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Chapter 4: Practical Implementation

4.1 Introduction

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

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

- Water by Design, 2009. Construction and Establishment Guidelines: Swales, Bioretention systems and Wetlands (Version 1, February 2009). South East Queensland Healthy Waterways Partnership, Brisbane.
- Water by Design, 2014. Bioretention Technical Design Guidelines (Version 1.1, October 2014). Healthy Waterways Ltd, Brisbane.
- Water by Design, 2012. Transferring Ownership of Vegetated Stormwater Assets (Version 1, February 2012).
- Water by Design, 2012. Maintaining Vegetated Stormwater Assets (Version 1, February 2012).
- Water by Design, 2012. Rectifying Vegetated Stormwater Assets (Draft, February 2012).
- Monash Water for Liveability Centre et al. 2014. Vegetation guidelines for stormwater biofilters in the south-west of Western Australia. Monash Water for Liveability, Clayton.
- Townsville City Council, 2011. 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.
- Moreland City Council and GHD, 2013. Streetscape WSUD raingarden & tree pit design package.

4.2 Construction and establishment

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

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

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

Important!

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

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

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

Cont.

Table 16. Continued

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

Cont.

Table 16. Continued

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

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Table 16. Continued

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

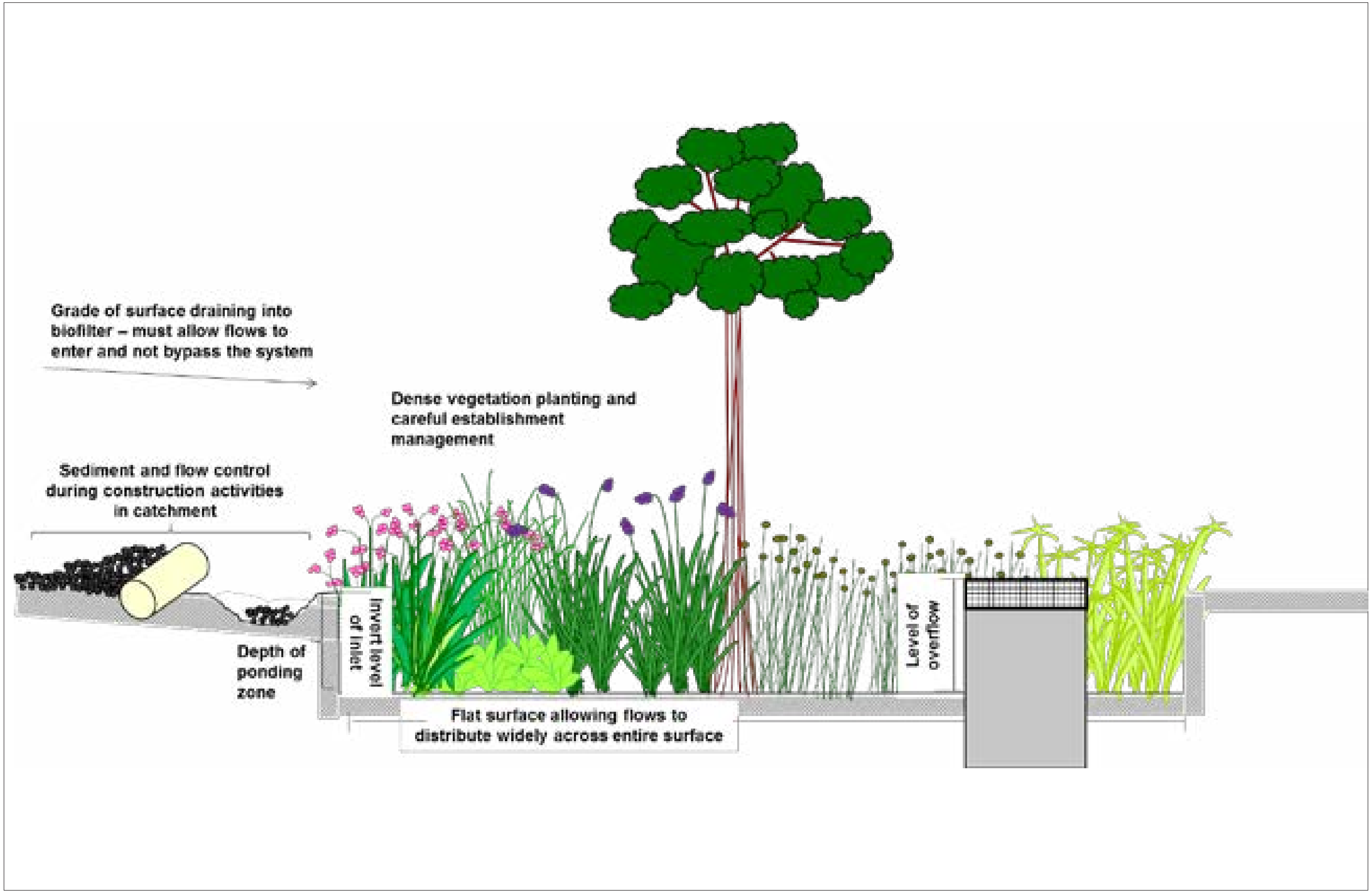
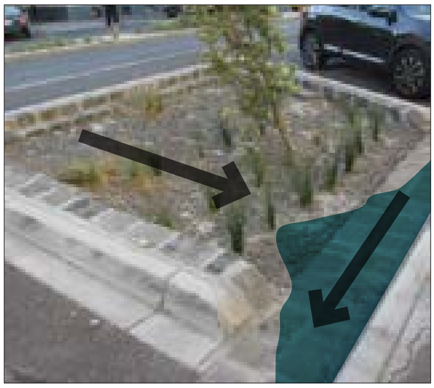


