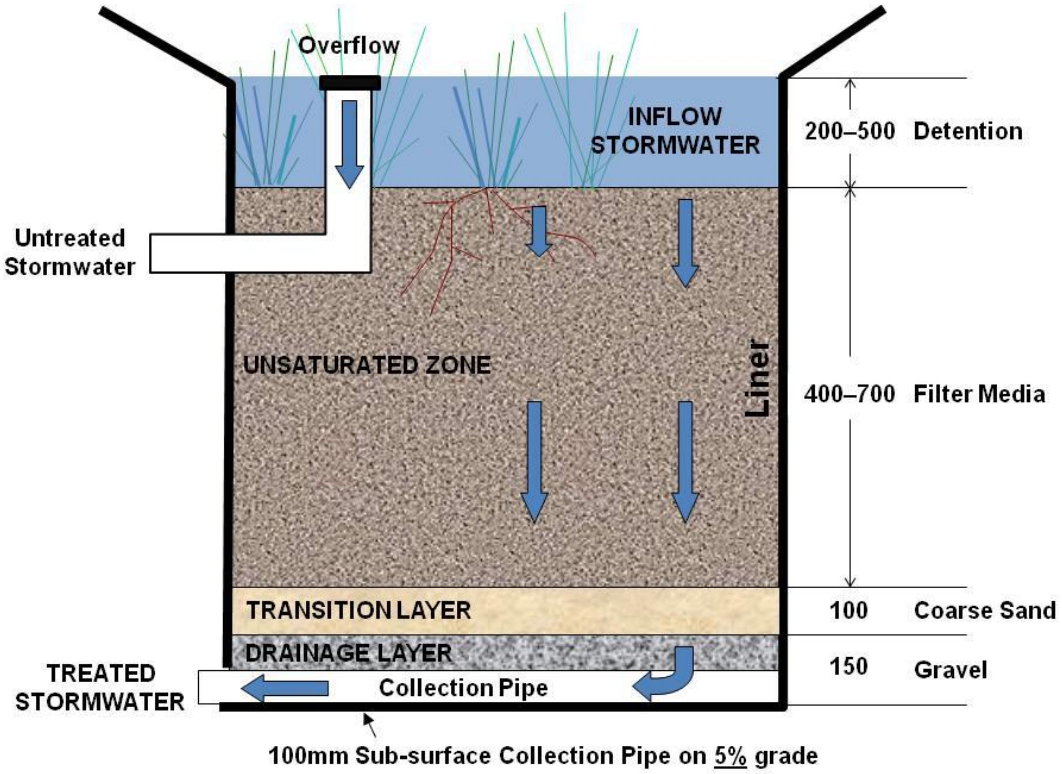


Figure 5. Lined standard biofiltration system.

These systems can be shaped to fit into the available space and therefore can 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 needs 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.

3.4.3 Unlined standard biofiltration system

This type of biofilter (Figure 6), along with the system described in Section 3.4.5, are the simplest forms of biofiltration systems to design and build. This system is highly recommended for:

- Sites where little or no exfiltration is allowed and the hydraulic conductivity of the surrounding soils is at least one order of magnitude lower than the filter media;
- 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); and
- Systems that are NOT designed for stormwater harvesting.

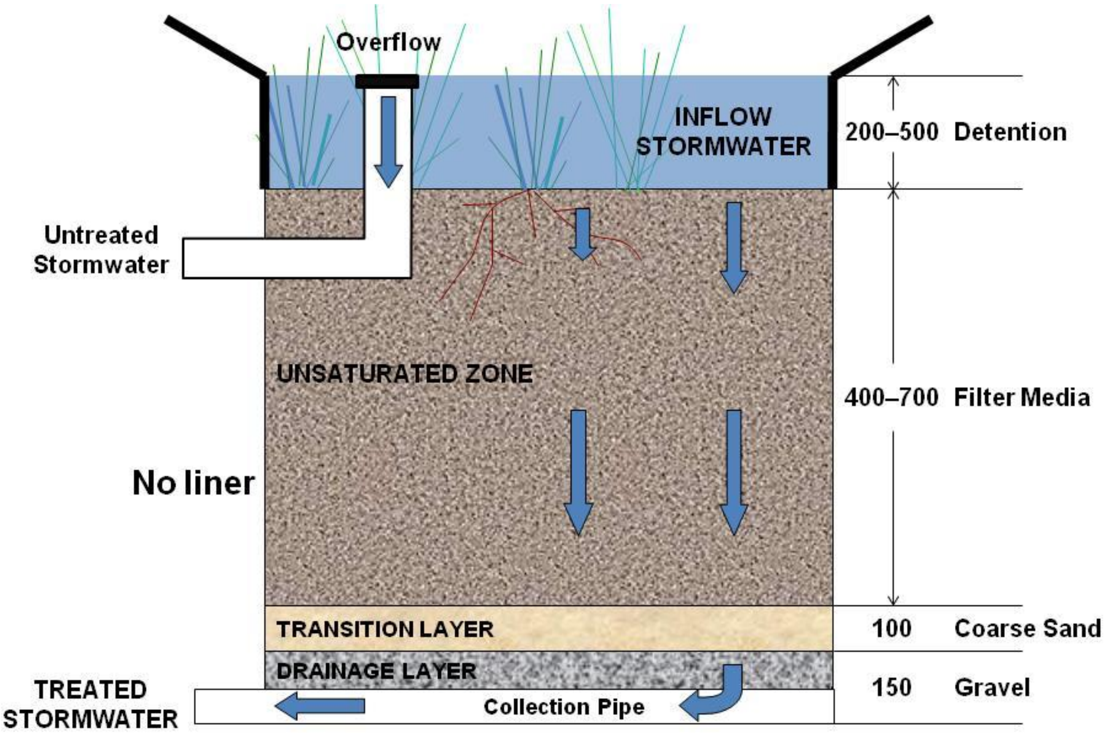


Figure 6. Unlined standard biofiltration system.

Figure 6 illustrates this type of system with a collection pipe at the bottom of the drainage layer, 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 in Section 3.5.10).

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 (eg. 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 & Mudd, 2006).

These systems can be shaped to fit into the available space and therefore can 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 needs 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.

3.4.4 Unlined biofiltration system with submerged zone

This configuration is suitable when exfiltration is allowed but the local climate is very dry (i.e., plant survival may be uncertain). However, the benefit of exfiltration will be very limited as it can only occur through the sides of the system (Figure 7). These systems are not recommended for stormwater harvesting applications.

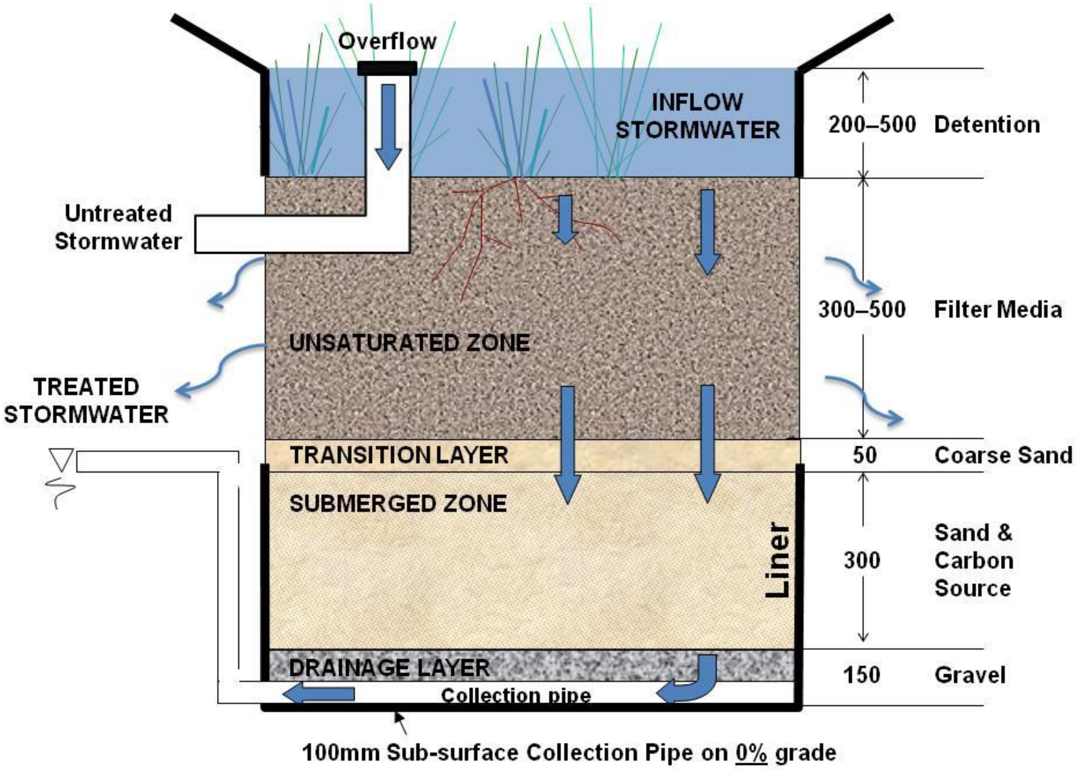


Figure 7. Unlined biofiltration basin with submerged zone

It is important to note that, even though this system is defined as unlined, the bottom and sides of the submerged zone still need to be lined in order to maintain a permanent 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 (eg. side butting up against road).

These systems can be shaped to fit into the available space and therefore can 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 needs 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.

3.4.5 Bio-infiltration system

This type of biofilter is a hybrid of the better known standard biofiltration systems and infiltration systems (Figure 8). It is highly recommended for:

- Sites where exfiltration is allowed;
- Providing both water quality improvement and reduction in runoff volumes; and
- Systems that are NOT designed for stormwater harvesting.

The only difference between standard biofiltration and bio-infiltration systems is that bio-infiltration systems do not contain a collection pipe in the drainage layer. Instead, this layer doubles as a detention layer where treated water is temporarily stored before exfiltrating to the surrounding soils. This configuration will help to improve the hydrology of receiving waterways by infiltrating stormwater at or near the source. 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 the surrounding soils have a good infiltration capacity.***

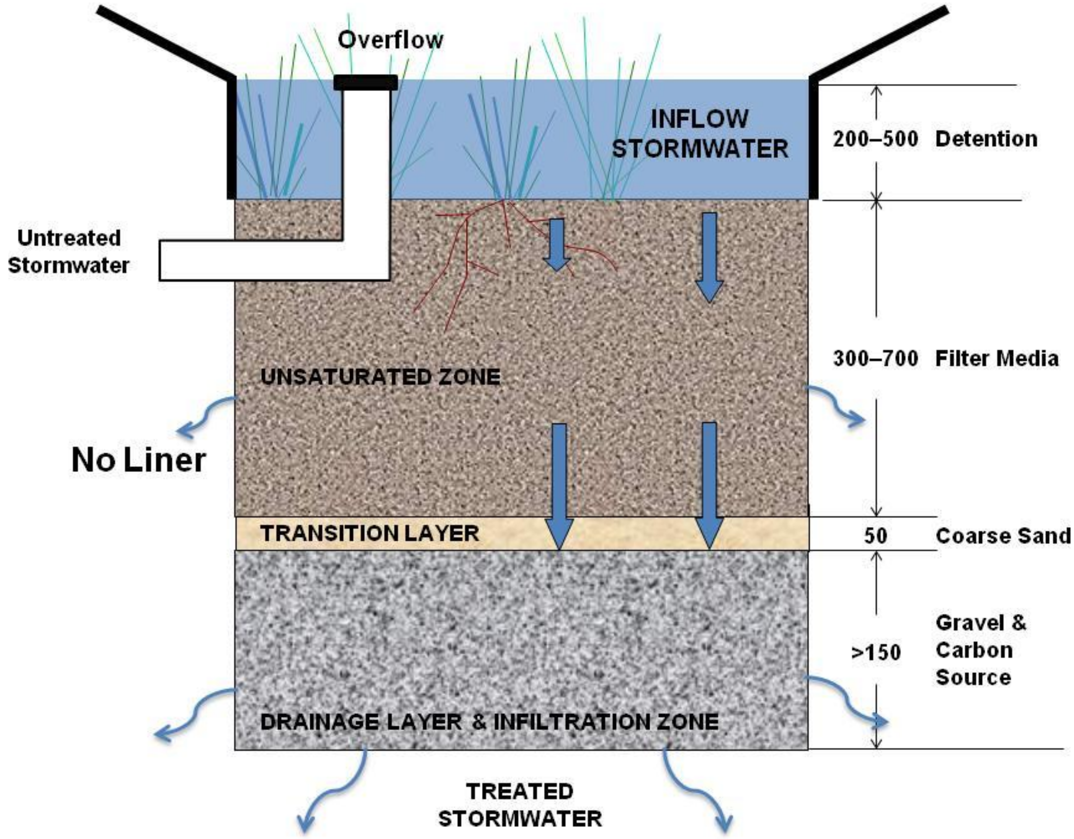


Figure 8. Schematic of a bio-infiltration system.

It is important to note that bio-infiltration systems can still have a submerged zone. 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 9.

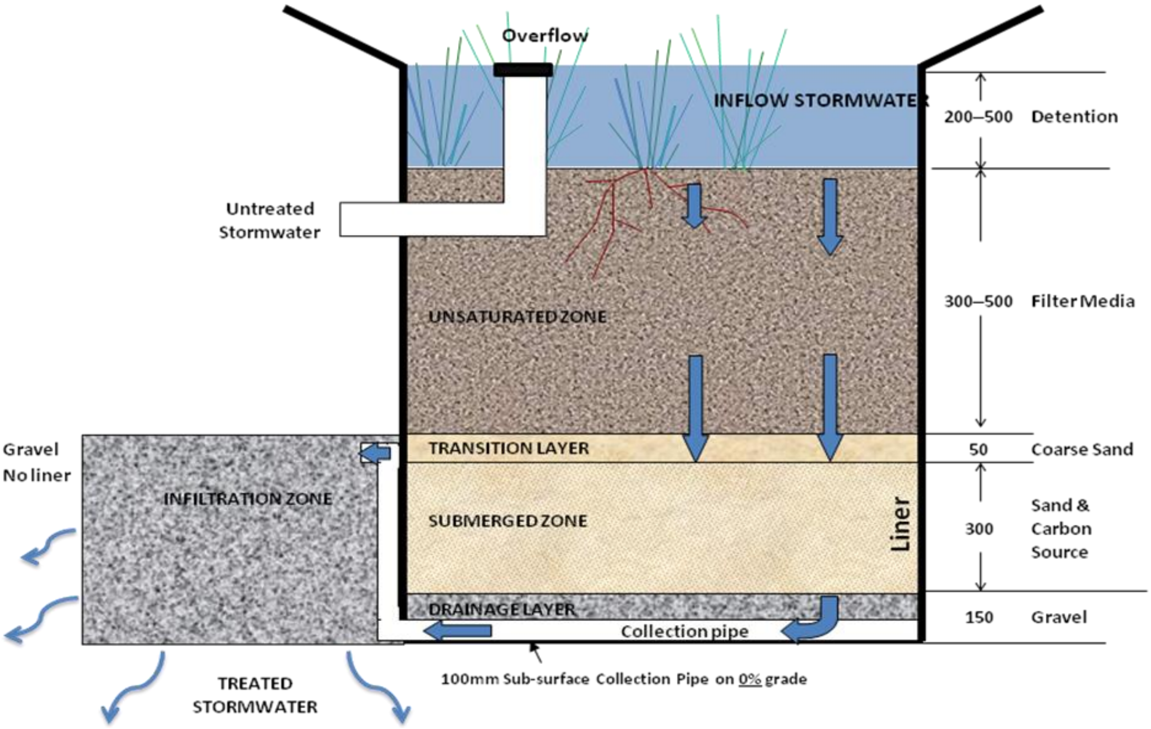


Figure 9. Schematic of a bio-infiltration system containing a submerged zone.

These systems can be shaped to fit into the available space and therefore can be built as simple trenches or basins. They can also be constructed as "on-line", conveyance (commonly referred to as bio-infiltration swales) or "off-line", non-conveyance (known generally as bio-infiltration basins) systems. Bio-infiltration 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 needs to be considered when designing the inflow and overflow zones. However, all other design elements are specified in the same way as for bio-infiltration basins.

3.5 DESIGN PROCEDURE

The general procedure for the design of a biofiltration system is illustrated in Figure 10. The components that control the volume of water that can be treated (filter surface area, extended detention depth, filter media hydraulic conductivity) and the level of treatment (filter media characteristics, vegetation, presence/absence of a submerged zone) are specified first, then the inflow and outflow controls are designed.

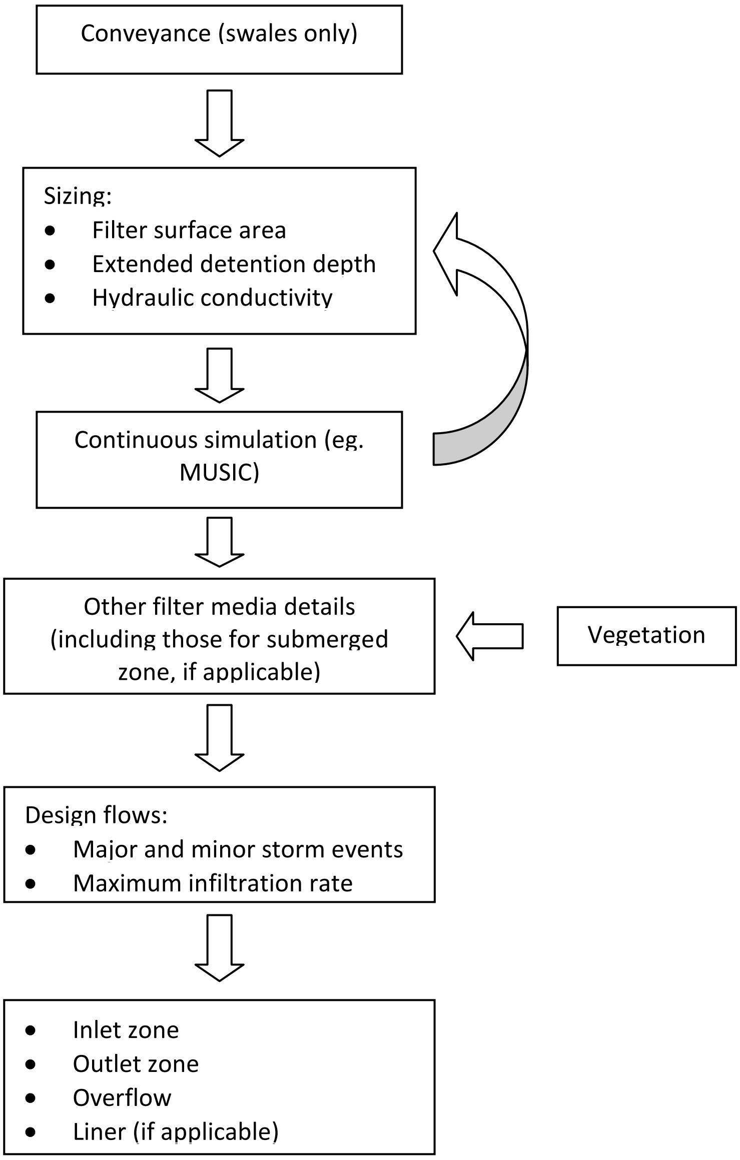


Figure 10. Procedure for specifying the components of a biofiltration system.

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

3.5.1 Conveyance

The swale component needs to be designed 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.

3.5.2 Sizing

The required size of a biofiltration system could be determined using performance curves such as those provided in the Water Sensitive Urban Design Technical Design Guidelines for South East Queensland (BCC & MBWCP, 2006), where the surface area can be selected according to the extended detention depth and desired pollutant removal performance. Note that performance curves representative of the local climate should be used; similar curves exist for most States and

Territories. However, the volumetric treatment (infiltration) capacity of a biofiltration system is also a function of the hydraulic conductivity of the filter media, and so this should also be considered in determining the size.

As a starting point, a biofiltration system with a surface area that is 2% of the impervious area of the contributing impervious catchment, an extended detention 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. 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 detention 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.

This preliminary design should be refined and adjusted as necessary using a continuous simulation model. See Appendix B for guidance on sizing using MUSIC.

☝ DESIGN TIPS

- Design and model based on K_s of ***half*** the design 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
- Ideas to increase effective size
  - Break up the catchment if space is limited
  - Increase ponding depth (use novel design to ensure safety)
- Consider hydrologic effectiveness during design

3.5.3 Filter Media Selection

1. Specify filter media type

Suitable filter media should be selected using the criteria described in FAWB’s Guidelines for Filter Media in Biofiltration Systems (see Appendix C version 3.01, noting that the ***most recent version*** of these guidelines should always be used). While other filter media types may be suitable, they should not be used unless their long-term hydraulic and pollutant removal performance has been tested ***prior*** to installation.

Guidance on additives:

- Exploded minerals

Use of exploded minerals, such as vermiculite and perlite, to boost the cation exchange capacity of the filter media have not been shown to have any short-term benefits in terms of pollutant removal, largely because the pollutants they are designed to target (heavy metals) are already effectively removed by all filter media types suitable for biofiltration systems. While vermiculite and perlite may play a role in the long-term retention of heavy metals, this can only be demonstrated through long-term testing and so remains a hypothesis. However, the porosity and stable structure of these materials has been shown to be useful in maintaining the infiltration capacity of the filter media during the establishment phase (Hatt *et al.*, 2009). For this reason, incorporation of exploded minerals into the filter media (10 – 20% by volume) could be considered. Note that mixing would need to be carried out on-site due to the different densities of the materials and that a 50 mm 'cap' of plain filter media should be used as exploded minerals float.

- Organic matter

It may be desirable to increase the organic content eg. to support particular plant growth (landscape requirements). In such cases, it is important to ensure that the nutrient content of the organic matter is kept low to avoid nutrient leaching (see Appendix C). It may also be appropriate to provide a layered structure, where only the top layers of the filter media have a higher organic content.

