A review of the application of Filterra® Biofiltration Systems in Australia

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Document Control Sheet

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Synopsis	This report provides an analysis of the application of Filterra® biofiltration systems as a stormwater treatment asset within Australia.

Executive Summary

Over recent decades, the implementation of stormwater control measures (SCMs) to achieve a more 'water sensitive' urban environment and reduce the hydrologic and water quality impacts of urban development has increased across Australia (and overseas) (Ma et al 2019, Hermawan et al 2019, Dalrymple et al 2018). Biofiltration systems (also called biofilters, bioretention basins, bioretention systems, bioswales and raingardens) are one of the most commonly used SCM given their flexible design, space efficiency and applicability at a variety of scales (Water By Design 2014).

A Filterra® biofiltration system is very similar to a 'typical' biofiltration system (using 'sandy loam' filter media). A key difference, however, is that Filterra® biofiltration systems utilise a filter media blend that can treat flows at a significantly higher flow rate than typical biofiltration filter media. Filterra® biofiltration systems can also achieve local stormwater pollution reduction targets with significantly less area (typically 0.3% of upstream area) relative to typical biofiltration systems (with 'sandy loam' media, typically 0.8 to 1.5% of upstream area).

This report provides a review of the performance of Filterra® biofiltration systems, and of their suitability for application within Australia. This review has shown that Filterra® biofiltration systems are an appropriate stormwater treatment asset type for application in Australian urban environments for both privately and publicly owned areas. This finding considers a range of factors, including the following:

- **Government approvals:** Filterra® biofiltration systems are accepted by local Governments in Australia and by over 500 jurisdictions in the USA, including a number of key states with the highest stormwater quality requirements.
- **Government approvals and case studies:** There are approximately 9000 examples of Filterra® systems in the USA, and five areas within Australia where they have been integrated. Stormwater treatment performance monitoring has been undertaken a total of five (5) times (including one in Australia at Western Sydney) operating in 'real world' conditions, all showing significant reductions in pollutant concentrations. The performance testing at the Western Sydney site demonstrated that the Filterra® biofiltration system was able to achieve significant reductions in stormwater pollutant concentrations, with a concentration efficiency ratio (ER) for total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN) of 85, 80 and 47% respectively (from a total of twenty seven qualifying events) after the 12-month establishment period.
- **Compliance with biofiltration requirements in Australia:** Filterra® biofiltration systems complies with the majority of the recommendations for biofiltration systems in Australia, as specified by guidelines published by the Cooperative Research Centre for Water Sensitive Cities (2015) and Water By Design (2014). The key difference is the saturated hydraulic conductivity of Filterra® biofiltration systems (3550mm/hour), which is considerably higher than the guideline recommended range of 100 to 300mm/hour. Filterra® filter media has, however, been optimised to operate under these high flow rates while maintaining pollutant removal performance, and appropriately supporting vegetation.

- **Peer reviews:** Three (3) separate peer reviews have been undertaken in relation to the applicability of Filterra® biofiltration systems as a stormwater improvement device within Australia, including specific regions within Victoria and Queensland. These peer reviews were undertaken by Professor Ataur Rahman from the University of Western Sydney, Ralf Pfleiderer from RPEC, and Damian McCann from AWC. All peer review reports advise that Filterra biofiltration systems are a suitable stormwater treatment asset for Australian conditions. Mr Pfleiderer and Mr McCann have also confirmed that monitoring undertaken (up to April 2020) complied with *Stormwater Quality Improvement Device Evaluation Protocol* (Stormwater Australia, 2018 Version 1.3) and that treatment performance monitoring of Filterra biofiltration systems should be modelled within MUSIC using the bioretention treatment node, with appropriate properties in accordance with the recommendations outlined in Table 3-1 of this report.
- **Life cycle cost analyses:** Life cycle cost analyses have been undertaken for an example 'typical' development land usage scenario using an extensive database of cost information for Filterra® biofiltration systems and other Ocean Protect SCMs and available cost data (from Melbourne Water (2013)) on 'typical' biofiltration systems and wetlands – excluding land costs for the stormwater treatment asset types assessed. The analyses show that Filterra® biofiltration basins were likely the second most cost-effective stormwater treatment scenario assessed (with the second lowest equivalent annual payment per unit of pollution removed per year) – likely more cost effective than typical wetlands, and typical 'at source' bioretention rain gardens and tree pit systems (but likely less cost effective than typical bioretention basins).

It is recommended that the treatment performance of Filterra® biofiltration systems be modelled within MUSIC using the bioretention treatment node, with appropriate properties (as outlined in Table 3-1). This has been based on a review of modelling options (within MUSIC), and a comparison of actual treatment performance monitoring results (as observed at a case study at Western Sydney, NSW, Australia) and modelling predictions (using the MUSIC bioretention treatment node). In this example, the application of MUSIC (and associated bioretention node) provided a reasonable estimate of the stormwater treatment performance of Filterra® biofiltration systems – with MUSIC predicted ER's of 95, 91 and 42% for TSS, TP and TN respectively, compared to observed ER's (from site monitoring) of 85, 80 and 47% respectively. This assessment subsequently indicates that the application of MUSIC (and associated bioretention node) may provide a reasonable estimate for the stormwater treatment performance of Filterra® biofiltration systems.

It should, however, be noted that (as outlined in Table 3-1), a Filterra® biofiltration system with a filter area equal to 0.3% of the upstream catchment is likely to provide optimal treatment performance. Whilst MUSIC may indicate a Filterra biofiltration system with a smaller area than 0.3% of the upstream catchment may be able to achieve given stormwater quality objectives, it is recommended that a Filterra® biofiltration size of 0.3% of upstream catchment be applied.

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1 Introduction

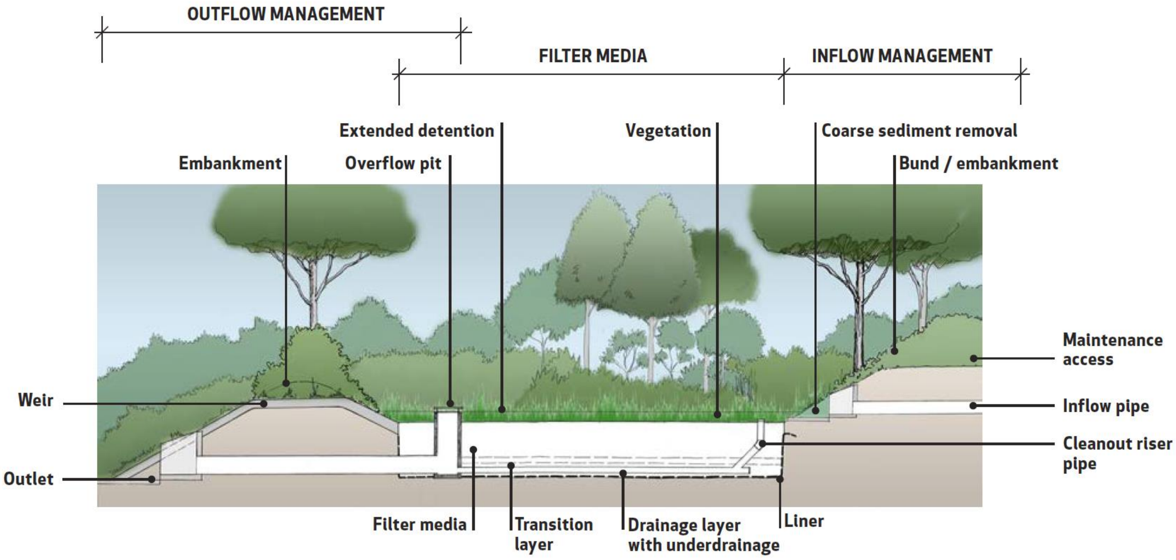
1.1 Background

It is commonly understood that unmitigated urban stormwater is a key contributor to reduced water quality and waterway health in Australia (and overseas) (Ma et al 2019, Hermawan et al 2019, Dalrymple et al 2018). Traditional urban development and associated stormwater drainage practices of conveying stormwater runoff to waterways as efficiently as possible (providing minimal opportunities for treatment and reuse) have been recognised as being unsustainable and inappropriate due to changed catchment hydrology (e.g. increased frequency and volume of stormwater flows) and increased stormwater pollutant loads to waterways and associated ecological impacts.

Water Sensitive Urban Design (WSUD) is an internationally recognised concept that offers an alternative to traditional development practices, providing a holistic approach to the design of urban development that aims to minimise the negative impacts on the natural water cycle and protect the health of waterways (South East Queensland Healthy Waterways Partnership 2006). Over recent decades, the implementation of stormwater control measures (SCMs) to achieve a more 'water sensitive' urban environment and reduce the hydrologic and water quality impacts of urban development has increased across Australia (and overseas) (Ma et al 2019, Hermawan et al 2019, Dalrymple et al 2018).

1.2 Biofiltration systems

Biofiltration systems (also called biofilters, bioretention basins, bioretention systems, bioswales and raingardens) are one of the most commonly used SCMs within Australia given their flexible design, space efficiency and applicability at a variety of scales (Water By Design 2014). Key components of a typical biofiltration system are illustrated in Figure 1-1.



Source: Water By Design (2014)

Figure 1-1 Components of a typical biofiltration system

The key function of biofiltration systems is to remove pollutants from stormwater (Water By Design 2014). Stormwater entering these systems percolates through the plant/ mulch/ soil environment and is treated through a variety of physical, chemical and biological processes before being discharged to groundwater or collected via slotted or perforated pipes and discharged to downstream drainage systems and/ or waterways. Key processes involved in the removal or transformation of stormwater pollutants are summarised in Table 1-1.

Table 1-1 Key processes involved in the removal or transformation of stormwater pollutants within biofiltration systems

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

*: Hydrocarbons, pesticides/herbicides, polycyclic aromatic hydrocarbons (PAHs), phenols, phthalates
Source: Payne et al (2015)

Biofiltration systems also reduce the frequency and volume of runoff discharged to downstream waterways via a combination of evapotranspiration and infiltration, mitigating the hydrologic changes due to urbanisation and associated impacts (e.g. scour/ erosion).

The filter media is a key component of a biofiltration system, providing the important roles of removing pollution and supporting vegetation. Within Australia, the Cooperative Research Centre (CRC) for Water Sensitive Cities (2015) and Water by Design (2014) are likely the most suitable guidelines in relation to the selection of suitable filter media for biofiltration systems.

The eWater CRC MUSIC software is commonly used to model the generation, transport and treatment of stormwater flows and pollutant loads. Guidelines outlining the recommended procedures for its application in Australia, including the modelling of biofiltration system performance include those prepared by Water By Design (2010b), BMT WBM (2015) and Melbourne Water (2016).

1.3 Filterra® biofiltration systems

A Filterra® biofiltration system is very similar to a typical biofiltration system (using 'sandy loam' filter media). A key difference, however, is that Filterra® biofiltration systems utilise a filter media blend that can treat flows at a significantly higher flow rate than typical biofiltration filter media and the media is produced to strict quality control procedures. Filterra biofiltration systems can achieve local stormwater pollution reduction targets with significantly less area (typically 0.3% of upstream area) relative to typical biofiltration systems (with 'sandy loam' media, typically 0.8 to 1.5% of upstream area).

1.4 Report objectives

The objectives of this report are to provide the following:

- A review of the suitability of Filterra® biofiltration systems within Australia
- A review of the methods for modelling the treatment performance of Filterra® biofiltration systems (and, if appropriate, identify a recommended method).

2 Review of Suitability of Filterra® Biofiltration Systems in Australia

2.1 Preamble

This section provides a review of the suitability of Filterra® biofiltration systems for Australian conditions, based on the following aspects:

- Research and development
- Government approvals
- Case studies
- Treatment performance monitoring
- Compliance with requirements for biofiltration systems in Australia
- Peer review
- Life cycle costs.

2.2 Research and development

The design and implementation of Filterra® biofiltration systems has been developed by Contech based on more than twenty years of research and development, testing and field monitoring (Contech 2016).

2.3 Government approvals

Filterra® biofiltration systems are accepted by the majority of local Governments in Australia. Table 2-1 provides a summary of Councils and regulatory authorities within Queensland, NSW and Victoria that have confirmed that they have 'no objection' to the use of Filterra® biofiltration systems, noting that any proposed system requires approval on a project-specific basis.

Table 2-1 Summary of Councils and regulatory authorities within Queensland, NSW and Victoria that have confirmed 'no objection' to use of Filterra® biofiltration systems

Council	Confirmed 'no objection' for use on public sites	Confirmed 'no objection' for use on private sites	Recommending modelling method in MUSIC
Queensland			
Brisbane City Council		✓	Bioretention node with properties in accordance with Table 3-1
Bundaberg Regional Council	✓	✓	
Cairns Regional Council	✓	✓	
Moreton Bay Regional Council		✓	
Redland City Council	✓	✓	
Townsville Regional Council	✓	✓	
Logan City Council		✓	Detention node and generic node with 81% TSS, 82.5% TP, 48.7% TN, 100% gross pollutant, and 6% flow removal up to treatment flow rate.
NSW			
Water NSW		✓	Detention node and generic node with 70% TSS, 58% TP, 38% TN, 100% gross pollutant, and 6% flow removal up to treatment flow rate.
Blacktown City Council		✓	Detention node and generic node with 79.5% TSS, 80.4% TP, 45.9% TN, 100% GP, and 2% flow removal up to treatment flow rate.
Campbeltown City Council	✓	✓	Bioretention node with properties in accordance with Table 3-1
Fairfield City Council	✓	✓	
Liverpool City Council	✓	✓	
Northern Beaches Council		✓	
Parramatta City Council	✓	✓	
Penrith City Council		✓	
Wollondilly Shire Council	✓	✓	
Victoria			
Bayside City Council	✓	✓	Bioretention node with properties in accordance with Table 3-1
Casey City Council	✓	✓	
Frankston City Council	✓	✓	
Greater Dandenong City Council	✓	✓	
Mornington Peninsula Shire Council	✓	✓	
Whittlesea City Council		✓	
Wyndham City Council		✓	
Mildura City Council	✓	✓	

Filterra® biofiltration systems are also accepted by over 500 jurisdictions in the USA, including a number of key states with the highest stormwater quality requirements. Numerous field and laboratory studies have been conducted within the USA on some of the approximately 9000 systems installed. Examples of these approvals are:

- Granted ESD (Environmental Site Design) status by the State of Maryland Dept of Environment (MDE).
- GULD-approved for TSS, Phosphorus, Heavy Metals, and Oil & Grease with the state of Washington Dept of Ecology (WA-Ecology).
- TAPE field tests completed under WA-Ecology requirements.
- Total third-party-protocol field/pilot tests include (1) TARP, (2) TAPE, (1) NJCAT and (1) NCDENR tests completed
    - TARP = Technology Acceptance Reciprocity
    - TAPE = Technology Acceptance Protocol – Ecology (State of Washington Dept of Ecology)
    - NJCAT = New Jersey Corporation for Advanced Technology (New Jersey Dept of Environment)
    - NCDENR = North Carolina Department of Environment and Natural Resources

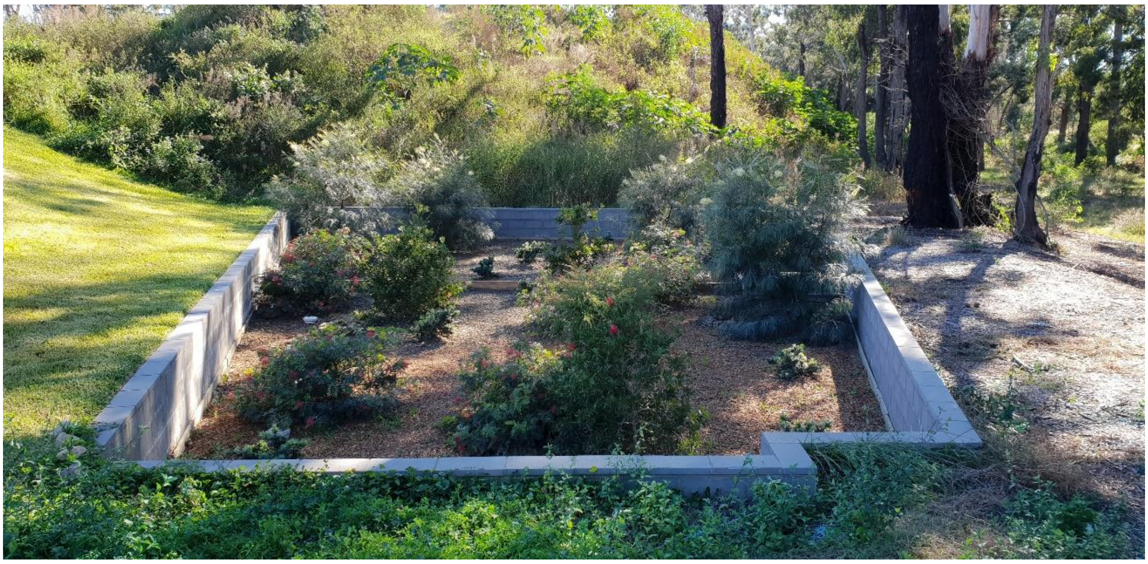
2.4 Case studies

There are approximately 9000 examples of Filterra® biofiltration systems in USA. Details of several of these systems are available at https://www.conteches.com/knowledge-center/case-studies.

Table 2-2 provides examples of case studies of Filterra® biofiltration systems in Australia, with example photos provided in Figure 2-1, Figure 2-2, Figure 2-3 and Figure 2-4.

Table 2-2 Summary of recent case studies of Filterra® biofiltration systems in Australia

Location	Site details	Date of installation
Warwick Farm racecourse, Sydney, NSW	• Two ‘basin’ systems (area 120 and 140m^2 each)	• November 2017
Western Sydney, NSW	• Single ‘tree pit’ system (area 1.45m^2)	• April 2018
Silverdale, NSW	• Two ‘basin’ systems (area 530 and 258 m^2 each)	• June 2020
Cammeray, NSW	• Single basin system (area 6m^2)	• June 2018
Old Beach, Tasmania	• Four ‘tree-pit’ systems (area 1.44m^2 each) • Additional 5 systems to be installed in next stage	• June 2018
Gold Coast, QLD	• One system (area 13m^2), treating recirculated late water only	• April 2019
Bells Creek, QLD	• Three systems (area 10, 12 and 12 m^2 each)	• September 2020



Review of Suitability of Filterra® Biofiltration Systems in Australia

Figure 2-1 Example photos of Filterra® biofiltration systems at Warwick Farm

Figure 2-2 Example photos of Filterra® biofiltration systems at Silverdale (during plant establishment)

Figure 2-3 Example photos of Filterra® biofiltration systems at Western Sydney, Old Beach, Cammeray and Gold Coast

Figure 2-4 Example photos of Filterra® biofiltration systems at Bells Creek (during plant establishment)

Section 2.5 and Appendix B describes the treatment performance monitoring of the case study at Western Sydney. Whilst treatment performance monitoring has not been undertaken of the other systems within Australia, the qualitative results of inspections and monitoring of these systems indicates that they are exhibiting appropriate vegetation growth and overall vitality which is indicative of a healthy biofiltration system achieving its design intent of improving water quality.

2.5 Treatment performance monitoring

Table 2-3 provides a summary of five recent examples of Filterra® biofiltration systems operating in 'real world' conditions where treatment performance monitoring has been undertaken.

Table 2-3 Summary of treatment performance monitoring case studies of Filterra® biofiltration systems

Location	Site details	Methodology summary	Performance summary	Further information
Falls Church Virginia, USA	• $3.3m^2$ system (0.7% of catchment); • 478m2 catchment (approx..209m2 asphalt paved parking lot and approx.. of lawn and sidewalk) • installed April 2018 • Mean rainfall 1113mm per year	• Monitored by University of Virginia • 13-month monitoring period (2004-05) • 16 real sampling events • Influent & effluent analysed for solids and nutrients • Flow-rates and volumes measured	• 88%, 60% and 40% concentration reduction efficiency ratio for TSS, TP and TKN respectively	• Stanford et al (2007)
		• Monitored by Americast • 7 simulated sampling events • 2-month monitoring period (2006-07) • flow and water quality monitored	• 70% concentration reduction efficiency ratio for TP	• Stanford (2009)
Virginia Beach, Virginia, USA;	• $2.2m^2$ system (unknown catchment area) • Installed April 2007 • Mean rainfall 1196mm/year	• Monitored by Contech • 9-year monitoring period (2008-16) • 92 real sampling events • water quality monitored	• 90%, 66% and 49% concentration reduction efficiency ratio for TSS, TP and TN respectively	• Contech (2016)
North Carolina State University, Fayetteville, North Carolina, USA	• $2.2m^2$ system (0.22% of catchment) • $1000m^2$ catchment (car park, 100% impervious) • Mean rainfall 1049mm per year	• Monitored by North Carolina University • 22-month monitoring period (2013-14) • 34 real sampling events • Influent & effluent analysed for solids, nutrients and metals • Flow-rates and volumes measured	• 81, 55 and 40% TSS, TP and TN load removal respectively • 92, 54 and 33% TSS, TP and TN mean concentration reduction respectively • 56% median peak flow reduction • 6% of unaccounted runoff volume loss	• Anderson et al (2015) • Smolek et al (2018) • Appendix B

Location	Site details	Methodology summary	Performance summary	Further information
Bellingham, Washington, USA	• $2.2m^2$ system (0.22% of catchment) • Installed in 2007 • $1000m^2$ catchment (residential) • Mean rainfall 885mm per year	• Monitored by Herrera Environmental Consultants • 8-month monitoring period (2013) • 22 sampling events • Influent & effluent analysed for solids, phosphorus, copper, zinc, pH and particle size distribution • Flow-rates and volumes measured	• 90.1% and 72.6% TSS and TP concentration reduction respectively	• Herrera (2014) • Appendix B
Western Sydney University, Kingswood, NSW, Australia	• $1.45m^2$ system (0.34% of catchment) • $420m^2$ catchment (car park, 100% impervious) • Mean rainfall 717mm per year	• Monitored by Ocean Protect • 37-month monitoring period (June 2018 to June 2021) • 38 sampling events (28 events after first 12 months of operation) • Influent & effluent analysed for solids and nutrients	• 85, 89 and 47% TP and TN concentration reduction efficiency ratio respectively following the first 12 months of operation	• Appendix B

It should be noted that volume reduction was not recorded for the Western Sydney site. Some flow reductions at the Western Sydney site, however, would have likely occurred – for example, due to soil storage and evapotranspiration. It is anticipated that the flow reductions for the Western Sydney site would be similar to those observed at the North Carolina site (average of 6% volumetric losses).