Figure 42. Critical quality control checks during and following construction

Figure 43. Common construction and establishment phase issues

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

No drop down into biofilter – flow cannot easily enter



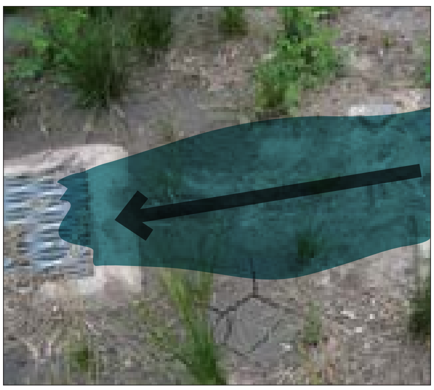
Slope follows road
Biofilter surface not flat– uneven flow distribution and poor channelling of flows to top of system

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

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

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

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



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

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

4.3 Inspection and maintenance requirements

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

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

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

Maintenance tip

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

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

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

4.3.1 Enabling successful maintenance systems

Organisational planning

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

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

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

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

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

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

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

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

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

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

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

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

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

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

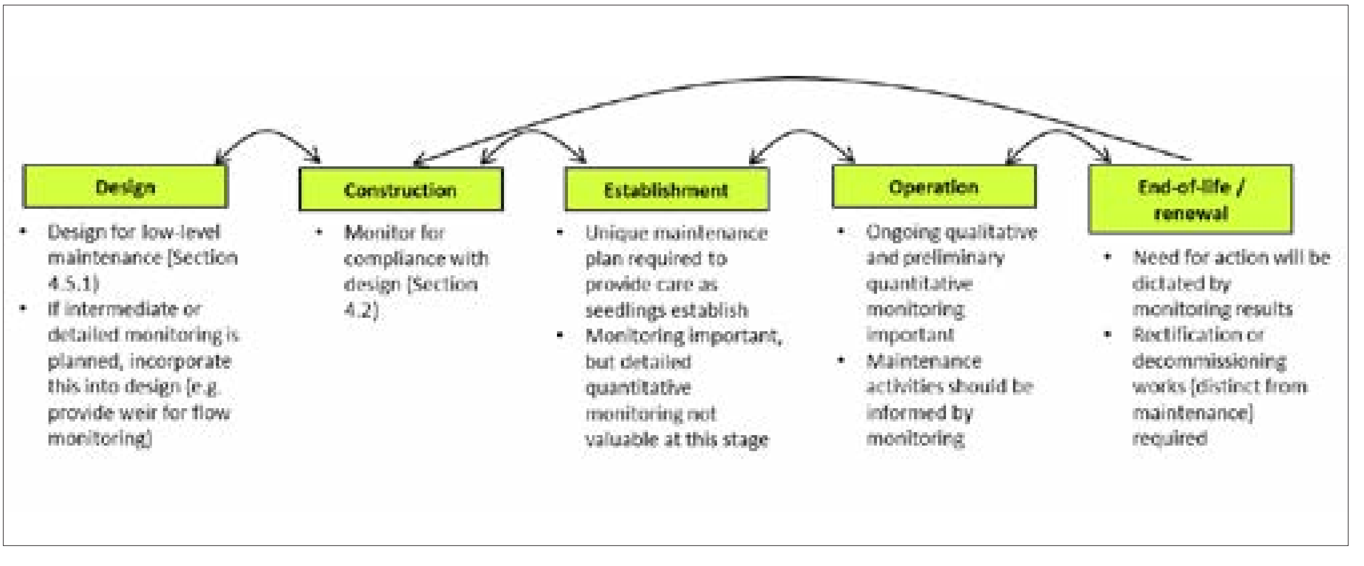


Figure 44. Project phases and interactions between stages

4.3.2 Inspection and maintenance program

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

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

- **Timing** - Maintenance should occur only after a reasonably rain free period, when the filter media in the biofilter is relatively dry. Inspections are also recommended following large storm events to check for scour and other damage.