- Commercial products

Commerically available products with high adsorption capacities that target specific pollutants, such as activated carbon (heavy metals) and Phoslock (phosphorus), might also be considered, but the benefits of these products should be weighed up against their cost, durability and sustainability (eg. manufacture, transport).

DESIGN TIPS

- Typical K_s range: 100 – 400 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

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 meets the required specifications (see Appendix C).

2. Specify filter media depth

The depth of the filter media can vary and will be partially determined by site conditions and landscape requirements. As a guide, the typical filter depth range is 400 – 600 mm, excluding the transitions and drainage layers. The minimum depth required to support plant growth (groundcovers, grasses, sedges, rushes, small shrubs) and ensure adequate removal of heavy metals (Hatt *et al.*, 2008) is 300 mm, while a depth of 800 mm is recommended for tree planting.

3.5.4 Submerged Zone

1. Submerged zone material

The submerged zone should be comprised of a mix of medium-to-coarse sand and carbon or a mix of fine gravel and carbon. The carbon source should be a mix of 5% mulch and 5% hardwood chips (approximately 6 mm grading), by volume.

2. Submerged zone depth

A depth of 450 mm has been shown to be optimal (Zinger *et al.*, 2007), however the feasibility of this will be determined by site conditions. A minimum of 300 mm is required for this zone to be effective.

IMPORTANT!

- A submerged zone with a depth of 300 mm will protect against drying for up to ***five weeks of continuous dry weather***. For climates where longer dry periods are likely, the depth of the submerged zone should be increased by ***120 mm for every additional week of dry weather***. Where this is not feasible, the submerged zone should be as deep as possible and filled up as required, either via surface irrigation or direct filling. For example, if the maximum possible depth is 300 mm but the biofilter is likely to experience seven weeks of dry weather (so the ideal depth is 540 mm), the submerged zone would need to be filled after five weeks.
- A 50 mm layer of plain sand i.e., not mixed with mulch and woodchips, should separate the filter media and the submerged zone to prevent the filter media from becoming permanently saturated, which may lead to leaching of pollutants, particularly nutrients.

DESIGN TIPS

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

  98 L sand (by volume)

  500 g readily biodegradeable material such as sugar-cane mulch (preferably low in nitrogen and phosphorus)

  1.5 kg hardwood chips

SUSTAINABILITY TIP

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

3.5.5 Design Flows

Estimate the following design flows:

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 biofiltration system (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 (i.e., contributing catchment area <50 ha), use the Rational Method to estimate minor and major flows. For large systems (i.e., contributing catchment area >50 ha), use runoff routing to estimate minor and major flows.

3.5.6 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.

Refer to local guidelines for design procedures for inlet zones. Refer also to local council regulations to ensure that their requirements for flow widths, etc. are met.

If inflows enter the biofiltration system over a flush kerb (distributed system), an area is needed for coarse sediments to accumulate (to avoid buildup and subsequent unintended diversion of flows around the system). This can be achieved by having a step down, where the vegetation and the 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 11).

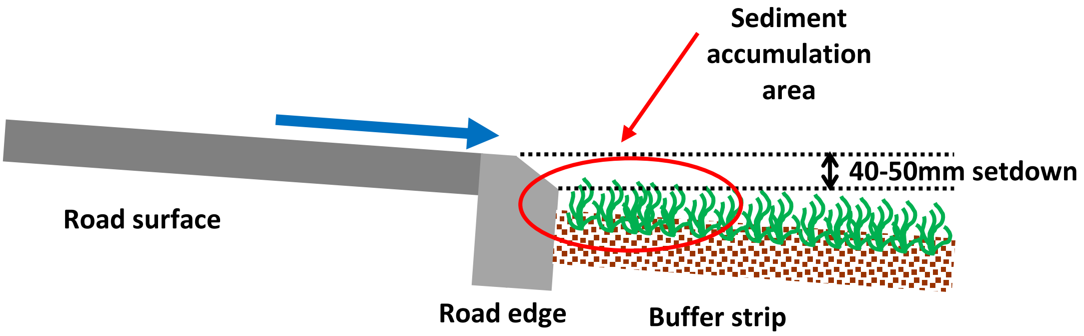


Figure 11. Edge detail of biofiltration inlet zone showing setdown (source: Melbourne Water, 2005).

If the entry point(s) for flows are concentrated, an energy dissipator 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 12 & Figure 13);

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 13); and

c) Surcharge pit – where piped inflows can be brought to the surface. Surcharge pits need to have drainage holes at the case to avoid standing water (Figure 14) and must be accessible so that any accumulated sediment can be removed. A removable geotextile layer aids cleaning of accumulated sediment (Figure 14).

☝ DESIGN TIP

- Consider the need for maintenance access when designing energy dissipation structures.

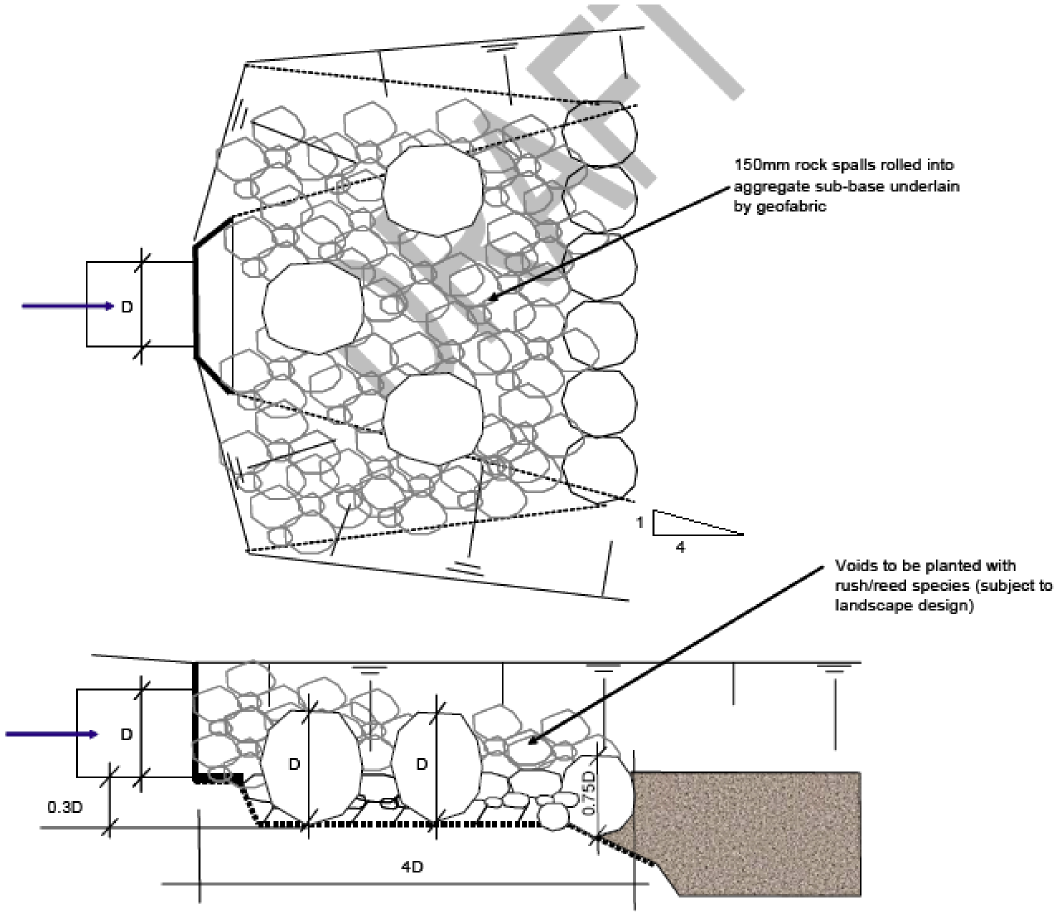


Figure 12. Rock beaching for scour protection in a biofilter receiving piped flows, where D represents the pipe diameter (source: BCC & MBWCP, 2006).

Figure 13. 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.

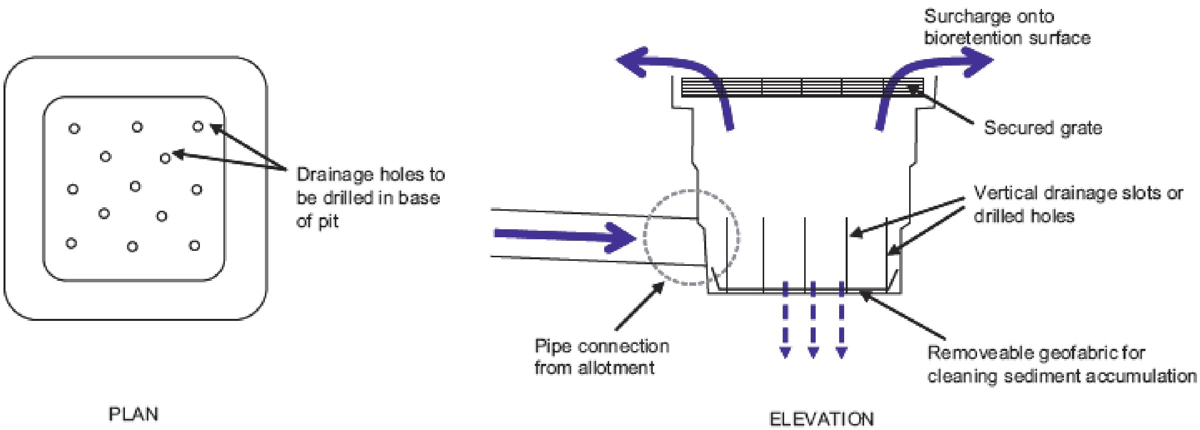


Figure 14. Surcharge inlet pit containing drainage holes at base of pit and removable geotextile layer for cleaning accumulated sediment (source: Melbourne Water, 2005).

IMPORTANT!

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

3.5.7 Overflow Zone

Design of the overflow zone is different for biofiltration basins and biofiltration swales. Where possible, minor floods should be prevented from entering a biofiltration basin to prevent scour and erosion, however the feasibility of this will depend on site conditions. 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, an normal side entry pit may be located immediately downstream of the inlet to the basin (Figure 15), to act as a bypass. When the level of water in the basin reaches the maximum extended detention 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 15).

Figure 15. 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 extended detention 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.

3.5.8 Transition Layer

1. Transition layer material

The transition layer material shall be a clean, well-graded sand material containing <2% fines. To avoid migration of the filter media into the transition layer, the particle size distribution of the sand should be assessed to ensure it meets 'bridging criteria', that is, the smallest 15% of the sand particles bridge with the largest 15% of the filter media particles (Water by Design, 2009b; VicRoads, 2004):

D_{15} (transition layer) ≤ 5 x D_{85} (filter media)

where: D_{15} 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} is the 85th percentile particle size in the filter media.

A dual-transition layer, where a fine sand overlays a medium-coarse sand, is also possible. While it is acknowledged that this can increase the complexity of the construction process, testing indicates that a dual-transition layer produces consistently lower levels of turbidity and concentrations of suspended solids in treated outflows than a single transition layer. Therefore, it is recommended that this design be specified for stormwater harvesting applications (to enable effective post-treatment disinfection) and where minimising the risk of washout during the establishment period is of particular importance.

2. Transition layer depth

The transition layer depth shall be a minimum of 100 mm.

Note: The transition layer can be omitted from a biofiltration system provided the filter media and drainage layer meet the following criteria as defined by the Victorian Roads *Drainage of Subsurface Water from Roads - Technical Bulletin No 32* (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)

These comparisons are best made by plotting the particle size distributions for the filter media and gravel on the same soil grading graphs and extracting the relevant diameters (Water by Design, 2009).

3.5.9 Drainage Layer

1. Drainage layer material

The drainage layer material is to be clean, fine gravel, such as 2 – 5 mm washed screenings. The drainage layer is to be clean, fine gravel, such as a 2 – 5 mm washed screenings. Bridging criteria should be applied to avoid migration of the transition layer into the drainage layer (Water by Design, 2009b; VicRoads, 2004):

D_{15} (drainage layer) ≤ 5 x D_{85} (transition layer)

where: D_{15} (drainage layer) is the 15th percentile particle size in the drainage layer material (i.e., 15% of the gravel is small than D_{15} mm), and
D_{85} (transition layer) is the 85th percentile particle size in the transition layer material.

SUSTAINABILITY TIP

- Materials such as crushed recycled concrete may also be appropriate for the drainage layer, however they ***must*** be washed i.e., not contain fine particles that could wash out of the drainage layer, negating solids removal and/or potentially block underdrain pipes.

2. Drainage layer depth

For standard biofiltration systems (i.e., no submerged zone):

Where there is an underdrain present, the depth of the drainage layer will be determined by the underdrainage pipe diameter, minimum pipe cover, the slope of the underdrain and the length of system being drained. In general, the minimum pipe cover of the gravel drainage layer should be 50 mm (to avoid ingress of the sand transition layer into the pipe). For example, for a biofiltration system with an underdrainage 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 16).

Where there is no underdrain, the gravel drainage layer acts also as a 'storage zone', to permit water to be stored during a storm event, and then released into underlying soils via exfiltration. In this case, the depth of the gravel layer should be determined using modelling, to determine the required depth to ensure required targets (eg. reductions in pollutant load, runoff volume and/or frequency) are met (Figure 17). As a general guide, the storage zone needs to be at least as large as the extended detention 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).

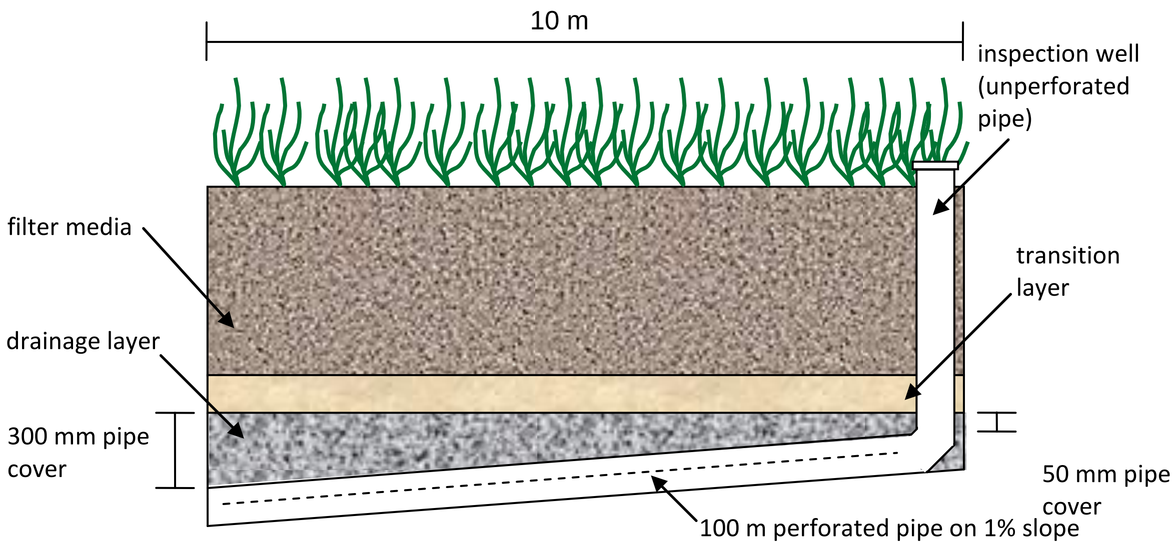


Figure 16. Long-section of a biofiltration system showing variable drainage layer depth.

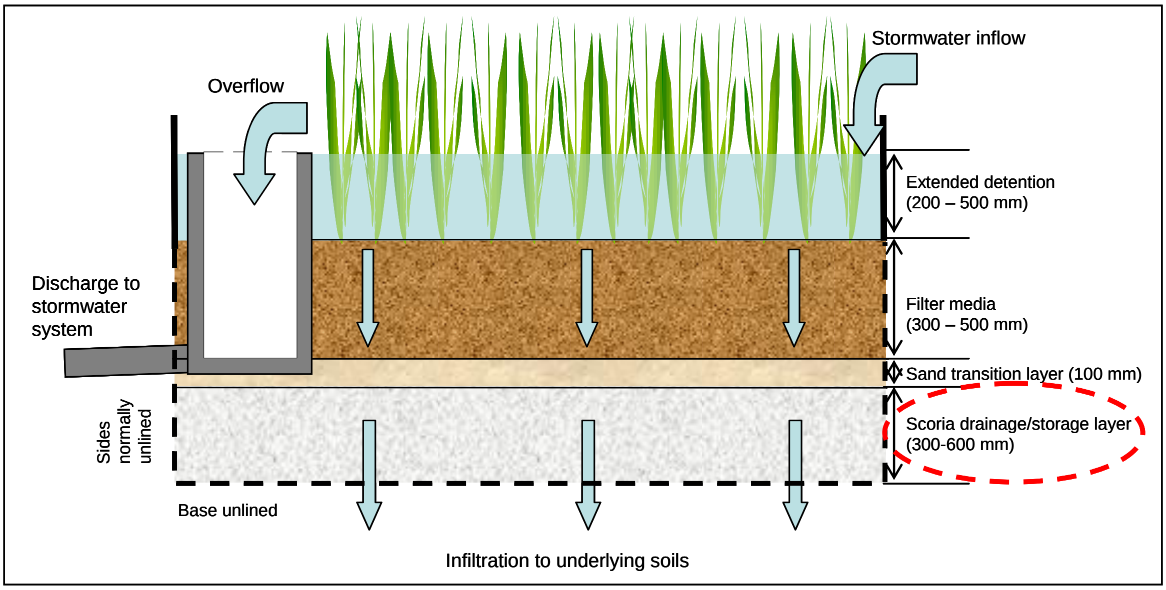


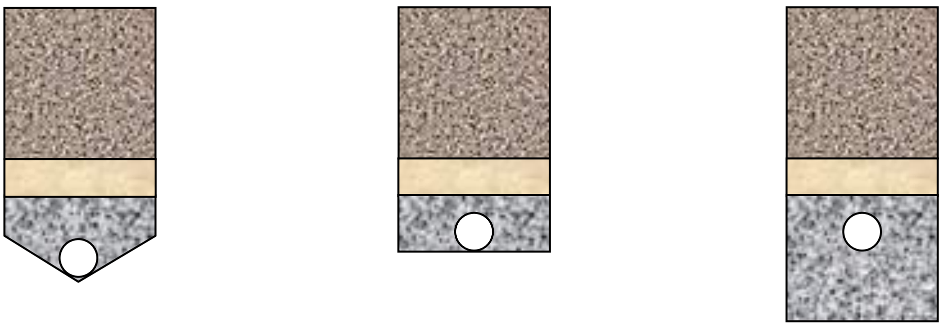
Figure 17. Use of the gravel drainage layer as a storage zone in a biofiltration system without underdrain.

For biofiltration systems containing a submerged zone:

The depth of the drainage layer in a biofiltration system with a submerged zone will be determined by the underdrainage pipe diameter and minimum pipe cover. In general, where the submerged zone material is sand-based, the minimum pipe cover by gravel should be 50 mm, to avoid ingress of the sand transition layer into the pipe. Where the submerged zone material is gravel-based, this also serves as the drainage layer (Figure 4, bottom).

DESIGN TIP

- Shaping the of 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 (right, see Section 3.5.10 for further details on this latter configuration).



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. An open-weave shade cloth can be placed between the filter media and the drainage layer to help prevent the downward migration of smaller particles if required, however this is only recommended where there is insufficient depth for a transition layer. A geotextile can be used to line the walls, but this is not considered necessary in most cases.

3.5.10 Underdrain

For lined standard biofiltration systems:
Slotted PVC pipes are preferable to flexible perforated ag-pipe, as they are easier to clean and ribbed pipes are likely to retain moisture which may attract plant roots into pipes. 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 16). 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) Material in the drainage layer will not wash into the perforated pipes.

For unlined standard biofiltration systems with underdrain:
In order to promote exfiltration, 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 18). However, the collection pipe must still be sized to convey the maximum infiltration rate in the same way as for lined standard biofiltration systems, to ensure that the system will be operational even without exfiltration (i.e., in case the bottom of the system clogs).

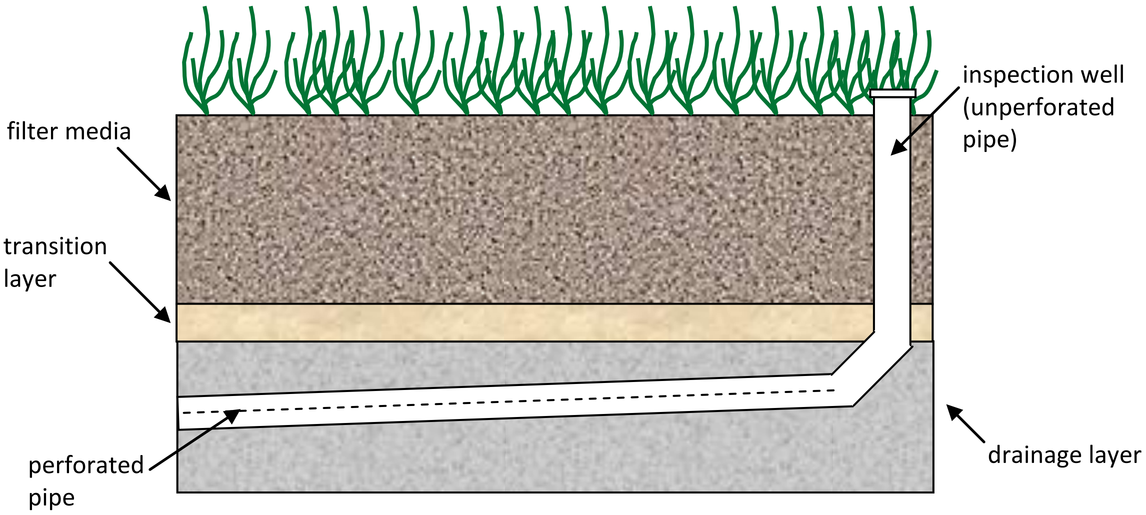


Figure 18. Long section of a biofiltration system showing collection pipe raise above bottom of drainage layer to promote exfiltration. Note series of 45° elbows rather than 90° elbows, to facilitate entry of maintenance equipment (eg. pipe snake or water jet).