2.6 Compliance with requirements for biofiltration systems in Australia

As outlined in Section 1.2, within Australia, CRC for Water Sensitive Cities (2015) and Water by Design (2014) are likely the most suitable guidance in relation to the recommended criteria for biofiltration systems. Water By Design (2014) largely requires compliance with CRC for Water Sensitive Cities (2015) and additional aspects. Table 2-4 provides a comparison of recommended biofiltration system specifications as outlined in CRC for Water Sensitive Cities (2015) and Water By Design (2014) against specification values for Filterra® biofiltration systems.

Table 2-4 Comparison of recommended values for Filterra® biofiltration systems against CRC for Water Sensitive Cities (2015) and Water By Design (2014) recommended criteria

Parameter	Filterra® biofiltration systems	Guideline recommendation		Filterra® biofiltration system compliance with guidelines	Comments
		CRC WSC (2015)	Water By Design (2014)		
Pre-treatment					
Requirement	Consistent with CRC WSC (2015) and Water By Design (2014)	Recommended, except in the case of: • Biofilters that only receive roof runoff; • Biofilters with catchments < 2 ha without identifiable sediment sources; • Biofiltration swales.	• None for roof runoff only or for catchments ≤ 2-ha • Vegetated swale, coarse sediment forebay, inlet pond, or gross pollutant trap for catchments > 2 and ≤5-ha • Catchments > 5-ha, inlet pond or gross pollutant trap	Yes	
Storage properties					
Extended detention depth	≤ 300mm	100 to 300mm	≤ 300mm	Yes	
Vegetation					
Species	A range of plant species are appropriate, consistent with the recommendations of CRC WSC (2015) and Water By Design (2014). See Table A-1 for recommended planting palette within Australia.	CRC WSC (2015) outlines desirable plant traits for biofiltration systems and a list of recommended plant species.	Water By Design (2014) provides a list of recommended plant species.	Yes	Locally specific recommended planting palettes for Filterra® biofiltration systems are available upon request.
Organic mulch layer					
Organic mulch layer	Approx. 75mm deep layer.	Recommended to generally avoid its usage.	50 to 75mm deep layer	Yes for Water By Design (2010). No for CRC WSC (2015)	Our experience indicates that this mulch layer is critical to the function of biofiltration systems (e.g. providing pre-treatment of solids, augmenting plant health). Mulch for Filterra® systems is tested for leaching, floatability, fertility and hydraulic capacity to ensure proper flow characteristics for permeability and water retention, and to ensure pollutant discharge does not occur and that no materials are present that could harm the vegetation.

Filter media					
Type (general)	Consists of gravel, sand, silt, clay and organics. Supports a range of vegetation types that are adapted to freely draining soils with occasional wetting.	Natural or amended soils or entirely engineered media, that can support a range of vegetation types that are adapted to freely draining soils with occasional wetting.	Sand and loam mix that supports vegetation growth.	Yes	Filterra® filter media has been optimised to operate under high flow rates and has been manufactured to the most rigorous Quality Assurance (QA) and Quality Control (QC) program of any biofiltration media.
Clay and silt content	<5%	<3%	2 to 6%	Yes	A range (<5%) is provided for Filterra® filter media as the particle size distribution is confidential.
Filter media depth	Approx. 530mm	Typically ranging from 400 to 600mm, with 800mm recommended for tree planting.	Minimum of 400mm, and a minimum of 700mm for trees	Yes for systems without trees. No for systems with trees.	Filterra® systems with trees apply only small tree species, shown to thrive at this filter depth.
Saturated hydraulic conductivity	3550mm/hour (minimum design target)	100 to 300mm/hour (typical)	100 to 300mm/hour	No	Filterra® filter media has been optimised to operate under high flow rates while maintaining pollutant removal performance, and appropriately supporting vegetation.
Total Nitrogen (TN) content	ca. 200	<1000mg/kg	Refers to FAWB (2009), which is the earlier version of CRC WSC (2015)	Yes	Appendix H provides test results for Filterra® filter media. Appendix I describes the rationale for the recommended TN and orthophosphate concentrations for MUSIC modelling.
Orthophosphate content	<0.1	<80mg/kg		Yes	
Organic matter content	10%	Minimum content ≤ 5% to support vegetation		Yes	
pH	5.5 to 7.5	5.5 to 7.5		Yes	
Electrical conductivity	ca. 0.034 dS/m	<1.2 dS/m		Yes	
Transition layer					
Requirement	Omitted. Top of drainage layer is approx. 50mm above the top of under-drainage.	Can be omitted provided the top of the drainage layer is at least 100mm above the top of the under-drainage pipe and filter media and drainage layer material comply following criteria: • D15(drainage layer) ≤ 5xD85(filter media) • D15(drainage layer) = 5 to 20xD15(filter media) • D50(drainage layer) ≤ 25xD50(filter media) • D60(drainage layer) ≤ 20xD10(filter media)			A Filterra® biofiltration system does not need a transition layer because QA processes have eliminated the need for one.

Drainage layer					
Depth	250mm	-	> 150mm (for Type 1 and 2 systems)	Yes	
Minimum pipe cover of the gravel drainage	Approx. 50mm (typical)	≥ 50mm (where transition layer present)		Yes	
Material below the under-drainage pipe	Approx. 50mm (typical)	-	≥ 200mm	No to Water By Design (2010)	
Type	Round gravel and pebbles.	Clean, fine aggregate, such as a 2 – 7 mm washed screenings.	Fine gravel (2-5mm) with less than 2% fines and a minimum saturated hydraulic conductivity of 4000mm/hr.		Ocean Protect follows Filterra® QA/QC system to ensure suitability and consistency of product.

Key findings from the comparison summarised in Table 2-4 are:

- Filterra® biofiltration systems comply with the majority of the recommendations for typical biofiltration systems, as specified in CRC for Water Sensitive Cities (2015) and Water By Design (2014)
- The key difference is the design saturated hydraulic conductivity of Filterra® biofiltration (3550mm/hour), which is considerably higher than the guideline recommended range of 100 to 300mm/hour. As outlined above, however, Filterra® filter media has been optimised to operate under these high flow rates while maintaining pollutant removal performance, and appropriately supporting vegetation.
- For aspects where Filterra® biofiltration systems do not comply with guideline recommendations, the design of any non-conforming aspect has been developed based on significant experience in both laboratory and field-based case studies. Any of the given non-compliances with CRC for Water Sensitive Cities (2015) or Water By Design (2014) are highly unlikely to cause any negative issues/ problems that may limit its function (or potential benefits, e.g. stormwater treatment).

Filterra® media QA/ QC Process

It should also be noted that the Filterra® media Quality Assurance and Quality Control (QA/QC) process is more stringent than public domain biofiltration media supplied on projects throughout Australia. Many certifying authorities and local governments rely on bulk test certificates which may not give an accurate representation of the biofiltration media for a specific project. Sometimes, media substitutions are made to meet project deadlines or simply because contractors are not soil scientists and have not been properly trained. Issues also occur between various locations where biofiltration media is manufactured to a common specification as for example, sands mined from an old agricultural field may be high in nutrients.

Filterra® media undergoes a separate QA/QC process to alleviate these above-mentioned issues through strict testing. It is important to define QA and QC separately as, with Filterra® media, Ocean Protect ensures there is as much significance put into oversight in the sourcing and mixing of the media (uniform specification) as there is in ensuring product consistency regardless of the media location.

QA is process oriented to ensure the developed process objectives are met, and improves production to prevent issues that may occur with biofiltration media into the future (e.g. leaching of nutrient or inadequate hydraulic conductivity). QC is product oriented and designed to evaluate a specific developed product/biofiltration media to reveal any product defects prior to the installation of the media.

2.7 Peer reviews

Three (3) separate peer reviews have been undertaken in relation to the applicability of Filterra® biofiltration systems as a stormwater improvement device under typical Australian urban runoff conditions. These peer reviews were undertaken by the following personnel:

- Professor Ataur Rahman from the University of Western Sydney
- Ralf Pfleiderer from RPEC
- Damian McCann from AWC

These peer reviews are provided in Appendices D, E and F respectively, and summarised in the following sub-sections.

2.7.1 Peer review by Professor Ataur Rahman

Professor Ataur Rahman from the University of Western Sydney was commissioned by Ocean Protect to undertake a peer review in relation to the applicability of Filterra® biofiltration systems as a stormwater improvement device under typical Australian urban runoff conditions.

This peer review report is provided in Appendix D, and states that "*it is highly likely that Filterra® Biofiltration System will achieve hydrologic and pollutant removal performances in typical Australian urban catchments (as required by the local councils) at least at the same level found by the North Carolina State University, Fayetteville, North Carolina*" (Rahman 2017). As described in Table 2-3, the Filterra® biofiltration system at the North Carolina site was recorded to achieve an average of 81, 55 and 40% reduction in TSS, TP and TN loads respectively.

This review was undertaken prior to the field study at Western Sydney. As described in Table 2-3 and Appendix B, the performance testing at the Western Sydney site demonstrated that the Filterra® biofiltration system was able to achieve significant reductions in stormwater pollutant concentrations – despite relatively low concentrations for TSS, TP and TN in incoming stormwater flows (which would be expected to decrease potential concentration reductions). These results generally correlate with the field study at North Carolina, which Professor Ataur Rahman based his review largely on.

2.7.2 Peer review by Ralf Pfleiderer

Ralf Pfleiderer of RPEC undertook a review of Filterra® biofiltration systems, with a particular focus on:

- Assessing whether performance monitoring undertaken to date (up to April 2020) compiles with the following SQIDEP (Stormwater Australia, 2018 Version 1.3) and the City of Gold Coast's "*Development Application Requirements and Performance Protocol for Proprietary Devices*" (April 2015)
- Suitability of Filterra® biofiltration systems to Victoria, Australia.

Key findings from Mr Pfleiderer's peer review report (provided in Appendix E) include the following:

- monitoring complied with the aforementioned protocols
- "appropriately designed, installed, established and maintained Filterra biofiltration systems would be expected to provide a suitable stormwater treatment function in Victorian (particularly Melbourne)"
- "The treatment performance of Filterra biofiltration systems can be modelled using MUSIC's bioretention node. The treatment node properties should be adjusted according to Table 3-1 in "*A review of the application of Filterra® Biofiltration Systems in Australia*"".

2.7.3 Peer review by Damian McCann

Damian McCann of AWC undertook a review of Filterra® biofiltration systems, with a particular focus on

- Assessing whether performance monitoring undertaken to date (up to September 2020) compiles with "*Stormwater Quality Improvement Device Evaluation Protocol*" (Stormwater Australia, 2018 Version 1.3) and Water by Design's (2010) "*MUSIC Modelling Guidelines*" (April 2015)
- Suitability of Filterra® biofiltration systems to Australian conditions, including the appropriateness for specific areas within Australia.

Key findings from Mr McCann's peer review report (provided in Appendix F) include the following:

- monitoring complied with the aforementioned protocols
- "AWC have been asked by Ocean Protect to consider the applicability of the results from this trial to other regions, including Logan City Council, south-east Queensland, North Queensland and Victoria. It is our opinion that Filterra biofiltration systems designed, installed, established and maintained in line with the trial system and design treatable flow rates evaluated here (1.42L/s), are likely to provide stormwater treatment performance at other locations similar with that observed at the trial site. This is probably a conservative treatable flow rate given our observation of up to 2.024L/s being treated during the trial
- "We agree with Ocean Protect's recommendation to conservatively size the Filterra system at 0.3% of contributing catchment, in accordance with Table 3-1 of the report "*A review of the application of Filterra Biofiltration Systems in Australia* (Ocean Protect, April 2020)".

2.8 Life cycle costs

As part of this report, a life cycle cost analysis has been undertaken for an example 'typical' development land usage scenario using an extensive database of cost information for Filterra® biofiltration systems and other Ocean Protect SCMs and available cost data (from Melbourne Water (2013)) on 'typical' biofiltration systems and wetlands – excluding land costs for the stormwater treatment asset types assessed. The methodology and results for this analysis are described in Appendix G.

This analysis shows that Filterra® biofiltration basins were the second most cost-effective stormwater treatment scenario (with the second lowest equivalent annual payment per unit of pollution removed per year) – likely more cost effective than typical wetlands, and typical 'at source' bioretention rain gardens and tree pit systems (but likely less cost effective than typical bioretention basins). This analysis subsequently indicates that Filterra® biofiltration basins may be a preferred asset type – particularly when space is constrained.

2.9 Conclusion

Based on the information presented in the above sections, Filterra® biofiltration systems are considered to be an appropriate stormwater treatment asset type for application in Australian urban environments for both privately and publicly owned and operated sites.

3 Modelling Filterra® treatment performance

3.1 Preamble

This section describes and assesses potential methods for modelling the treatment performance of Filterra® biofiltration systems, and identifies the most appropriate method.

3.2 Modelling software

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) is a software tool that simulates the behaviour of stormwater in urban catchments. MUSIC is the preferred tool for demonstrating the performance of stormwater quality treatment systems (Water By Design 2010, BMT WBM 2015).

Within MUSIC, the user is required to specify source nodes, which represent the stormwater flow and pollutant generating areas of the site being modelled. Treatment nodes can also be included to simulate (and assess) the operation of any stormwater treatment devices (e.g. biofiltration) within the site being modelled.

3.3 Treatment node options

As outlined in the previous section, MUSIC models the performance of stormwater treatment devices using 'treatment nodes'. A range of treatment nodes are available within MUSIC. The potential treatment node options for modelling the performance of Filterra® biofiltration systems are:

- Bioretention
- Media filtration
- Generic treatment.

The following sections describe the applicability of these node types for modelling Filterra® biofiltration systems.

3.3.1 Bioretention

The 'bioretention' treatment node within MUSIC is for the modelling of biofiltration systems (described in Section 1.2) and applies significant research and guidance in relation to the performance of biofiltration systems (eWater 2014). In particular, the treatment node allows the model user to specify values for parameters known to have significant influence on the performance of biofiltration systems, including (but not limited to):

- Filter media soil type, nutrient concentrations and saturated hydraulic conductivity
- Vegetation properties
- Submerged zone presence (and properties, if applicable).

The application of the bioretention treatment node has, however, some limitations. For example, eWater (2014) states that it might be inaccurate when predicting treatment performance for systems with a filter media depth, influent pollutant concentration or submerged zone depth outside the tested range. Of particular relevance to modelling Filterra® biofiltration systems, eWater (2014) states that the model also assumes that the biofiltration filter media is sandy loam and that there is likely to be some uncertainty when systems with other types of filter media (such as sand or gravel) or other carbon sources are modelled. Nevertheless, the bioretention treatment node within MUSIC allows the model user to specify the filter media soil type (with options of ‘sand’, ‘loamy sand’, ‘sandy loam’, ‘silt loam’, ‘loam’) in addition to the filter media nutrient concentrations and saturated hydraulic conductivity.

Table 3-1 outlines the recommended properties for a bioretention treatment node if used to model the Filterra® biofiltration systems, and those given by Healthy Land and Water (2018) for biofiltration systems.

Table 3-1 Recommended bioretention treatment node properties for Filterra® biofiltration systems and from Healthy Land and Water (2018)

Parameter	Recommended value for Filterra® biofiltration systems*	Healthy Land and Water (2018) recommended value for biofiltration systems	Comments
Inlet properties			
Low-flow bypass (m^3/s)	User defined		
High-flow bypass (m^3/s)	User defined		
Storage properties			
Extended detention depth (mm)	≤ 300mm	300mm	
Surface area	User defined		
Filter and media properties			
Filter area (m^2)	User defined		A Filterra® biofiltration system with a filter area equal to 0.3% of the upstream catchment is likely to provide optimal treatment performance.
Unlined filter media perimeter (m)	User-defined		
Saturated hydraulic conductivity (mm/hour)	3550	200 (but also run 50 mm/hr for sensitivity and present results)	
Filter depth (m)	0.53	0.4 to 1.0m (typically 0.5-0.6m)	
Total Nitrogen (TN) content (mg/kg)	500	User defined (use 400 mg/kg if unknown)	See Appendix H and Appendix I for information relevant to recommended values for Filterra® biofiltration systems.
Orthophosphate content	1	User defined (use 300 mg/kg if unknown)	
Infiltration properties			
Exfiltration rate (mm/hr)	User defined		
Vegetation properties			
Plant selection	User defined ('vegetated with nutrient effective plants' recommended)		
Outlet properties			
Overflow weir width (m)	User defined	Typically greater than or equal to surface area (m^2)/10	
Underdrain present	Yes	Typically Yes	
Submerged zone with carbon present	No	User defined	
Depth (of submerged zone)	-	User defined	

*: Peer reviews for Filterra® biofiltration systems undertaken by Ralf Fleiderer and Damian McCann (provided in Appendices E and F respectively) refer to Table 3-1 of the April 2020 version of this report. The recommended properties for Filterra® biofiltration systems outlined in the April 2020 version of this report are identical to those given above.

As outlined above, it is recommended that any Filterra® biofiltration systems modelled in MUSIC apply parameter values consistent with given design parameters and (where appropriate) consistent with Healthy Land and Water (2018) guideline values for biofiltration systems.

Appendix C describes the methodology and results of modelling a Filterra® biofiltration system at Western Sydney as a bioretention treatment node (in MUSIC), with comparisons made between MUSIC predictions and monitoring data recorded at the site. In this example, the application of MUSIC (and associated bioretention node) provided a reasonable estimate of the stormwater treatment performance of Filterra® biofiltration systems – with MUSIC predicted ER's of 95, 91 and 42% for TSS, TP and TN respectively, compared to observed ER's (from site monitoring) of 85, 80 and 47% respectively. The assessment indicates that the application of MUSIC (and associated bioretention node) may provide a reasonable estimate for the stormwater treatment performance of Filterra® biofiltration systems.

3.3.2 Media filtration

The media filtration node within MUSIC has been set up to account for filtration systems (both proprietary and non-proprietary) which operate in such a way that they are not properly represented by other MUSIC treatment nodes (Water By Design 2010, Healthy Land and Water 2018).

This treatment node is similar to the bioretention node in MUSIC, with two components for stormwater treatment – in the storage over the filter media, and within the filter media itself. Pollutant removal through the filtration medium is modelled using empirical equations derived from analysis of data published in the technical literature (eWater 2014). This node is nearly identical to the previous MUSIC Version 3 bioretention node, and when Version 3 models are imported into Versions 5 and, the user selects the Version 3 bioretention nodes to be upgraded, the media filtration node is used. This is done to ensure a similar performance between Version 3 and Version 5/ 6 models, however does not account for improved understanding regarding the performance of biofiltration systems (integrated into the bioretention treatment node in MUSIC Version 5 and 6) (eWater 2014)

eWater (2014) states that the data supporting the predicted performance of media filtration systems comes from a range of studies around the world, including systems for gravel, sand and soil, some of which include vegetated systems, but advise that "*where possible, data derived from the specific type of system to be used should be used to the calibrate the media filtration node*", which "*can be done by editing the parameters of the pollutant removal equations"* but should only be done using data from *"published, peer-reviewed studies*".

eWater (2014) also states that "*when a vegetated filtration system is to be configured in MUSIC … it is strongly recommended that the bioretention node is used*". Given that Filterra® biofiltration systems are vegetated filtration systems and can be appropriately modelled as a bioretention node (with parameter values adjusted as appropriate, in accordance with Table 3-1), it is likely more appropriate to model Filterra® biofiltration systems as a bioretention node (relative to the media filtration node).

3.3.3 Generic treatment

Generic treatment nodes require the user to specify the pollutant reduction rates (under 'Transfer Functions') and are commonly applied to model the performance of proprietary SCMs (e.g. StormFilter®, Jellyfish®). This node does not have any storage/ detention component, but this can be approximately represented by using a separate treatment node (e.g. sedimentation basin) upstream of the generic treatment node.

For this method, the most appropriate method to model a Filterra® biofiltration system (or any biofiltration or media filtration system) would include a combination of the following:

- **Sedimentation basin** treatment node, with storage properties to representant the storage/ detention component (e.g. zero permanent pool depth). The pollutant decay characteristics of the treatment node could be adjusted, if appropriate.
- **Generic** treatment node, which would receive the flow and pollutant time series from the detention node. Pollutant removal through the filter media (and within the storage component, if appropriate) would be defined by adjusted pollutant reduction transfer functions. Flows exceeding the filter media could be accounted for by specifying a high flow bypass rate within this node, or by incorporating an appropriate secondary drainage link.

For generic treatment nodes, Water By Design (2010) states that *"authorities should not accept models which use the pollutant reduction function unless the applicant has demonstrated that the proposed treatment measure operates in a manner which cannot be represented using one of the other MUSIC treatment nodes*". Given that (as described in Section 3.3.1), the operation of Filterra® biofiltration systems can be represented using the bioretention treatment node, the application of a generic treatment node (as a single node or in combination with another node) to represent Filterra® biofiltration systems would be inconsistent with the aforementioned recommendations from Water By Design (2010).

3.4 Recommendation

It is recommended that the treatment performance of Filterra® biofiltration systems be modelled within MUSIC using the bioretention treatment node, with appropriate properties (as outlined in Table 3-1). It should, however, be noted that (as outlined in Table 3-1), a Filterra® biofiltration system with a filter area equal to 0.3% of the upstream catchment is likely to provide optimal treatment performance. Whilst MUSIC may indicate a Filterra biofiltration system with a smaller area than 0.3% of the upstream catchment may be able to achieve given stormwater quality objectives, it is recommended that a Filterra® biofiltration size of 0.3% of upstream catchment be applied.