- **Frequency** - Recommended frequencies are given in Table 17. However, this will vary throughout the project life, with more frequent inspections required during establishment. It may also differ between systems, depending upon factors such as public visibility or sediment and litter load input from the catchment, or with the level of service to which the asset owner commits.

- **Typical maintenance activities** will focus upon either the vegetation, filter media or hydraulic aspects of the system:

  - **Vegetation** - Vegetation plays a key role in pollutant removal processes and in maintaining the porosity of the filter media. Hence, a strong healthy growth of vegetation is critical to the treatment performance of biofilters. The most intensive period of maintenance is during the plant establishment period (i.e., the first two years), when weed removal and replanting may be required. However, care during this early phase will reduce long-term maintenance requirements and lessen the likelihood that an expensive re-plant of the entire system will be required. Readers are directed to the 'Construction and Establishment Guidelines' by Water by Design (2009) for detailed information on vegetation establishment (also discussed in Section 4.2).

  - **Filter media** – The surface of the biofilter is vulnerable to erosion, scour, damage from pedestrians or vehicles, sediment and litter accumulation, clogging and moss growth. These compromise the function of the system, in terms of the infiltration rate and the capacity to treat stormwater volumes.

  - **Hydraulic components** - Inflow systems and overflow pits require careful monitoring, as these can be prone to scour, sediment accumulation and litter accumulation. Debris can block inlets or outlets and can be unsightly, particularly in high visibility areas. Inspection and removal of debris should be undertaken regularly, and debris should be removed whenever it is observed on a site. Sediment accumulation across the media surface should also be closely monitored and removed when significant. Where sediment forebays or other pre-treatment measures are adopted, regular inspection of the pre-treatment system is required (three monthly) with removal of accumulated sediment undertaken as required (typically once per year).

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

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

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

Cont.

Table 17. Continued

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

Cont.