For biofiltration systems containing a submerged zone:

There are two possible configurations for an underdrain in a biofiltration system with a submerged zone:

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 19). The collection pipe(s) does not need to be sloped as the outlet is elevated. Slotted PVC pipes are preferable to flexible perforated ag-pipe, as they are easier to clean and ribbed pipes are likely to retain moisture which may attract plant roots into pipes, however this necessitates a drainage layer to ensure that finer material from the filter media and transition layers are not washed into the collection pipe(s). The upstream end of the collection pipe should extend to the surface to allow inspection and maintenance; the vertical section(s) of the pipe should be unperforated and capped. 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 it does not become a choke in the system.

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

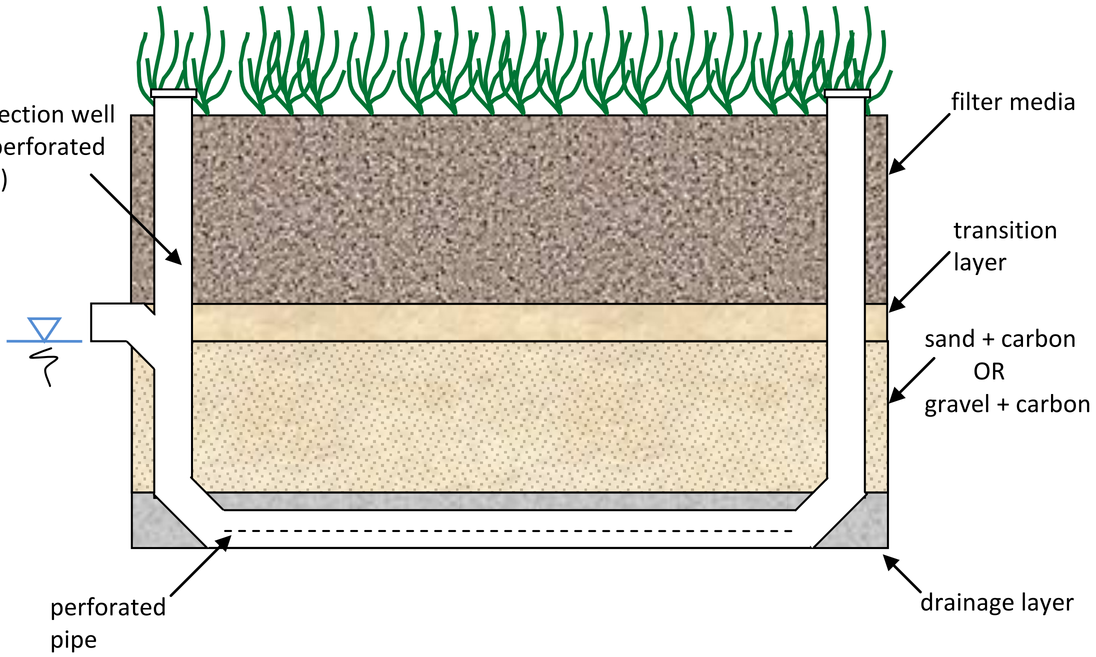


Figure 19. Long section of a biofiltration system with a submerged zone showing collection pipe and riser outlet (Note that, in this system, the transition layer is between the filter media and submerged zone). Note series of 45° elbows rather than 90° elbows, to facilitate entry of maintenance equipment (eg. pipe snake or water jet).

2. Riser outlet only (no perforated pipe)

A collection pipe is not strictly necessary in a biofiltration system with a submerged zone; inclusion of a riser outlet confines exit flow to be via this path and the drainage layer can act as a surrogate collection pipe (Figure 20). 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.

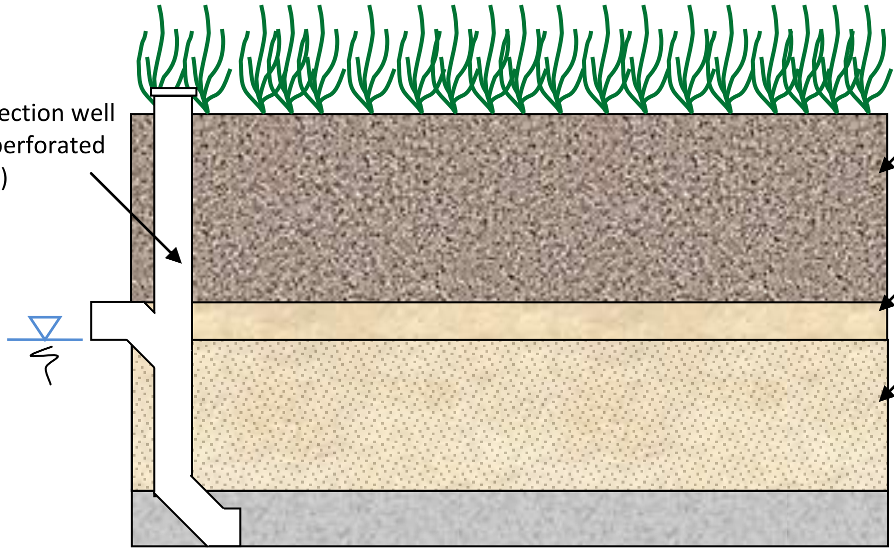


Figure 20. Long section of a biofiltration system with a submerged zone showing riser outlet (Note that, in this system, the transition layer is between the filter media and submerged zone). An appropriate screen should be placed over the outlet pipe entry in the drainage layer, to prevent ingress of gravel.

> **DESIGN TIP**
>
> - The perforations in the collection pipes should be small enough that the drainage layer cannot fall into the pipes. A useful guide is to check to that the D_{85} (drainage layer) is greater than the pipe perforation diameter.
> - Use 45^{o} connectors to soften the bends in the collection pipe(s) for easier maintenance access.
> - Place screen over entry into outlet pipe in gravel drainage layer, to avoid ingress of gravel into pipe.

3.5.11 Liner

The following are feasible options for lining a biofiltration system, 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 native soil is 1 – 2 orders of magnitude less than that of the filter media) flow will preferentially be vertical to the underdrain and little exfiltration will occur. 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 will preferentially be vertical and there is little opportunity for exfiltration through sides of the system.

IMPORTANT!

- For an unlined biofiltration system with a submerged zone, the bottom and sides of the submerged zone still need to be lined in order to maintain a permanent pool of water.

DESIGN TIP

- 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.

3.5.12 Vegetation

1. Specify vegetation type

Plants are essential for ensuring effective removal of nutrients, particularly nitrogen, as well as for maintaining the long-term infiltration capacity of biofiltration systems. However, some species are more effective than others in their ability to adapt to the conditions within a biofilter, along with their influence on the nutrient removal and hydraulic conductivity of the biofilter.

a) Prepare potential species list

A list of potentially suitable species should be drafted; desirable plant traits for nutrient removal are listed in Table 3. Other useful sources of information include local plant experts, local council, nurseries, and reference books. Potentially suitable species may be native or introduced; this will determined by biodiversity considerations, site conditions, design objectives (eg. treatment, habitat creation), and the surrounding landscape (eg. aesthetic considerations, shade). It is important to note that the example plants listed in **Table 3** are not meant to be exhaustive or exclusive. Other plants which share the same desirable traits are likely to be appropriate. However, we recommend wherever possible that at least 50% of the plants be made up of Type A plants, that is, plant species that have been shown to be effective for nutrient removal (**Table 3**). Where possible, these should be evenly spread across the biofilter surface, to ensure optimum performance.

In terms of maintaining infiltration capacity, results from field-scale testing suggests that any plant species will be useful. However, if this issue is of particular concern, it is recommended that plant species with thick roots, such as *Melaleuca ericifolia*, be specified.

Table 3. Desirable plant traits for biofiltration systems and example plants (Bratieres *et al.*, 2008; Read *et al.*, in press).

Objective	Desirable traits	Example plants	
		Type A*	Type B*
Nutrient removal	• High relative growth rate • High total root, leaf & shoot biomass • High root density • High root: shoot ratio • High length of longest root • High leaf area ratio	• *Carex appressa* • *Melaleuca ericifolia* • *Goodenia ovata* • *Ficinia nodosa* • *Juncus amabilis* • *Juncus flavidus*	• *Microlaena stipoides* • *Dianella revoluta* • *Leucophyta brownii* • *Lomandra longifolia* • *Banksia marginata* • *Pomaderris paniculosa*

*Type A plants have been demonstrated to be effective for removal of nutrients, while Type B plants have been shown to be non-effective for nutrient removal.

☝ **DESIGN TIP**

- Use Type A plants wherever possible to ensure effective nutrient removal (see **Table 3** for further details).
- If maintaining a high infiltration capacity is of particular importance, specify inclusion of *Melaleuca ericifolia*.

Where there is a desire to use a plant species other than Type A plants (**Table 3**), or if it is known that Type A plants listed will not grow well in the local climate, the information in Figure 21 can be used to screen potentially useful plant species and compare their expected performance against the tested range. These graphs illustrate the relationship between a number of key plant root traits and total nitrogen phosphorus concentrations in biofilter effluent. Selection of plant species using this approach should be conducted in consultation with a local plant expert. It is suggested that the percent root mass is the most useful trait, as it is the characteristic for which there is already information available or is most easily acquired. For the purposes of direct comparison, it is noted that the plant characteristics illustrated below are for plants that were approximately eleven months old.

b) Assess hydrologic requirements

Suitable species for biofiltration systems need to be tolerant of drought, freely draining filter media and variable periods of inundation.

c) Growth form

Suitable species should have extensive root structures and should not be shallow rooted. Ideally the roots should penetrate the entire 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).

d) Other

Depending on the site conditions, other possible issues that might need to be considered include frost tolerance, shade tolerance, and landscape requirements (eg. height restrictions). Non-invasive species should always be specified.

e) Hydraulic conductivity of filter media

If a filter medium with a high hydraulic conductivity is specified, specialised plant species are likely to be required (i.e., very drought tolerant), unless a submerged zone is included.

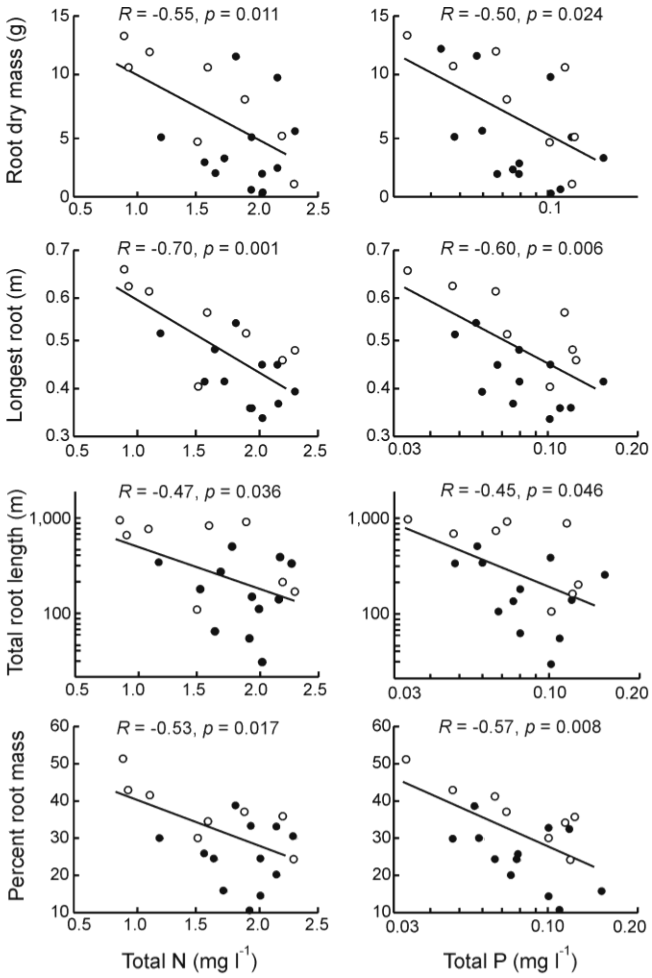


Figure 21. Correlations of plant root traits with total nitrogen and phosphorus concentrations in biofilter effluent. The results of Pearson correlation are given. Note: some axes are $\log_{10}$-transformed. Monocots, open symbols; dicots, filled symbols (after Read *et al.*, in press).

SUSTAINABILITY TIP

- Consider biodiversity and habitat creation when specifying vegetation. In this instance, at least 50% of plants should made up of Type A species (see **Table 3**), while the remainder should be specified according to the design objective.

2. Other design considerations

- Planting density

The overall planting density should be high (at least 10 plants/m^2 for sedges and rushes) to increase root density, 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. One exception to this recommendation may be the case where the biofilter is providing pre-treatment for a stormwater harvesting system. In that case, it may be desirable to reduce evapotranspiration by minimising plant densities. However, caution should be applied in this case, because very low densities will increase the likelihood of weed invasion.

- Zoning in large systems

In large biofiltration systems, 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. Conversely, plants near the inlet may be frequently inundated, and potentially impacted by higher flow velocities, and so plants capable of tolerating these conditions should be selected.

- Range of species

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.

- Layout of planting

Dominant species 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.

- Mulch

The use of an organic mulch should generally be avoided for systems where there is an overflow pit, due to the risk of clogging. In the case of bio-infiltration, a mulch may be used, however there is still a risk of excessive movement of material during high flows. A gravel mulch may be used where there is a need to protect the soil from erosion or decrease the drop to the ponding zone (for safety reasons), whilst still maintaining an acceptable ponding volume (see Section 3.6.1). However, high planting densities should be used, to compensate for the reduced spread of plants caused by the gravel mulch.

3. Timing for planting

In temperate climates, planting should be undertaken generally 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. Local botanists or nurseries should be consulted.

3.6 OTHER CONSIDERATIONS

3.6.1 General

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

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

- For vehicular traffic: where there is the likelihood of vehicles mounting the kerb (eg. on a bend), concrete edge restraints should be used, although these may not be required on traffic buildouts where landscaping is behind the kerb.

Pre-treatment (clogging prevention): the need for this will be determined by the size of the bioifltration system and the expected sediment load i.e., systems that are small relative to the size of their catchment or where sediment concentrations are high should include some sort of pre-treatment measure (eg., sedimentation pond, buffer strip, sedimentation pit/tank, sediment forebays) to protect against premature failure due to clogging. Care should be taken to identify any potential sources of high pollutant loads (eg. non-vegetated or damaged existing treatment systems, unsecured batters, high numbers of deciduous tress). In the case of biofiltration swales, the swale component is likely to provide sufficient pre-treatment to protect the biofiltration component.

Other:

- Safety – eg. maintaining clear sightlines for traffic and pedestrians
- Consider owners of other infrastructure – will maintenance of these assets impact on the biofiltration system? Will installation of a biofiltration system adjacent to other infrastructure impact access to these assets? (see Section 3.6.2 for further discussion)
- In some cases, local planning and development guidelines conflict with WSUD (eg. kerb type) – as discussed in Chapter 2 (*Planning for Biofiltration*) these documents are likely to be reviewed as WSUD becomes more mainstream, however, in the meantime, conflicts might need to be resolved on a case-by-case basis.
- Effective use of available space - breaking up the catchment

IMPORTANT!

- Steep slopes can be difficult due to high flow velocities, which can lead to scour and erosion problems. Where slopes are steep, it is critical that inflows are tightly controlled. Additionally, the use of linear systems that incorporate check dams to restrict flow velocities may be more useful than basins. Where slopes exceed 5%, biofiltration swales are unlikely to be a feasible stormwater management option.
- It is ***strongly recommended*** that biofilters are vegetated, as plants have been demonstrated to play a key role in preventing nutrient leaching and maintaining infiltration capacity. Further, it is unlikely that non-vegetated soil-based filters will remain so; rather, they will be populated by weeds.
- For larger bioretention systems, a maintenance access track for maintenance vehicles (eg. 4WD ute) should be provided to the full perimeter of the system for maintenance efficiency and ease.

3.6.2 Interaction with services

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

DESIGN TIP

Ideas for ensuring both filter integrity and public safety

Seating also serves to keep pedestrian traffic away from filter surface

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

A deep gravel layer on the filter surface provides extra extended detention whilst still ensuring pedestrian safety by avoiding large steps, although this design solution is likely to restrict the spread of vegetation.

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 22).

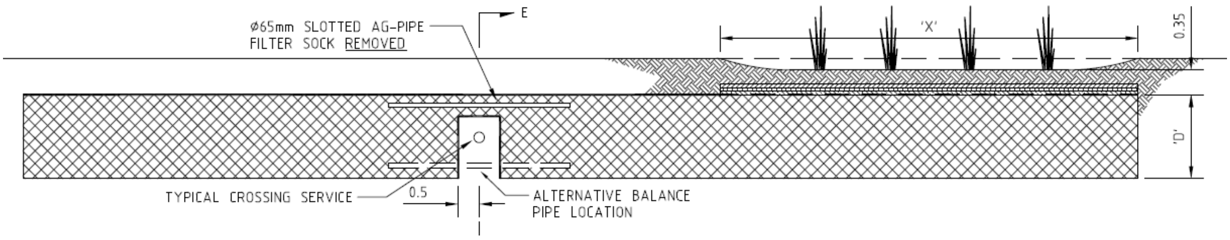


Figure 22. Example of innovative design to overcome interaction with services. In this example, the bio-infiltration system is constructed either side of a sewer line, with a connecting pipe in between, avoiding excavation underneath and surrounding the sewer.

3.6.3 Biofiltration Swales

- 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 biofiltration swales are installed in median strips, provision for pedestrian crossings must be incorporated.
- Where biofiltration systems are installed in nature strips, driveway crossings must be incorporated, and consideration to interaction with other services must be given, at the start of the design process.

3.6.4 Stormwater Harvesting

- Given their effective treatment of pollutants, biofilters are certainly a suitable treatment option for stormwater harvesting with respect to water quality. However, biofilters also reduce runoff volumes by an average of 30% due to evapotranspiration, thus reducing available yield.
- In order to maximise the volume of treated water, a lower planting density could be used, but this is likely to reduce the treatment capacity (for nutrients only). However, for most stormwater harvesting applications (eg. irrigation, toilet flushing), nutrient removal is not critical, therefore it is worth considering using a lined system that is vegetated with small plants such as grass to minimise evapotranspiration losses (suspended solids and heavy metals will still be effectively removed).
- For stormwater harvesting applications where treatment of pathogens is critical, biofilters can provide effective pre-treatment – while they do not reduce pathogen concentrations to levels that satisfy water quality criteria, they improve the quality of the stormwater such that post-disinfection (eg. UV disinfection) will be effective.

DESIGN TIP

- Where nutrient removal is not critical, use a lined system and small plants such as grass to maximise the yield of treated stormwater. Avoid the use of trees and other large, "water hungry" plant species.
- Where pathogen removal is essential, include post-disinfection such as UV treatment.

3.7 REFERENCES

Bratieres, K., T. D. Fletcher, A. Deletic and Y. Zinger (2008). Optimisation of the treatment efficiency of biofilters; results of a large-scale laboratory study. *Water Research* **42**(14): 3930-3940.

BCC and MBWCP (2006). Water sensitive urban design: technical design guidelines for South East Queensland. Brisbane City Council & Moreton Bay Waterways and Catchments Partnership.

Deletic, A. and G. Mudd (2006). *Preliminary results from a laboratory study on the performance of bioretention systems built in Western Sydney saline soils*. Facility for Advancing Water Biofiltration.

Hatt, B. E., T. D. Fletcher and A. Deletic (2008). Hydraulic and pollutant removal performance of fine media stormwater filtration systems. *Environmental Science & Technology* **42**(7): 2535-2541.

Hatt, B. E., T. D. Fletcher and A. Deletic (in press). Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale. *Journal of Hydrology*.

Le Coustumer, S., T. D. Fletcher, A. Deletic and S. Barraud (2008). *Influence of time and design on the hydraulic performance of biofiltration systems for stormwater management.* Paper presented at the 11th International Conference on Urban Drainage (ICUD), Edinburgh, Scotland. International Water Association.

Melbourne Water (2005). WSUD Engineering Procedures: Stormwater Melbourne, CSIRO Publishing.

Read, J., T. D. Fletcher, P. Wevill and A. Deletic (in press). Plant traits that enhance pollutant removal from stormwater in biofiltration systems. *International Journal of Phytoremediation*.

Water by Design (2009a). Concept Design Guidelines for Water Sensitive Urban Design Version 1, South East Queensland Healthy Waterways Partnership, Brisbane. March 2009. Available at: http://www.waterbydesign.com.au/conceptguide

Water by Design (2009b). *Construction and Estabhlishment Guidelines: Swales, Bioretention Systems and Wetlands*, South East Queensland Healthy Waterways Partnership, Brisbane. Available at: http://www.waterbydesign.com.au/CEguide

Zinger, Y., T. D. Fletcher, A. Deletic, G. T. Blecken and M. Viklander (2007). Optimisation of the nitrogen retention capacity of stormwater biofiltration systems. Novatech 2007, 6th International Conference on Sustainable Techniques and Strategies in Urban Water Management, Lyon, France.

CHAPTER 4: PRACTICAL IMPLEMENTATION

4.1 INTRODUCTION

This chapter provides general guidance on the construction, establishment 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 at-source and end-of-line biofiltration systems.

The document includes information on:

- Construction and establishment;
- Maintenance requirements;
- Monitoring requirements; and
- Checking tools (for designers and council development assessment officers).

The information presented in this document is intended to provide a broad, national approach to the construction and establishment of biofiltration systems, 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:

- Healthy Waterways Partnership, v1 June 2006[4]. Water Sensitive Urban Design: Technical Design Guidelines for South East Queensland
- Townsville City Council, in prep. Water Sensitive Urban Design for the Coastal Dry Tropics (Townsville): Technical Design Guidelines for Stormwater Management.
- Melbourne Water, 2005. WSUD Engineering Procedures: Stormwater. CSIRO Publishing
- Victorian Stormwater Committee, 1999. Urban Stormwater: Best Practice Environmental Management Guidelines. CSIRO Publishing
- LHCCREMS (Lower Hunter and Central Coast Regional Environmental Management Strategy) 2002, Water Sensitive Urban Design in the Sydney Region. LHCCREMS, NSW
- New South Wales Department of Environment and Climate Change. Managing Urban Stormwater: Urban Design. Department of Environment and Climate Change in association with the Sydney Metropolitan Catchment Management Authority (CMA)
- Stormwater Trust and the Upper Parramatta River Catchment Trust, 2004. Water Sensitive Urban Design Technical guidelines for Western Sydney.