This recommendation is consistent with the advice given in the peer review reports provided by Ralf Pfleiderer and Damian McCann (provided in Appendices E and F respectively), and summarised in Sections 2.7.2 and 2.7.3 respectively.

4 Conclusion

This report has provided a review of the performance of Filterra® biofiltration systems, and of their suitability for application within Australia. This review has included the following:

- Overview of case studies of Filterra® biofiltrations systems and associated Government approvals
- Comparison of Filterra® biofiltration systems with requirements for typical biofiltration systems, in accordance with Australian guideline recommendations
- Review of treatment performance monitoring for Filterra® biofiltration systems operating in 'real world' conditions, including a site in Western Sydney, NSW, Australia
- Peer reviews undertaken in relation to the applicability of Filterra® biofiltration systems by Professor Ataur Rahman from the University of Western Sydney, Ralf Pfleiderer from RPEC, and Damian McCann from AWC.
- Review of life cycle costs for Filterra® biofiltration systems for an example scenario, with comparisons made to other stormwater treatment asset types.

This review has shown that Filterra® biofiltration systems are an appropriate stormwater treatment asset type for application in Australian urban environments for both privately and publicly owned and operated sites.

It is recommended that the bioretention treatment node (in eWater's MUSIC software) be applied in modelling the performance of these systems, with appropriate properties (as outlined in Table 3-1).

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Appendix A Frequently Asked Questions

This appendix outlines frequently asked questions regarding the application of Filterra® biofiltration systems in Australia, and responses prepared by the authors of this report. These questions have been derived from consultation from stormwater professionals in private industry and government.

Question: What is different about Filterra® bioretention media that allows high flow rates ?

The key differences are the components of the media blend, the entire media manufacturing, and system delivery process. Ocean Protect are confident that there is no biofiltration media that is made to the same or even remotely similar standards anywhere (within Australia and overseas) and is as consistent with the design specifications under operating conditions.

Question: Is the given saturated hydraulic conductivity for Filterra® biofiltration systems a typical value for a new installation or for an 'older' system (that has been operating for several years, accounting for some blockage, etc) ?

For design/ modelling purposes, it is recommended that the design saturated hydraulic conductivity for Filterra® biofiltration systems is 3550mm/hour. This is a conservative value, and we would expect higher values in typical systems. The design saturated hydraulic conductivity (3550mm/hour) is slightly above our lower 95th percentile saturated hydraulic conductivity of approximately 3300mm/hour. Based on longer-term field monitoring, we would expect typical values (for systems that have been operating for several years or more) to be approximately 4500mm/hour.

Question: The high flow rates of the Filterra® biofiltration systems suggest a very low percentage of smaller particles, which may have implications for moisture retention and plant growth. Are you able to provide further detail on particle size distribution of the Filterra® filter media ?

We are unable to provide a breakdown of the media particle size except for what is already provided in Table 3-1 (i.e. clay and silt content <5%).

Some of the media components do aid in retaining moisture and we have a recommended plant palette (see Table A-1) that lends itself to drier soil types, and we are looking to expand the existing recommended plant list.

Question: Is there anything in the Filterra® filter media (or other components of a typical Filterra® biofiltration system) that is potentially hazardous or harmful to human or environmental health ?

No.

Question: What sort of flow retention (and 'losses') are expected in Filterra® biofiltration systems ?

The predicted average annual water retention for Filterra® biofiltration systems within Australia is approximately 5% when using trees/shrubs (and not grasses). Slightly higher retention is expected in systems with grasses, which Ocean Protect are currently investigating.

Ocean Protect are also investigating the potential for Filterra® biofiltration systems to include a 'wicking' system that will store additional water to passively irrigate (i.e. without power supply or pumps) vegetation – and, ultimately, increase the real volumetric loss from the Filterra® biofiltration system (if preferred).

Question: Is it possible to reduce the peak flow rate discharged from Filterra® biofiltration systems ?

Peak flow rates out of any Filterra® biofiltration system can be decreased by restricting (‘throttling’) the outlet of the Filterra biofiltration system. This is not typically a concern given systems are largely focussed on managing (and providing treatment to) small/ frequent rainfall events, but this can be done reasonably easily.

Question: What information is available on the lifespan of the Filterra® biofiltration media (or how long will the media last) ?

Filterra® biofiltration systems are expected to be capable of achieving pollutant removal efficiencies and system longevity on par with conventional (slow flow rate) bioretention systems (with ‘sandy loam’ media). The major challenge to the longevity of the Filterra® biofiltration system is sediment build-up on the surface of the Filterra® biofiltration system, which could restrict free flow of runoff, trash and debris into the system. Provided routine maintenance is performed, the Filterra® system will theoretically last indefinitely, since it essentially sequesters and recycles nutrients, metals, and organics in the biomass (i.e., plant and microbes) (Length et al 2010).

There are systems that have been monitored in North America for the past 15 years from varying land-use with varying degrees of maintenance. All these system indicate a life span in excess of the 15 years, however, with the sacrificial mulch layer (that is highly effective at screening out a large proportion of the solids before flows flow into the filter media layer), we would expect a lifespan either the same or in excess of typical biofiltration systems.

Question: What are the typical installation and ongoing costs of a Filterra® biofiltration system ?

The typical installation cost for a typical Filterra® biofiltration system is approximately $1000/m^2 to $1200/m^2 (cost per square metre of biofiltration filter media). This cost includes installation of the media (and mulch and vegetation) and the first twelve (12) months of maintenance. For the supply media alone, the cost is approximately $1500/m^3.

The typical ongoing maintenance cost for a typical Filterra® biofiltration system is approximately $60/m^2 per annum (cost per square metre of biofiltration filter media). Ocean Protect also provide ‘long term asset management’ plans where the system can be essentially ‘leased’ (with zero or reduced initial costs, provided a long term maintenance agreement with Ocean Protect is applied).

It is worth noting that whilst the biofiltration media is different for Filterra® biofiltration systems, Ocean Protect also recommend a different approach to the design, implementation and management for the systems. Many failures of ‘typical’ (sandy loam) biofiltration system are due to variations in either design, media supply, construction and/ or lack of maintenance. Ocean Protect can provide a complete turnkey solution from design, supply, installation together with a minimum 12 months maintenance of every Filterra® biofiltration system.

Question: What are the typical maintenance activities required for a Filterra® biofiltration system ?

Like any stormwater treatment asset, the function and stormwater treatment performance of Filterra® biofiltration systems is highly dependent on these assets being appropriately managed. As required for typical biofiltration systems, typical maintenance activities for Filterra® biofiltration systems includes overall system inspection, pruning of vegetation (as required) and removal of litter. The mulch layer for Filterra® biofiltration systems also should be replaced approximately every 6 to 12 months.

Litter and sediment accumulate on the top of the mulch and this material is easily removed and typically disposed to landfill. Fresh double-shredded hardwood mulch is then placed on top of the filter media (to an approximate depth of 75mm, as per Table 2-4) and not removed until the next maintenance visit. Hardwood mulch is a highly effective and an inexpensive pretreatment layer that protects not only the filter media but also the vegetation.

Question: What are the technical limitations to applying Filterra® biofiltration systems ?

Like all biofiltration/retention systems, baseflow and high sediment loading will adversely affect the system, which Ocean Protect consider as part of every design. Ocean Protect also design the larger Filterra® biofiltration systems in segments (or individual 'cells') even though there is no theoretical limitation on system size.

The only real limitations would be the fixed media depth of 530mm and plant selection. Filterra® biofiltration systems already have a lower hydraulic impact than traditional biofiltration system (with sandy loam filter media) as the system typically has a lower ponding depth and no need for a transition layer in the media.

Question: How big is a typical Filterra® biofiltration system ?

Within Australia, it is recommended that Filterra® biofiltration systems have a filter area equal to 0.3% of the upstream catchment. This system size is typically sufficient to achieve the local stormwater quality management targets. A reduced size may be possible if pretreatment of flows (e.g. by a swale, wetland) is present upstream of the Filterra® biofiltration system.

A typical Filterra® biofiltration system is subsequently significantly smaller than a typical biofiltration system (with sandy loam filter media), which typically needs to be approximately 0.8 to 1.5% of the upstream catchment area to achieve local stormwater quality management targets.

Question: Does Filterra® biofiltration systems require a mulch layer ?

As outlined in Table 2-4, this mulch layer is critical to the function of biofiltration systems, providing pretreatment and protection of the engineered filter media, augmenting within-storm unit treatment processes (e.g. inert filtration and reactive filtration). The mulch layer also helps to retain moisture in the Filterra® system, which supports vegetation.

Question: Does the mulch float and/ or leach nutrients?

Filterra® biofiltration systems include a 3-inch (approx. 75mm) layer of double-shredded hardwood mulch above the filter media surface. As outlined in Table 2-4, the mulch for Filterra® biofiltration systems is tested for a range of aspects, including leaching, floatability, fertility, and hydraulic capacity to ensure proper flow characteristics for permeability and water retainage, and to ensure pollutant discharge does not occur, and that no materials are present that could harm the vegetation..

We do not recommend alternative mulches (e.g. sugarcane mulch, pebbles) sometimes applied in conventional (slow rate, sandy loam) biofiltration systems.

Question: Can I apply different depths for the Filterra® biofiltration system than recommended ?

Table 2-4 and Table 3-1 outline recommended depths for the extended detention depth (≤ 300mm, which includes the recommended 75mm layer of mulch), filter media depth (530mm) and drainage layer (250mm). We do not recommend applying smaller depths for the mulch, filter media and drainage layer.

The extended detention depth can be reduced to 75mm (to only include the mulch layer) given the high drainage rate of the filter media (and subsequent reduced need to temporarily store inflows above the filter media). Similarly, it is possible to apply a larger extended depth (higher than the recommended maximum of 300mm) in some cases (e.g. for systems integrated within detention basins).

It is best to liaise directly with Ocean Protect personnel to discuss site specific constraints and potential design solutions.

Question: Does the monitoring of Filterra® biofiltration systems comply with SQIDEP (Stormwater Quality Improvement Device Evaluation Protocol) from Stormwater Australia and City of Gold Coast's SQID Protocol ?

The monitoring undertaken to date satisfies all technical aspects of the SQIDEP (V1.3) and City of Gold Coast (April 2015) testing protocols. This has been confirmed by two separate peer reviews by Ralf Pfleiderer and Damian McCann (provided in Appendices E and F respectively), and summarised in Sections 2.7.2 and 2.7.3 respectively. Additional information regarding compliance with the aforementioned protocols can be provided, upon request.

Question: Where is the Filterra® media produced ?

For Australian projects, Filterra® media is produced in an Ocean Project facility at Alexandria, NSW.

Question: Is there an alternative supplier of Filterra® media besides Ocean Protect ?

Within Australia, Ocean Protect is currently the sole producer/ provider of Filterra® biofiltration media. Filterra® biofiltration media is also available from Contech Engineered Solutions (headquarters in Ohio, USA). Ocean Protect anticipates that alternative suppliers of high flow rate biofiltration media will also be available within Australia in approximately 5 to 10 years.

Question: If Ocean Protect ceases operations, where can I get Filterra® media from ?

Ocean Protect (formerly known as 'Stormwater360 Australia') has been in operation for over fifteen (15) years, and the likelihood of ceasing operations is very low. Nevertheless, as outlined above, Filterra® biofiltration media is also available from Contech Engineered Solutions (headquarters in Ohio, USA).

Question: What plants are suitable for Filterra® biofiltration systems ?

Table A-1 outlines the recommended plant species across the filter media of Filterra® biofiltration systems within Australia. Ocean Protect are planning to expand this plant list in the near future.

Table A-1 Recommended plant species for Filterra® biofiltration systems

Common Name	Scientific Name	Plant Type	Sun	Drought Tolerance (1 Wet, 5 Hardy)	Height (m)	Spread (m)	Region/Distribution	Comments
Prickly Moses	*Acacia ulicifolia*	Small Shrub	Full/Shade	5 - Well Drained	3	2	N Qld, NSW, Vic, Tas	Not readily available.
Lilly Pilly	*Acmena smithii*	Evergreen Tree	Full/Shade	5 - Once Established	6	6	Coastal N Qld to Vic	Cultivars may be hedges.
Swamp Banksia	*Banksia robur*	Evergreen Shrub	Full/Part	5 - Once Established	2	2	East Coast	Endemic to Australia. Check regional suitability.
Boronia	*Boronia microphylla*	Evergreen Shrub	Part	3 - Moist Preferred	1	1	East Coast	95 spp endemic to Australia. Majority in SW WA. Suited to moist protected sites.
Soft Boronia	*Boronia mollis*	Evergreen Shrub	Full/Part	4 - Moist Preferred	1.5	1.5	Far North Coast NSW	
Pinnate Boronia	*Boronia pinnata*	Evergreen Shrub	Part	2 - Moist	1.5	1.5	East Coast NSW	
(Dwarf) Weeping Bottlebrush	*Callistemon viminalis*	Evergreen Shrub/Tree	Full	5 - Once Established	1.5-2	2	Eastern Australia	Many cultivars, region suited
(Dwarf) Crimson Bottlebrush	*Callistemon citrinus*	Egreen Medium Shrub	Full/Part	4 - Moist/Dry	2	2	NSW Coastal	Many cultivars, P tolerant
Bottlebrush	*Callistemon 'Little John'*	Evergreen Shrub	Full/Part	4 - Moist/Dry	1	1.5	Eastern Australia	Many cultivars region suited
NSW Christmas Bush	*Ceratopetalum gummiferum*	Egreen Large Shrub	Full/Part	4 - Moist/Dry	<5	<5	NSW Coastal	Pruning possible to limit size
White Correa	*Correa alba*	Evergreen Shrub	Full/Part	5 - Once Established	1.5	1.5	NSW, Vic Coastal	Other spp regionally suited
Pink Wax Flower	*Eriostemon australasius*	Evergreen Shrub	Part	2 - Moist	1.5	1.5	Far North Coast NSW	Other spp SEQ - hardy cultivars
Grevillea	*Grevillea 'Robyn Gordon'*	Evergree Shrub	Full/Part	5 - Once Established	1.5	2	Widespread	Many regional suited cultivars
Hakea	*Hakea myrtoides*	Dwarf Shrub	Full/Part	5 - Once Established	1	1	Widespread	Many Hakea spp available that may provide better regional suitability
Manuka/Tea Tree	*Leptospernum scoparium*	Shrub/Small Tree	Full/Part	4 - Moist/Dry	2.5	2.5	Cooler Climate	Many spp & cultivars suited to different habitats

Paperbark/Tea Tree	*Mellaleuca stypheloides*	Shrub/Small Tree	Full/Part	3 - Moist Preferred	3	1.5	Widespread	Many different spp & cultivars suited to a variety of climatic conditions
Native Daphne	*Pittosporum undulatum*	Tree	Full/Part	5 - Once Established	12	7	East Coast of NSW but is capable of very adapting to a range of climates	Usually smaller as a cultivar. Considered a weed in some States and regions within Australia.
Powderpuff Lilly Pilly	*Syzygium wilsonii*	Shrub/Small Tree	Full/Part	4 - Moist/Dry	2-6	2-3	Nth Coastal, WA, Qld, NT & NSW	Regional hybrids have been developed.
Riberry, Cherry Alder, Small Leaved Lilly Pilly	*Syzygium luehmannii*	Shrub/Small Tree	Full/Part	5 - Once Established	7	3	Sub-tropical, Nth NSW to Nth Qld.	Hardy plant that may be used to form a hedge.
Swamp Foxtail Grass	*Pennisetum alopecuroides*	Grass	Full/Frost	5 - frost, poor soils and innundation.	1	0.6		This species self-seeds readily and can become invasive.
Tall Sedge	*Carex appressa*	Grass	Full	5	1.2	0.5	Australia-wide	tough densely tufted sedge. Full sun, boggy conditions, fast growing, long lived, very hardy
Spiny headed mat rush 'lush green'	*Lomandra longafolia*	Grass	Full/Part	5 - Frost / Low Water/Drought	0.8	1.2	NSW, Vic, Qld, WA, SA, Tas	Large perennial tussock grass with strong architectural shape. Forms dense tussocks of stiff, long flat leaves
kangaroo grass	*Themeda australis*	Grass	Full/Part	4 - drought conditions	0.4	0.3	Australia-wide	Densely tufted small perennial tussock forming grass with attractive seed heads

NOTE: The plants listed herein have been selected as a general subjective guide to assist in the selection of species (spp)/ cultivars, which would be suitable for use in Filterra® biofiltration systems. The use of Common Names to describe specific plants can be misleading. Wherever possible, it is recommended to use the Scientific Name when describing a specific plant. Further many other specific spp/ cultivars exist for each genus and local nurseries/horticulturalists/Botanic Gardens should be consulted regarding the suitability of specific plants to local soil and climatic conditions. Other considerations include site specific weather patterns and climate (wind, frost etc) and the suitability of the soil/media for specific plant species especially in Australia where most plants have evolved in low Phosphorus soil conditions or soils that have a high acidity or alkalinity.

Appendix B Stormwater treatment performance for a high flow rate biofiltration system at Western Sydney, Kingswood, NSW

B.1 Preamble

As outlined in Section 2.5, stormwater treatment performance monitoring has been undertaken for a Filterra® biofiltration system at Western Sydney, NSW, Australia. This appendix describes the methodology and results of that assessment.

B.2 Background

As outlined in Section 2.4, there are approximately 9000 Filterra® biofiltration systems in USA, including systems that have undergone extensive stormwater treatment performance monitoring at Virginia (Shaw et al 2006, Stanford et al 2009, Contech 2016), Washington (Herrera 2014), and North Carolina (Smolek et al 2018).

Whilst Filterra® systems have also been installed at locations within Australia, there had previously been no treatment performance monitoring at a ‘real world’ site within Australia. Study authors and the Engineering Department of the Western Sydney University subsequently developed and implemented a Filterra® biofiltration system to assess its performance within Australia.

B.3 Methodology

B.3.1 Site details

The site is located at a car park in Western Sydney, Kingswood, NSW, Australia (hereafter referred to as ‘the site’). The car park is swept periodically, but minor amounts of sediment and organic debris are typically present at the car park. The carpark consists entirely of an impervious asphalt surface and has a high usage rate.

An aerial photo of the site from January 2018 is shown in Figure B-1. An example photo of the car park is provided in Figure B-2.

Figure B-1 Aerial photo of the site, catchment and equipment

Figure B-2 Example photo of the car park

A Filterra® biofiltration system was installed at the southern edge of the car park. The system receives runoff from an area of 420m^2 (which is 100% impervious), determined by land survey and site inspections. The catchment is illustrated in Figure B-1.

The Filterra® biofiltration system was installed at the site in April 2018. The system has a total area of 1.45m^2 (0.34% of catchment) and 0.53m depth of Filterra® filter media, with a design treatable flow rate of 1.42 L/s. Slotted pipes are located within a gravel surround (immediately below the Filterra® filter media).

Example photos of the Filterra® biofiltration system are provided in Figure B-3. A schematic of the system is provided in Figure B-4.