Table 17. Continued

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

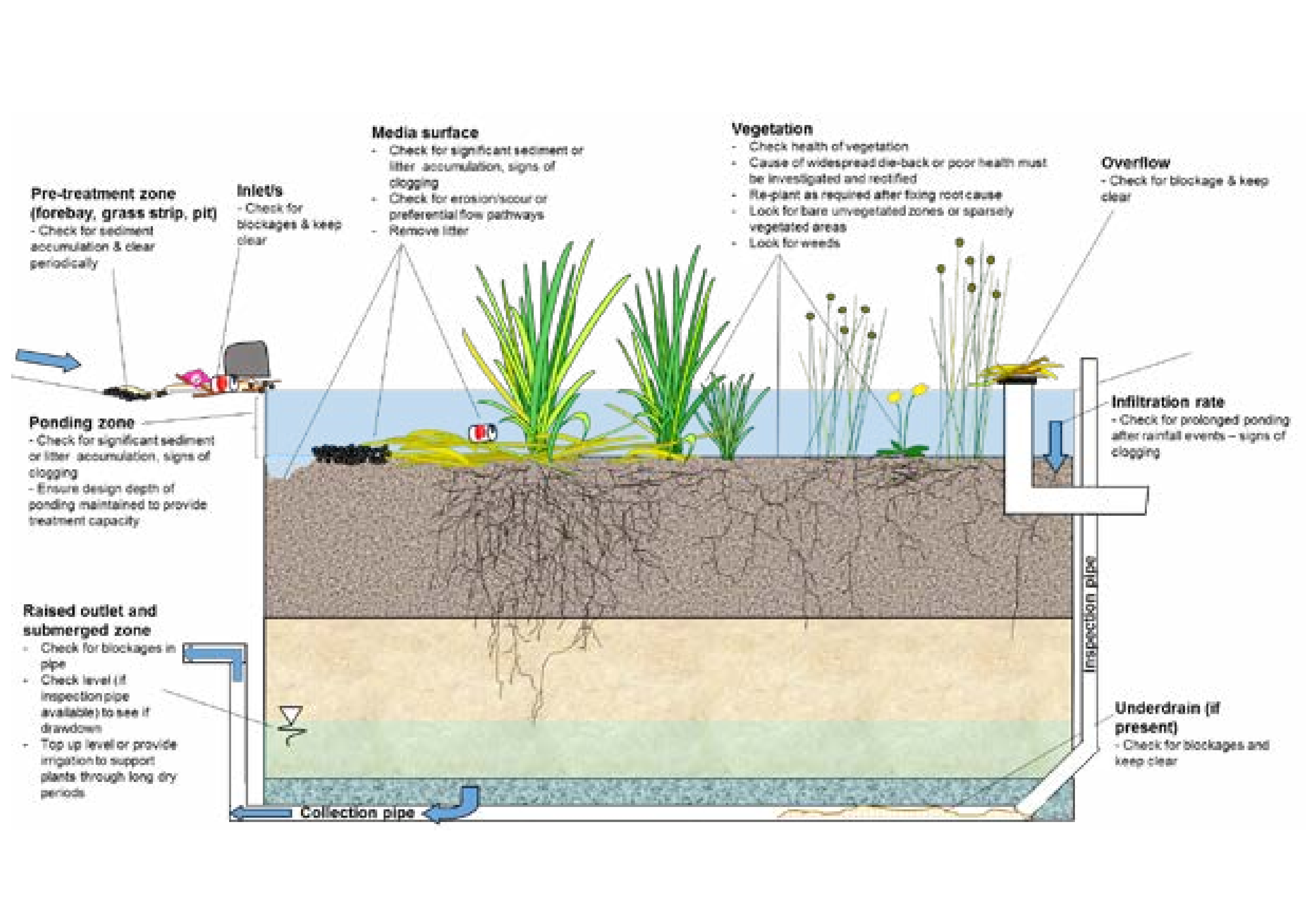


Figure 45. Critical checks and tasks for a monitoring and maintenance program

Maintenance tips

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

Important!

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

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

Table 18. Common maintenance issues

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

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

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

Table 18. Continued

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

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

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

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

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

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

Vehicle and pedestrian damage – impacts vegetation health and causes compaction

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

Weeds – unsightly and can reduce treatment capacity

4.3.3 Monitoring

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

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

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

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

Important!

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

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

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

Monitoring tip

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

Important!

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

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

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

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Table 19. Continued

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

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Table 19. Continued

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

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

4.4 Remedial works, re-sets and biofilter lifespan

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

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

4.4.1 Pollutant accumulation and lifespan

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

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

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

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

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

For tree pits:

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

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

Table 20. Pollutant accumulation and expected lifespan for various pollutants

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

Cont.

Table 20. Continued

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

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

4.4.2 Management, renewal and re-sets

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

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

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

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

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

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

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

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

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

4.5 References

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.

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

Browne, D., Whiteoak, K. & Obaid, N. 2013. The business case for pro-active WSUD maintenance. Proceedings of the *8th International Water Sensitive Urban Design Conference*, 25-29 November 2013, Gold Coast, Qld. Engineers Australia.

Dahmani-Muller, H., Van Oort, F., Gélie, B. & Balabane, M. 2000. Strategies of heavy metal uptake by three plant species growing near a metal smelter. *Environmental Pollution*, 109, 231-238.

Daly, E., Deletic, A., Hatt, B. & Fletcher, T. 2012. *Modelling of stormwater biofilters under random hydrologic variability: a case study of a car park at Monash University*, Victoria (Australia). Hydrological Processes, 26, 3416-3424.