4.2 CONSTRUCTION AND ESTABLISHMENT

The construction and establishment phase is generally accepted as being the critical phase for determining the success or failure of vegetated stormwater management systems. As such, careful construction and establishment procedures are key to ensuring long-term performance, avoiding expensive retrofits, and minimising future maintenance requirements.

[4] An update of the HWP WSUD Guidelines for SEQ was in progress at the time of writing this report.

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.

Water by Design, a program of the South East Queensland Health Waterways Partnership, released a new set of Construction and Establishment Guidelines for vegetated stormwater management systems in March 2009 (Water by Design, 2009) and FAWB refers industry practitioners to these guidelines. The guidelines were developed in collaboration with local government compliance officers, site superintendents, civil and landscape contractors, and practitioners with significant on-ground experience, and provide clear, practical and up-to-date guidance for constructing and establishing biofiltration systems. Of particular note are the step-by-step sequences for civil construction, building phase protection and landscape establishment for four alternative construction sequences. In addition, separate compliance procedures for both small and very large systems are identified (in accordance with a risk assessment approach) to ensure that smaller, distributed systems are not disadvantaged through onerous compliance requirements. These guidelines are nationally relevant and it is ***strongly recommended*** that they be consulted. The following is a summary of the key contents of the biofiltration system section of the guidelines (links with other sections of these guidelines are noted):

- *Roles and responsibilities* – provides clear definition of the roles and responsibilities of the various parties to ensure clear communication and that contractors are supported by designers and site superintendents.
- *Timing for construction and establishment* – outlines when biofilters should be constructed in the context of other works on a construction site, addresses issues such as coordination with erosion and sediment control activities during the construction phase and protecting the biofilters from stormwater inflows during the civil and landscape works stages, to avoid damaging both the biofiltration system and downstream waterways.
- *Civil considerations and specifications* – identifies a number of issues associated with the civil works, including:
    - Ordering materials and timing for supply to ensure efficient civil construction;
    - Construction tolerances and survey methods for each system element;
    - Design and construction requirements for hydraulic structures;
    - Underdrainage (note that this complements the guidance given in Section 3.5.10 of these Adoption Guidelines);
    - Installing and compacting filter media;
    - Construction issues with large systems;
    - Interaction with services (note that this builds on the discussion in Section 3.6.2 of these Adoption Guidelines);
    - Coarse sediment capture for easy and infrequent maintenance; and
    - Provision of maintenance access.
- *Filter media specification and certification* – there is significant overlap between this section and the guidance given in Chapter 3 of these Adoption Guidelines (largely because it refers to FAWB's Guidelines for Filter Media in Biofiltration Systems), however Water by Design's guidelines provide additional, good advice on certification and chain of custody, and compliance testing.

- *Landscape considerations and specifications* – offers clear, practical advice on plant procurement, pre-planting measures to aid plant establishment, planting procedures, establishment activities, and how to assess whether plants are successfully established.
- *Managing sediment* – contains a discussion of the challenges associated with the creation of a development site, in particular, managing sediment-laden runoff from the catchment during the building phase.
- *Staged construction and establishment methods* – explains how to integrate biofilter construction with other catchment works and outlines a number of staged construction and establishment methods that accommodate a range of scenarios. It is noted these alternative construction sequences offer varying benefits in terms of cost, environmental protection, contract administration, establishment timeframes and visual amenity. *Step-by-step sequence* field sheets for each staged construction and establishment method are also provided for the purposes of being laminated and used on construction sites.
- *Potential failure* scenarios and required actions for *rectification* (note that there is some overlap between this section and Section 4.3 of these Adoption Guidelines).
- *Certification and compliance* – there is often confusion about the responsibility for certification and asset handover because biofilters involve both civil and landscape works. This section provides guidance on who is responsible for certification, the required supporting documentation (including Construction and Establishment Sign-Off Forms), and when to schedule hold points in construction and compliance inspections.
- *Civil and landscape contracts* – gives advice on the content of contracts to ensure all parties are aware of construction responsibilities and certification requirements, as well as clarification of ownership and maintenance responsibilities during both the handover from civil contractor to landscape contractor and the building phase.
- *Sign-off forms* – these define the key items for delivering and inspecting biofiltration systems and form the basis of the certification and compliance requirements. They are intended to be used by contractors, construction site superintendents, designers and local authority compliance inspectors to ensure that biofiltration systems are constructed as designed.

4.3 MAINTENANCE REQUIREMENTS

Vegetation plays a key role in maintaining the porosity of the filter media of a biofiltration system and a strong healthy growth of vegetation is critical to its treatment performance. 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.

Inflow systems and overflow pits require careful monitoring, as these can be prone to scour and litter build up. Debris can block inlets or outlets and can be unsightly, particularly in high visibility areas. Inspection and removal of debris should be done regularly, and debris should be removed whenever it is observed on a site. 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).

For larger biofiltration systems, a maintenance access track for maintenance vehicles (eg. 4WD ute) should be provided to the sediment forebay for maintenance efficiency and ease.

In addition to the vegetation establishment activities described in Water by Design's Construction and Establishment Guidelines (see Section 4.2), typical maintenance of biofiltration system elements will involve:

- Routine inspection of the biofiltration system profile to identify any areas of obvious increased sediment deposition, scouring from storm flows, rill erosion of the batters from lateral inflows, damage to the profile from vehicles and clogging of the biofiltration system (evident by a 'boggy' filter media surface);
- Routine inspection of inflows systems, overflow pits and underdrains to identify and clean any areas of scour, litter build up and blockages;
- Removal of sediment where it is smothering the biofiltration system vegetation;
- Where a sediment forebay or other pre-treatment measure is adopted, removal of accumulated sediment and debris;
- Repairing any damage to the profile resulting from scour, rill erosion or vehicle damage by replacement of appropriate fill (to match on-site soils) and revegetating;
- Regular watering/irrigation of vegetation until plants are established and actively growing;
- Removal and management of invasive weeds (manual weed removal is preferable to herbicide use, as discussed below);
- Removal of plants that have died and replacement with plants of equivalent size and species, as detailed in the plant schedule – Note: it may also be worth considering occasionally harvesting plants to open the canopy and promote groundcover growth;
- Pruning to remove dead or diseased vegetation material and to stimulate growth; and
- Vegetation pest monitoring and control.

The following additional maintenance tasks are required if a submerged zone is included in the design:

- Check that the weir/up-turned pipe is clear of debris; and
- Check that the water level in the submerged zone is at the design level (note that drawdown during extended dry periods is expected).

A more detailed description of maintenance tasks and recommended frequences is given in Table 4.

Resetting (i.e., complete reconstruction) of the biofiltration system will be required if the system fails to drain adequately or if it is determined that the filter media has reached it maximum pollutant retention capacity (the lifespan of filter media is expected to be in the order of 10 − 15 years). Maintenance should only occur after a reasonably rain free period, when the filter media in the biofiltration system is dry. Inspections are also recommended following large storm events to check for scour and other damage.

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). Maintenance personnel and asset managers will use this Plan to ensure the biofiltration systems continue to function as designed. An example operation and maintenance inspection form is included in the checking tools provided in Section 4.5. This form must be developed on a site-specific basis as the nature and configuration of biofiltration systems varies significantly. A maintenace requirements summary is provided in Appendix H; this summary could be laminated for on-site reference.

☝ 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 (eg. parks, nature strips)
- If pressure jets are used to clear underdrains, care should used in perforated pipes to avoid damage

Table 4. Maintenance tasks and recommended frequencies.

Filter Media Tasks	
Sediment deposition	Remove sediment build up from forebays and other pre-treatment measures in biofiltration systems and from the surface of biofiltration street trees. **Frequency - 3 MONTHLY, AFTER RAIN**
Holes or scour	Infill any holes in the filter media. Check for erosion or scour and repair. Provide energy dissipation (eg. rocks and pebbles at inlet) if necessary. **Frequency - 3 MONTHLY, AFTER RAIN**
Filter media surface porosity	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. A symptom may be that water remains ponded in the biofiltration system for more than a few hours after a rain event. Repair minor accumulations by raking away any mulch on the surface and scarifying the surface of the filter media between plants. For biofiltration 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**
Litter control	Check for litter (including organic litter) in and around treatment areas. Remove both organic and anthropogenic litter to ensure flow paths and infiltration through the filter media are not hindered. **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS**
Horticultural Tasks	
Pests and diseases	Assess plants for disease, pest infection, stunted growth or senescent plants. Treat or replace as necessary. Reduced plant density reduces pollutant removal and infiltration performance. **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS**
Maintain original plant densities	Infill planting − between 6 and 10 plants per square metre should be adequate (depending on species) to maintain a density where the plants' roots touch each other. Planting should be evenly spaced to help prevent scouring due to a concentration of flow. **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS**
Weeds	It is important to identify the presence of any rapidly spreading weeds as they occur. The presence of such weeds can reduce dominant species distributions and diminish aesthetics. Weed species can also compromise the systems long-term performance. Inspect for and manually remove weed species. Application of herbicide should be limited to a wand or restrictive spot spraying due to the fact that raingardens and biofiltration tree pits are directly connected to the stormwater system. **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS**

Table 4 cont...

Drainage Tasks	
Underdrain	Ensure that underdrain pipes are not blocked to prevent filter media and plants from becoming waterlogged. If a submerged zone is included, check that the water level is at the design level, noting that drawdown during dry periods is expected. 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**
High flow inlet pits, overflow pits 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**
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 design capacity (eg. unusually high sediment loads may require installation of a sediment forebay). **Frequency – TWICE A YEAR AFTER RAIN**

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 ensure optimal performance.
- It is illegal to use some herbicides in aquatic situations. Given that treated water from biofiltration systems generally discharges directly to drainage and receiving waters, the potential for herbicide contamination of waterways must be considered. For guidance on using herbicides for weed control, please consult the following Cooperative Research Centre for Australian Weed Management guidelines:

  Herbicides: knowing when and how to use them

  http://www.weedscrc.org.au/documents/gl02_herbicide_use.pdf

  Herbicides: guidelines for use in and around water

  http://www.weedscrc.org.au/documents/gl01_herbicides_water.pdf

4.4 PERFORMANCE ASSESSMENT

This section discusses the need to monitor, how to match monitoring activities to management objectives, and the types of monitoring activities that could be carried out, including the frequency and level of expertise required for each activity. There are two main types of monitoring: qualitative and quantitative. There are several levels of quantitative monitoring; each of these is discussed and guidance on when these should be implemented is given.

The Institute for Sustainable Water Resources (ISWR) is currently preparing a Stormwater Monitoring Protocol that provides detailed guidance on designing, implementing and operating a monitoring program. This document is due to be completed in the second half of 2009. The following section draws on (but significantly abbreviates) this protocol, which should be referred to for further information.

4.4.1 Why monitor?

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

- To demonstrate compliance with legislative requirements (eg. load reduction targets);
- To assess overall and/or long-term performance (eg. large scale stormwater quality improvement);
- To collect data for model development; and
- To understand detailed processes.

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*** (eg. alternative filter media, plant species, sizing) and biofilters that are used for stormwater harvesting ***should be carefully monitored***.

4.4.2 Setting monitoring program objectives

Performance monitoring can quickly become resource intensive, therefore it is crucial that monitoring objectives are clearly developed in order to best use the available resources. In general, the aim of a monitoring program will be to assess whether the system meets the management objectives, 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.

> **IMPORTANT!**
>
> Biofilters require an establishment period of approximately two years to allow the filter media to settle and the vegetation to reach its design conditions. This ***must*** be taken into account when designing a monitoring program. For example, while 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), detailed water quality monitoring during this period would not provide an assessment of the system's optimal treatment performance.

Once the objectives of the monitoring program have been agreed on, 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. Guidance for selecting appropriate parameters for different objectives is given in Table 5.

Table 5. Monitoring objectives and parameters.

Objective	What to monitor
Pollution control	Concentrations in and out (important for lotic receiving waters) – nutrients, metals Inflows and outflows – use in conjunction with concentration for determination of loads (important for lentic receiving waters)
Flow management	Inflows and outflows – for determination of: • Runoff frequency reduction • Peak flow reduction • Reduction in runoff volume
Stormwater harvesting	Peak pollutant concentrations in the treated water (outflows) – metals, pathogens

4.4.3 Develop the monitoring program

The following types of information should be collected, where available:

- Catchment characteristics – catchment area, slope, nature and extent of imperviousness, geological charcteristics, 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.

> **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.

As mentioned previously, there are two levels of monitoring:

- Qualitative – this should be carried out for ***every*** system; and
- Quantitative – of which there are three sub-levels:
  - Preliminary – this should be carried out for ***every*** system;
  - Intermediate – appropriate for assessing new design configurations where the available budget does not allow for detailed monitoring; and
  - Detailed – appropriate for assessing new design configurations, and for model development.

Each of these levels of monitoring is described in the following sections.

4.4.4 Qualitative monitoring

Qualitative monitoring largely consists of visual assessment and is largely carried out during routine maintenance. Elements that should be monitored, the problems they indicate and suggested management actions are summarised in Table 6.

IMPORTANT!

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

4.4.5 Quantitative monitoring

There are three levels of quantitative monitoring: preliminary, intermediate and detailed. The amount of effort, expense and expertise required increases with each level of monitoring. In general, preliminary quantitative monitoring will be adequate for assessing the performance of biofilters that are designed according to these guidelines, however detailed assessment of different designs and biofilters used for stormwater harvesting should be undertaken. 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.

Table 6. Qualitative monitoring tasks.

Parameter	Indicator of	Possible Cause	Possible Management Action(s)
Plant health	Too much water	System undersized	Replace filter media with that of a higher infiltration capacity
		Poor infiltration capacity (water logging)	As above
	Too little water	System oversized (eg. plants further from inlet are drier)	Consider installing a choke on outlet OR Replant with dry tolerant plants
		Inlet levels wrong (system is bypassing too early)	Reset inlet levels
	Poor flow control	Excessive inflow velocities (at inlet)	• Install/augment energy dissipation device • Relocate inlet
		Inadequate provision for bypass of high flows (damage throughout system)	• Install/augment energy dissipation device • Reconfigure inlet to prevent high flows entering system • Relocate inlet
Erosion	Poor flow control	Excessive inflow velocities	• Install/augment energy dissipation device • Relocate inlet
		Inadequate provision for bypass of high flows (damage throughout system)	Reconfigure inlet to prevent high flows entering system
Build-up of sediment on filter surface	Clogging	Excessive loads of sediment	• Install pre-treatment device (see Chapter 3 for ideas) • Scarify the filter surface between plants and/or densely vegetate to break up the clogging layer
		System undersized	
		Inadequate pre-treatment	

4.4.5.1 Preliminary monitoring

Preliminary quantitative assessment does not require specialised knowledge in order to be performed correctly. There are two aspects to preliminary assessment of biofilter performance:

- Monitoring of the hydraulic conductivity of the filter media; and
- Long-term accumulation of toxicants.

<u>Hydraulic conductivity</u>

The hydraulic conductivity of filter media should be monitored *in situ* using the method described in Practice Note 1: *In situ* measurement of hydraulic conductivity (Appendix E). The recommended monitoring frequency is as follows:

- One month after the system comes on-line;
- 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.

<u>Accumulation of heavy metals</u>

A FAWB 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, 1999) for 10 – 15 years.

Filter media samples should be collected and analysed for heavy metals during Year 5 of operation. For biofiltration systems with a surface area less than 50 m^2, the filter media should be sampled at three points that are spatially distributed (one should be located near the inlet). For systems with a surface area greater than 50 m^2, an extra monitoring point should be added for every additional 100 m^2. At each monitoring point, a sample should be collected at the surface and another at a depth of 10 cm to assess whether heavy metals are migrating through the filter media. In order to minimise the potential for sample contamination and achieve accurate results, soil samples should be collected according to standard protocol in appropriately prepared containers (see AS 1289.1.2.1 – 1998 and Box 1) and 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.

See Section 4.4.6 for guidance on interpreting test results.

4.4.5.2 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 (NH_4^+), oxidised nitrogen (NO_x), organic nitrogen (ON), and orthophosphate (PO_4^{3-}, 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 4.4.6 for guidance on interpreting test results.

4.4.5.3 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 4.4.5.2 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 4.4.5.1 (Treatment Performance).

See Section 4.4.6 for guidance on interpreting test results.

4.4.6 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.

4.4.6.1 Benchmarks for performance assessment

A number of state, territories, regions and municipalities stipulate performance targets for WSUD, which often include biofiltration systems (eg. 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***, provided the standard of design for a biofiltration system is in accordance with Chapter 3 (*Technical Considerations*) of these guidelines. More specific guidance on soil and water quality benchmarks is given below.

<u>Accumulation of heavy metals</u>
Test results should be compared 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) in Table 5-A. The appropriate guideline will be determined by the location of the biofilter. The required 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, levels should continue to be checked at five-year intervals.

Note: Accumulated heavy metals will be concentrated at the surface of the filter media. Therefore, when heavy metals accumulate to levels of concern, this should be managed by scraping off and replacing the top 100 mm of filter media.

<u>Water quality</u>
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 (eg. 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).

4.5 CHECKING TOOLS

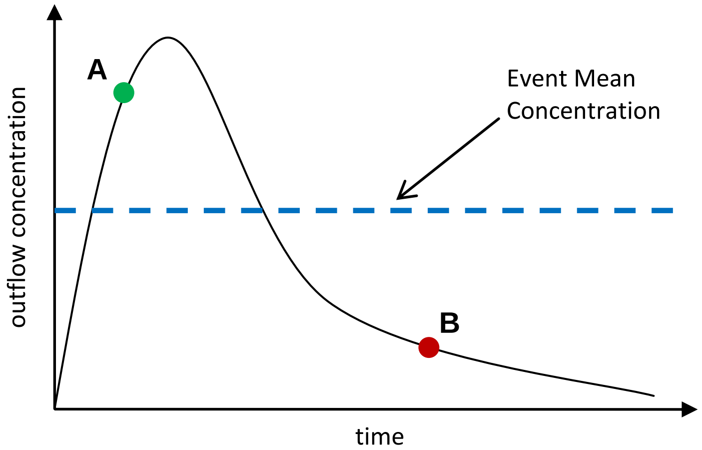
This section provides a number of checking aids for designers and local government development assessment officers. The following checking tools are provided:

- Operation and Maintenance Inspection Form; and
- Asset Transfer Checklist (following 'on-maintenance' period).

Construction and Establishment Sign-Off forms are included in Water by Design's Construction and Establishment Guidelines (see Section 4.2 for further details).

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.



4.5.1 Operation and Maintenance Inspection Form

The example form provided in Section 4.5.3 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 and complexity of the system. 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.

4.5.2 Asset Transfer Checklist

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. The proposed owner should be responsible for performing the asset transfer checklist. For details on asset transfer specific to each council, contact the relevant local authority to obtain their specific requirements for asset transfer. The table in Section 4.5.4 provides an indicative asset transfer checklist.

4.5.3 Biofiltration System Maintenance Inspection Checklist

BIOFILTRATION SYSTEM MAINTENANCE CHECKLIST			
Inspection frequency:	1 – 6 monthly	**Date of visit:**	
Location:			
Description:			
Asset ID:			
Site visit by:			

INSPECTION ITEMS	Y	N	Action required (details)
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.)?			
Watering 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?			
Resetting of system required?			
Weir/up-turn pipe is clear of debris (if applicable)?			
Water level in submerged zone as designed (if applicable)?			

COMMENTS

4.5.4 Biofiltration System 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		
Maintenace plans and indicative maintenance costs provided for each asset?	Y	N
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?		

4.6 REFERENCES

ANZECC and ARMCANZ (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1, The Guidelines (Chapters 1-7). Available at: http://www.mincos.gov.au/publications/australian_and_new_zealand_guidelines_for_fresh_and_marine_water_quality

Australian Standard (1998). AS 1289.1.2.1-1998 Sampling and preparation of soils - Disturbed samples - Standard method. Homebush, New South Wales, Standards Australia.

Australian/New Zealand Standard (1998). AS/NZS 5667.1:1998 Water quality - Sampling, Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples. Homebush, New South Wales, Standards Australia.

Leinster, S. (2006). Delivering the final product - establishing vegetated water sensitive urban design systems. *Australian Journal of Water Resources* **10**(3): 321-329.

NEPC (1999). Guideline of the Investigation Levels for Soil and Groundwater, Schedule B(1), National Environment Protection Measure. Available at: http://www.ephc.gov.au/pdf/cs/cs_01_inv_levels.pdf

Water by Design (2009). *Construction and Establishment Guidelines: Swales, Bioretention Systems and Wetlands*, South East Queensland Healthy Waterways Partnership, Brisbane. Available at: http://www.waterbydesign.com.au/CEguide

APPENDIX A PUBLICATIONS

FAWB PUBLICATIONS

Policy and Organisational Receptivity

Brown, R. R. and J. M. Clarke (2007). The transition towards Water Sensitive Urban Design: The story of Melbourne. Report No. 07/01, Facility for Advancing Water Biofiltration, Monash University: 67 pp.

Brown, R. R. and M. Farrelly (2007). Institutional impediments to advancing sustainable urban water management: A typology. 13th International Rainwater Catchment Systems Conference and 5th International Water Sensitive Urban Design Conference. Sydney, Australia.

Brown, R. R. and J. M. Clarke (2007). The transition towards water sensitive urban design: a socio:technical analysis of Melbourne, Australia. Novatech 2007. 6th International Conference on Sustainable Techniques and Strategies in Urban Water Management. Lyon, France. **1**: 349-356.