Figure B-3 Example photos of the Filterra® biofiltration system and sampling facilities at the site

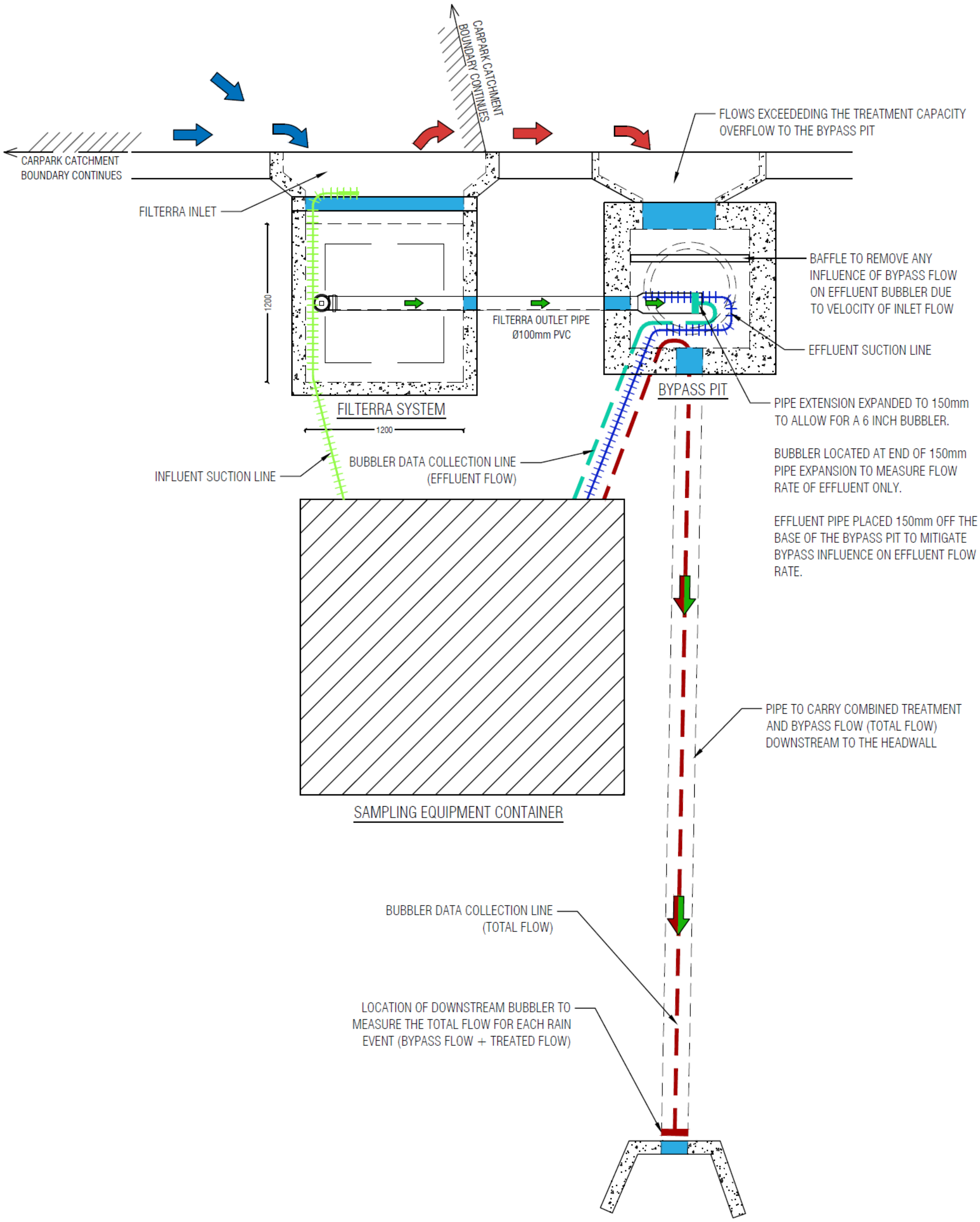

Figure B-4 Schematic plan drawing of Filterra® biofiltration system at site

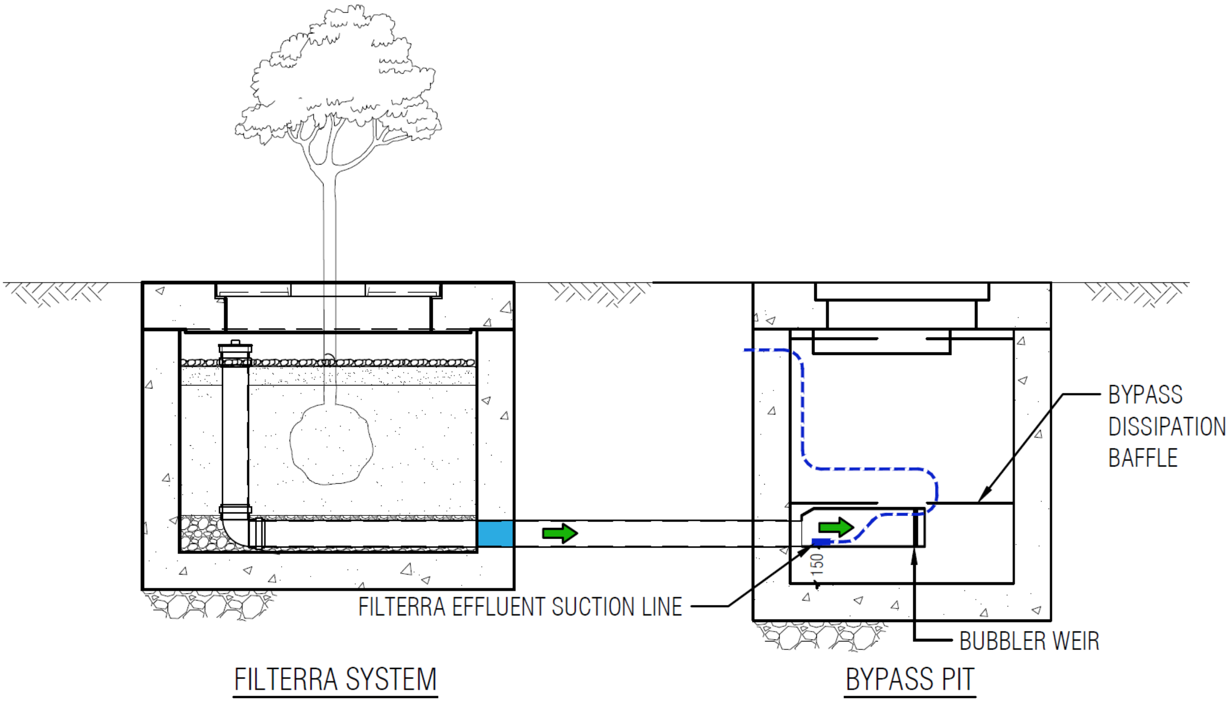

Figure B-5 Schematic section drawing of Filterra® biofiltration system at site

The Filterra® biofiltration system at the site has been maintained in accordance with typical/ standard maintenance procedures for these asset. In summary, the system is maintained approximately every twelve (12) months, with the most recent maintenance on 30 March 2021. Specific maintenance activities that have been undertaken have been: inspection of Filterra® biofiltration system and surrounding area; temporary removal of tree grate to access filter media surface; removal of debris, litter and mulch; mulch replacement; and plant health evaluation and pruning, as necessary.

B.3.2 Sampling design

The equipment and sampling techniques used for this study were in accordance with the Project Plan developed by Ocean Protect in consultation with both City of Gold Coast's (2016) *Development Application Requirements and Performance Protocol for Proprietary Devices* and Stormwater Australia's (2018) *Stormwater Quality Improvement Device Evaluation Protocol Field Monitoring*. The Project Plan generally satisfied most conditions outlined in both field testing protocols detailed below in Table B-1.

Table B-1 Summary of required field testing protocol at site

Criteria	Requirement
Minimum number of aliquots	> 8
Minimum storm coverage	> 50% of storms have >70% hydrograph coverage
Antecedent dry period	> 6 hours
Minimum Rainfall Depth	minimum required to take a composite sample
Minimum Storm Duration	5 minutes

Ocean Protect personnel were responsible for the installation, operation, and maintenance of the sampling equipment. Ocean Protect personnel provided sample retrieval, system reset, and sample submittal activities. Water sample processing and analysis was performed by ALS and Western Sydney University.

A small double-door cabinet was provided, installed, maintained, and operated by Ocean Protect personnel for sampling purposes. The cabinet is a fully enclosed, self-contained stormwater monitoring system, specially designed and built by Ocean Protect for remote, extended-deployment stormwater monitoring. The design allows for remote control of sampling equipment, eliminates confined space entry requirements, and streamlines the sample and data collection process and operation of the equipment.

Influent and effluent water quality samples were collected using individual ISCO 6712 Portable Automated Samplers configured for 9.5 litre wide-mouth carboy bottles with disposable sample liners for sample collection. The samplers were connected to two parallel 12V DC batteries recharged with a solar panel mounted to the roof of the shipping container. The influent sampler was equipped with an ISCO 730 Bubbler Weir module, connected directly to the ISCO 6712 sampler, and installed within a pre-configured and calibrated 152mm diameter Thel-Mar Weir for flow measurement of treated effluent and sample pacing. Initially, a ISCO 750 Bi-Directional Area Velocity Flow Module with a Low Profile Area Velocity Flow Sensor was connected to the ISCO 6712 effluent sampler for total flow analysis and effluent sample pacing. Within the first 6 months, the ISCO 750 Module was removed and replaced with another ISCO 730 Bubbler Weir module installed within a 203mm diameter Thel-Mar Weir for total flow analysis. Flow rates were recorded every minute.

The bubblers were regularly checked for calibration by submersing the weir in water and setting the depth on the sampler with the bubbler module to the depth measured. The tables for the flow against height are provided by Thel-mar and input into the samplers.

Rainfall was measured at 1-minute intervals using two (2) 0.25mm resolution ISCO 674 tipping bucket-type rain gauges, securely installed on the container and regularly inspected. The sample intake for each automated sampler was connected to a stainless steel sample strainer (9/16″ diameter, 6″ length, with multiple ¼″ openings manufactured by ISCO) via a length of 3/8″ ID Acutech Duality PTFE tubing. The rain gauges were factory calibrated and do not require further calibration except to ensure there is nothing obstructing or interfering with the tip bucket. The rain gauges were installed and maintained according to manufacturer's instructions, and checked and cleared of debris regularly. The rain gauges were located on the shipping container and protected from excessive wind velocities that could skew accuracy of measurement. The two (2) rain gauges were installed approximately 1 m apart and results were compared periodically to ensure accuracy.

Sample strainers and flow measurement equipment were secured to the invert of the influent and effluent pipes using stainless steel spring rings with all components supplied and setup in general accordance with ISCO's guidelines. Each sampler was also connected to an ISCO 6712Gi Global Digital Cell Phone Modem (two) to allow for remote communication and data access. Effluent samples were sampled prior to mixing effluent flows with any bypass flows.

Samplers were programmed to enable the sampling program to trigger on flow. Once enabled, the samplers collected flow-proportional samples allowing the specified pacing volume to pass before taking a sample. The sample collection program was a one-part program developed to maximize the number of water quality aliquots/samples collected as well as the coverage of the storm event for an anticipated rainfall depth. Influent and effluent sample collection programs were configured to collect a minimum of eight aliquots per bottle. Due to the variability among precipitation events, the sample pacing specifications were varied in consultation with the most up-to-date precipitation forecasts and remotely programmed by Ocean Protect personnel prior to all storm events.

Following a precipitation event, Ocean Protect personnel communicated with the automated sampling equipment to confirm sample collection and then to dispatch personnel to retrieve the samples and reset the automated sampling equipment. Samples where then split using the appropriately sized Bel-Art's Churn Splitter – one for the influent and one for the effluent to reduce the likelihood of contamination and to provide subsamples in accordance with the manufacturer's guidelines. Sub-samples were delivered to ALS (a NATA-accredited laboratory) on ice (<4º C) and accompanied by chain-of-custody documentation and analysis was carried out in accordance with Table B-2.

Table B-2 Water quality analytical parameters and methods for the site

Parameter	Abbreviation	Analytical method	Limit of Reporting
Ammonia as N	Amm.N	APHA 4500 NH3- - G	0.01 mg/L
Nitrate + Nitrite as N	NOx	APHA VCl3 reduction 4500 NO3- + NO2-B	0.01 mg/L
Nitrate as N	-	APHA VCl3 reduction 4500 NO3- + NO2-B	0.01 mg/L
Nitrite as N	-	APHA 4500 NO2- - I	0.01 mg/L
Total Kjeldahl Nitrogen (TKN) as N	TKN	APHA 4500 Norg – D + APHA 4500 NH3-G	0.1 mg/L
pH (pH units)	pH	APHA 4500 H+ - B	0.01 pH units
Phosphorus Total as P	TP	APHA 4500 P - F	0.01 mg/L
Filtered Total Phosphorous as P	Ortho-P	APHA 4500 P - F	0.01 mg/L
Phosphorus Reactive as P	DP	APHA 4500 P – F	0.01 mg/L
Solids - Suspended Solids - Standard level	TSS	APHA 2540 D	5 mg/L

B.3.3 Sampling events

The Filterra® biofiltration system was monitored between May 2018 and June 2021, with a total of thirty eight (38) qualifying runoff events recorded during this period. A total of twenty eight (28) events qualifying events were recorded following the first 12-months of system establishment (i.e. the first 12 months following system installation, when the planted vegetation is undergoing significant growth and the system is not fully operational). Figure B-6 illustrates the timing of the sampling events compared to a time series of rainfall data recorded at the site, noting the sampling equipment was taken off-line between March and May 2019 due to suspected herbicide contamination, which resulted in significant plant die-off during this time. Table B-3 also provides a summary of recorded rainfall at the site and flow discharged from the system.

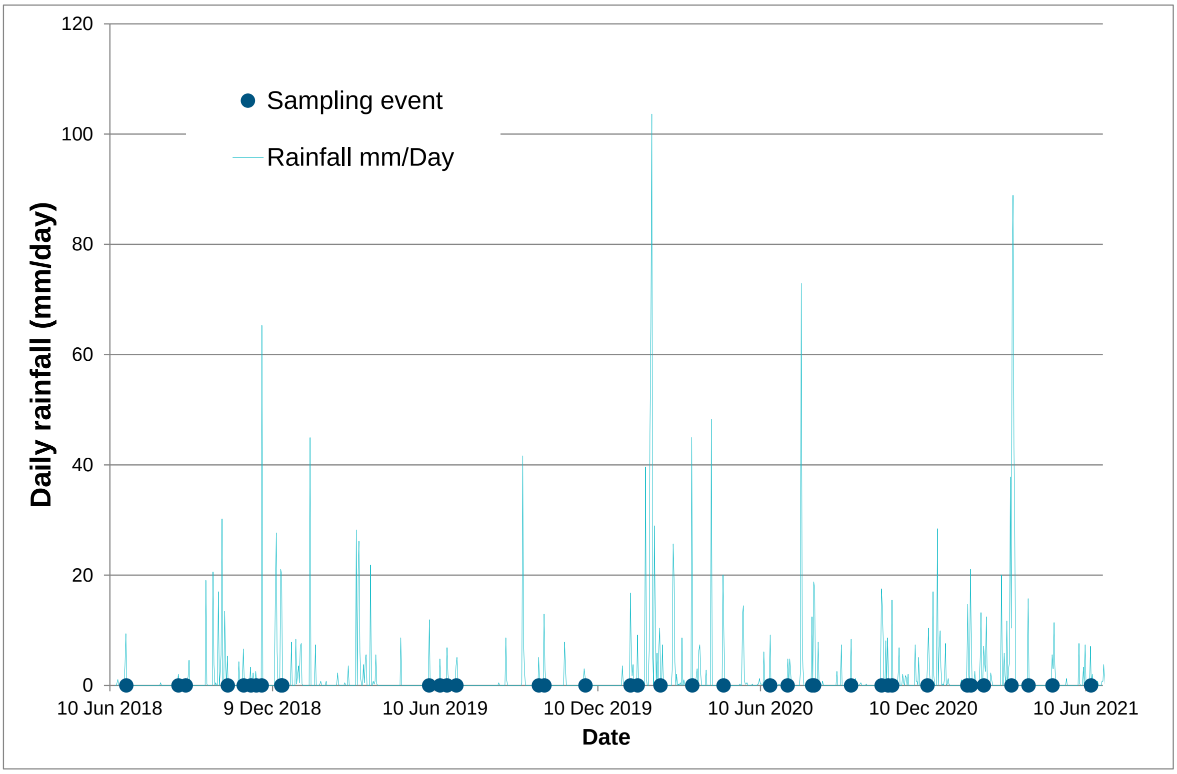

Figure B-6 Time series of site rainfall and timing of sampling events

Table B-3 Summary of recorded rainfall and flow data for site

Event Date	Max. rainfall intensity (mm/hr)	Mean rainfall intensity (mm/hr)	Total rainfall (mm)	Total runoff volume (L)	Peak flow (L/s)	Mean flow (L/s)	Sampling duration (hr)	Sampling coverage (%)	Number of aliquots
28 Jun 2018	10.16	0.88	8.4	2313	0.577	0.068	6.3	58%	23
26 Aug 2018	2.54	0.09	2.5	565	0.210	0.005	25.3	98%	38
3 Sep 2018	2.54	0.10	1.3	450	0.178	0.010	10.3	99%	22
20 Oct 2018	30.48	0.59	5.3	1507	2.024	0.047	7.5	99%	35
7 Nov 2018	5.08	0.35	7.4	2616	0.350	0.034	13.3	84%	50
15 Nov 2018	5.08	0.33	3.3	1060	0.423	0.029	8.1	100%	28
21 Nov 2018	5.08	0.19	2.5	445	0.194	0.009	3.3	99%	12
27 Nov 2018	38.10	2.25	65.8	15421	2.024	0.146	24.1	100%	105
19 Dec 2018	38.10	1.95	20.1	5385	1.731	0.146	1.5	39%	50
20 Dec 2018	106.68	2.51	20.1	2798	2.024	0.097	0.6	91%	50
3 Jun 2019	7.62	0.64	12.7	4856	1.003	0.068	10.7	100%	68
16 Jun 2019	12.70	0.33	4.8	1814	0.958	0.034	10.7	99%	47
23 Jun 2019	7.62	0.50	6.9	2232	0.741	0.046	9.0	99%	39
4 Jul 2019	12.70	0.31	8.6	3192	0.913	0.032	9.0	23%	32
5 Oct 2019	10.16	0.47	5.1	765	0.461	0.020	5.1	99%	18
11 Oct 2019	12.70	0.87	10.4	2436	1.146	0.056	6.8	99%	41
26 Nov 2019	15.24	0.22	1.5	210	0.538	0.008	2.2	99%	6
16 Jan 2020	17.78	0.64	17.0	4652	1.146	0.049	14.5	79%	50
24 Jan 2020	17.78	0.56	7.6	1786	1.196	0.036	6.4	89%	28
18 Feb 2020	43.18	1.32	10.4	2168	2.024	0.076	1.1	98%	72
25 Mar 2020	88.90	2.63	45.2	7058	2.024	0.114	1.2	82%	80
29 Apr 2020	81.28	2.08	21.8	3812	2.024	0.101	1.4	83%	45
21 Jun 2020	25.40	0.71	8.9	1787	1.731	0.040	6.3	54%	35
10 Jul 2020	7.62	0.24	6.1	822	0.194	0.009	16.3	67%	28
7 Aug 2020	10.16	0.73	12.4	2387	0.278	0.039	11.8	99%	36
9 Aug 2020	22.86	1.03	29.7	6874	0.577	0.066	22.7	99%	44
20 Sep 2020	12.70	0.69	8.9	1981	0.499	0.043	6.4	86%	24
24 Oct 2020	7.62	0.66	32.3	12270	0.538	0.070	34.8	68%	66
5 Nov 2020	12.70	0.61	13.0	4695	0.826	0.061	18.9	100%	48
15 Dec 2020	53.34	0.30	17.3	2970	2.024	0.014	50.8	100%	47
28 Jan 2021	5.08	0.39	18.8	4266	0.162	0.024	41.7	100%	65
1 Feb 2021	60.96	1.95	27.7	4061	1.003	0.080	8.3	100%	31
16 Feb 2021	33.02	0.40	10.2	1521	1.246	0.017	4.4	42%	15
11 Mar 2021	7.62	0.35	7.9	1402	0.226	0.017	15.0	98%	19
19 Mar 2021	48.26	2.58	282.2	47430	0.658	0.120	65.0	73%	100
7 Apr 2021	43.18	1.01	17.3	2486	2.024	0.040	15.3	100%	39
4 May 2021	5.08	0.30	8.4	1739	0.226	0.017	22.8	100%	50
16 Jun 2021	7.62	0.50	4.8	1325	0.538	0.038	5.6	100%	40

B.4 Results & discussion

Table B-4 provides the results of the monitoring. Table B-5 provides the calculated concentration reduction efficiencies (CREs). Table B-6 provides a statistical summary of the monitoring results. provides the influent nitrogen speciation percentages. Plots and box plots of recorded influent and effluent concentrations are also provided in Figure B-7 and Figure B-8. Table B-8 also provides a comparison of influent EMC values recorded at the site and those given in MUSIC modelling guidelines within Australia by Water By Design (2010), BMT WBM (2015) and Melbourne Water (2018). Table B-9 provides a comparison of the percentage fraction of total nitrogen as dissolved nitrogen against that recommended in the E2DesignLab (2015) report *Development Application Requirements and Performance Protocol for Proprietary Devices on the Gold Coast* and Blacktown City Council's (2020) *Water sensitive urban design (WSUD) developer handbook – MUSIC modelling and design guide*. Table B-10 provides a comparison the of performance monitoring data during and after the first twelve months of operation (noting that the first twelve months of operation the system is 'establishing', i.e. planted vegetation is undergoing significant growth and system is not fully operational). Table B-11 provides a summary comparison of biofiltration performance monitoring at various sites, including the study site, other Filterra® biofiltration systems, and typical biofiltration systems.