E2DesignLab 2014a. *City of Port Phillip - Review of street scale WSUD*. Final Report. Prepared for City of Port Phillip. Melbourne, Australia.

E2DesignLab 2014b. *City of Port Phillip - Streetscape WSUD: Targeted Maintenance*. Prepared for City of Port Phillip. Melbourne, Australia.

Glaister, B., Cook, P., Fletcher, T. & Hatt, B. 2013. Long-term phosphorus accumulation in stormwater biofiltration systems at the field scale. Proceedings of the *8th International Water Sensitive Urban Design Conference*, 25-29 November 2013, Gold Coast, Qld. Engineers Australia.

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

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

Hatt, B. E., Steinel, A., Deletic, A. & Fletcher, T. D. 2011. Retention of heavy metals by stormwater filtration systems: Breakthrough analysis. *Water Science & Technology*, 64, 1913-1919.

Kandra, H. S., Deletic, A. & McCarthy, D. 2014. Assessment of impact of filter design variables on clogging in stormwater filters. *Water Resources Management*, 28, 1873-1885.

Le Coustumer, S., Fletcher, T. D., Deletic, A., Barraud, S. & Poelsma, P. 2012. The influence of design parameters on clogging of stormwater biofilters: A large-scale column study. *Water Research*, 46, 6743-6752.

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

Ma, J., Lenhart, J. H. & Tracy, K. 2013. Solids Loading Capacity of Stormwater Biomedia for Estimating Biofilter Longevity. *World Environmental and Water Resources Congress 2013, Showcasing the Future*. ASCE.

Macmahon, D., Sharley, D., Pettigrove, V. 2013a. *A review of soil disposal guidelines with an emphasis on Zinc contamination*. CAPIM.

Macmahon, D., Townsend, K., Sharley, D. 2013b. *Assessment of the vertical distribution of pollutants from two model sediment ponds in Melbourne*. Melbourne Water and CAPIM.

NEPC 1999a. *Guideline of the Investigation Levels for Soil and Groundwater*, Schedule B(1). National Environment Protection Measure.

NEPC 1999b. *National Environment Protection (Assessment of Site Contamination)* Measure 1999.

Parsons Brinckerhoff 2013. *Water Sensitive Urban Design Life Cycle Costing - Data Analysis Report*. Melbourne, Australia: Report prepared for Melbourne Water.

Payne, E. G., Fletcher, T. D., Russell, D. G., Grace, M. R., Cavagnaro, T. R., Evrard, V., Deletic, A., Hatt, B. E. & Cook, P. L. 2014. Temporary Storage or Permanent Removal? The Division of Nitrogen between Biotic Assimilation and Denitrification in Stormwater Biofiltration Systems. *PloS one*, 9, e90890.

Rascio, N. & Navari-Izzo, F. 2011. Heavy metal hyperaccumulating plants: How and why do they do it? And what makes them so interesting? *Plant Science*, 180, 169-181.

Virahsawmy, H., Stewardson, M., Vietz, G. & Fletcher, T. D. 2014. Factors that affect the hydraulic performance of raingardens: implications for design and maintenance. *Water Science and Technology*, 69, 982-988.

Walsh, C. J., Fletcher, T. D. & Ladson, A. R. 2005. Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. *Journal of the North American Benthological Society*, 24, 690-705.

Water by Design 2009. *Construction and establishment guidelines - swales, bioretention systems and wetlands*. Version 1, February 2009. South East Queensland Healthy Waterways Partnership, Brisbane.

Water by Design 2012. *Transferring Ownership of Vegetated Stormwater Assets*. Version 1, February 12. Healthy Waterways, Ltd. Brisbane.

Water by Design 2015. *Guide to the Cost of Maintaining Bioretention Systems*. Version 1, February 2015. Healthy Waterways, Ltd. Brisbane, Australia.

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

Zhang, K., Randelovic, A., Page, D., McCarthy, D. T. & Deletic, A. 2014b. The validation of stormwater biofilters for micropollutant removal using in situ challenge tests. *Ecological Engineering*, 67, 1-10.

Zinger, Y., Deletic, A., 2012. *Kfar-Sava Biofilter: The first milestone towards creating water sensitive cities in Israel*. Monash Water for Liveability, Monash University, Jewish National Fund of Australia Inc., CRC for Water Sensitive Cities, December 2012.