Brown, R. R. and M. A. Farrelly (2007). Advancing urban stormwater quality management in Australia: A survey of stakeholder perceptions of institutional drivers and barriers. Report No. 07/05,National Urban Water Governance Program, Monash University. Available at www.urbanwatergovernance.com

Filter Media

Bratieres, K., T. D. Fletcher and A. Deletic (2009). The advantages and disadvantages of a sand based biofilter medium: results of a new laboratory trial. 6th International Water Sensitive Urban Design Conference and Hydropolis #3, Perth, Australia.

Hatt, B. E., T. D. Fletcher and A. Deletic (2008). Hydraulic and pollutant removal performance of fine media stormwater filtration systems. *Environmental Science & Technology* **42**(7): 2535-2541.

Hatt, B. E., T. D. Fletcher and A. Deletic (2007). Stormwater reuse: designing biofiltration systems for reliable treatment. *Water Science and Technology* **55**(4): 201-209.

Hatt, B. E., T. D. Fletcher and A. Deletic (2007). The effects of drying and wetting on pollutant removal by stormwater filters. Novatech 2007. 6th International Conference on Sustainable Techniques and Strategies in Urban Water Management, Lyon, France.

Hatt, B. E., T. D. Fletcher and A. Deletic (2007). Hydraulic and pollutant removal performance of stormwater filters under variable wetting and drying regimes. *Water Science & Technology* **56**(12): 11-19.

Vegetation

Read, J., T. D. Fletcher, P. Wevill and A. Deletic (in press). Plant traits that enhance pollutant removal from stormwater in biofiltration systems. *International Journal of Phytoremediation*.

Read, J., T. Wevill, T. D. Fletcher and A. Deletic (2008). Variation among plant species in pollutant removal from stormwater in biofiltration systems. *Water Research* **42**(4-5): 893-902.

Bratieres, K., T. D. Fletcher, A. Deletic and Y. Zinger (2008). Optimisation of the treatment efficiency of biofilters; results of a large-scale laboratory study. *Water Research* **42**(14): 3930-3940.

Fletcher, T. D., Y. Zinger and A. Deletic (2007). Treatment efficiency of biofilters: results of a large scale biofilter column study. 13th International Rainwater Catchment Systems Conference and 5th International Water Sensitive Urban Design Conference, Sydney, Australia.

Submerged Zone

Blecken, G.-T., Y. Zinger, A. Deletic, T. D. Fletcher and M. Viklander (in press). Influence of intermittent wetting and drying conditions on heavy metal removal by stormwater biofilters. *Water Research*.

Blecken, G.-T., Y. Zinger, A. Deletic, T. D. Fletcher and M. Viklander (2009). Impact of a submerged anoxic zone and a cellulose based carbon source on heavy metal removal in stormwater biofiltration systems. *Ecological Engineering* **35**(5): 769-778.

Zinger, Y., T. D. Fletcher, A. Deletic, G. T. Blecken and M. Viklander (2007). Optimisation of the nitrogen retention capacity of stormwater biofiltration systems. Novatech 2007, 6th International Conference on Sustainable Techniques and Strategies in Urban Water Management, Lyon, France.

Zinger, Y., A. Deletic and T. D. Fletcher (2007). The effect of various intermittent wet-dry cycles on nitrogen removal capacity in biofilters systems. 13th International Rainwater Catchment Systems Conference and 5th International Water Sensitive Urban Design Conference, Sydney, Australia.

Hydraulic Performance

Le Coustumer, S., T. D. Fletcher, A. Deletic, S. Barraud and J.F. Lewis (in press). Hydraulic performance of biofilter systems for stormwater management: influences of design and operation. *Journal of Hydrology*.

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, Facility for Advancing Water Biofiltration and Melbourne Water Corporation (Healthy Bays and Waterways).

Le Coustumer, S. and S. Barraud (2007). Long-term hydraulic and pollution retention performance of infiltration systems. *Water Science and Technology* **55**(4): 235-243.

Le Coustumer, S., T. D. Fletcher, A. Deletic and S. Barraud (2007). Hydraulic performance of biofilters: first lessons from both laboratory and field studies. Novatech 2007. 6th International Conference on Sustainable Techniques and Strategies in Urban Water Management, Lyon, France.

Le Coustumer, S., T. D. Fletcher, A. Deletic and S. Barraud (2007). Hydraulic performance of biofilters for stormwater management: first lessons from both laboratory and field studies. *Water Science and Technology* **56**(10): 93-100.

Field Studies

Hatt, B. E., T. D. Fletcher and A. Deletic (2009). Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale. *Journal of Hydrology* **365**(3-4): 310-321.

Hatt, B. E., T. D. Fletcher and A. Deletic (2009). Pollutant removal performance of field-scale biofiltration systems. *Water Science & Technology* **59**(8): 1567-1576.

Hatt, B. E., T. D. Fletcher and A. Deletic (2008). Improving stormwater quality through biofiltration: Lessons from field studies. 11th International Conference on Urban Drainage. Edinburgh, UK.

Lewis, J. F., B. E. Hatt, S. Le Coustumer, A. Deletic and T. D. Fletcher (2008). The impact of vegetation on the hydraulic conductivity of stormwater biofiltration systems. 11th International Conference on Urban Drainage. Edinburgh, UK.

Hatt, B. E., J. Lewis, A. Deletic and T. D. Fletcher (2007). Insights from the design, construction and operation of an experimental stormwater biofiltration system. 13th International Rainwater Catchment Systems Conference and 5th International Water Sensitive Urban Design Conference, Sydney, Australia.

Smith, N., R. Allen, A. McKenzie-McHarg, A. Deletic, T. D. Fletcher and B. Hatt (2007). Retrofitting functioning stormwater gardens into existing urban landscapes. Cairns International Public Works Conference, Cairns.

Other

Blecken, G.-T., Y. Zinger, T. M. Muthanna, A. Deletic, T. D. Fletcher and M. Viklander (2007). The influence of temperature on nutrient treatment efficiency in stormwater biofilter systems. *Water Science and Technology* **56**(10): 83-91.

Deletic, A. and G. Mudd (2006). Preliminary results from a laboratory study on the performance of bioretention systems built in Western Sydney saline soils, Facility for Advancing Water Biofiltration.

APPENDIX B GUIDANCE FOR SIZING BIOFILTRATION SYSTEMS USING MUSIC

IMPORTANT!

- This guide has been written for MUSIC v3.1 and should be used to provide appropriate modelling of biofiltration systems in MUSIC v3.1.

  Users should refer to the User Guide for guidance on how to model biofiltration systems (referred to as bioretention systems) in MUSIC v4. MUSIC v4 (and later versions) uses the results from FAWB's research to take into account the design and operational factors which influence biofiltration treatment performance (e.g. filter media type and depth, presence and type of vegetation, presence and type of underdrain, presence of lining, etc.). In MUSIC v4, the user can readily model model a range of biofiltration systems, including designs with a saturated zone or a system without an underdrain (i.e., a vegetated infiltration system).

Users should refer to the MUSIC User Manual for general guidance on how to model stormwater treatment systems with the MUSIC model. In particular, Chapter 3 gives step-by-step instructions on how to model treatment systems, including biofiltration systems. However, this Appendix demonstrates how MUSIC can be used to evaluate the performance of biofilters with regards to:

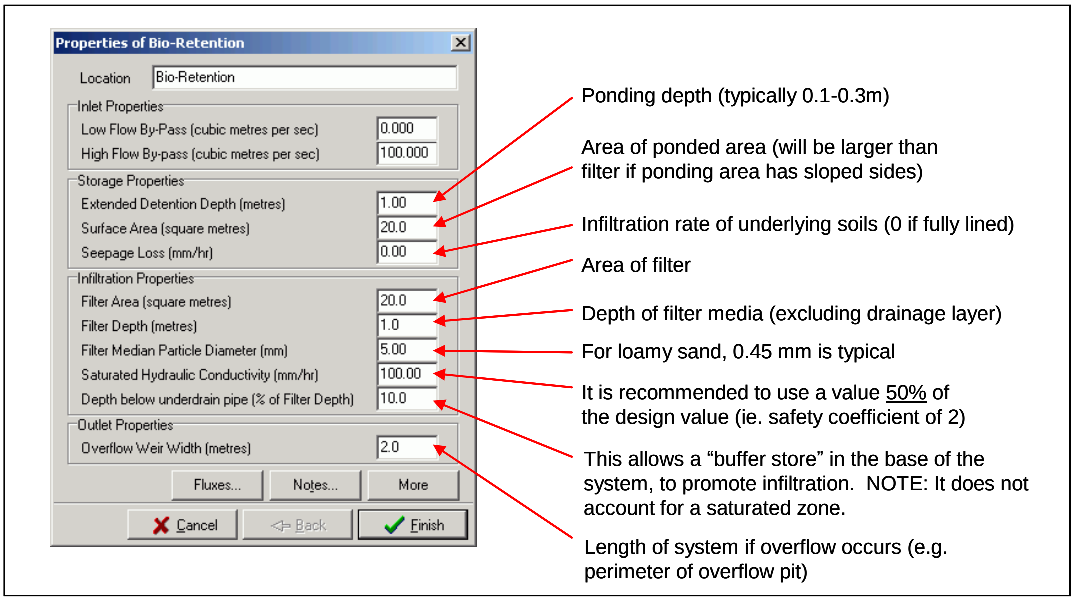
1. Pollutant loads
2. Pollutant concentrations
3. Flow rates
4. Runoff frequency

Before using MUSIC to model proposed biofilter designers, the objectives need to be clearly defined, because the objectives will define which of these four performance measures are of primary interest.

It is, however, important to note that version 3.0 of MUSIC does **not** account for the presence of a submerged zone at the base of the biofilter.

Basic modelling process

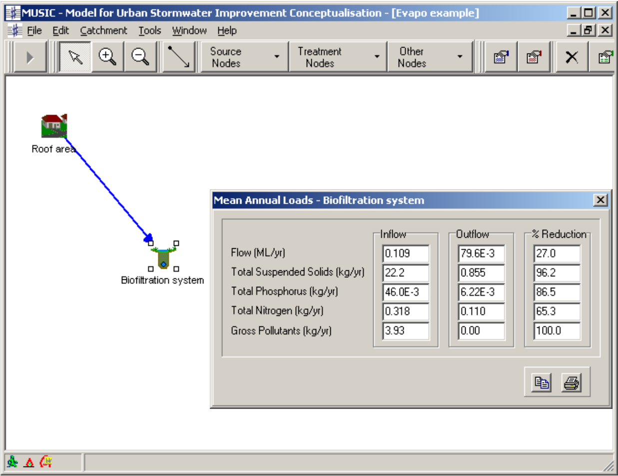
The basic parameters of the biofiltration system should be entered using the MUSIC "Bioretention" node dialogue box:

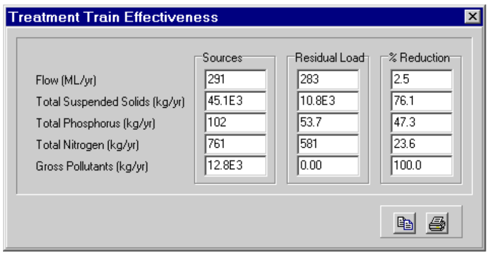


It is important that the model accurately represents the system as it is proposed to be built. For example, the seepage rate should be ideally based on a test of the hydraulic conductivity of the underlying soils, or at least on a conservative estimate.

Evaluating pollutant loads

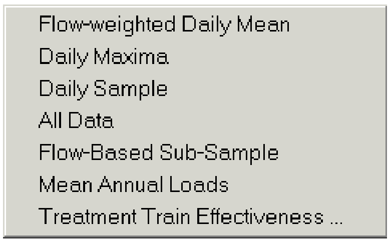
Evaluating the pollutant load reduction performance of a biofilter is easy in MUSIC, by simply right-clicking on the biofiltration node and choosing Statistics – Mean Annual Loads. In the case where the performance of several biofilters (either in parallel or in series) within a catchment is being evaluated, use Statistics – Treatment Train Effectiveness.

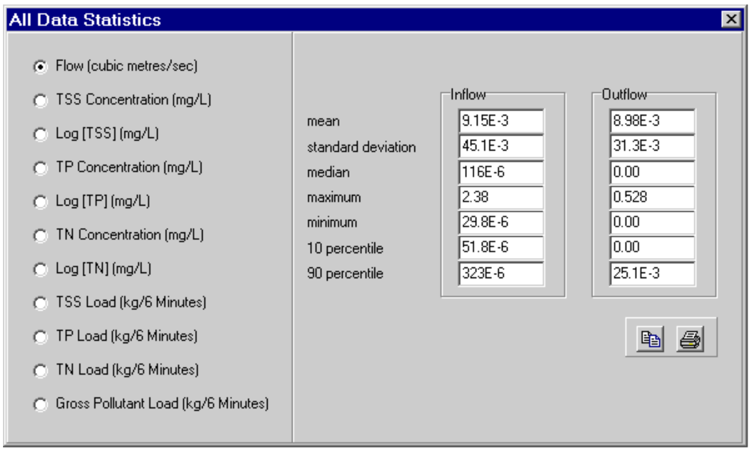




Evaluating pollutant concentrations and flow rates

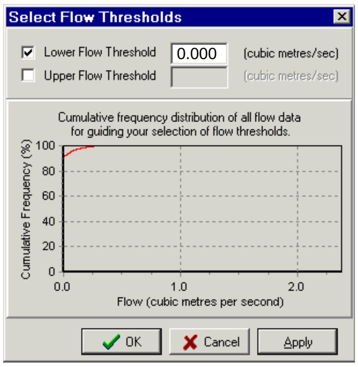
To evaluate the performance of pollutant concentrations, use Statistics and then choose from the desired statistic (eg. Daily Maximum, Flow Weighted Mean, All Data, etc). The approach for evaluating flow rates is exactly the same as for concentrations except that it is the flow rather than TSS, TP or TN that is selected, for which the statistics are to be presented.

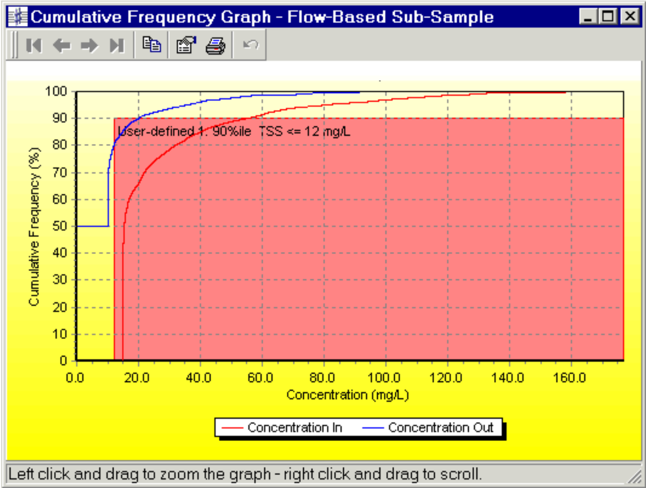




See Chapter 4 of the MUSIC manual for further guidance, including information on excluding zero-flow periods from the statistics (so that the mean value is not “distorted” by many timesteps with zero flow and thus zero concentration.

The Cumulative Frequency Graph can also be used to investigate the probability of exceeding a given pollutant concentration or flow rate (again, this would normally be done for non-zero flows, by using the Flow-Based Sub-Sample Bounds on the context-sensitive menu of the treatment node:





Evaluating runoff frequency

Evaluation of the runoff frequency objective with MUSIC v3.0 requires the export of data into Excel for subsequent analysis.

There are two basic components to the modelling:

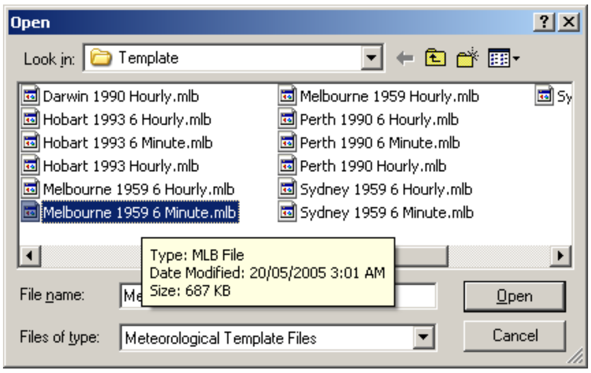
1. Determining the pre-development runoff frequency; and
2. Modelling the post-development runoff frequency.

The modelling must be done using a 6 minute timestep. The model results are then exported (at daily timestep) to Excel, to calculate the daily runoff frequency.

Modelling the pre-development runoff frequency

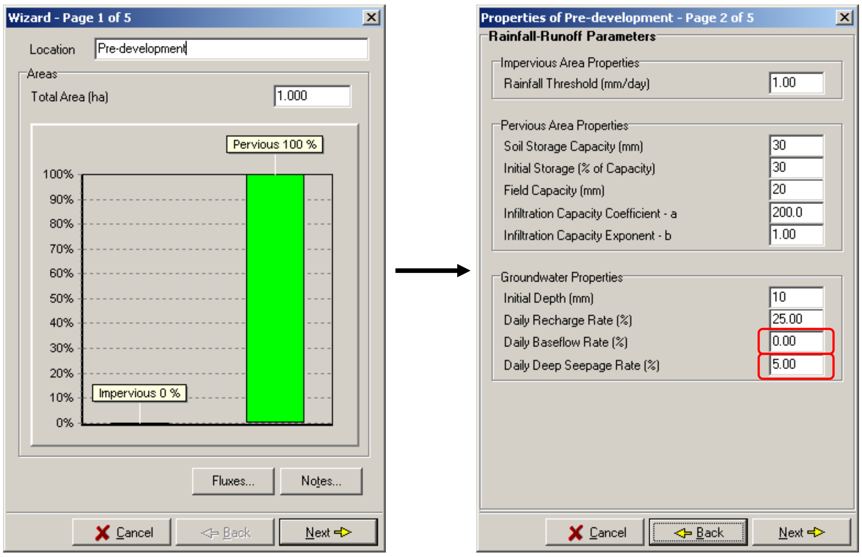
Step 1. Select or create the appropriate climate template

- Select a <u>6 minute timestep</u> climate template for one or more years (model should either use a single year which has been assessed as being representative of long-term climatic characteristics, or a representative five year period):



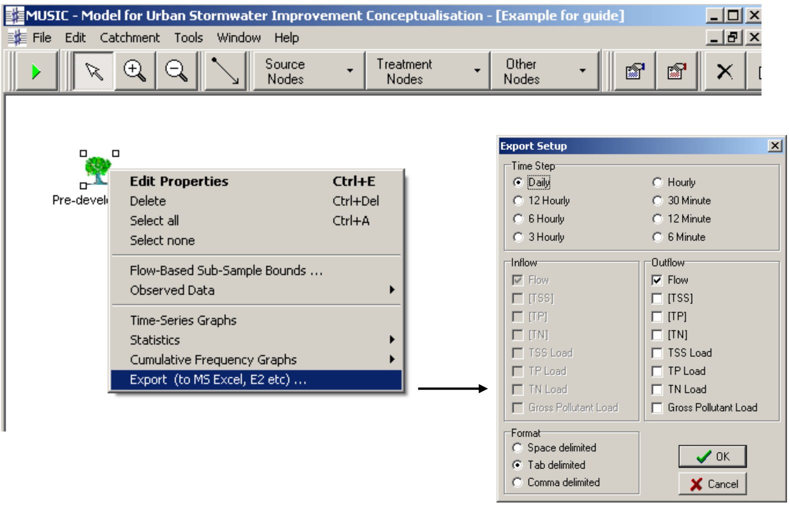
Step 2. Create a pre-development source node

- Create any type of source node (it could be urban, forested or agriculture – since we are only trying to model runoff, and not water quality). The node should have:
  1. Appropriate rainfall-runoff properties for the location (default properties for Melbourne are given in Appendix I of the MUSIC manual)
  2. A Daily Drainage Rate of 0 (since we wish to calculate the days of <u>surface flows</u>, and do not want MUSIC to add in baseflows) and a Daily Deep Seepage rate of 5% (highlighted):



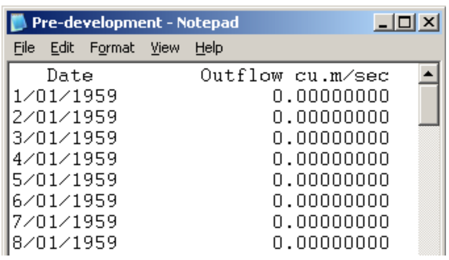
Step 3. Run model and export results

- Run the model.
- Export the results at daily timestep, selecting only flow, and choosing the "Tab delimited" format:



Step 5. Import and analyse results

- Open the export file in Notepad (just double click on the created text file):



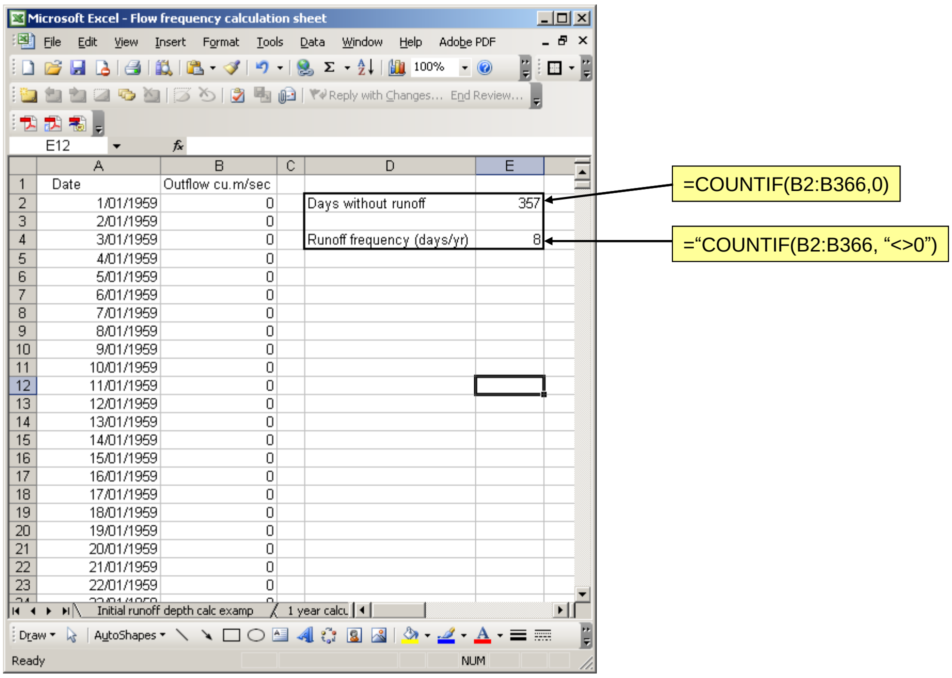
Pre-development - Notepad

File Edit Format View Help

Date	Outflow cu.m/sec
1/01/1959	0.00000000
2/01/1959	0.00000000
3/01/1959	0.00000000
4/01/1959	0.00000000
5/01/1959	0.00000000
6/01/1959	0.00000000
7/01/1959	0.00000000
8/01/1959	0.00000000

- Select All and Copy
- Open Microsoft Excel and paste into spreadsheet

- Calculate the runoff frequency (i.e., the number of days with <u>non-zero</u> flows) using the simple Excel functions shown below (in the case shown below (for Melbourne 1959), the natural runoff frequency is 8 days):



Modelling the post-development runoff frequency

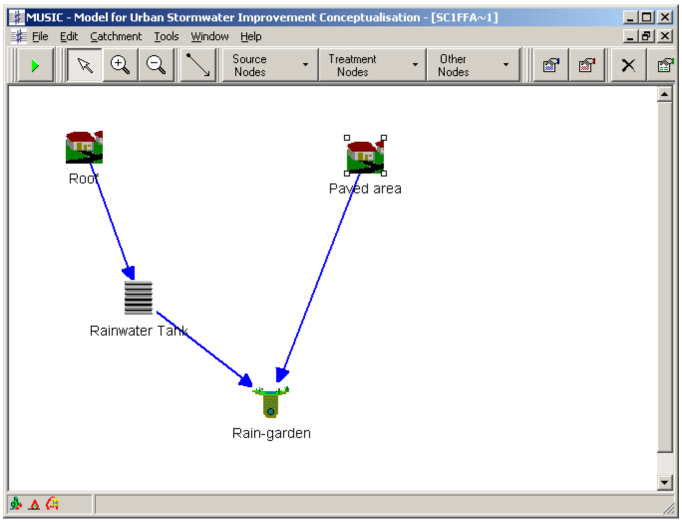
Modelling the post-development runoff frequency uses the same basic process as described for the pre-development situation.