Table B-4 Results of treatment performance monitoring

Event Date	TSS (mg/L) Influent	TSS (mg/L) Effluent	DP (mg/L) Influent	DP (mg/L) Effluent	TP (mg/L) Influent	TP (mg/L) Effluent	NOx (mg/L) Influent	NOx (mg/L) Effluent	NH_3 (mg/L) Influent	NH_3 (mg/L) Effluent	DIN (mg/L) Influent	DIN (mg/L) Effluent	TKN (mg/L) Influent	TKN (mg/L) Effluent	TN (mg/L) Influent	TN (mg/L) Effluent
28 Jun 2018	13.0	*2.5*	0.040	0.040	0.060	0.040	1.060	0.100	0.200	0.140	1.260	0.240	0.500	0.200	1.560	0.300
26 Aug 2018	19.0	*8.0*	0.110	0.020	0.170	0.050	1.130	1.170	0.690	0.200	1.820	1.370	2.200	1.100	3.330	2.270
3 Sep 2018	22.0	*6.0*	0.090	0.030	0.160	0.070	0.670	1.020	0.570	0.240	1.240	1.260	1.700	0.800	2.370	1.820
20 Oct 2018	60.0	*12.0*	0.005	0.005	0.130	0.005	1.530	0.830	0.460	0.080	1.990	0.910	1.400	0.500	2.930	1.330
7 Nov 2018	31.0	*10.0*	0.010	0.020	0.070	0.040	0.510	0.420	0.430	0.240	0.940	0.660	1.000	0.700	1.510	1.120
15 Nov 2018	22.0	*15.0*	0.020	0.020	0.110	0.070	0.670	1.260	0.520	0.300	1.190	1.560	1.200	1.000	1.870	2.260
21 Nov 2018	15.0	*2.5*	0.030	0.020	0.070	0.060	0.660	0.660	0.480	0.250	1.140	0.910	1.000	0.500	1.660	1.160
27 Nov 2018	52.0	*10.0*	0.010	0.010	0.120	0.040	0.300	0.260	0.170	0.050	0.470	0.310	0.600	0.050	0.900	0.310
19 Dec 2018	15.0	*8.0*	0.005	0.010	0.060	0.020	0.650	0.620	0.440	0.140	1.090	0.760	0.700	0.400	1.350	1.020
20 Dec 2018	51.0	*8.0*	0.005	0.005	0.190	0.050	0.860	0.620	0.470	0.200	1.330	0.820	0.800	0.300	1.660	0.920
3 Jun 2019	29.0	*9.0*	0.010	0.010	0.040	0.005	0.200	0.220	0.190	0.120	0.390	0.340	0.600	0.300	0.800	0.520
16 Jun 2019	16.0	*2.5*	0.020	0.020	0.050	0.005	0.250	0.200	0.360	0.150	0.610	0.350	0.600	0.300	0.850	0.500
23 Jun 2019	30.0	*6.0*	0.005	0.005	0.070	0.010	0.150	0.170	0.220	0.060	0.370	0.230	0.600	0.100	0.750	0.270
4 Jul 2019	26.0	*2.5*	0.030	0.005	0.130	0.020	0.610	0.200	0.470	0.030	1.080	0.230	1.200	0.300	1.810	0.500
5 Oct 2019	36.0	*10.0*	0.005	0.005	0.060	0.020	0.620	0.300	0.340	0.110	0.960	0.410	0.800	0.300	1.420	0.600
11 Oct 2019	90.0	*2.5*	0.005	0.005	0.120	0.005	0.260	0.190	0.260	0.100	0.520	0.290	0.400	0.100	0.660	0.290
26 Nov 2019	138.0	*41.0*	0.005	0.020	0.760	0.040	0.280	0.750	0.005	0.000	0.285	0.750	3.900	0.700	4.180	1.450
16 Jan 2020	92.0	*11.0*	0.020	0.005	0.290	0.050	0.700	0.840	0.760	0.410	1.460	1.250	2.300	1.300	3.000	2.140
24 Jan 2020	98.0	*36.0*	0.005	0.010	0.160	0.070	0.320	0.440	0.370	0.160	0.690	0.600	1.200	0.700	1.520	1.140
18 Feb 2020	13.8	*2.5*	0.005	0.005	0.080	0.067	0.450	0.373	0.288	0.157	0.738	0.530	0.425	0.233	0.875	0.607
25 Mar 2020	39.0	*2.5*	0.005	0.005	0.150	0.020	0.180	0.190	0.320	0.060	0.500	0.250	0.400	0.200	0.580	0.390
29 Apr 2020	52.0	*8.0*	0.005	0.005	0.120	0.030	0.140	0.210	0.250	0.140	0.390	0.350	0.800	0.400	0.940	0.610
21 Jun 2020	8.0	*2.5*	0.005	0.005	0.010	0.005	0.060	0.060	0.120	0.060	0.180	0.120	0.200	0.050	0.260	0.110
10 Jul 2020	15.0	*2.5*	0.005	0.005	0.040	0.005	0.260	0.180	0.170	0.060	0.430	0.240	0.600	0.200	0.860	0.380
7 Aug 2020	11.0	*2.5*	0.005	0.005	0.020	0.005	0.210	0.110	0.230	0.070	0.440	0.180	0.400	0.200	0.610	0.310
9 Aug 2020	39.0	*2.5*	0.005	0.005	0.040	0.005	0.060	0.050	0.210	0.005	0.270	0.055	0.300	0.050	0.360	0.100
20 Sep 2020	26.0	*2.5*	0.040	0.005	0.080	0.010	0.005	0.060	0.010	0.005	0.015	0.065	0.300	0.100	0.305	0.160
24 Oct 2020	12.0	*2.5*	0.005	0.005	0.060	0.020	0.060	0.005	0.005	0.005	0.065	0.010	0.400	0.300	0.460	0.305
5 Nov 2020	15.0	*2.5*	0.020	0.005	0.110	0.005	0.005	0.040	0.005	0.005	0.010	0.045	0.600	0.200	0.605	0.240
15 Dec 2020	38.0	*11.0*	0.005	0.005	0.090	0.150	0.180	0.110	0.005	0.005	0.185	0.115	1.200	1.200	1.380	1.310
28 Jan 2021	20.0	*12.0*	0.005	0.005	0.110	0.080	0.260	0.490	0.330	0.020	0.590	0.510	1.100	0.900	1.360	1.390
1 Feb 2021	60.0	*2.5*	0.030	0.005	0.170	0.020	0.060	0.040	0.005	0.005	0.065	0.045	0.200	0.050	0.260	0.090
16 Feb 2021	24.0	*2.5*	0.080	0.005	0.200	0.070	0.060	0.005	0.050	0.010	0.110	0.015	0.300	0.200	0.360	0.205
11 Mar 2021	20.0	*2.5*	0.005	0.005	0.070	0.030	6.660	2.120	0.005	0.005	6.665	2.125	1.000	0.500	7.660	2.620
19 Mar 2021	264.0	*6.0*	0.005	0.005	0.970	0.005	0.005	0.005	0.010	0.005	0.015	0.010	0.200	0.050	0.205	0.055
7 Apr 2021	28.0	*2.5*	0.005	0.005	0.140	0.040	0.250	0.190	0.005	0.050	0.255	0.240	0.400	0.500	0.650	0.690
4 May 2021	27.0	*6.0*	0.005	0.010	0.230	0.100	0.460	0.380	0.020	0.090	0.480	0.470	1.600	1.000	2.060	1.380
16 Jun 2021	34.0	*5.0*	0.010	0.005	0.080	0.020	0.430	0.360	0.200	0.060	0.630	0.420	0.700	0.300	1.130	0.660
Mean	**42.1**	**7.4**	**0.018**	**0.010**	**0.147**	**0.036**	**0.559**	**0.401**	**0.254**	**0.100**	**0.812**	**0.501**	**0.890**	**0.429**	**1.449**	**0.830**
Median	**27.5**	**5.5**	**0.005**	**0.005**	**0.110**	**0.025**	**0.270**	**0.215**	**0.225**	**0.065**	**0.510**	**0.345**	**0.650**	**0.300**	**1.035**	**0.603**

*: Italicised values were recorded as below the laboratory level of reporting (LOR), and are presented as being equal to half of the LOR.

Table B-5 Concentration reduction efficiencies

Event Date	TSS CRE%	DP CRE%	TP CRE%	NOx CRE%	NH_3 CRE%	TKN CRE %	DIN CRE%	TN CRE%
28 Jun 2018	81%	0%	33%	91%	30%	60%	81%	81%
26 Aug 2018	58%	82%	71%	-4%	71%	50%	25%	32%
3 Sep 2018	73%	67%	56%	-52%	58%	53%	-2%	23%
20 Oct 2018	80%	0%	96%	46%	83%	64%	54%	55%
7 Nov 2018	68%	-100%	43%	18%	44%	30%	30%	26%
15 Nov 2018	32%	0%	36%	-88%	42%	17%	-31%	-21%
21 Nov 2018	83%	33%	14%	0%	48%	50%	20%	30%
27 Nov 2018	81%	0%	67%	13%	71%	92%	34%	66%
19 Dec 2018	47%	-100%	67%	5%	68%	43%	30%	24%
20 Dec 2018	84%	0%	74%	28%	57%	63%	38%	45%
3 Jun 2019	69%	0%	88%	-10%	37%	50%	13%	35%
16 Jun 2019	84%	0%	90%	20%	58%	50%	43%	41%
23 Jun 2019	80%	0%	86%	-13%	73%	83%	38%	64%
4 Jul 2019	90%	83%	85%	67%	94%	75%	79%	72%
5 Oct 2019	72%	0%	67%	52%	68%	63%	57%	58%
11 Oct 2019	97%	0%	96%	27%	62%	75%	44%	56%
26 Nov 2019	70%	-300%	95%	-168%	100%	82%	-163%	65%
16 Jan 2020	88%	75%	83%	-20%	46%	43%	14%	29%
24 Jan 2020	63%	-100%	56%	-38%	57%	42%	13%	25%
18 Feb 2020	82%	0%	17%	17%	46%	45%	28%	31%
25 Mar 2020	94%	0%	87%	-6%	81%	50%	50%	33%
29 Apr 2020	85%	0%	75%	-50%	44%	50%	10%	35%
21 Jun 2020	69%	0%	50%	0%	50%	75%	33%	58%
10 Jul 2020	83%	0%	88%	31%	65%	67%	44%	56%
7 Aug 2020	77%	0%	75%	48%	70%	50%	59%	49%
9 Aug 2020	94%	0%	88%	17%	98%	83%	80%	72%
20 Sep 2020	90%	88%	88%	-1100%	50%	67%	-333%	48%
24 Oct 2020	79%	0%	67%	92%	0%	25%	85%	34%
5 Nov 2020	83%	75%	95%	-700%	0%	67%	-350%	60%
15 Dec 2020	71%	0%	-67%	39%	0%	0%	38%	5%
28 Jan 2021	40%	0%	27%	-88%	94%	18%	14%	-2%
1 Feb 2021	96%	83%	88%	33%	0%	75%	31%	65%
16 Feb 2021	90%	94%	65%	92%	80%	33%	86%	43%
11 Mar 2021	88%	0%	57%	68%	0%	50%	68%	66%
19 Mar 2021	98%	0%	99%	0%	50%	75%	33%	73%
7 Apr 2021	91%	0%	71%	24%	-900%	-25%	6%	-6%
4 May 2021	78%	-100%	57%	17%	-350%	38%	2%	33%
16 Jun 2021	85%	50%	75%	16%	70%	57%	33%	42%
Mean	78%	1%	66%	-39%	19%	52%	11%	42%
Median	81%	0%	73%	16%	57%	50%	33%	42%

*: Negative (red) values show a recorded increase in pollutant concentrations across the system.

Table B-6 Statistical summary of monitoring results

Analyte	no. of events	Range of Influent EMCs (mg/L)	Median Influent EMC (mg/L)	Mean Influent EMC (mg/L)	Range of Effluent EMCs (mg/L)	Median Effluent EMC (mg/L)	Mean Effluent EMC (mg/L)	Median Conc. Removal Efficiency (Mean CRE, %)	Efficiency Ratio (ER, %)
TSS	38	8 - 264	27.5	42.1	*2.5* - 41	5.5	7.4	81%	82%
DP	38	*0.005* - 0.11	*0.005*	0.018	*0.005* - 0.04	*0.005*	0.010	0%	46%
TP	38	0.01 - 0.97	0.110	0.147	*0.005* - 0.15	0.025	0.036	73%	76%
NOx	38	*0.005* - 6.66	0.270	0.559	*0.005* - 2.12	0.215	0.401	16%	28%
NH_3-N	38	*0.005* - 0.76	0.225	0.254	*0.005* - 0.41	0.065	0.100	57%	61%
DIN	38	0.01 - 6.665	0.510	0.812	0.01 - 2.125	0.345	0.501	50%	38%
TKN	38	0.2 - 3.9	0.650	0.890	0.05 - 1.3	0.300	0.429	33%	52%
TN	38	0.205 - 7.66	1.035	1.45	0.055 - 2.62	0.60	0.83	42%	43%

Table B-8 Influent nitrogen speciation percentages

Event Date	% of NOx as % of TN	NH_3 as % of TN	DIN as % of TN	TKN as % of TN
28 Jun 2018	68%	13%	81%	32%
26 Aug 2018	34%	21%	55%	66%
3 Sep 2018	28%	24%	52%	72%
20 Oct 2018	52%	16%	68%	48%
7 Nov 2018	34%	28%	62%	66%
15 Nov 2018	36%	28%	64%	64%
21 Nov 2018	40%	29%	69%	60%
27 Nov 2018	33%	19%	52%	67%
19 Dec 2018	48%	33%	81%	52%
20 Dec 2018	52%	28%	80%	48%
3 Jun 2019	25%	24%	49%	75%
16 Jun 2019	29%	42%	72%	71%
23 Jun 2019	20%	29%	49%	80%
4 Jul 2019	34%	26%	60%	66%
5 Oct 2019	44%	24%	68%	56%
11 Oct 2019	39%	39%	79%	61%
26 Nov 2019	7%	0%	7%	93%
16 Jan 2020	23%	25%	49%	77%
24 Jan 2020	21%	24%	45%	79%
18 Feb 2020	51%	33%	84%	49%
25 Mar 2020	31%	55%	86%	69%
29 Apr 2020	15%	27%	41%	85%
21 Jun 2020	23%	46%	69%	77%
10 Jul 2020	30%	20%	50%	70%
7 Aug 2020	34%	38%	72%	66%
9 Aug 2020	17%	58%	75%	83%
20 Sep 2020	2%	3%	5%	98%
24 Oct 2020	13%	1%	14%	87%
5 Nov 2020	1%	1%	2%	99%
15 Dec 2020	13%	0%	13%	87%
28 Jan 2021	19%	24%	43%	81%
1 Feb 2021	23%	2%	25%	77%
16 Feb 2021	17%	14%	31%	83%
11 Mar 2021	87%	0%	87%	13%
19 Mar 2021	2%	5%	7%	98%
7 Apr 2021	38%	1%	39%	62%
4 May 2021	22%	1%	23%	78%
16 Jun 2021	38%	18%	56%	62%
Mean	30%	22%	52%	70%
Median	30%	24%	53%	70%

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Figure B-7 Plots of recorded influent and effluent concentrations at the site

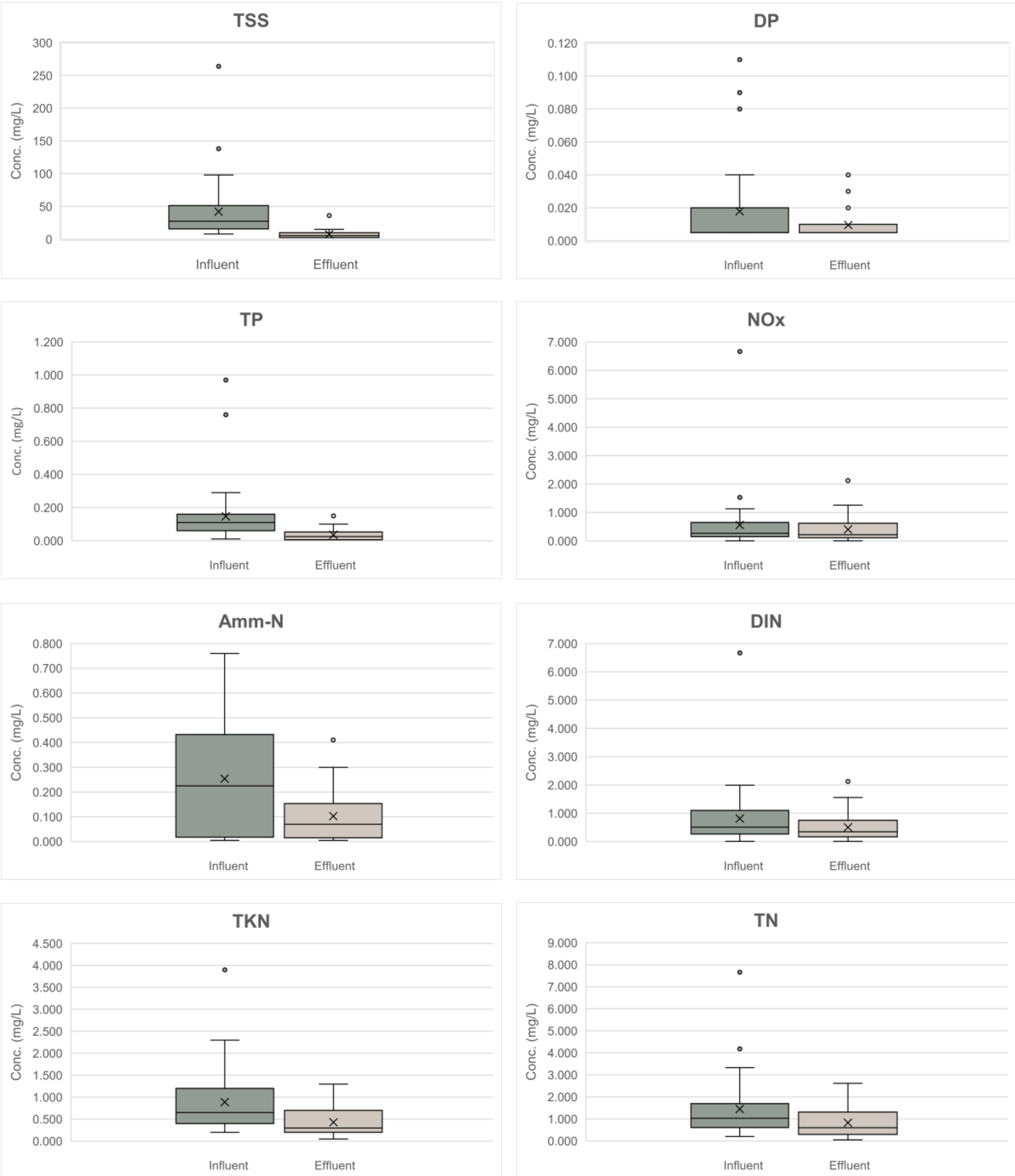

Figure B-8 Box plots of recorded influent and effluent concentrations at the site

Table B-8 Comparison of site influent EMC with MUSIC guideline EMC values

Parameter	Site Influent (mg/L)	Water By Design (2010)[1]	BMT WBM (2015)[2]	eWater, Melbourne Water (2016)[3]
TSS EMC	42.1	269	269	270
TP EMC	0.147	0.501	0.501	0.500
TN EMC	1.449	1.82	2.19	2.20

1: Values are from Event Mean Concentrations (EMCs) for 'Urban residential roads' as given by Water By Design (2010) *MUSIC Modelling Guidelines*

2: Values are for EMC for sealed roads as given by BMT WBM (2015) *NSW MUSIC Modelling Guidelines*

3: Values are default values from for urban residential for the eWater MUSIC software, which are recommended for application by Melbourne Water *(2016) MUSIC Guidelines - Recommended input parameters and modelling approaches for MUSIC*.

Table B-9 Comparison of site influent % dissolved nitrogen with E2DesignLab (2015) & Blacktown City Council (2020) recommended values

Parameter	Site		E2DesignLab (2015)[1]		Blacktown City Council (2020)
	Mean	Range	Typical	Minimum Mean	Minimum Mean
% fraction of TN dissolved	52%	2 to 87%	Approx. 50%	40%	25%

1: Values are from E2DesignLab (2015) *Development Application Requirements and Performance Protocol for Proprietary Devices on the Gold Coast*, August 2015, Internal report.

Table B-10 Comparison of performance monitoring data during and after first twelve months

Parameter (and associated period)	No. of events	TSS Influent (mg/L)	TSS Effluent (mg/L)	TP Influent (mg/L)	TP Effluent (mg/L)	TN Influent (mg/L)	TN Effluent (mg/L)
Mean - first 12 months	10	30	8.2	0.114	0.045	1.914	1.251
Mean - after 12 months	28	46	7.2	0.159	0.033	1.283	0.679
ER % - first 12 months	10	73%		61%		35%	
ER % - after 12 months	28	85%		80%		47%	

Table B-11 Summary comparison of biofiltration performance monitoring

Reference	Biofiltration system details	Methodology summary	TSS ER (%)	TP ER (%)	TN ER (%)
Current study	Western Sydney, NSW, Australia; installed April 2018, 1.45m^2 area (0.34% of catchment); 0.53m deep Filterra® filter media; Bush Christmas' Lilly Pilly (*Syzygium australe*)	28 real events after 'establishment'; flow & water quality monitored; 2019-21	85%	80%	47%
Stanford et al (2006)	Falls Church Virginia, USA; installed April 2018, 3.3m^2 area (0.7% of catchment); 0.53m deep Filterra® filter media; unidentified shrub/ tree	16 real events; flow and water quality monitored; 2004-2005	88%	60%	- (40% for TKN)
Stanford (2009)		7 simulated events; flow and water quality monitored; 2006-2007	-	70%	-
Herrera (2014)	Bellingham, Washington, USA; 2.2m^2 area (0.13% of catchment); installed 2007, 0.53m deep Filterra® filter media; unidentified shrub/ tree	22 real events; water quality monitored in 2013	94%	70%	-
Contech (2016)	Virginia Beach, Virginia, USA; 2.2m^2 area (unknown catchment area); installed 2007, 0.53m deep Filterra® filter media; unidentified shrub/ tree	92 real events; water quality monitored; 2008-2016	90%	66%	49%
Smolek et al (2018):	North Carolina State University, Fayetteville, North Carolina, USA; installed 2012, 2.2m^2 area (0.22% of catchment); 0.53m deep Filterra® filter media; Crepe myrtle (*Lagerstroemia* spp)	34 real events; flow & water quality monitored; 2013-14	95%	64%	27%
Birch et al (2005)	Sydney, NSW, Australia; 420m^2 biofiltration system (approx..4% of catchment); up to 1.1m deep filter media (1:6 mixture of zeolite and coarse, pure quartzitic sand with a mean diameter of 2 mm.); unknown planting	9 real events; water quality monitored; between October & December 1999	50%	65%	N/A
Hunt et al (2006)	Greensborough, North Carolina, USA; constructed 2000-01; two cells, 10m^2 each (5% of catchment); both with 1.2m 'organic sandy soil' filter, cell G1 included 0.45 to 0.6m internal water storage, approx. 20m^2 area; planted with river birch, common rush, yellow flag iris & sweetbay	11 real events; flow & water quality monitored; 2002-03	N/A	-409% (G1), -2900% (G2),	224% (G1), -312% (G2)
Davis (2007)	Maryland, USA; installed 2003; 2 parallel cells, 26m^2 area each (2.2% of catchment), Cell A 0.9m filter (50% sand, 30% topsoil, 20% hardwood mulch) with 80mm surface hardwood, Cell B as per Cell A but with 0.3m anaerobic sump (sand & newspaper mix); vegetated	12 real events; water quality monitored; 2003-04	22% (Cell A), 41% (Cell B)	74% (Cell A), 68% (Cell B)	N/A
McKenzie-McHarg et al (2008):	Brisbane, QLD, Australia; 20m^2 area (approx. 4% of catchment); 0.4m sandy loam filter media; vegetated	4 simulated events between 2006-2007; 3000L dose per event; flow & water quality monitored	87%	83%	28%
Hatt et al (2009)	Monash University, VIC, Australia; 3 cells, each 1.5m^2 area (1% of catchment); 0.5m deep filter media (Cell 1, sandy loam; Cell 2, 80% sandy loam, 10% vermiculite, 10% perlite, by volume; Cell 3, 80% sandy loam, 10% compost, 10% hardwood mulch, by volume; dense planting (native sedges & rushes)	Real events; water quality data for 38 events; flow data for 28 events; monitored 2006-2007	87% (Cell 1), 92% (Cell 2), 90% (Cell 3)	-2140% (Cell 1), -1286% (Cell 2), -1423% (Cell 3)	18% (Cell 1), 0% (Cell 2), 18% (Cell 3)

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Reference	Biofiltration system details	Methodology summary	TSS ER (%)	TP ER (%)	TN ER (%)
Hatt et al (2009)	McDowall, Brisbane, QLD, Australia; constructed 2006; 20m^2 area (2% of catchment); 0.4m deep sandy loam filter media; re-planted with *Carex* spp. in 2007	4 simulated events in June & October 2007	89%	83%	19%
Roberts et al (2012):	Wakerley, QLD, Australia; constructed 2007; 3 cells (955m^2 each, 0.3% of catchment) with upstream sediment basin; sandy loam filter media; 0.9m saturated zone in Cell 3; variety of plant species	53 to 74 real events for each cell; water quality monitored 2009-10	36% (Cell 1), 53% (Cell 2), 44% (Cell 3)	25% (Cell 1), 34% (Cell 2), 38% (Cell 3)	-28% (Cell 1), -11% (Cell 2), 19% (Cell 3)
Lucke et al (2015, 2017):	Caloundra, QLD, Australia; constructed 2005; 3 systems (7m^2 each); 0.9m depth sandy loam media; *L.longifolia*	1 simulated event at each system at typical TSS/TP/TN concentrations[#]; approx. 2-year 30-min events; 2014	-25%	91%	-25%
Peljo et al (2016)	Caloundra, QLD, Australia; constructed 2013; 4 systems approx.10m^2 each (approx. 1% of catchment); 0.4m deep sandy loam filter media; *Juncus & Carex spp*	2 simulated events at each of 4 systems in June 2015	91%	83%	33%
Johnson et al (2019):	Chapel Hill, North Carolina, USA; constructed 2001; 90m^2 area (14% of catchment in 2002-03; 8% of catchment 2003-present); 1.2m deep sandy filter media; perennial grasses, trees & shrubs	**1st study:** 10 real events; flow & water quality monitored; 2002-2003 **2nd study:** 18 real events; flow & water quality monitored; 2017-2018	N/A	-38% (1st), -21% (2nd)	-26% (1st), 39% (2nd)
Bonneau et al (2020)	Melbourne, VIC, Australia; 1800m^2 biofiltration system (0.5% of catchment); 0.8m average filter depth (0.35m sandy loam, 0.1m sand, 0.05m gravel, 0.3m scoria) – with bottom 0.5m being a submerged zone (of un-lined basin); densely vegetated with a mixture of swamp grasses (e.g. *Centella cordi folla*, *Amphibromus nervosus*), sedges (e.g. *Carex appressa*) and common spike rush (e.g. *Eleocharis acuta*).	13 real events analysed for water quality; 2013-2016	93%	84%	73%

Flow

The design treatable flow rate of Filterra® biofiltration systems is 3560mm/hour (Lenhart et al 2015, Smolek et al 2018). Eight (8) of the thirty eight (38) events sampled exceeded this design treatable flow rate, with a peak measurement of 2.024 L/s (5060mm/hour) recorded for six of the events. Due to the limitation of the flow capacity through the 152mm Thel-Mar weir, higher flow rates (above 2.024 L/s) through the system were unable to be qualified. The flow rate measured through the system were under typical operational conditions (i.e. 150mm peak hydraulic head filtering through all components of the system being the mulch layer, media layer (saturated) through to the underdrain). No mixing of bypass flows were possible to over-estimate the treatment flow rate recorded.

Suspended solids

Significant reductions in TSS concentrations were recorded for all events, with an concentration ER of 85% (with concentration reductions ranging from 32 to 98%) for all qualifying events. Particle Size Distribution analysis was completed for three (3) events (24 January 2020, 29 April 2020 and 10 July 2020) with an average d50 of 53.6µm and 21.2µm for the influent and effluent respectively. The average d90 for the three events sampled indicates almost all particles above 100µm being removed by the Filterra® biofiltration system.

TSS concentrations in stormwater flowing from the car park catchment (and entering the Filterra® biofiltration system) were significantly lower than that recommended in MUSIC guidelines (see Table 9) for comparable land use. For example, the mean TSS concentration recorded in inflows to the Filterra® biofiltration system was 42.1mg/L, significantly lower than the guideline recommended EMC values of 269 and 270mg/L (see Table 8). As described by Neumann et al (2010), for example, it is easier for SCMs to achieve higher pollutant concentration reduction rates when runoff has higher pollutant concentrations. Higher TSS concentration reductions would subsequently be anticipated for the Filterra® biofiltration systems with higher TSS influent concentrations. Therefore, higher TSS concentration reductions would be likely for Filterra® biofiltration systems receiving flows with TSS concentrations similar to values recommended in the aforementioned guidelines.

Higher TSS concentration ERs were observed for Filterra® biofiltration systems assessed by Shaw et al (2006), Richardson et al (2009), Hererra (2015), Contech (2016), and Smolek et al (2018). These studies, however, recorded significantly higher TSS inflow concentrations (relative to the site), which (as described above) would favour higher TSS concentration reductions. The TSS inflow concentrations observed in all Filterra® biofiltration system monitoring studies to date were also significantly lower than those recommended in MUSIC Guidelines, indicating that higher TSS CREs would be likely at TSS concentrations closer to guideline values.

Higher TSS CRE’s were observed after the first 12 months of operation, with an average ER of 73% observed in the first 12 months, and 85% after this 12-month establishment period (following installation). This increase in TSS removal is likely (at least in part) due to enhanced filtration processes of the plant, mulch and soil environment after the 12-month establishment period.

As summarised in Table 8, high TSS ER’s are consistently observed for Filterra biofiltration systems. Whilst high TSS ER’s have been observed for other (typical) biofiltration systems outlined in Table 8, some studies have observed significantly lower TSS ER’s. This variable TSS ER for typical biofiltration systems may, however, be due to a range of factors, including (but not limited to) variable filter media characteristics, climatic conditions, influent concentrations and monitoring methodologies.

Nutrients

TP and TN concentration ERs observed across the system after establishment were 80% and 47% respectively. The ER for TP was higher than observed by the other Filterra® biofiltration studies given in Table 8. The ER for TN at the site was higher than that observed by Smolek et al (2018) but lower than that observed by Contech (2016).

TP and TN EMCs observed in flows to the Filterra® biofiltration systems at the site were significantly lower than that recommended by MUSIC guidelines (see Table 9). As for TSS, the ability of any SCM to reduce nutrient concentrations would be decreased at lower inflow concentrations.

The majority of the recorded phosphorus concentrations observed in flows to and from the Filterra® biofiltration system at the site consisted of particulate phosphorus, with relatively low concentrations of dissolved phosphorus. For nitrogen, a mean of 52% of recorded inflow concentrations were dissolved inorganic nitrogen (ranging from 2 to 87%), which complies with the recommended minimum mean of 40% given by E2DesignLab (2015) and minimum mean of 25% given by Blacktown City Council (2020).

As observed for TSS, higher TP and TN ERs were observed at the site after the first 12 months of operation, with ER’s of 61 and 35% observed in the first 12 months for TP and TN respectively, and 80% and 47% after this 12-month establishment period. This increase in TP and TN removal is likely (at least in part) due to enhanced filtration and biological treatment processes of the plant, mulch and soil environment after the 12-month establishment period.

As summarized in Table 8, high TP and TN ER’s are consistently observed for Filterra biofiltration systems. In comparison, nutrient ER’s for other biofiltration systems are highly variable, with several studies observing increases in nutrient concentrations across the biofiltration systems. As for TSS, this variable nutrient concentration reduction for other biofiltration systems may be due to a range of factors including (but not limited to) variable filter media characteristics, climatic conditions, influent concentrations and monitoring methodologies.

B.5 Conclusion

Stormwater treatment performance testing was undertaken for a Filterra® biofiltration system located in a car park at Western Sydney, NSW, Australia. The sampling and monitoring protocol was designed and implemented in consultation with both City of Gold Coast’s (2016) *Development Application Requirements and Performance Protocol for Proprietary Devices* and Stormwater Australia’s (2018) *Stormwater Quality Improvement Device Evaluation Protocol Field Monitoring*.

The performance testing at the site demonstrated that the Filterra® biofiltration system was able to achieve significant reductions in stormwater pollutant concentrations, with a concentration ER for

TSS, TP and TN of 85, 80 and 47% respectively after the 12-month establishment period. These concentration reductions were achieved despite relatively low concentrations for TSS, TP and TN in incoming stormwater flows (which would be expected to decrease potential concentration reductions).

These results generally correlate with a similar assessments of Filterra® biofiltration systems in the USA described by others, and provide evidence of the ability of an appropriately designed, installed and operated Filterra® biofiltration system to provide a stormwater treatment function (and protect water quality within downstream waterways) within Australia. As Filterra® biofiltration systems require significantly less area relative to typical biofiltration systems (with sandy loam media), there is anticipated to be significant opportunity for their integration – particularly in highly constrained urban areas.

Appendix C MUSIC modelling of Filterra® biofiltration system at University of Western Sydney

C.1 Preamble

As described in Section 3.2, MUSIC is the preferred tool for demonstrating the performance of stormwater quality treatment systems (Water By Design 2010, BMT WBM 2015). As described in Section 3.3.1, Filterra® biofiltration systems can be modelled in MUSIC using a bioretention treatment node.

This appendix describes the methodology and results of modelling the Filterra® biofiltration system at Western Sydney (described in Appendix A) as a bioretention treatment node (in MUSIC), with comparisons made between MUSIC predictions and monitoring data recorded at the site.

C.2 Methodology

C.2.1 Software

The eWater CRC MUSIC software (Version 6) has been used in these assessments. This is the latest version of MUSIC (at the time of report writing).

C.2.2 Source node

Within MUSIC, the user is required to specify source nodes. The source nodes represent the stormwater flow and pollutant generating areas of the site.

A single source node was used to represent the catchment flowing to the Filterra® biofiltration system at the site. A summary of the source node properties used in the MUSIC modelling is provided in Table C-1.

Table C-1 Summary of source node properties applied in modelling

Parameter	Unit	Value	Comments
Land usage classification	-	Urban residential roads	Unless otherwise stated, rainfall-runoff and pollutant export properties in accordance with Water By Design (2010)
Area	ha	0.042	See Appendix A.
Imperviousness	%	100%	
TSS/ TP/ TN EMC's	mg/L	Varies	Pollutant concentrations as recorded in site monitoring (for influent, See Table B-8). In the absence of a recorded concentration corresponding to rainfall events within the modelling event, the previous recorded concentrations available are applied for flows from the catchment (represented by the source node).
Estimation method	-	Mean	See above for assumptions related to pollutant concentrations. No stochastic generation of pollutants assumed.

C.2.3 Treatment node

A single bioretention node was used to represent the Filterra® biofiltration system at the site. A summary of the treatment node properties used in the MUSIC modelling is provided in Table C-2. The layout of the source and treatment nodes within MUSIC is illustrated in Figure C-1.

Table C-2 Summary of treatment node properties applied in modelling

Parameter	Unit	Value	Comments
Inlet properties			
Low-flow bypass	m^3/s	0	All flows enter system.
High-flow bypass	m^3/s	100	Default value. Overflow of high flows determined by system storage.
Storage properties			
Extended detention depth	mm	150	From as-constructed drawings.
Surface area	m^2	1.45	
Filter and media properties			
Filter area	m^2	1.45	From as-constructed drawings.
Unlined filter media perimeter	m	N/A	Zero exfiltration assumed.
Saturated hydraulic conductivity	mm/hour	3550	Design rate.
Filter depth	m	0.53	From as-constructed drawings.
Total Nitrogen (TN) content	mg/kg	400	Based on filter media results given in Table H-3.
Orthophosphate content	mg/kg	0.1	
Infiltration properties			
Exfiltration rate	mm/hr	0	Zero exfiltration assumed.
Vegetation properties			
Plant selection	-	'vegetated with nutrient effective plants'	A single 'Bush Christmas' Lilly Pilly (*Syzygium australe*) tree is within the system. This species is not identified as a 'plant with effective nutrient removal' by CRC for Water Sensitive Cities (2015) or as 'core functional bioretention species' by Water By Design (2014). The species does, however, appear to function as a 'plant with effective nutrient removal'.
Outlet properties			
Overflow weir width	m	1.2	From as-constructed drawings.
Underdrain present	-	Yes	
Submerged zone with carbon present	-	No	

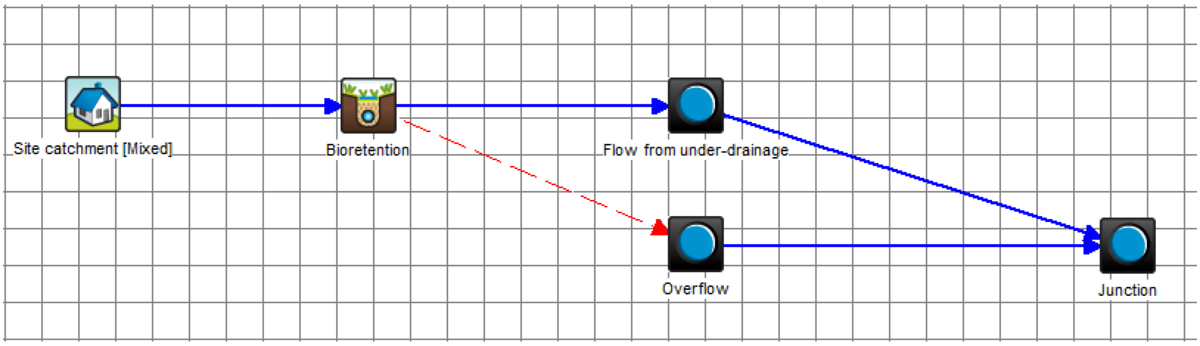

Figure C-1 Layout of MUSIC model for site

C.2.4 Meteorological data

Modelling was performed from 1 June 2019 to 30 June 2021, using 6-minute rainfall data recorded at the site and monthly areal PET from Parramatta (provided within MUSIC). This period includes all site monitoring data (27 qualifying events) following the 'establishment' of the system, assumed to be after the first twelve (12) months of operation (noting the system was installed in April 2018).

C.3 Results

Table C-3 presents a comparison of the predicted average annual flows and pollutant loads for the site against observed concentration efficiency ratio (ER) (between 1 June 2019 and 31 June 2021). Table C-4 presents a comparison of the recorded influent and effluent concentrations at the site (as part of site monitoring, described in). It should be noted that the pollutant concentration statistics from MUSIC are only for periods where flow was predicted in MUSIC (i.e. results exclude all periods of zero flow).

Table C-3 Comparison of Predicted Average Annual Flows and Loads for Site against observed concentration efficiency ratio (1 June 2019 to 30 June 2021)

	Average annual flows and loads predicted in MUSIC			Observed Concentration Efficiency Ratio (%)
Parameter	Sources	Residual	% Reduction	
Flow (ML/year)	0.304	0.301	0.9	N/A
TSS (kg/year)	25.40	3.09	88	85%
TP (kg/year)	0.079	0.012	85	80%
TN (kg/year)	0.367	0.215	41	47%
Gross pollutants (kg/year)	7.56	0	100	N/A

Table C-4 Comparison of recorded influent and effluent concentrations recorded at site and as predicted by MUSIC (1 June 2019 to 30 June 2021)

Parameter	Unit	Value predicted by MUSIC[1]	Value using site monitoring data[2]
TSS mean influent concentration	-	90	46
TP mean influent concentration	ha	0.274	0.159
TN mean influent concentration	%	1.20	1.28
TSS mean effluent concentration	mg/L	5.0	7.2
TP mean effluent concentration	mg/L	0.025	0.033
TN mean effluent concentration	mg/L	0.69	0.68
TSS ER	%	95%	85%
TP ER	%	91%	80%
TN ER	%	42%	47%

1: Values are only for periods where flow was predicted (i.e. results exclude all periods of zero flow).
2: See .

Flows

The MUSIC analysis of the period between 1 June 2019 and 30 June 2021 predicts a volumetric flow reduction of 0.9% across the Filterra® biofiltration system. Whilst flow-rates were not recorded at the Western Sydney site, this value is less than the 6% reduction in flows for the Filterra® biofiltration system observed by Smolek et al (2018).

Suspended solids

The Filterra® biofiltration system is predicted by MUSIC to result in a significant reduction in TSS loads and concentrations over the modelling period. The predicted TSS concentration efficiency ratio (ER) of 95% is higher than that recorded (of 85%). However, this predicted TSS concentration ER of 95% is similar to the recorded TSS concentration reduction of TSS concentrations of 91% as recorded by Anderson and Smolek (2015). This indicates that MUSIC may provide an approximate estimate of TSS concentration reduction for Filterra® biofiltration systems.

Nutrients

MUSIC predicts high TP and TN load and concentration reductions across the Filterra® biofiltration system. The TP concentration ER predicted in MUSIC is higher than observed in monitoring data, whilst the TN concentration ER predicted by MUSIC is lower than that observed.

Summary

It is likely that MUSIC (and associated bioretention node) provides an reasonable prediction of TSS, TP and TN load and concentration reductions for the Filterra® biofiltration system at the site. It should, however, be noted that this comparison utilises the recorded performance data at just one site.

Appendix D Peer Review of Filterra® biofiltration systems by Professor Ataur Rahman

This appendix provides the peer review of Filterra® biofiltration systems undertaken by Professor Ataur Rahman from Western Sydney University for Ocean Protect (formerly Stormwater360 Australia).

WESTERN SYDNEY
UNIVERSITY

School of Computing, Engineering and Mathematics
Western Sydney University, Sydney, Australia
Locked Bag 1797, Penrith, NSW 2751, Australia

Date 5 October 2017

Mr Michael Wicks
Technical Director
Stormwater 360, Australia

Dear Sir,

Please find attached a peer review report in relation to the applicability of Filterra® Bioretention System as a stormwater improvement device under typical Australian urban runoff conditions.

It has been found that Filterra® Bioretention System is highly likely to achieve hydrologic and pollutant removal performances in typical Australian urban catchments (as required by the local councils) at least at the same level found by the North Carolina State University, Fayetteville, North Carolina, USA testing (reported in Anderson and Smolek, 2015).

This conclusion has been arrived mainly based on the review of field study and test results on Filterra® carried out by North Carolina State University during 2013-14 (over 22 months) to assess its hydrologic and pollutant removal performances and comparison with similar field and laboratory testing of a number of bioretention systems in Australia.

Yours sincerely,

Associate Professor Ataur Rahman, PhD, FIE Aust., M. ASCE
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Peer Review: StormFilter® as a stormwater improvement device

1. Background

Urbanisation has major negative impacts including increased flood peak & volume and deteriorated water quality. A range of stormwater treatment technologies have been developed to reduce the negative impacts of urbanisation, for example, wetlands, sedimentation ponds, infiltration systems and, more recently, bioretention systems (e.g. Davis, 2005; Wong, 2006). Bioretention systems, also known as biofilters or raingardens, are the most widely used stormwater 'best management practice' in the US (Davis et al., 2009) and becoming quite popular in other countries like Australia (Wong, 2006).

Bioretention systems typically consist of small areas which are excavated and backfilled with a mixture of high-permeability soil and organic matter to maximize infiltration and vegetative growth and are covered with native vegetation (Roy-Poirier et al., 2010). The vegetation is selected to be resistant to environmental stresses and generally include small plants and shrubs. A layer of mulch is often added to cover the soil media and retain solids. An inlet structure is built to route urban runoff from the surrounding area to the unit, while an overflow structure bypasses flows above the ponding capacity of the unit. In regions having native soils of low permeability, an underdrain structure is constructed at the bottom of the facility to prevent water from standing in the unit for extended periods of time. Biofiltration system is a recommended and increasingly popular technology for stormwater management; however, there is a general lack of performance data for these systems, particularly at the field scale (Hatt et al., 2009).

The water quality performance of bioretention systems has mainly been assessed in laboratory conditions (e.g. Bratieres et al., 2008; Lucas and Greenway, 2008). These studies generally report high removals of sediments, heavy metals and phosphorus from synthetic stormwaters. The removal of nitrogen, and particularly nitrate, has been variable with the bioretention systems (Hatt et al., 2007). Recent studies have suggested that laboratory-scale filter columns do not satisfactorily replicate field-scale conditions leading to the needs for field evaluation of bioretention systems (Hatt et al., 2008).

This review focuses on Filterra® Bioretention Systems that offers a unique version of the typical flow-through filter by coupling high volume treatment with an engineered bioretention media (e.g. 140 in/hr, equivalent to 3556 mm/hr design infiltration rate) (Anderson and Smolek, 2015).

2. Review of Bioretention System

Bioretention system is an engineered stormwater control measure that provides soil and vegetation treatment to stormwater runoff. A variety of pollutants are present in stormwater sediments, which can be removed by physical processes such as sedimentation and filtration, provided by a bioretention system. Dissolved pollutant removal in traditional bioretention system occurs through a combination of processes such as adsorption, precipitation, ion exchange, and biological processes (Davis et al., 2009).

Removal of sediments in stormwater is generally high by bioretention system (54 to 99%) aided by filtration and sedimentation (Hatt et al., 2009). The top mulch layer in bioretention system has been shown to filter most of the TSS in the runoff (Hsieh and Davis, 2005).

Phosphorus removal rate by bioretention system has been reported to be in the range of 52 to 99% aided by filtration, sorption and plant uptake (Hunt et al., 2012). However, it is more difficult to remove dissolved phosphorus by traditional bioretention systems.