Step 1. Select or create the appropriate climate template

- Select the same <u>6 minute timestep</u> climate template as used for the pre-development analysis.

Step 2. Create the model with impervious areas and proposed treatment systems

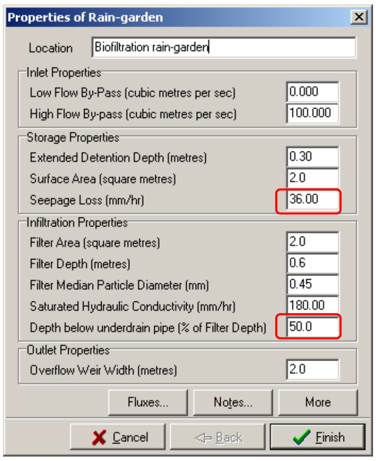
- Whilst you may model pervious areas for the normal MUSIC modelling (to analyse removal of TSS, TP and TN, you need <u>only include</u> the <u>impervious areas</u> when modelling runoff frequency. If you include pervious areas (with a daily baseflow rate set), they will produce baseflow, which MUSIC will interpret as contributing to daily runoff frequency; therefore, if you include pervious areas, the daily baseflow rate should be set to zero (and the daily seepage rate set to 5%, as per Step 2 for the pre-development frequency analysis.
- Create the network of treatment systems to retain stormwater from these impervious areas: eg. rain-garden, rainwater tank, infiltration system. The example below shows a rainwater tank being used to harvest water from a house roof, with overflow going to a rain-garden (biofiltration system). Runoff from the paved area also goes to the biofiltration system:

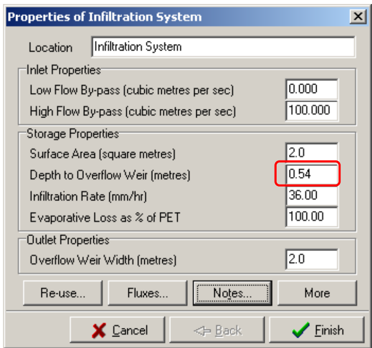


- The design (and thus modelling) of treatment systems for reducing runoff frequency will be somewhat different to that for simply reducing pollutant loads. Systems which promote infiltration and stormwater harvesting with regular demands (eg. toilet flushing, etc.) will be most effective. For example, one solution (subject to appropriate distances to infrastructure) is to construct a biofiltration system with an unlined base, and the underdrain raised above the base, to allow water from small rainfall events to infiltrate to surrounding soils (see left-hand side diagram below with highlighted seepage loss and depth below underdrain parameters. Another option is to use no underdrain at all (having only an overflow pipe); in this case (right-hand size diagram), it can be modelled with a simple infiltration system node in MUSIC. The only 'trick' here is to model the extended detention depth as:

  Extended detention depth = ponding depth + infiltration depth x porosity.

  For a sandy-loam system (to support plants), the porosity ≈ 0.4. Therefore (in example below); if the ponding depth was 0.3m and the filter medium was 0.6m deep, the "depth to overflow) would be 0.3 + (0.6 x 0.4) = 0.54 m (highlighted below):



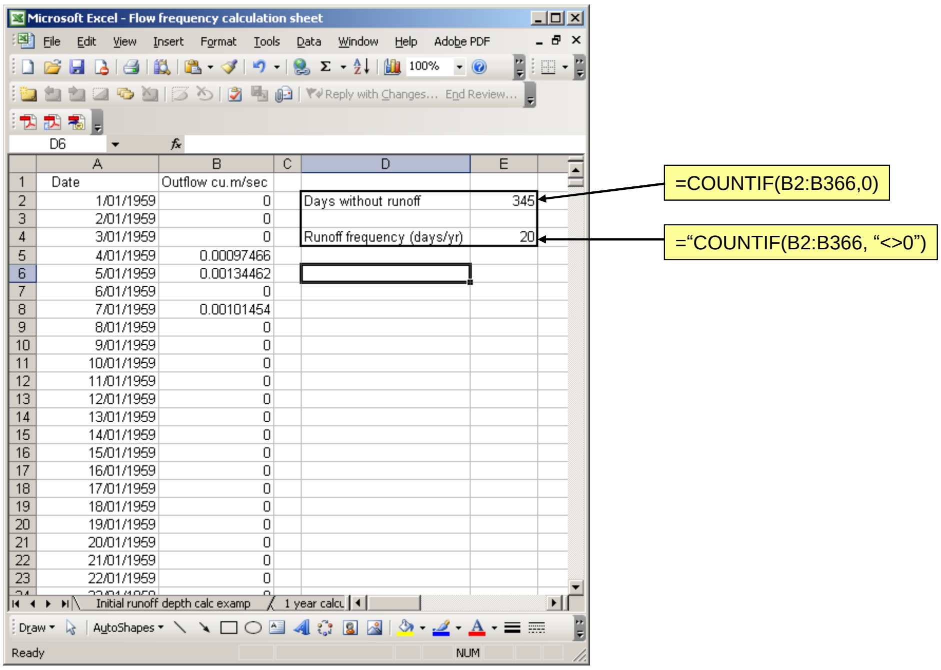


Step 3. Run model and export results

- Run the model.
- Export the results from the most downstream node (in the example above, this would be the rain-garden), at daily timestep, selecting only flow, and choosing the "Tab delimited" format.

Step 4. Import and analyse results

- Follow the same steps as per the pre-development frequency; open the exported text file in Notepad, Select All and then Copy; paste into Excel, and then calculate the runoff frequency (ie. the number of days with <u>non-zero</u> flows.
- The number of days <u>per year</u> with non-zero flows should not be more than 15 days greater than for the pre-development case (for the example below, it is 12 days; ie. 8 + 12 = 20):



The effect of evapotranspiration in biofiltration systems

MUSIC v3 does not account for the effect of evapotranspiration within a biofiltration system (rain-garden), even through recent research has shown that it can result in a reduction of mean annual flow by about 30% (Hatt *et al.*, 2009). It is hoped that version 4.0 of MUSIC will address this issue.

APPENDIX C GUIDELINES FOR FILTER MEDIA IN BIOFILTRATION SYSTEMS

GUIDELINES FOR FILTER MEDIA IN BIOFILTRATION SYSTEMS (Version 3.01) June 2009

The following guidelines for filter media in biofiltration systems have been prepared on behalf of the Facility for Advancing Water Biofiltration (FAWB) 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 FAWB guideline specifications (published in 2006 (Version 1.01), 2008 (Version 2.01)). It attempts to provide a simpler and more robust guideline for both soil-based and engineered filter media. FAWB acknowledges the contribution of 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.

1 GENERAL DESCRIPTION

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 minimum cover over underdrainage pipe). The biofiltration system will operate so that water will infiltrate into the filter media and move vertically down through the profile.

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. The material should be based on **natural or amended natural soils** or it can be **entirely engineered**; in either case, it can be of siliceous or calcareous origin. In general, the media should have an appropriately high permeability under compaction and should be free of rubbish, deleterious material, toxicants, declared plants and local weeds (as listed in local guidelines/Acts), and should not be hydrophobic. The filter media should contain some organic matter for increased water holding capacity but be low in nutrient content. In the case of natural or amended natural soils, the media should be a **loamy sand**.

Maintaining an adequate infiltration capacity is crucial in ensuring the long-term treatment efficiency of the system. The ability of a biofiltration system to detain and infiltrate incoming stormwater is a function of the filter surface area, extended detention (ponding) depth, and the hydraulic conductivity of the filter media (Figure 1). Most importantly, design of a biofiltration system should optimize the combination of these three design elements.

For a biofiltration system in a temperate climate with an extended detention 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 2). 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 in order to achieve the required treatment performance using the same land space (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 infiltration capacity can still be maintained by offsetting another of the design elements. For example, a filter media with a lower hydraulic conductivity may be used, but the surface area or the extended detention depth would need to be increased in order to maintain the treatment capacity. Similarly, if the available land were the limiting design element, the system could still treat the same size storm if a filter media with a higher hydraulic conductivity were installed. Where a hydraulic conductivity greater than 300 mm/hr is prescribed, potential issues such as higher watering requirements during the establishment should be considered. Biofiltration systems with a hydraulic conductivity greater than 600 mm/hr are unlikely to support plant growth due to poor water retention, and may also result in leaching of pollutants. However plant survival might be possible if the outlet pipe were raised to create a permanently submerged zone.

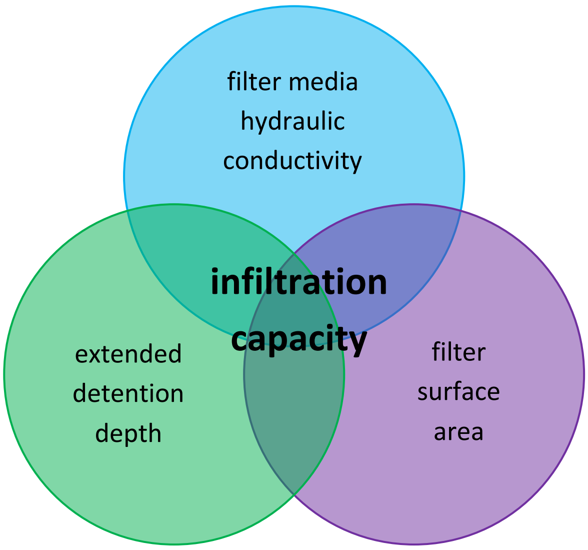


Figure 1. Design elements that influence infiltration capacity.

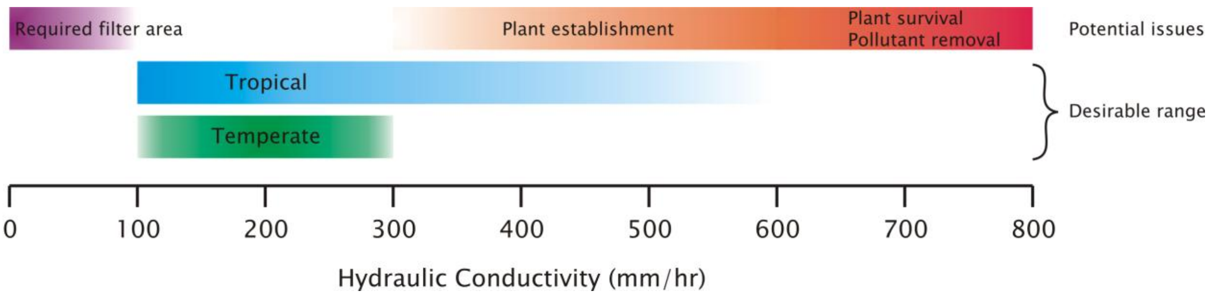


Figure 2. Recommended filter media hydraulic conductivity range and potential issues

The infiltration capacity of the biofiltration system will initially decline during the establishment phase 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 (see Appendix A). In order to ensure that the system 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 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 TESTING REQUIREMENTS

2.1 Determination of Hydraulic Conductivity

The hydraulic conductivity of potential filter media should be measured using the ASTM F1815-06 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.

Note: if a hydraulic conductivity lower than 100 mm/hr is prescribed, the level of compaction associated with this test method may be too severe and so underestimate the actual hydraulic conductivity of the filter media under field conditions. However, FAWB considers this to be an appropriately conservative test, and recommends its use even for low conductivity media.

2.2 Particle Size Distribution

Particle size distribution (PSD) is of secondary importance compared with hydraulic conductivity. 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. However, 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 to Coarse Sand	40-60%	(0.25-1.0 mm)
Coarse Sand	7-10%	(1.0-2.0 mm)
Fine Gravel	<3%	(2.0-3.4 mm)

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)** to reduce the likelihood of structural collapse of such soils.

The filter media should be well-graded i.e., it should have all particle size ranges present from the 0.075 mm to the 4.75 mm sieve (as defined by AS1289.3.6.1 - 1995). There should be no gap in the particle size grading, and the composition should not be dominated by a small particle size range. This is important for preventing structural collapse due to particle migration.

2.3 Soil-Based Filter Media: Properties

The following specifications are based on results of extensive treatment performance testing conducted by FAWB as well as recommendations made by AS4419 – 2003 (Soils for Landscaping and Garden Use). Filter media must be tested for the following; media that do not meet these specifications should be rejected or amended:

i. Total Nitrogen (TN) Content – <1000 mg/kg.

ii. Orthophosphate (PO_4^{3-}) Content – <80 mg/kg. Soils with total phosphorus concentrations >100 mg/kg should be tested for potential leaching. Where plants with moderate phosphorus sensitivity are to be used, total phosphorus concentrations should be <20 mg/kg.

iii. Organic Matter Content – at least 3% (w/w). An organic content lower than 3% is likely to have too low a water holding capacity to support healthy plant growth. In order to comply with both this and the TN and PO_4^{3-} content requirements, a low nutrient organic matter will be required.

iv. pH – as specified for 'natural soils and soil blends' 5.5 – 7.5 (pH 1:5 in water).

v. Electrical Conductivity (EC) – as specified for 'natural soils and soil blends' <1.2 dS/m.

Optional testing:

vi. Dispersibility – this should be carried out where it is suspected that the soil may be susceptible to structural collapse. If in doubt, then this testing should be undertaken.

Potential filter media should generally be assessed by a horticulturalist to ensure that they are capable of supporting a healthy vegetation community. This assessment should take into consideration delivery of nutrients to the system by stormwater. Any component or soil found to contain high levels of salt (as determined by EC measurements), high levels of clay or silt particles (exceeding the particle size limits set above), or any other extremes which may be considered retardant to plant growth should be rejected.

3 ENGINEERED FILTER MEDIA

Where there is not a locally available soil-based material that complies with the properties outlined in Sections 2.1 - 2.3, 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. 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. The **top 100 mm of the filter medium** should then be ameliorated with appropriate organic matter, fertiliser and trace elements (Table 1). This amelioration is required to aid plant establishment and is designed to last four weeks; the rationale being that, beyond this point, the plants receive adequate nutrients via incoming stormwater.

Table 1. 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

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 soil-based filter medium (Bratieres *et al.*, 2009). However, it is recommended that a submerged zone be included in biofiltration systems that utilise such a free draining filter medium to provide a water source for vegetation between rainfall events.

4 TRANSITION LAYER

The transition layer prevents filter media from washing into the drainage layer. Transition layer material shall be a clean, well-graded sand material containing <2% fines. To avoid migration of the filter media into the transition layer, the particle size distribution of the sand should be assessed to ensure it meets 'bridging criteria', that is, the smallest 15% of the sand particles bridge with the largest 15% of the filter media particles (Water by Design, 2009; VicRoads, 2004):

D_{15} (transition layer) $\leq 5 \times D_{85}$ (filter media)

where: D_{15} (transition layer) is the 15^{th} 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 85^{th} percentile particle size in the filter media.

A dual-transition layer, where a fine sand overlays a medium-coarse sand, is also possible. While it is acknowledged that this can increase the complexity of the construction process, testing indicates that a dual-transition layer produces consistently lower levels of turbidity and concentrations of suspended solids in treated outflows than a single transition layer. Therefore, it is recommended that this design be specified for stormwater harvesting applications (to enable effective post-treatment disinfection) and where minimising the risk of washout during the establishment period is of particular importance.

The transition layer can be omitted from a biofiltration system provided the filter media and drainage layer meet the following criteria as defined by the Victorian Roads *Drainage of Subsurface Water from Roads - Technical Bulletin No 32* (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)

These comparisons are best made by plotting the particle size distributions for the filter media and gravel on the same soil grading graphs and extracting the relevant diameters (Water by Design, 2009).

5 DRAINAGE LAYER

The drainage layer collects treated water at the bottom of the system and converys it to the underdrain pipes. Drainage layer material is to be clean, fine gravel, such as a 2 – 5 mm washed screenings. Bridging criteria should be applied to avoid migration of the transition layer into the drainage layer (Water by Design, 2009; VicRoads, 2004):

D_{15} (drainage layer) ≤ 5 x D_{85} (transition layer)

where: D_{15} (drainage layer) is the 15th percentile particle size in the drainage layer material (i.e., 15% of the gravel is smaller than D_{15} mm), and

D_{85} (transition layer) is the 85th percentile particle size in the transition layer material.

Note: The perforations in the underdrain pipes should be small enough that the drainage layer cannot fall into the pipes. A useful guide is to check to that the D_{85} (drainage layer) is greater than the pipe perforation diameter.

Geotextile fabrics are **not recommended** for use in biofiltration systems due to the risk of clogging. An open-weave shade cloth can be placed between the transition layer and the drainage layer to help reduce the downward migration of smaller particles if required, however this should only be adopted where there is insufficient depth for transition and drainage layers.

6 INSTALLATION

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.

7 FIELD TESTING

It is recommended that field testing of hydraulic conductivity 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.

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. 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.

REFERENCES

ASTM International (2006). ASTM F 1815-06: Standard test methods for saturated hydraulic conductivity, water retention, porosity, and bulk density of putting green and sports turf root zones. West Conshohocken, U.S.A.

Bratieres, K., T. D. Fletcher and A. Deletic (2009). The advantages and disadvantages of a sand based biofilter medium: results of a new laboratory trial. 6th International Water Sensitive Urban Design Conference and Hydropolis #3, Perth, Australia.

Hatt, B. E., T. D. Fletcher and A. Deletic (2009). Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale. *Journal of Hydrology* **365**(3-4): 310-321.

Le Coustumer, S., T. D. Fletcher, A. Deletic and S. Barraud (2007). Hydraulic performance of biofilters for stormwater management: first lessons from both laboratory and field studies. Water Science and Technology 56(10): 93-100.

Standards Australia (1995). AS1289.3.6.1 - 1995: Methods of testing soils for engineering purposes - Soil classification tests - Determination of the particle size distribution of a soil - Standard method of analysis by sieving. Sydney, Australia, Standards Australia International Ltd.

Standards Australia (2003). AS4419 - 2003: Soils for landscaping and garden use. Sydney, Australia, Standards Australia International Ltd.

VicRoads (2004). Drainage of Subsurface Water from Roads – Technical Bulletin No. 32. Available at: http://webapps.vicroads.vic.gov.au/vrne/vrbscat.nsf

Water by Design (2009). *Construction and Estabhlishment Guidelines: Swales, Bioretention Systems and Wetlands*, South East Queensland Healthy Waterways Partnership, Brisbane.

APPENDIX A

Figure A.1 illustrates the change in hydraulic conductivity during the establishment phase of a Melbourne biofiltration system containing a sandy loam filter media. The hydraulic conductivity initially declines as the filter media is compacted under hydraulic loading, but recovers back to the design value (as indicated by the dashed horizontal line) as plant growth and increased rooting depth counters the effects of compaction and clogging.