Nitrogen removal rate by bioretention system has been found to be in the range of 30 to 99% achieved by microbial metabolism, plant uptake and denitrification (Davis et al., 2009). However, aerobic bioretention conditions, which are common in flow-through media in bioretention can add nitrate-nitrogen rather than remove it. An anoxic condition is needed to convert nitrate to nitrogen gas. This can be achieved by adding an upturned elbow, anoxic zone, or internal water storage zone in bioretention systems.

Metal removal rate by bioretention system has been reported to be 54 to 99% aided by sorption, filtration, plant uptake, hydrolysis and precipitation (Passeport and Hunt, 2009). Most metal removal in bioretention system occurs in the top 5 to 20 cm of media and mulch (Davis et al., 2009).

3. Filterra® System Components

The Filterra® system is a high filtration rate stormwater treatment device that uses proprietary bioretention filtration media topped with mulch in combination with a planted tree species (Figure 1) (Anderson and Smolek, 2015). Stormwater runoff enters the system through a wide open-throated kerb inlet. Similar to conventional bioretention system, an underdrain surrounded by washed aggregate drains treated stormwater to the existing drainage infrastructure.

Figure 1. A typical Filterra site with overflow bypass pipe (Anderson and Smolek, 2015).

4. Review of Field Testing on Filterra® Bioretention System

A Filterra® Bioretention System was monitored by North Carolina State University, Fayetteville, North Carolina, USA as detailed in Anderson and Smolek (2015) during 2013-14 (for 22 months). An existing parking lot of an AmtrakTM train station was retrofitted with a 6-foot by 4-foot (i.e. 1.2 m×1.8 m approximately) Filterra® system, which treated 0.25 acres (about 1000 m^2) of impervious asphalt and concrete catchment (Figure 2). The Filterra® system area was approximately 0.22% of the catchment area. The maximum impervious drainage area for the 6-foot by 4-foot system installed in Fayetteville is 0.21 acres according to the Filterra® sizing chart for the region (for 1 inch design storm) (equivalent to 0.26% of the catchment area). Hence, the Filterra® system in the North Carolina State University testing was slightly undersized. The system was installed in September, 2012 and activated on 2nd October 2012 by Contech Engineered Solutions and performance data were obtained for 22 months during 2013-14. The site area on average receives 1049 mm of rainfall per year. The Filterra® system is shown in Figure 3.

Filterra® sizing utilizes a conservative design flow rate of about 3.5 m per hour. To design the Filterra® to treat the necessary (e.g. 25 to 40 mm) water quality volume, sizing chart for Filterra® is available, which was utilized to estimate maximum size drainage area for a Filterra® unit using a “worst case” 100% impervious drainage area.

Automatic water quality samplers were installed to collect influent and effluent samples. All rainfall at the site was measured using a tipping-bucket rain gauge. To obtain flow-weighted composite samples for each storm event, runoff was routed to the influent sampling location into a sharp-crested compound weir flow-measuring device. The sampling procedure generally meets the international standards (Anderson and Smolek, 2015).

The collected water quality samples were tested for event mean concentrations of total suspended solids (TSS), suspended sediment concentration (SSC), total ammoniacal nitrogen (TAN), nitrate/nitrite-nitrogen ($NO_{2,3}$-N), total Kjeldahl nitrogen (TKN), total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), total copper (Cu), dissolved copper, total zinc (Zn), and dissolved zinc (Anderson and Smolek, 2015).

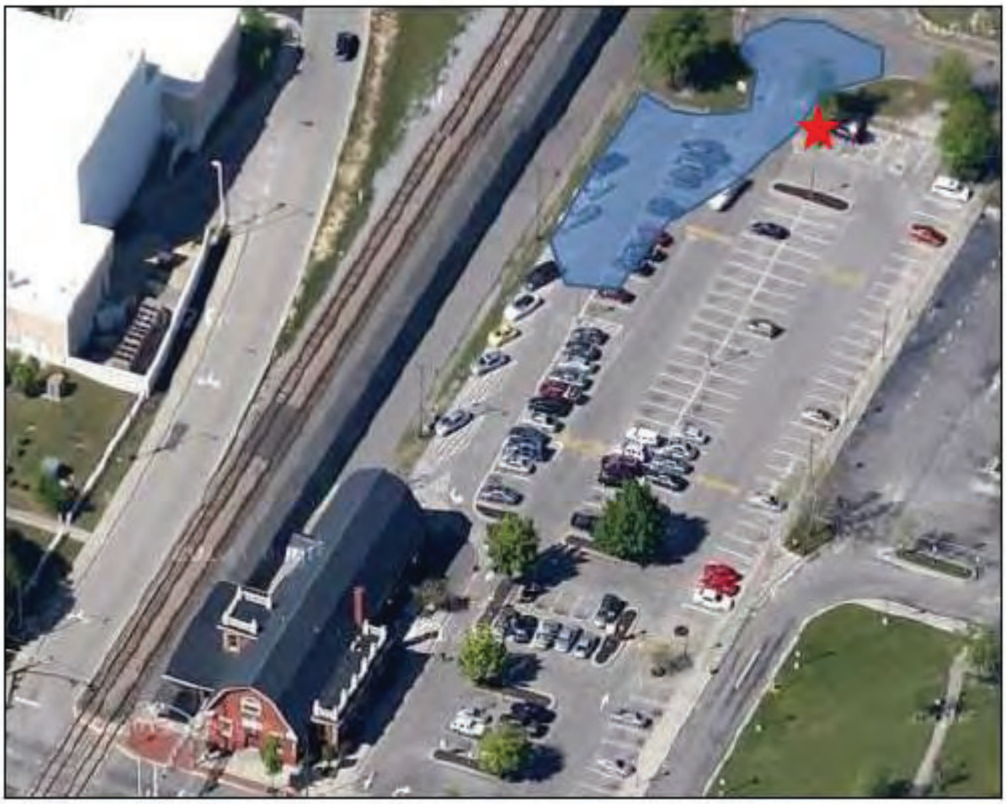

Figure 2. Location of Filterra® at city-owned AmtrakTM parking lot in Fayetteville, North Carolina (Anderson and Smolek, 2015).

Figure 3. Filterra® at city-owned AmtrakTM parking lot in Fayetteville (Anderson and Smolek, 2015).

Study results show that the Filterra® system reduced median peak flow by 56% for storms monitored in the study (0.10 to nearly 5 inches, equivalent to 2.54-127 mm, in depth) during the study period (2013-2014). About 72% of inflow volume was treated by the Filterra®, while the remainder was either bypass flow (22%) or a combination of soil storage and/or instrument error (6%). Filterra® was found to behave similarly to widely-used and approved BMPs in North Carolina (Anderson and Smolek, 2015). As reported by HEC (2009), substantial water losses were observed in the Filterra test systems at the Port of Tacoma between the influent and effluent monitoring stations during the start of the monitoring year in May and June 2008. This water loss ranged from 1.2 to 57 percent, with a median value of 27 percent. As reported in HEC (2009), a study performed by Filterra and Randolph-Macon College showed that volume storage capacity of the Filterra system increased as a function of system size and drying period, and would be ideal for capturing small, low intensity events and dry weather flows. Standard Filterra systems retained between 17.5 and 28.9 percent of the influent water volume based on a 0.1-inch rainfall intensity, which is the 80th percentile of the rainfall intensities measured in the Mid-Atlantic region of USA. Based on these results, the volume reduction in the Filterra® system may be taken as 6% as found in the North Carolina State University testing (given Filterra® system was undersized at 0.22% of the catchment area, if the system was sized at 0.3% of the catchment area, the water loss would have been higher).

Over a 22-month monitoring period, the Filterra® significantly reduced TSS concentrations with an efficiency ratio of 96%, a cumulative load reduction of 76%, and a median storm-by-storm TSS load reduction of 80%. Another sediment metric, Suspended Sediment Concentration (SSC), was also measured, resulting in a 97% significant efficiency ratio, a 77% cumulative load reduction, and a 77% median storm-by-storm load reduction. The 95% confidence interval of the mean TSS removal on a per storm event basis was estimated to be 90% - 94%.

Total phosphorus concentrations were notably reduced with an efficiency ratio of 64%, a cumulative load reduction of 54% and a 63% median storm-by-storm load reduction. Overall cumulative percent loading reduction was 54%, indicating excellent removal of phosphorus for bioretention without internal water storage. Concentrations of both total dissolved phosphorus (TDP) and soluble reactive phosphorus (SRP) were very low both entering and leaving the system (below what is expected on an urban watershed).

Total nitrogen concentrations were significantly reduced with an efficiency ratio of 39%, a cumulative load reduction of 39% and a 45% median storm-by-storm load reduction. Although total nitrogen was reduced, likely due to filtration of particulate-bound N, nitrate export was witnessed. This finding was expected, and is typical in systems that do not have apparent mechanisms for denitrification.

Total zinc concentrations were also significantly reduced with an efficiency ratio of 69%. For the Filterra® system as a whole, cumulative percent load reductions for TSS, TP and TN were 76%, 54% and 39%, respectively. When only storms that did not produce bypass were considered, the cumulative percent load reduction increased to 96%, 75%, and 45% for TSS, TP and TN, respectively (Anderson and Smolek, 2015).

5. Field Testing on Filterra® Bioretention System in Fayetteville, North Carolina vs. Australian data

Birch et al. (2005) assessed the efficiency of stormwater infiltration basin to remove contaminants from urban stormwater runoff in eastern Sydney. They monitored seven rainfall events. The TSS removal efficiency of the stormwater infiltration basin was about 50% on average, whereas the removal efficiencies of Cu, Pb and Zn were on average 68%, 93% and 52%, respectively. The mean removal efficiencies for total phosphorus (TP) and total Kjeldahl Nitrogen (TKN) were found to be 51% and 65%, respectively.

Hatt et al. (2007) conducted a laboratory-scale gravel infiltration system in Monash University, Clayton, Victoria to test the pollutant removal under a range of water level regimes, including both constant and variable water levels. Gravel filters were found to be very effective for removal of sediment and heavy metals under all water level regimes, even as the system clogged over time. Despite the sediment particle size distribution being much smaller than the filter media pore size, sediment and its associated pollutants were effectively trapped in the top of the gravel filter, even when the water level was allowed to vary. A media depth of 0.5m was found to achieve adequate pollutant removal. The removal efficiencies for TSS, TP, TN and zinc were 92%, 53%, 44% and 38%.

Bratieres et al. (2008) conducted a large-scale column study in purpose built greenhouse in Melbourne to test the performance of biofilters for the removal of sediment, nitrogen and phosphorus from stormwater runoff. A variety of factors were tested, using 125 large columns including plant species, filter media, filter depth, filter area and pollutant inflow concentration. The results demonstrate that vegetation selection is critical to performance for nitrogen removal (e.g. Carex appressa and Melaleuca ericifolia performed significantly better than other tested species). Whilst phosphorus removal was consistently very high (typically around 85%), biofilter soil media with added organic matter reduced the phosphorus treatment effectiveness. Biofilters built according to observed ‘optimal specifications’ can reliably remove both nutrients (up to 70% for nitrogen and 85% for phosphorus) and suspended solids (consistently over 95%).The optimally designed biofilter is at least 2% of its catchment area and possesses a sandy loam filter media, planted with C. appressa or M. ericifolia.

Hatt et al. (2009) investigated the hydrologic and pollutant removal performance of three field-scale biofiltration systems in Australia (one at Monash University, Clayton, Victoria and the other at McDowall, Queensland). They found that Biofilters effectively attenuated peak runoff flow rates by at least 80%. Performance assessment of a lined biofilter demonstrated that retention of inflow volumes by the filter media, for subsequent loss via evapotranspiration, reduced runoff volumes by 33% on average. Retention of water was found to be most influenced by inflow volumes, although only small to medium storms could be assessed. Vegetation was shown to be important for maintaining hydraulic capacity, because root growth and senescence countered compaction and clogging. Suspended solids and heavy metals were effectively removed, irrespective of the design configuration, with load reductions generally in excess of 90%. In contrast, nutrient retention was variable, and ranged from consistent leaching to effective and reliable removal, depending on the design. It was recommended that to ensure effective removal of phosphorus, a filter medium with low phosphorus content needs to be selected. They noted that nitrogen was more difficult to remove because it is highly soluble and strongly influenced by the variable wetting and drying regime that is inherent in biofilter operation.

Table 1 compares the pollutant removal efficiencies of Filterra® Bioretention System tested in Fayetteville, North Carolina with four Australian studies. It can be seen that TSS removal efficiency of Filterra® is 96%, which matches very well with the studies by Hatt et al. (2007) (92%), Bratieres et al. (2008) (95%) and Hatt et al. (2009) (90%) .

It can be seen that TP removal efficiency of Filterra® is 64%, which is higher than the value found by Hatt et al. (2007) (53%), but smaller than the value found by Bratieres et al. (2008) (85%). It should be noted that study by Bratieres et al. (2008) was greenhouse experiment but Fayetteville, North Carolina study with Filterra® was a field study.

Table 1. Comparison of Filterra® Bioretention System tested in Fayetteville, North Carolina vs. Australian data

Pollutant	Filterra® (field tested in North Carolina, USA) (Anderson and Smolek, 2015)	Other bioretention/ infiltration systems tested in Australia	Reference
TSS	96%	50%	Birch et al. (2005): field study site in eastern Sydney
		92%	Hatt et al. (2007): laboratory experiment at Monash University Clayton, Victoria
		95%	Bratieres et al. (2008): Greenhouse experiment, Melbourne, Victoria
		90%	Hatt et al. (2009): Monash University, Clayton, Victoria and McDowall, Queensland
TP	64%	51%	Birch et al. (2005): field study site in eastern Sydney
		53%	Hatt et al. (2007): laboratory experiment at Monash University Clayton, Victoria
		85%	Bratieres et al. (2008): Greenhouse experiment, Melbourne, Victoria
		Not available	Hatt et al. (2009): Monash University, Clayton, Victoria and McDowall, Queensland
TN	39%	65% (TKN)	Birch et al. (2005): field study site in eastern Sydney
		44%	Hatt et al. (2007): laboratory experiment at Monash University Clayton, Victoria
		Up to 70%	Bratieres et al. (2008): Greenhouse experiment, Melbourne, Victoria
		Not available	Hatt et al. (2009): Monash University, Clayton, Victoria and McDowall, Queensland
Zn	69%	52%	Birch et al. (2005): field study site in eastern Sydney
		38%	Hatt et al. (2007): laboratory experiment at Monash University Clayton, Victoria
		Not available	Bratieres et al. (2008): Greenhouse experiment, Melbourne, Victoria
		Not available	Hatt et al. (2009): Monash University, Clayton, Victoria and McDowall, Queensland

There are little published data on contaminants in runoff from carparks in Australia. The contaminant concentrations and load in the carpark runoff depend on factors such as traffic volume in the carpark, surrounding land use, adopted maintenance mode and frequency. The small catchment size of carpark is likely to show a first flush effect after the heavy rainfall events. Hence, comparison of contaminants in the carpark runoff from different studies located in different regions must be interpreted in light of the local conditions.

Fletcher et al. (2004) recommended the event mean concentrations (EMC) for a number of land uses in Australia, which are widely used in design (Table 2). It is found that contaminant concentrations for the case of Mitchell Community College carpark testing are much smaller than reported by Fletcher et al. (2004).

Table 2. EMC for different land uses in Australia (Fletcher et al., 2004) compared with Mitchell Community College carpark testing (values in parentheses indicate Fayetteville Filterra® Bioretention result)

Contaminant	Range (mg/L)	Typical value (mg/L)
Suspended solids	900 - 800 (20 - 730)	270 (120)
Total Nitrogen	1.00 - 5.00 (0.35 - 2.62)	2.2 (1.20)
Total Phosphorus	0.15 - 1.5 (0.03 - 0.59)	0.5 (0.130)

In another study by Morison (2001) for St Martins Shopping Village carpark in Western Sydney using a rainfall simulator (calibrated for a 1 in six month storm of 15 minutes duration) showed a first flush effect for 10 minutes with an approximate EMC for a duration of 15 minutes of Suspended Solids (95 mg/L), Total Nitrogen (1.85 mg/L) and Total Phosphorus (0.15 mg/L). The results from Morison (2001) and Fletcher et al. (2004) when compared with Mitchell Community College carpark testing exhibit a large difference, which perhaps are due to different land use characteristics and traffic volume representing local conditions.

It should be highlighted that if the EMC in the influent is higher, the contaminant removal efficiency by a stormwater quality improvement device should be higher. Hence, it is highly likely that the efficiency ratio for Fayetteville Filterra® Bioretention system would be much higher if the influent EMCs were higher as reported in Australia.

6. Conclusion

Based on this literature review, the following conclusions can be made:

- The sampling and monitoring protocol of field testing of Filterra® Bioretention System by North Carolina State University, Fayetteville, North Carolina, USA as detailed in Anderson and Smolek (2015) generally follows the international and Australian standards of field testing. Hence, the test results from this study are deemed to be reliable.

- In the North Carolina State University testing, a 6-foot by 4-foot Filterra® was adopted for 0.25 acres of impervious asphalt and concrete catchment area, i.e. the Filterra® system area was approximately 0.22% of the catchment area. According to the local Filterra® sizing guideline, the treatment area should have been 0.21 acres (i.e. Filterra® system area should have been 0.26% of the catchment area). Based on these data, the minimum sizing criterion of Filterra® for Australia may be taken as 0.3 % of catchment area.

- Results from North Carolina State University testing show that the 1.2 m×1.8m Filterra® system reduced median peak flow by 56% for storms (2.54-127 mm in depth) monitored during the study period for treatable catchment area of about 1000 m^2. About 72% of inflow volume was treated by the Filterra®. The mean annual rainfall in the study area is 1049 mm. Depending on the local rainfall and given catchment area in Australia, the appropriate size of the Filterra® system needs to be calculated.

- Based on the results of the North Carolina State University testing and other similar studies, the volume reduction in the Filterra® system (due to factors such as storage and evapotranspiration) may be taken as 6% of rainfall volume (generally applicable for smaller rainfall events e.g. 3 mm or less), which is ideal for capturing small, low intensity rainfall events and dry weather flows.

- The pollution removal efficiencies of Filterra® Bioretention System in the North Carolina State University testing has been found to be about 96%, 64%, 39% and 69% for TSS, TP, TN and Zn. When only storms that did not produce bypass were considered, the cumulative percent load reduction increased to 96%, 75%, and 45% for TSS, TP and TN, respectively (Anderson and Smolek, 2015).These pollution removal efficiencies for Filterra® Bioretention System are likely to vary from site to site depending on the surrounding urban land use condition and rainfall characteristics; and these values are shown to match quite well with similar Australian studies with the bioretension systems. Hence, it is highly likely that Filterra® Bioretention System will achieve hydrologic and pollutant removal performances in typical Australian urban catchments (as required by the local councils) at least at the same level found by the North Carolina State University, Fayetteville, North Carolina, USA field testing as detailed in Anderson and Smolek (2015).

- Based on this review, for typical stormwater modelling (e.g. using MUSIC) in Australia using Filterra® Bioretention system, the following pollution removal efficiencies may be adopted: 96% (for TSS), 64% (for TP) and 39% (for TN) together with a volume reduction of 6%. It should be noted that the removal efficiencies recommended are less than the cumulative percent load reduction for storms (without bypass).

- It should be noted that TN removal efficiency is subject to greater uncertainty as bioretention systems do not have adequate mechanisms for denitrification. It is suggested that field testing of Filterra® Bioretention System should be conducted in typical Australian urban catchments of the discrete nutrient speciation (for N) removals to confirm above findings of this review.

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Appendix E Peer Review of Filterra® biofiltration systems by Ralf Pfleiderer

This appendix provides the peer review of Filterra® biofiltration systems undertaken by Ralf Pfleiderer from RPEC for Ocean Protect.

RPEC Ralf Pfleiderer Environmental Consulting

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Tuesday, 5 May 2020

Peer review – Filterra Biofiltration system

This peer review is for Ocean Protect's Filterra biofiltration system and its suitability to conditions in Victoria, Australia.

The review is based on a site inspection of the in ground systems at Western Sydney University and Warwick Farm in Sydney on 17 March 2020 (via video conference due to the Convid-19 restrictions), documentation and field monitoring data provided by Ocean Protect.

I am basing this review on the information supplied and applying my knowledge of Victorian biofiltration/raingarden systems. I have 20 years of experience in designing, building and maintaining these systems as a consultant, working in local government (City of Melbourne) and through hands-on experience at Wave Maintenance and Australia Ecosystems.

In my opinion, Filterra biofiltration systems should perform adequately in Victoria, meeting the required best practice standards. It should be pointed out that the Filterra biofiltration system is installed and maintained by the Ocean Protect's in house team or by approved installers. Therefore, they stand behind their product. The capital and operational cost per square metre is higher than the average raingarden installation, but, given the lower footprint due to its higher flow throughput, it can have a lower life cycle cost. Its treatment performance has been proven through several field monitoring studies to meet or exceed the required standards for TSS (80-96%) and TP (54-69%) when sized at 0.3% of the catchment. Results from studies to date shows it falls just short for TN at 35-40% removal. The target 45% TN removal can be achieved by a slight increase in the sizing of the system or utilising vegetation recognised (e.g. in FAWB guidelines) as providing effective nutrient removal". At Western Sydney, a Lilly Pilly is used, which is not recognised as being an effective nutrient removing plant. Higher nutrient removals would be expected if effective nutrient removal vegetation were used.

As the industry is aware, there are many raingardens and biofiltration systems out there that are not meeting their design intentions. This is sometimes due to bad design or construction not complying to the design, particularly regarding levels and the installed filter soil. But they mostly fail due to lack of maintenance, particularly sediment removal. As Ocean Protect is willing to stand behind Filterra biofiltration systems and undertake the required maintenance, I think the Filterra biofiltration systems are likely to overcome many of the difficulties commonly experienced by typical biofiltration systems. Being a vegetation-based system, it also provides greening and biodiversity outcomes, unlike other proprietary cartridge filters on the market.