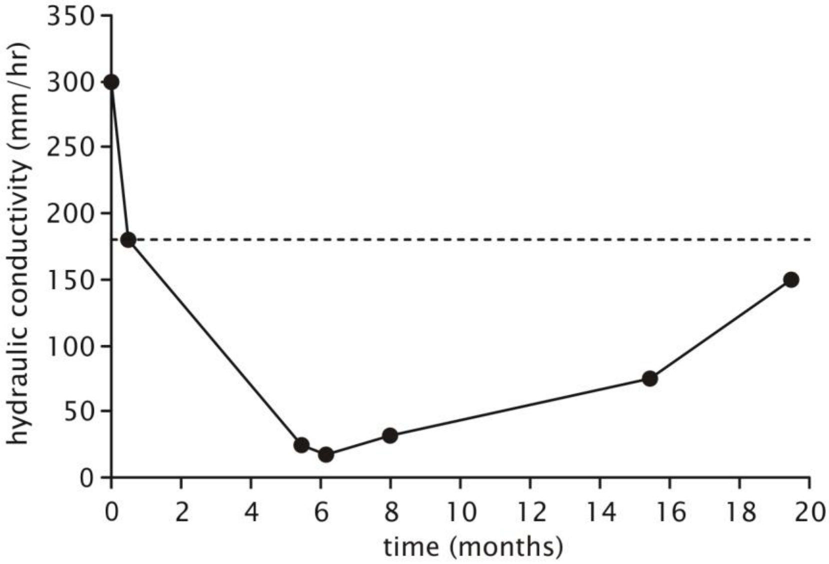


Figure A.1 Evolution of hydraulic conductivity during the first 20 months of a biofiltration system (after Hatt *et al.*, 2009)

APPENDIX D EXAMPLE MAINTENANCE PLAN

FAWB
Facility for Advancing
Water Biofiltration

Biofiltration Systems
MAINTENANCE PLAN

EXAMPLE

June 2009

Table of Contents

1 BIOFILTRATION SYSTEM 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. In the case of tree pits, the understorey (or groundcover) vegetation reduces the likelihood of clogging at the surface of the filter media.

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.

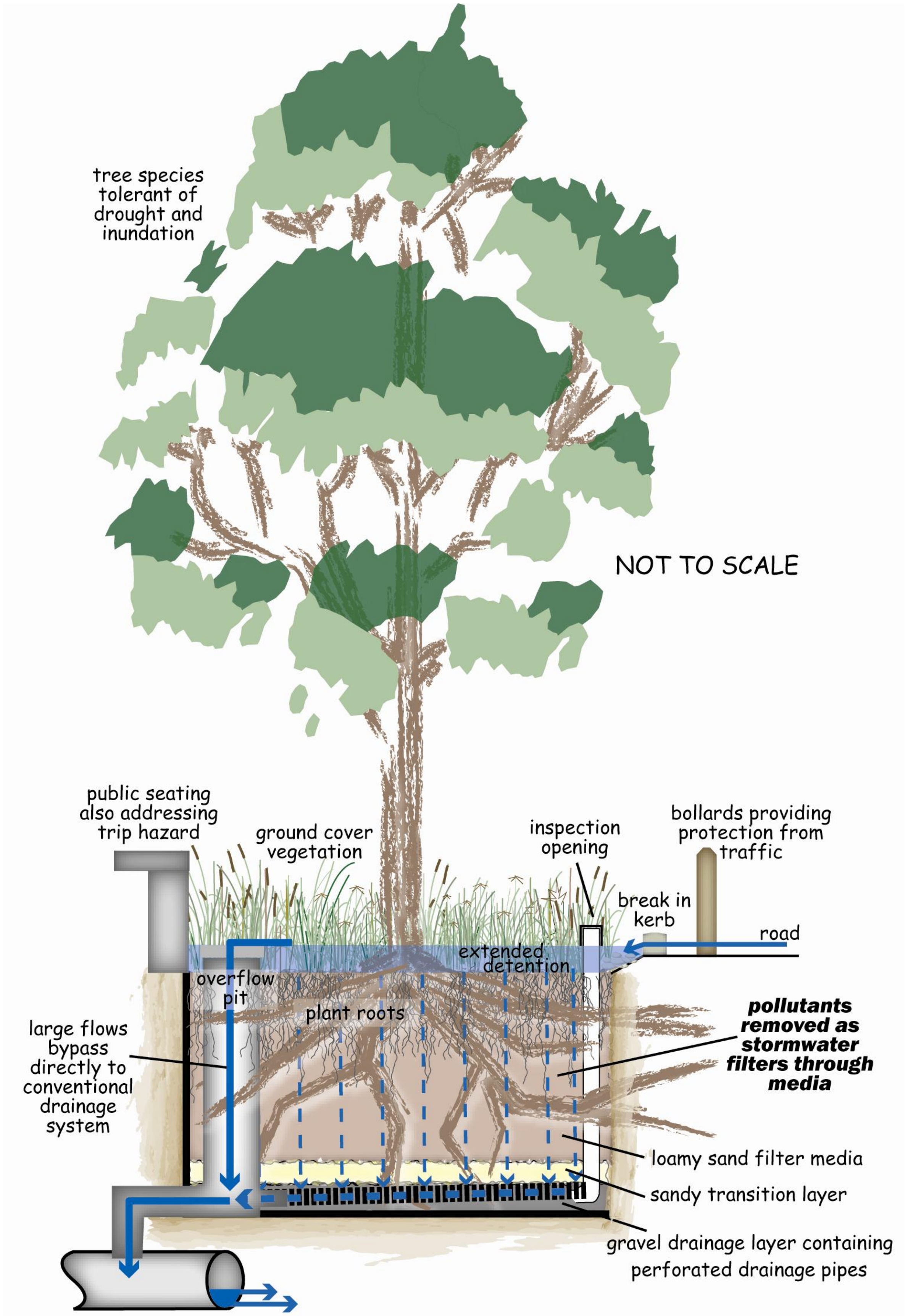


Figure 1. Conceptual drawing of a biofiltration system illustrating stormwater flow pathways and subsurface infrastructure requiring maintenance.

2 MINIMISING LONG-TERM MAINTENANCE

Three 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 three 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; 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. 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 structure 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 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, 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 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.

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.

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 2. Protection of filter media with a geofabric and turf cover (left) and use of a sacrificial sediment forebay during construction and plant establishment (right).

3.2 Irrigation

Plants and trees in biofiltration systems will probably require irrigation during the establishment phase. Irrigation should be applied directly to the surface of the filter media. The use of Ag pipes for irrigating young trees is not recommended as it creates a short-circuit pathway, or preferential flow path, for stormwater. The stormwater flows straight down the Ag pipes and into the drainage layer at the base where it is conveyed downstream to the conventional stormwater system, effectively bypassing any pollutant removal processes that occur as the stormwater filters through the filter media (Figure 3).

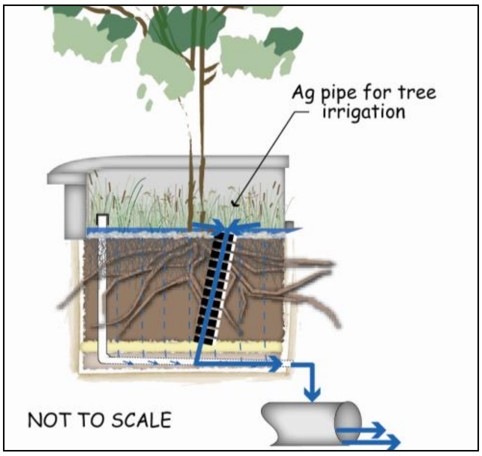


Figure 3. Concept illustration showing how Ag pipes installed for tree watering can result in short-circuiting and reduced stormwater treatment.

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 LONG-TERM MAINTENANCE TASKS

4.1 Schedule of visits

4.1.1 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 might be determined after the system has established.
Maintenance	

4.2 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

4.2.1 FILTER MEDIA TASKS	
Sediment deposition	Remove sediment build up from forebays and other pre-treatment measures in biofiltration systems and from the surface of biofiltration street trees. **Frequency - 3 MONTHLY, AFTER RAIN**
Holes or scour	Infill any holes in the filter media. Check for erosion or scour and repair, provide energy dissipation (e.g. rocks and pebbles at inlet) if necessary. **Frequency - 3 MONTHLY, AFTER RAIN**
Filter media surface porosity	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. A symptom may be that water remains ponded in the biofiltration system for more than a few hours after a rain event. Repair minor accumulations by raking away any mulch on the surface and scarifying the surface of the filter media between plants. For biofiltration 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**
Litter control	Check for litter (including organic litter) in and around treatment areas. Remove both organic and anthropogenic litter to ensure flow paths and infiltration through the filter media are not hindered. **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS**
4.2.2 HORTICULTURAL TASKS	
Pests and diseases	Assess plants for disease, pest infection, stunted growth or senescent plants. Treat or replace as necessary. Reduced plant density reduces pollutant removal and infiltration performance. **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS**
Maintain original plant	Infill planting: Between 6 and 10 plants per square metre should (depending on species) be adequate to maintain a density where the plants' roots touch each other.

densities	Planting should be evenly spaced to help prevent scouring due to a concentration of flow. **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS**
Weeds	It is important to identify the presence of any rapidly spreading weeds as they occur. The presence of such weeds can reduce dominant species distributions and diminish aesthetics. Weed species can also compromise the systems long term performance. Inspect for and manually remove weed species. Application of herbicide should be limited to a wand or restrictive spot spraying due to the fact that rain gardens and biofiltration tree pits are directly connected to the stormwater system. **Frequency - 3 MONTHLY OR AS DESIRED FOR AESTHETICS**
4.2.3 DRAINAGE TASKS	
Underdrain	Ensure that underdrain pipes are not blocked to prevent filter media and plants from becoming waterlogged. If a submerged zone is included, check that the water level is at the design level, noting that drawdown during dry periods is expected. 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**
High flow inlet pits, overflow pits 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. 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 mature catchment). **Frequency - MONTHLY AND OCCASIONALLY AFTER RAIN**
4.2.4 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**

4.2.5 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.

	Section 1		Section 2	
	Maintenance Required?		Maintenance Performed	
	Yes	No	Yes	No
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.*				
Filter media (*CIRCLE* – pooling water/accumulation of silt & clay layer/scour/holes/sediment build up)	☐	☐	☐	☐
Litter (*CIRCLE* - large debris/accumulated vegetation/anthropogenic)	☐	☐	☐	☐
2. Vegetation				
Vegetation health (*CIRCLE* - signs of disease/pests/poor growth)	☐	☐	☐	☐
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				
	Section 1		**Section 2**	
	Maintenance Required?		Maintenance Performed?	
	Yes	No	Yes	No
Perforated pipes (*CIRCLE* – full blockage/partial blockage/damage)	☐	☐	☐	☐
Inflow areas (*CIRCLE* – scour/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				
	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				

5 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

APPENDIX E PRACTICE NOTE 1: *IN SITU* MONITORING OF HYDRAULIC CONDUCTIVITY

CONDITION ASSESSMENT AND PERFORMANCE EVALUATION OF BIOFILTRATION SYSTEMS

PRACTICE NOTE 1: *In Situ* Measurement of Hydraulic Conductivity

Belinda Hatt, Sebastien Le Coustumer

June 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 *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.

1. SCOPE OF THE DOCUMENT

This Practice Note for *In Situ* Measurement of Hydraulic Conductivity is designed to complement FAWB's Guidelines for Filter Media in Biofiltration Systems, Version 3.01 (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

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 m^2, *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 m^2,an extra monitoring point should be added for every additional 100 m^2. 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

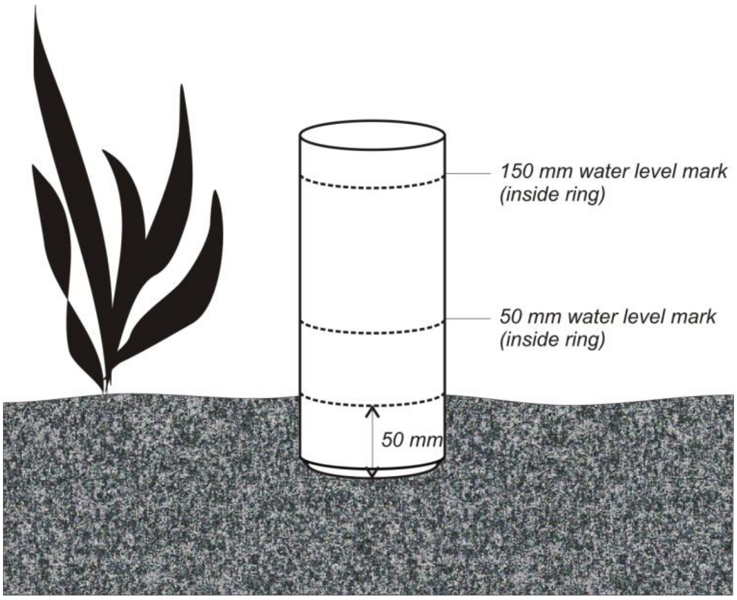


Figure 2. Diagram of single ring infiltrometer.

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):

$$K(h) = K_{fs} e^{\alpha h} \qquad \text{Eqn. 1}$$

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.

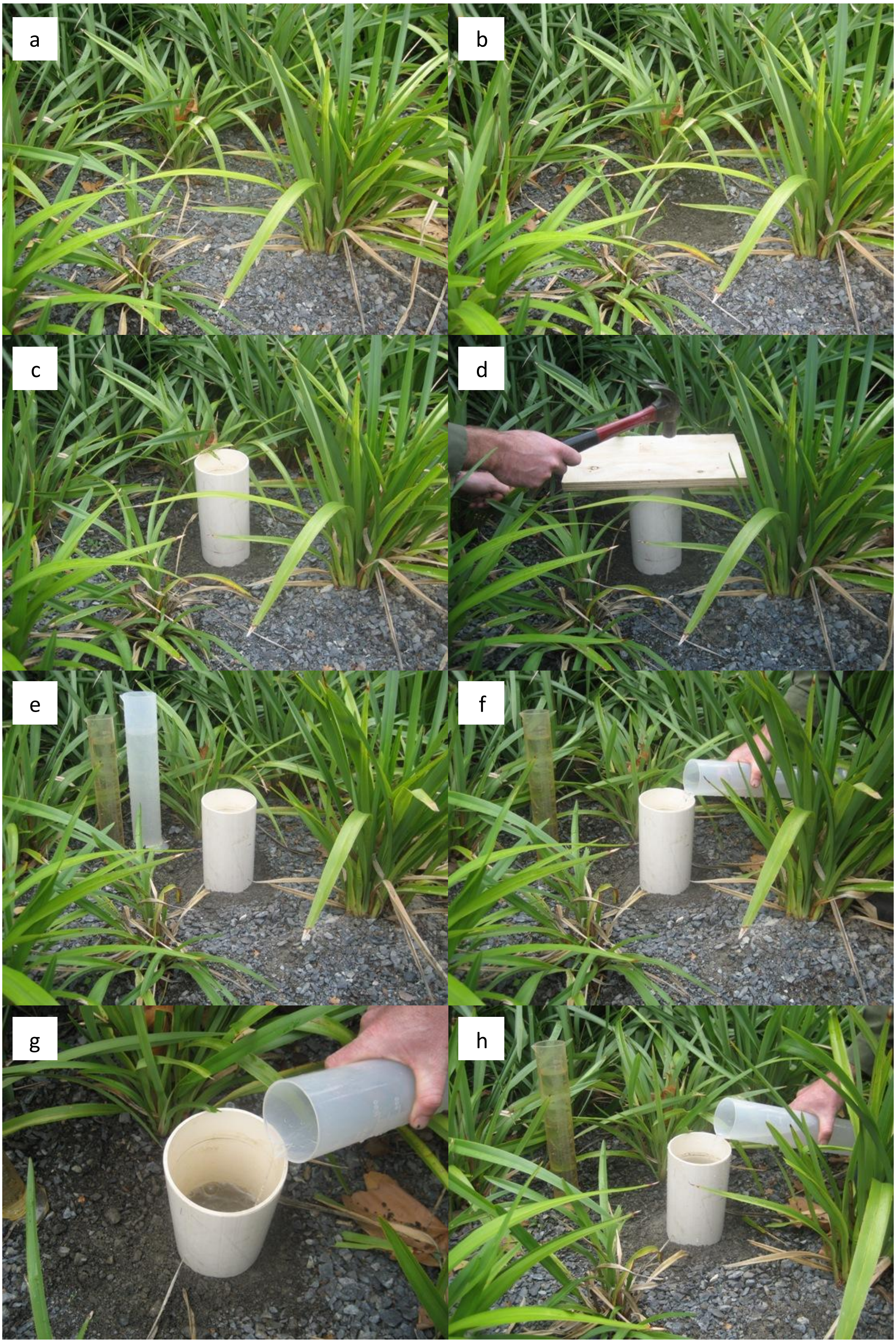


Figure 3. Measuring hydraulic conductivity.

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.

3 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.

4 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).

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 = 150 mm		
Time (min)	Volume (mL)	Q (mL/s)

APPENDIX F PRACTICE NOTE 2: PREPARATION OF SEMI-SYNTHETIC STORMWATER

CONDITION ASSESSMENT AND PERFORMANCE EVALUATION OF BIOFILTRATION SYSTEMS

PRACTICE NOTE 2: Preparation of Semi-Synthetic Stormwater

Belinda Hatt and Peter Poelsma

February 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 Preparation of Semi-Synthetic Stormwater is part of a series of Practice Notes being developed to assist practitioners with assessing the performance of biofiltration systems.

1. SCOPE OF THE DOCUMENT

This Practice Note for Preparation of Semi-Synthetic Stormwater is designed to complement FAWB's Performance Assessment of Biofiltration Systems using Simulated Rain Events. Semi-synthetic stormwater is also appropriate for laboratory-scale testing of biofiltration and other stormwater treatment systems (eg. porous pavements, constructed wetlands).

2. INTRODUCTION

There are advantages and disadvantages to using either "natural" or "synthetic" stormwater for performance assessment. The advantage of using natural stormwater (i.e., stormwater collected from a drainage outlet) is that the physical, chemical and biological characteristics will be truly representative of real stormwater. However, the disadvantage is that maintaining consistency of concentration and characteristics (eg. sediment particle size distribution (PSD)) will be very difficult, potentially introducing an artefact of inflow variations into the measurement of treatment performance. Collection of natural stormwater can be logistically difficult and is dependent on rain events, an almost certain complication to any monitoring program. The advantage of using synthetic (i.e., using laboratory chemicals) stormwater is that is readily available and will better achieve consistency, however it will introduce artefacts due to unnatural composition (Deletic & Fletcher, 2006). Semi-synthetic stormwater represents an appropriate compromise because it is prepared using sediment sourced from a stormwater pond. Since it is actual stormwater sediment, this should also largely achieve desired nutrient and heavy metal concentrations; any deficiencies can then be topped up using laboratory-grade chemicals.

3. METHODOLOGY

The basic procedure in preparing semi-synthetic stormwater is to collect sediment from a stormwater pond, prepare a slurry of known sediment concentration, mix this with dechlorinated water[1] and add laboratory-grade chemicals as required. The first time sediment is collected, pilot study-type testing of the slurry needs to be conducted to characterise the sediment (pollutant concentration, PSD, as described in Section 3.3.3). For subsequent collections, only the sediment concentration of the slurry needs to be tested.

3.1 Target characteristics

3.1.1 Pollutant concentrations

There is a high level of spatial and temporal variability in stormwater pollutant concentrations. Where local stormwater quality data is available, these should be the target pollutant concentrations. However, where such data is not available, typical pollutant concentrations for runoff from urban areas would be appropriate targets (Table 1).

Table 1. Typical stormwater pollutant concentrations (Duncan, 1999; Taylor *et al.*, 2005).

Pollutant	Concentration (mg/L)
Total Suspended Solids (TSS)	150
Total Nitrogen (TN)	2.2
Nitrate/Nitrite (NO_x)	0.74
Ammonia (NH_3)	0.34
Dissolved Organic Nitrogen (DON)	0.69
Particulate Organic Nitrogen (PON)	0.50
Total Phosphorus (TP)	0.35
Filterable Reactive Phosphorus (FRP)	0.12
Cadmium (Cd)	0.0045
Chromium (Cr)	0.025
Copper (Cu)	0.05
Lead (Pb)	0.14
Manganese (Mn)	0.23
Nickel (Ni)	0.031
Zinc (Zn)	0.25
Total Petroleum Hydrocarbons (TPH) + Polyaromatic Hydrocarbons (PAH)	10

The list of stormwater pollutants presented in Table 1 is by no means exhaustive, however these are the pollutants that are of most concern where the management objective is protection of aquatic ecosystems. It may not be possible to analyse for all of these pollutants, depending on the available budget, however the minimum suite of pollutants should include TSS, TN, TP, Cd, Cu, Pb, Zn. If reuse is planned, pathogens are a key water quality issue and should be considered as an additional pollutant.

3.1.2 Particle size distribution

The PSD of stormwater sediment varies widely according to catchment characteristics, as well as rainfall patterns and intensity. Like pollutant concentrations, local information should form the basis

[1] Mains or recycled water is suitable

of appropriate targets, however where this data does not exist, it would be appropriate to aim for a median particle size (d_{50}) of 25 - 60 µm (Siriwardene *et al.*, 2007).

Note: Given the large spatial and temporal variation in PSDs, it is neither feasible nor justified to try to match an exact PSD. However, many stormwater pollutants are known to attach to very small particles (eg. heavy metals are strongly correlated to particles that are <15 µm, Sansalone & Buchberger, 1995), therefore it should be ensured that this fraction is adequately represented (5 – 15 % of weight fraction).

3.2 Collection of stormwater sediment

Collect sediment from near (but a short distance from) the inlet of a stormwater pond or wetland using a shovel; sediment very close to the inlet is dominated by coarse sand and gravel. Slowly scrape the surface of the sediment layer (this is the "freshest" sediment i.e., it has most recently been stormwater), taking care to minimise disturbance. The amount of sediment that needs to be collected will depend on the volume of stormwater to be prepared; as a general guide, 5 L of sediment will make 3000 L of semi-synthetic stormwater.

3.3 Preparation and analysis of sediment slurry

A slurry is a concentrated mixture of sediment and water. This is prepared by wet sieving the sediment using a small volume of water.

3.3.1 Apparatus

The following apparatus is required:

- Scoop
- Sieve (see below for guidance on appropriate size)
- Collection vessel
- Small cup or beaker
- Spatula or rubber squeegee
- Water

Biofilters (and other stormwater treatment structures) may or may not incorporate pre-treatment. Where systems do not have pre-treatment facilities, a 1 mm sieve should be used to remove very large particles, while a 300 µm sieve should be used for systems that do have pre-treatment. The aim of this procedure is to try to replicate the realistic nature of the inflow sediment that will enter the biofiltration system in operation.

Caution: Stormwater sediment potentially contains pathogens and, while the risk of falling ill is low, appropriate protocols for safe-handling of environmental samples should be followed, including long gloves, covered skin, and safety glasses. Personnel should also have received necessary vaccinations; consult a general practitioner or health advisor for further information.

3.3.2 Procedure

a. Place the sieve on top of the collection vessel

b. Place several scoops of sediment on the sieve
c. Pour a cup of water over the sediment
d. Use spatula or squeegee to stir sediment around, allowing water to wash particles through to the collection chamber
e. Wash and stir the sediment in the sieve with ten cups of water, then discard the fraction that did not pass through the sieve

   Note: When all the clean water has washed through the sieve, use the cup to scoop up supernatent liquid from the collection vessel (avoid scooping up settled sediment) and use this liquid to wash the sediment in the sieve, stirring with the spatula while doing so.
f. Repeat Steps b to e until the required volume of slurry (plus some extra for analysis) has been prepared.

3.3.3 Analysis

The first time sediment is collected from a stormwater pond, all of the tests described below must be carried out in order to characterise the sediment. For subsequent collections, only the sediment concentration of the slurry needs to be analysed, provided that inflow samples of the stormwater are collected during testing.

<u>Sediment concentration</u>. The method for measuring the sediment concentration of the slurry is an adaptation of the Australian Standard method for determination of total solids in waters (Australian Standard, 1990). Rapidly stir the slurry so that all particles are in suspension and immediately collect three 100 mL samples of the slurry (continue stirring between each sample collection), transfer each sample to a pre-weighed container, and dry in an oven at 105^{o} for one hour. Allow the containers to cool at room temperature before weighing again. Calculate the sediment concentration of each sample using Equation 1 and determine the average.

$$c_s = \frac{m_{c+s} - m_c}{v}$$

Equation 1

where: c_s = sediment concentration in slurry (mg/L)

m_{c+s} = dry mass of container + slurry (mg)

m_c = mass of container (mg)

v = volume of slurry (0.1 L)

Note: The target sediment concentration should be around 300 $\pm$ 200 g/L.

<u>Particle size distribution</u>. There is a high level of uncertainty associated with measurement of the PSD, and low levels of agreement between test methods. Consistently using the same test method is therefore more important than the actual test method. PSD is typically measured using sieving techniques or particle sizers; given that both methods have their advantages and disadvantages, it is recommended that the test method that is most readily available and convenient be adopted, and then used consistently for all subsequent tests.

Pollutant concentration. A sub-sample of the slurry should be mixed with water to achieve the target TSS concentration; see Section 3.5 for guidance on calculating the required volumes. A sample of this should then be analysed for all the pollutants of interest by a NATA-accredited laboratory.

3.4 Addition of laboratory grade chemicals

Once the pollutant concentration of the slurry/water mix has been determined, the need for "topping up" pollutant concentrations can be assessed. Where this is required, laboratory grade chemicals should be used. The chemicals that should be used for each pollutant are listed in Table 2; see Section 3.5 for guidance on calculating the required amount to add.

Table 2. Chemicals for topping up stormwater pollutant concentrations. Note that it is important to use these particular chemicals due to solubility considerations e.g. Lead (Pb) forms an insoluble salt with sulphate (SO_4) and chloride (Cl).

Pollutant	Compound to dose with
TN	n/a*
NO_x	potassium nitrate (KNO_3)
NH_3	ammonium chloride (NH_4Cl)
DON	nicotonic acid ($C_6H_5O_2N$)
PON	n/a†
TP	n/a†
FRP	potassium phosphate (KH_2PO_4)
Cd	1000 mg/L standard solution
Cr	chromium nitrate ($Cr(NO_3)_3$)
Cu	copper sulphate ($CuSO_4$)
Pb	lead nitrate ($Pb(NO_3)_2$)
Mn	manganese nitrate ($Mn(NO_3)_2$)
Ni	nickel nitrate ($Ni(NO_3)_2$)
Zn	zinc chloride ($ZnCl_2$)
TPH & PAH	diesel

*TN is the sum of NO_x, NH_3, DON and PON; if the targets concentrations of these constituents are met, then the target TN concentration will also be achieved.

†PON is sourced from the slurry, while TP is the sum of particulate phosphorus sourced from the slurry and FRP.

Caution: Aquire and observe the Material Safety Data Sheets (MSDS) for each chemical that is used and follow appropriate protocols for safe handling and storage of chemicals.

3.5 Preparation of stormwater

Sections 3.5.1 – 3.5.3 describe the calculations required to determine to final volumes. The spreadsheet "Practice Note 2_Preparation of semi-synthetic stormwater_dosing calculations.xls", available at http://www.monash.edu.au/fawb/products/index.html, can also be used to calculate the required mass of chemicals and slurry needed to prepare the semi-synthetic stormwater.

3.5.1 Dechlorinated water

Mains water generally contains residual chlorine, which should be neutralised with sodium thiosulphate ($Na_2S_2O_3$) prior to preparing the semi-synthetic stormwater (to avoid it having an effect on the biological community in the biofilter). The amount of sodium thiosulphate to add: 0.1 g/100 L water.

3.5.2 Amount of slurry to add

The amount of slurry to add is calculated using Equation 2:

$$v_s = \frac{TSS \times v_{st}}{c_s} \qquad \textbf{Equation 2}$$

where: v_s = volume slurry (L)

TSS = target TSS concentration (mg/L)

v_{st} = volume semi-synethic stormwater (L)

c_s = sediment concentration in slurry (mg/L)

3.5.3 Mass of chemicals to add

The amount of chemical to add is calculated by substracting the concentration achieved by adding the slurry from the target concentration and converting the difference to a mass (Equation 3). Since the concentration is reported as mg/L of the pollutant of interest (e.g. Cu), the calculation includes a conversion from the mass of that pollutant to the equivalent mass of the compound (e.g. $CuSO_4$).

$$m(\text{dosing compound}) = (c_t - c_{sw}) \times v_{st} \times \frac{1}{\frac{Mr(\text{pollutant of interest})}{Mr(\text{dosing compound})}}$$

Equation 3

where: m(dosing compound) = mass of dosing compound (mg)

c_t = target pollutant concentration (mg/L)

c_{sw} = pollutant concentration achieved by slurry/water mix (mg/L)

v_{st} = volume semi-synthetic stormwater (mg/L)

Mr(pollutant of interest) = molecular mass of pollutant of interest (g/mol)

Mr(dosing compound) = molecular mass of dosing compound (g/mol)

For example, the target concentration for Cu is 0.05 mg/L, however a slurry prepared from sediment Wetland A and mixed with water to the target TSS concentration only has a Cu concentration of 0.01 mg/L. Therefore, the concentration needs to be increased by 0.04 mg/L. The molecular mass of Cu is 63.55 g/mol, while that of $CuSO_4$ is 159.62 g/mol. To prepare 600 L of semi-synthetic stormwater that meets the target Cu concentration, 0.06 g of $CuSO_4$ needs to be added to the slurry/water mix.

$$m(CuSO_4)=(0.05-0.01)\times 600\times \frac{1}{\frac{63.55}{159.62}}=60mg=0.06g$$

3.5.4 Mixing the semi-synthetic water

The water, slurry and chemicals (as required) should be mixed in a tank and stirred continuously (this can be mechanical or manual). It is important that the stormwater is mixed for at least ten minutes to allow for the adsorption of various pollutants to particles in the mixture − the proportion of dissolved and particulate pollutants has a major influence on treatment performance. Slurry can be prepared and kept for several weeks, if refrigerated in a container with a secure lid (to reduce evaporation), however stormwater should be used on the day it is prepared.

REFERENCES

Australian Standard (1990). AS 3550.4-1990 Waters - Part 4: Determination of solids - Gravimetric method. Homebush, New South Wales, Standards Australia.

Deletic, A. and T. D. Fletcher (2006). Performance of grass filters used for stormwater treatment - a field and modelling study. *Journal of Hydrology* 317(3-4): 261-275.

Duncan, H. P. (1999). Urban Stormwater Quality: A Statistical Overview. Melbourne, Australia, Cooperative Research Centre for Catchment Hydrology: 80.

Sansalone, J. J. and S. G. Buchberger (1995). An infiltration device as a best management practice for immobilizing heavy metals in urban highway runoff. *Water Science and Technology* 32(1): 119-125.

Siriwardene, N. R., A. Deletic and T. D. Fletcher (2007). Clogging of stormwater gravel infiltration systems and filters: insights from a laboratory study. *Water Research* 41(7): 1433-1440.

Taylor, G. D., T. D. Fletcher, T. H. F. Wong, P. F. Breen and H. P. Duncan (2005). Nitrogen composition in urban runoff - implications for stormwater management. *Water Research* 39(10): 1982-1989.

APPENDIX G PRACTICE NOTE 3: PERFORMANCE ASSESSMENT OF BIOFILTRATION SYSTEMS USING SIMULATED RAIN EVENTS

PRACTICE NOTE 3: 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.

1. SCOPE OF THE 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.

$$\text{interval} = \frac{3000\,\text{L} \times 0.7}{14} = 150\,\text{L}$$

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 (NH_4^+), oxidised nitrogen (NO_x), organic nitrogen (ON), and orthophosphate (PO_4^{3-}, 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: l_{in} = inflow load (mg)

v_{in} = total inflow volume (L)

c_{in} = inflow pollutant concentration (mg/L)

$$l_{out} = \sum_{i=1}^{N} v_{i,out} c_{i,out}$$

where: l_{out} = outflow load (mg)

$v_{i,out}$ = volume between samples i and i-1

$c_{i,out}$ = 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 CRESCENT, 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 2**a, 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 2**d and e). It takes approximately 25 minutes to prepare and discharge the five batches to the biofilter (**Figure 2**f 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, NO_x, NH_3, 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 (NO_x)	0.59
Ammonia (NH_3)	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.

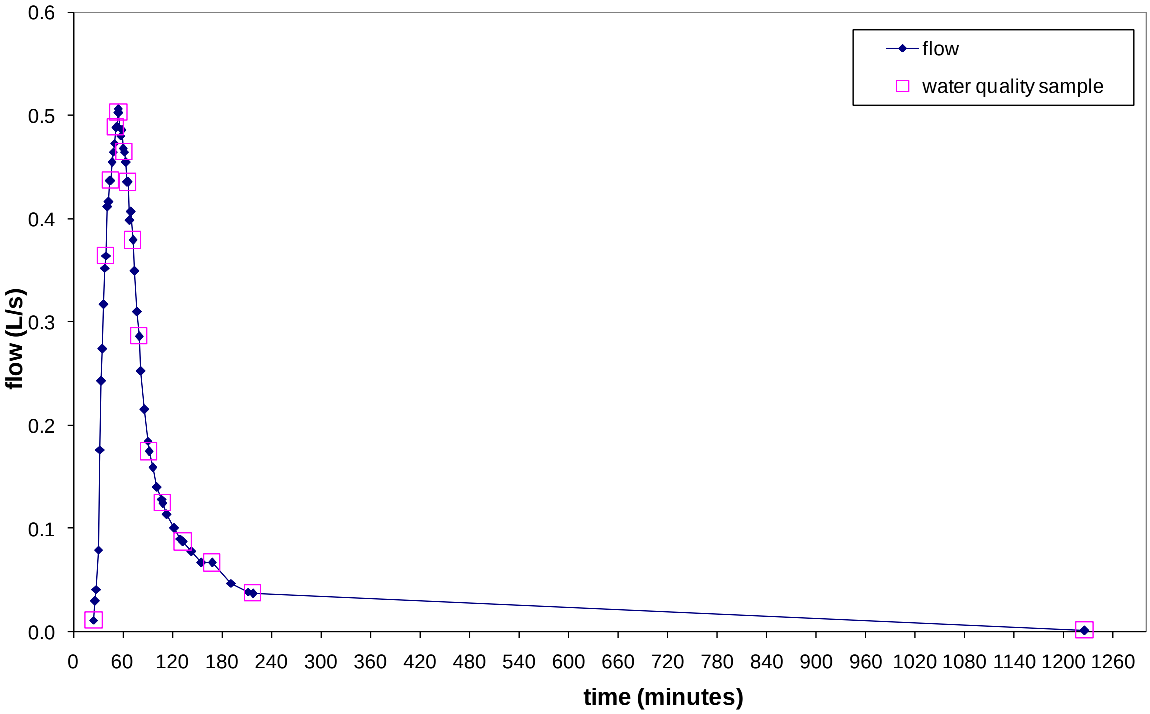


Figure 3. Typical hydrograph for a rain event simulation at the Saturn Crescent biofiltration system showing water quality sample collection times.

REFERENCES

Australian/New Zealand Standard (1998). AS/NZS 5667.1:1998 Water quality - Sampling, Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples. Homebush, New South Wales, Standards Australia.

Hatt, B. E., T. D. Fletcher and A. Deletic (2009). Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale. *Journal of Hydrology* **365**(3-4): 310-321.

Wong, T. H. F., Ed. (2006). Australian Runoff Quality: A Guide To Water Sensitive Urban Design. Sydney, Engineers Australia.

APPENDIX H MAINTENANCE REQUIREMENTS FOR BIOFILTRATION SYSTEMS: FIELD SHEET

MAINTENANCE REQUIREMENTS FOR BIOFILTRATION SYSTEMS

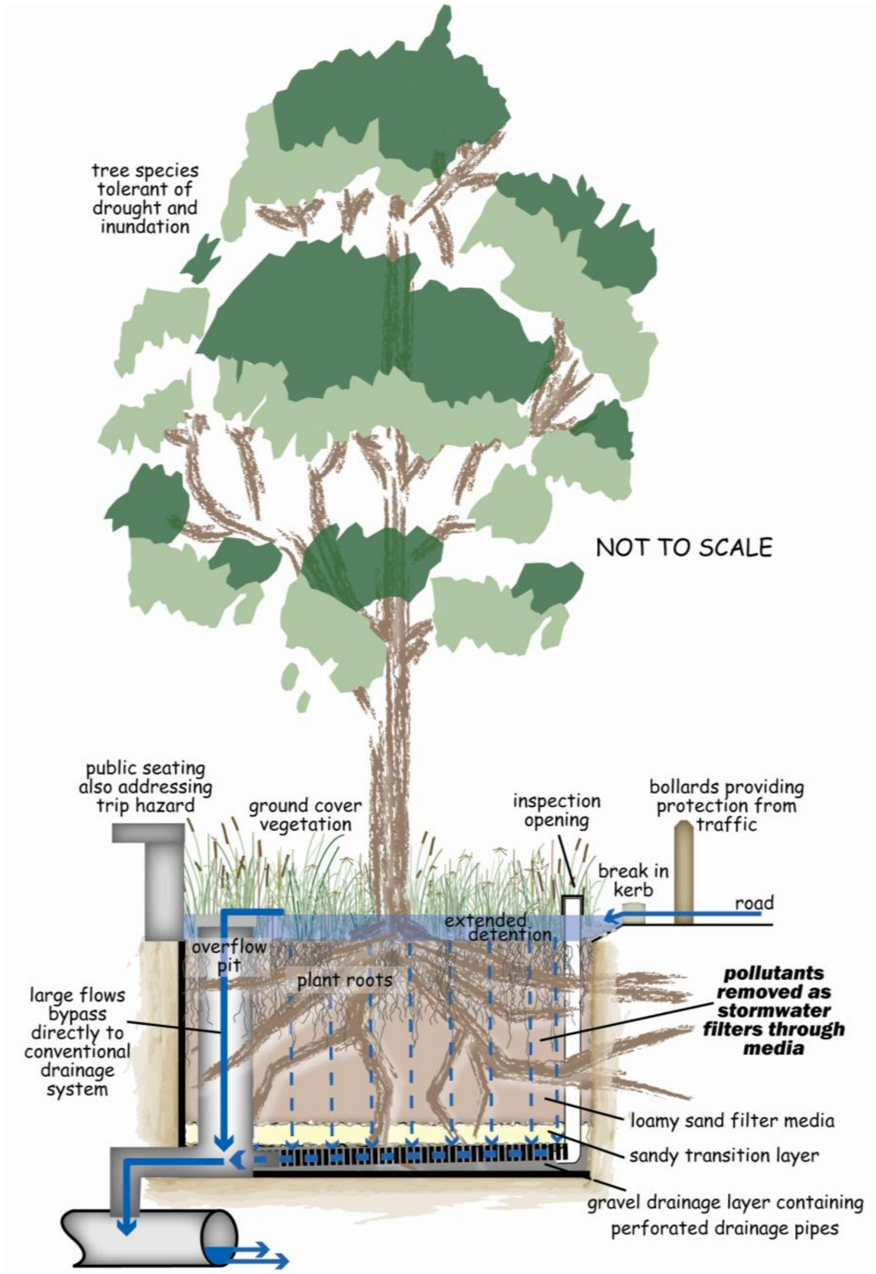


Figure 1. Conceptual drawing of a biofiltration system illustrating stormwater flow pathways and subsurface infrastructure.

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 upturned 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.

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.	

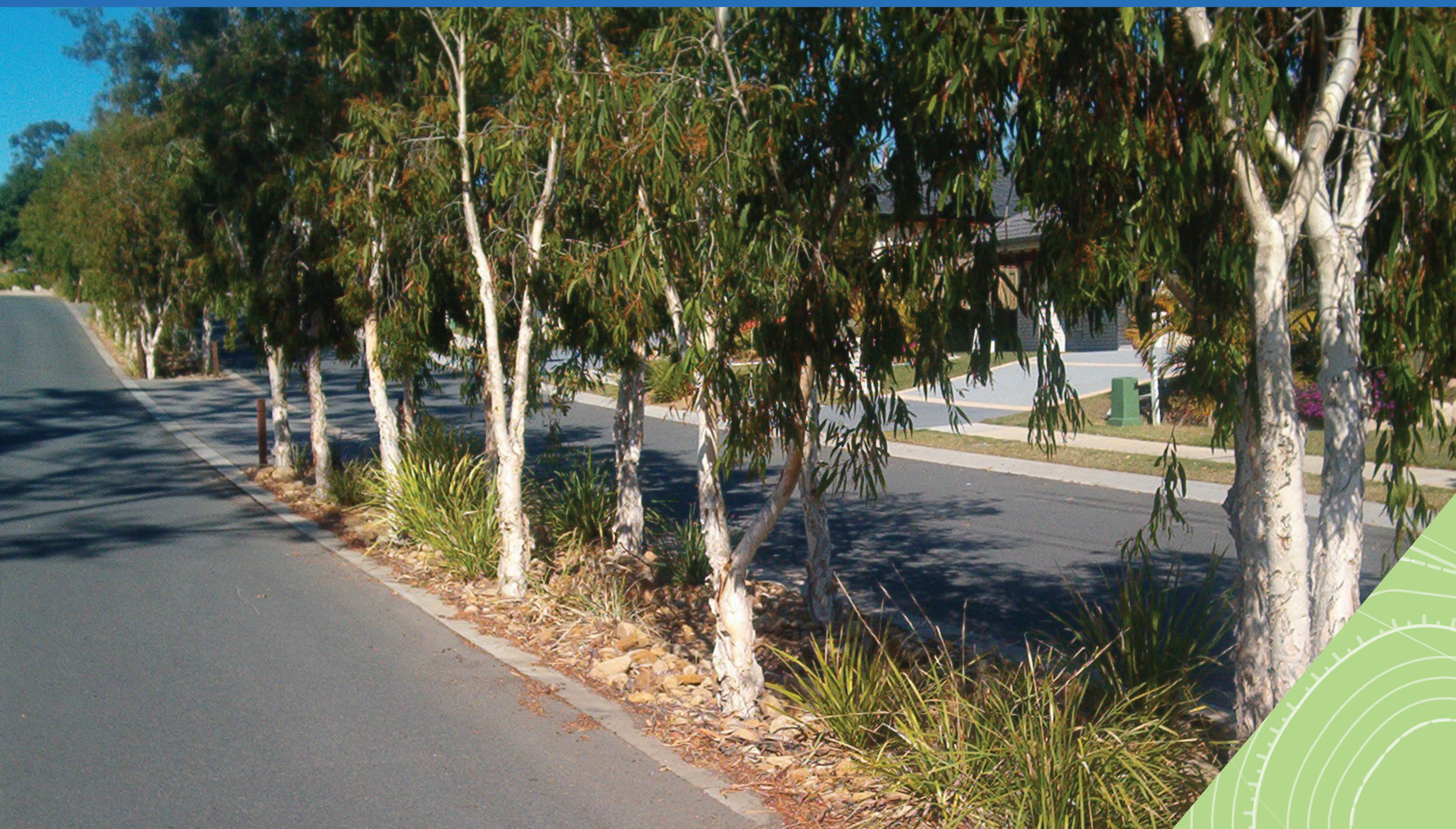
MAINTENANCE REQUIREMENTS FOR BIOFILTRATION SYSTEMS

Table 2. Inspection and maintenance tasks for biofiltration systems.

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	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	Flow paths and infiltration through the filter media may be hindered.	• Remove both organic and anthropogenic litter
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, or as desired for aesthetics	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 • 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/m^2 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
DRAINAGE			
Check that 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 that the water level in the submerged zone (if applicable) is at the design level	6 monthly, after rain	Drawdown during dry periods is expected.	• Check outflow level is correct and reset as required
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	A blocked grate or inlet would cause nuisance flooding.	• Replace dislodged or damaged pit covers as required • Remove sediment from pits and entry sites (likely to be an irregular occurrence in mature catchments)
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)

FAWB
Facility for Advancing
Water Biofiltration

FAWB Office
Monash University Department of Civil Engineering
Building 60, Clayton Campus
MONASH UNIVERSITY, VIC 3800, Australia
Phone +61 3 9905 4957 Fax +61 3 9905 5033
fawb@eng.monash.edu.au
www.monash.edu.au/fawb



The Facility for Advancing Water Biofiltration, FAWB, is a joint venture research facility between EDAW Australia and Monash University under the auspices of the Victorian Government's Science Technology and Innovation Initiative.

Collaborators
Adelaide and Mount Lofty Ranges Natural Resources Management Board, SA
Brisbane City Council, Qld
Landcom, NSW
Manningham City Council, Vic
Melbourne Water, Vic
VicRoads, Vic

Victoria
The Place To Be