Kind Regards,

Ralf Pfleiderer
Principal
Ralf Pfleiderer Environmental Consulting

Industry experience

I have an Environmental Engineer qualification and am well-recognised within Melbourne's Water Sensitive Urban Design (WSUD) and Integrated Water Management (IWM) industry: with twenty years' experience in both private and public enterprise. In all my work, I have applied my engineering skills within a landscape, green infrastructure and open space context

Over my twenty-year career I have:

- Delivered many iconic wetland and stormwater harvesting projects through my work with the City of Melbourne and Australian Ecosystems including: Trin Warren Tam-boore wetland at Royal Park, stormwater harvesting schemes at Fitzroy Gardens, Darling Street, Birrarung Marr, Alexander, Queen Victoria Garden, Lincoln Square and Ievers Reserve and many housing development treatment wetlands, including Waterways, Mernda Villages, Caroline Springs, Cairnlea and the Eynesbury Estate.
- Been involved in the delivery of streetscape projects including: Retrofitting stratavault infiltration pits to existing mature trees at Atherton Rd Oakleigh, Passive irrigation soak wells for Moonee Valley City Council and raingarden installations for the City of Melbourne at Docklands, Howards St and Hardiman St as well as many tree pit raingardens.
- Coordinated the design and installation, monitoring and review of the permeable pavement infiltration trenches at Eades Pl, Harris St, Abbotsford St and Collins St.
- Undertaken formal audits of WSUD infrastructure for the following councils; Melton, Melbourne, Monash and Stonnington. Informal review of systems in Darebin, Kingston, Port Phillip, Moreland, Casey and Mannington.
- Provided raingarden rectification designs for Monash and Stonnington councils.
- Undertaken raingarden and tree pit maintenance for City of Stonnington.
- Provided Stormwater harvesting system maintenance and rectification for Banyule city council.
- Managed and/or undertaken wetland planting and maintenance on 100+ constructed wetlands across Melbourne and Victoria during the 10 years at Australian Ecosystems

I have also served seven years on the Stormwater Victoria (SV) committee, three years as president (2013-2016). Being actively involved with SV has greatly extended my network and knowledge of the industry. During my time at City of Melbourne I also looked to connect with council officers in similar roles to share and exchange knowledge, allowing us to share and overcome issues quicker. Given this is a very new and evolving industry, there are many issues that need resolving as well as many new ideas and innovations to consider. A healthy network of peers makes this easier.

In 2012 I participated in the Water Sensitive Cities Study tour. Together with eighteen other water industry professionals from around Australia, we visited IWM projects across Australia and in Singapore, the UK, Sweden, Germany and the Netherlands. This has further developed our understanding of how to apply to IWM in other contexts. It also developed our networks beyond our local contacts.

All this has exposed me to biofiltration approaches and problems in many different contexts and provided me with a good understanding of issues to avoid.

Biofiltration / Raingarden issues

Over my time in the WSUD/IWM industry I have seen many hundreds of raingardens, many variations of raingarden designs as they have evolved and I have found plenty of evidence showing their failed construction or supervision with specification not adhered to. I have additionally made return visits to see how they preform over time and how, with lack of maintenance, these system deteriorate quickly to not serving as a water quality improvement asset at the very least, and at worst, being an eye sore and public safety risk.

Key failure modes of biofiltration/raingarden systems include:

- Sediment and leaf litter blocking inlets, excluding water from entering.
- Sediment or clay clogging the filter media surface.
- Leaf litter and sediment accumulating and building up in the EDD area with plant roots establishing within this zone.
- Outlet structures built too low, not allowing for extended detention.
- Inlets too narrow hence blocking easily with leaf litter and/or sediment.
- Incorrect filter media installed.

A flow on problem from sediment accumulating on top of the filter media, which it will, especially if there is no sediment trap at the inlet or this trap is not cleaned regularly, is when rock mulch is used (a common practice in Melbourne). The sediment accumulates in the void amongst the rock and generally, to remove the sediment, the rock mulch is removed and replaced as well. This double or triples the volume needing to be disposed of and therefore the cost as well. It is also a wasted resource.

Some of the issues listed above are sometimes caused by bad design. Many can be traced back to construction compromises or not following the intended design. But most are resolved by regular maintenance by crews with specific WSUD knowledge and the functionality of the raingarden in mind.

Filterra biofiltration systems

The design and implementation of Filterra® biofiltration systems has been developed by Contech Engineered Solutions based on more than twenty years of research and development, testing and field monitoring (Contech 2016). Contech Engineered Solutions have been operating in North America for 35 years. They provide cost-effective engineered site solutions for contractors, engineers, architects, and owners. Their portfolio includes bridges, drainage, erosion control, retaining wall, sanitary sewer, and stormwater management products.

Filterra biofiltration systems is similar to typical biofiltration systems in its function and application but has been optimized for high volume/flow treatment and high pollutant removal. The high treatment volumes allow for a significantly lower footprint, down to 0.3% of the catchment area, while still achieving best practice pollution reduction targets. Typical biofiltration systems are sized at 0.8 to 1.5% of the catchment area. It is also produced under strict quality control procedures, unlike the filter media samples provides by soil suppliers.

The Filterra biofiltration system also utilises some additional innovations:

- Double shredded hardwood mulch is used on top of the Filterra media. This mulch layer effectively captures the sediment entering the system before it gets to the filter media. The mulch is removed and replaced annually to prevent clogging. Being organically based, it can be composted or recycled.
- By using the organic mulch there is no issue with using a wide-open inlet and allowing all sediment and litter to enter. The annual clean out effectively restores the cleaning capacity of the system (more regular cleaning for leaf and litter can be undertaken for aesthetic reasons or to unblock the inlet during times of high litter loads such as Autumn).
- Ocean Protect install and maintain their systems for a minimum of one year (and ideally longer) therefore ensuring quality control and standing behind their systems effectiveness. They also offer a design service.

Monitoring results

The Filterra biofiltration system was developed in the USA through many years of research, monitoring and development by Contech, based on studies from the University of Virginia. More than 8500 systems have been installed across nine states in the USA. The Filterra systems monitoring results have also recently been published by North Carolina State University and Bellinghams in Washington.

Locally, Ocean Protect is undertaking monitoring of a field site at Western Sydney University. This is a small tree pit system in the university car park. Ocean Protect have installed a high-tech remote auto sampling monitoring station within a container next to the tree pit. Measuring in and outflow as well as nutrients in and out, this data is being assessed against the SQUID protocol and more stringent City of Gold Coast's *Development Application Requirements and Performance Protocol for Proprietary Devices* (2015). These results have been provided and reviewed. A summary of the results is provided in *A review of the application of Filterra® Biofiltration Systems in Australia April 2020.*

The WSU field monitoring has been running for over 18 months and has the following results.

	TSS	TP	TN
All qualifying data	Median CRE 80.0% ER 77.3%	Median CRE 70.6% ER 78%	Median CRE 35.0% ER 38.1%
SQIDEP – Selecting 15 best results for TN	Median CRE 80.8% ER 79.7%	Median CRE 84.6% ER 81.1%	Median CRE 54.6% ER 53.7%

The WSU car park site is small and has low nutrient inputs. This makes nutrient reduction a challenge for any system. The higher the input the easier it is to strip nutrients and therefore better performance. That the TN reduction is not 45% is not surprising given the mean influent of 1.679mg/L and that the system does not have a denitrification process.

I do not pretend to be an expert on the process of field monitoring and result analysis. Ocean Protect have been open with sharing the monitoring results, providing chain of custody documents and running through the monitoring process and equipment. Other experts including Associate Professor Ataur Rahman from the Civil Engineering Department at the Western Sydney University have reviewed the data thoroughly. His peer review is provided as an attachment to *A review of the application of Filterra® Biofiltration Systems in Australia April 2020.*

Conclusion

The Filterra biofiltration system is a novel new approach to biofiltration of stormwater on the Australian market. With its high flow filter media (>3500mm/hr) it takes a vastly different approach to the usual loamy sand filter media system with a recommended hydraulic conductivity of 180-300mm/hr.

The evidence provided by Ocean Protect through its trial sites in Sydney look promising. The monitoring data shows good results, despite the catchment being very low in inflow nutrients.
Monitoring undertaken to date for Filterra biofiltration systems complies with Stormwater Australia's SQIDEP (Version 1.3) and City of Gold Coast's "Development Application Requirements and Performance Protocol for Proprietary Devices" (DesignFlow 2015)

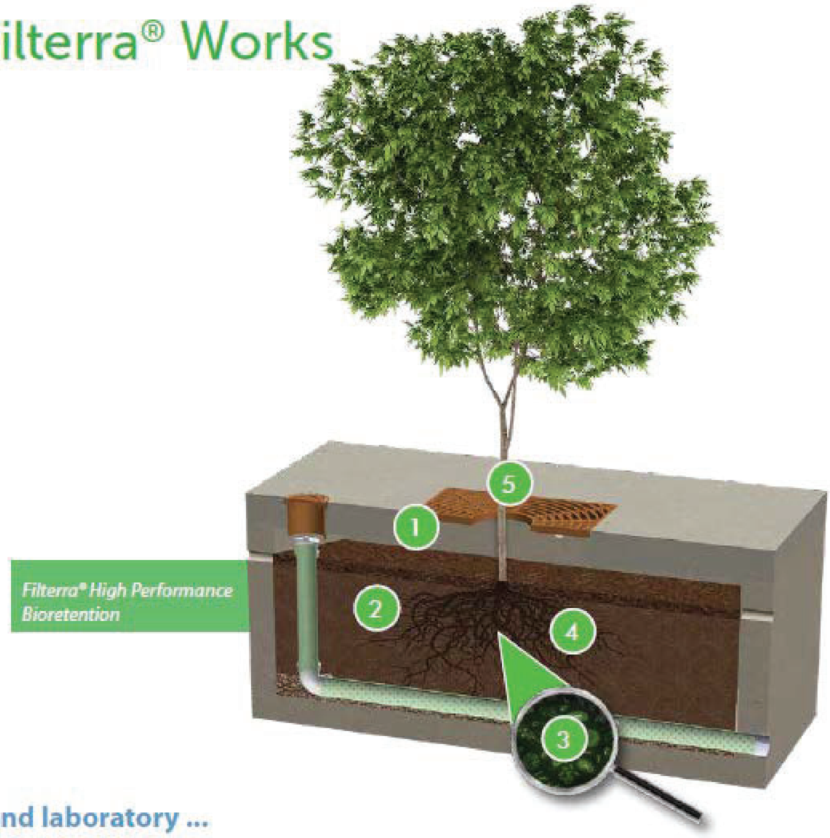
Appropriately designed, installed, established and maintained Filterra biofiltration systems would be expected to provide a suitable stormwater treatment function in Victorian (particularly Melbourne).

The treatment performance of Filterra biofiltration systems can be modelled using MUSIC's bioretention node. The treatment node properties should be adjusted according to Table 3-1 in *A review of the application of Filterra® Biofiltration Systems in Australia*". Sometimes, using this approach, MUSIC indicates that a Filterra biofiltration system with a smaller area than 0.3% of the upstream catchment may be able to achieve given stormwater quality objectives. However, it is recommended that a Filterra biofiltration size of 0.3% of upstream catchment be applied.

The Filterra biofiltration system addresses several of the systemic issues with biofiltration systems including its use of hardwood mulch as a sediment trap and moisture retention layer.

I would recommend the consideration of the Filterra biofiltration system as an option for your next biofiltration project.

How the Filterra® Works



Tested in the field and laboratory ...

1. Stormwater enters the Filterra through a pipe, curb inlet, or sheet flow and ponds over the pretreatment mulch layer, capturing heavy sediment and debris. Organics and microorganisms within the mulch trap and degrade metals and hydrocarbons. The mulch also provides water retention for the system's vegetation.

2. Stormwater flows through engineered Filterra media which filters fine pollutants and nutrients. Organic material in the media removes dissolved metals and acts as a food source for root-zone microorganisms. Treated water exits through an underdrain pipe or infiltrates (if designed accordingly).

3. Rootzone microorganisms digest and transform pollutants into forms easily absorbed by plants.

4. Plant roots absorb stormwater and pollutants that were transformed by microorganisms, regenerating the media's pollutant removal capacity. The roots grow, provide a hospitable environment for the rootzone microorganisms and penetrate the media, maintaining hydraulic conductivity.

5. The plant trunk and foliage utilize nutrients such as Nitrogen and Phosphorus for plant health, sequester heavy metals into the biomass, and provide evapotranspiration of residual water within the system.

Appendix F Peer Review of Filterra® biofiltration systems by Damian McCann

This appendix provides the peer review of Filterra® biofiltration systems undertaken by Damian McCann from AWC for Ocean Protect.

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Brad Dalrymple

Ocean Protect

29 Chetwynd Street

Loganholme QLD 4129

16th June 2021

AWC Reference: 1-201279_Filterra_SQIDEP_Review_Final

Dear Brad,

RE: Filterra SQIDEP and MUSIC Modelling Guideline Review

Australian Wetlands Consulting (AWC) was commissioned to audit the performance monitoring of the Filterra Biofiltration System in Australia and confirm compliance with two documents:

- Stormwater Australia's *SQIDEP (Version 1.3)*
- MUSIC Modelling Guidelines (Water by Design, 2010), specifically Section 4.5 Biofiltration systems and Section 4.8 Gross Pollutant Traps

Ocean Protect supplied the following materials pertaining to the performance monitoring:

- *A review of the application of Filterra Biofiltration Systems in Australia* (Ocean Protect, April 2020) that contained in Appendix B *Stormwater treatment performance for a high flow rate biofiltration system at Western Sydney, Kingswood, NSW* as an Appendix (B)
- A Microsoft excel file *Filterra WSU biofiltration system SQIDEP Compliance 201028* containing data and statistical analysis from the monitoring undertaken at Western Sydney
- Laboratory Chain of Custody (COC) documentation and Certificates of Analysis from samples collected during the monitoring undertaken at Western Sydney
- Individual storm reports containing time, date and duration of the storm event; rainfall and flow data; number of aliquots; and a hydrograph from the monitoring undertaken at Western Sydney
- Statutory Declaration confirming the system has been maintained in accordance with typical/standard maintenance procedures
- Particle size distribution results for two storm events

Due to the COVID-19 pandemic, a site inspection of the monitoring site at the Western Sydney University Campus, Kingswood, was conducted remotely on 23rd March 2020.

Based on a review of the information provided and the remote site inspection, AWC confirm that the field testing of the Filterra Biofiltration System conducted at the Western Sydney site complies with the requirements of SQIDEP (v1.3) Field Evaluation pathway as shown in Table 1 attached.

The following key information needs to be highlighted with regards to any Treatment Claims that can be made for the Filterra system evaluated under the SQIDEP framework:

- The system evaluated has an external high-flow bypass mechanism (bypass occurs prior to the treatment element of the device). The outlet flow was sampled prior to mixing with any bypassed flows. Thus, no pollutant removal can be claimed for bypassed flow (bypassed flow must be assumed to have zero removal under the protocol);
- The tested device had a design Treatable Flow Rate of 1.42 L/s (assuming a saturated hydraulic conductivity of the Filterra biofiltration system of 3550 mm/hour). Hydraulic monitoring confirmed the device treated flows up to at least 2.024L/s which was the limit of the monitoring equipment used;
- The tested device had a total area of 1.45 m^2, equating to 0.35% of the catchment area;
- We recommend that the performance of Filterra biofiltration systems be modelled in MUSIC using the bioretention node with properties as recommended in Table 3-1 of the report "*A review of the application of Filterra® Biofiltration Systems in Australia.*"
- The Pollutant Concentration Reduction Claims that can be made as a result of the described field evaluation are shown in Table One (we note that volumetric losses are anticipated across biofiltration systems, including Filterra, and these were not assessed as part of this review):

Table 1 Summary of pollution reduction at Filterra Trial, UWS, Kingswood, Sydney

Analyte	Median CRE (%)	Average CRE (%)	Efficiency Ratio (%)
TSS	83.3	81.7	81
TP	85.7	77.1	82.5
TN	49.2	48.6	48.7

Furthermore, AWC have been asked by Ocean Protect to consider the applicability of the results from this trial to other regions, including Logan City Council, south-east Queensland, North Queensland and Victoria. It is my opinion that Filterra biofiltration systems designed, installed, established and maintained in line with the trial system and design treatable flow rates evaluated here (1.42L/s), are likely to provide stormwater treatment performance at other locations similar with that observed at the trial site. This is probably a conservative treatable flow rate given our observation of up to 2.024L/s being treated during the trial.

Despite MUSIC modelling suggesting a sizing of around 0.1% of catchment is appropriate, we agree with the Ocean Protect's recommendation to conservatively size the Filterra system at 0.3% of contributing catchment, in accordance with Table 3-1 of the report "*A review of the application of Filterra Biofiltration Systems in Australia (Ocean Protect, November 2020)*".

Conclusion

AWC has reviewed the performance trial of the Filterra proprietary device and supporting data from the trial in Kingswood, NSW. We confirm the trial is consistent with SQIDEP V1.3 and confirm the following performance:

Parameter	Value
Treatable Flow Rate (L/s)	1.42
Pollutant Reduction % (TSS;TP;TN)	81; 82.5; 48.7

We have also modelled the Filterra product performance using the MUSIC Modelling Guidelines (2010) and confirm claimed treatment performance for the Filterra device complies with Water by Design's (2010) *MUSIC modelling Guidelines* (section 4.8) and that performance has been demonstrated with rigorous scientific testing. These results have been accepted in a credible industry journal and the influent concentrations observed are typical of the urban land use for which the device is intended.

I believe the performance observed in western Sydney are transferrable to other locations since the key variables are treatable flow rate, appropriate media and catchment characteristics.

I hope this summary is clear but please contact me with any questions.

Your sincerely,

Damian McCann

Director

References

Dalrymple B, Wicks M. (2020). A review of the application of Filterra®. Prepared on behalf of Ocean Protect.

Drapper D, Lucke T (2015). *Characterisation of Stormwater Pollutants from Various Catchment types in South-east Queensland*. Presented at the 2015 WSUD & IECA Conference.

Duncan H.P. (1999). *Urban Stormwater Quality: A Statistical Overview (Report 99/3).* CRC for Catchment Hydrology.

Smolek, A. P., et al. (2018). "Hydrologic and Water-Quality Evaluation of a Rapid-Flow Biofiltration Device." *Journal of Environmental Engineering* 144(2): 05017010.

Stormwater Australia (2018) *Stormwater Quality Improvement Device Evaluation Protocol. Version 1.3 December 2018.*

Water by Design (2010). *MUSIC Modelling Guideline, Version 1.0.*

Water by Design (2018). *Draft MUSIC Modelling Guideline, November 2018, Consultation Draft*. A Healthy Land and Water Initiative.

Attachment 1

Table 2 Assessment of the Filterra Biofiltration System performance monitoring undertaken at Western Sydney against SQIDEP (v1.3) requirements (the respective page number where the requirement is discussed in SQIDEP v1.3 is shown for ease of reference).

SQIDEP Requirement	Initial AWC comments	Complianc	Ocean Protect Response	Final AWC comments / compliance
Catchment area (p14)	420m^2	Y		
Land Use (p14)	Car Park	Y		
Percentage Impervious cover (p14)	100%	Y		
Aerial photos (p14)	Figure B-1	Y		
Site Photos (p14)	Figures B-2 and B-3	Y		
Potential pollutant sources (p14)	Vehicles, leaves, grass, human litter.	Y		
Site map showing: (p14) • Catchment area • Drainage system layout • Treatment device • Sampling points	Catchment was defined by land survey and site inspections. Now described in report.	Y		
Treatable flow rate (TFR) (p14)	1.42L/s. Now provided in report. Equal to the design flow rate multiplied by the filter area (3.560m/hr x 1.44m^2)	**Y**		
Rainfall ≤ 5 min time interval (p15)	1 minute. Detail now provided in report. Individual flow files can be provided upon request.	**Y**		
Rainfall ≤ 0.25mm increments (p15)	0.25mm tip	Y		
Rainfall - Location shown on site map (p15)	Placed on monitoring station at the site	**Y**		
Rainfall - Checked, cleared of debris and calibrated at least two times during the testing period (p15)	2 Gauges used. Factory calibrated. Checked for Debris.			
Rainfall - Protected from excessive wind velocities (p15)	Bolted to roof of container and is stable. The tipping bucket itself is designed to be shielded from the wind. Detail now provided in report.	**Y**		
Min 15 events (p15-16)	Results for all 23 qualifying	Y		

SQIDEP Requirement	Initial AWC comments	Complianc	Ocean Protect Response	Final AWC comments / compliance
	storms at Western Sydney are provided.			
Achieve at least 90% statistical significance between paired samples of influent and effluent (p15-16)	Paired t test calculation in sheet Paired t test calculation provided spreadsheet	Y		
Each monitoring program will need to identify the period delineating the end of one event and beginning of the next – typically 24hrs or the time taken to reset monitoring equipment (p15-16)	Table B-3 provides the date of each event and the sampling duration in hours	Y		
Hydrographs for each event to demonstrate the program has representatively captured the event (p15-16)	Hydrographs provided	**Y**		
Min 2 peak inflows from the sampled events should exceed 75% of the design TFR of the device + 1 ⩾ than its design TFR (p15-16)	TFR is 1.2L/s	Y		
Events to be sufficiently distributed throughout the monitoring period to capture seasonal influences on storm conditions & The independent evaluation panel must be satisfied that the qualifying storms includes a good range of storm event (longer and shorter duration) (p15-16)	Monitoring (3/06/19 to20/10/2020). 17 events Number of events per season: Summer: 3 Autumn: 2 Winter: 8 Spring: 4 Summer and Autumn under-represented, however, drought conditions existed for much of 2019 and early 2020 and likely impacted	**Y**		Y

SQIDEP Requirement	Initial AWC comments	Complianc	Ocean Protect Response	Final AWC comments / compliance
	the range of storm events that were able to be used. The representativeness of the storm events is difficult to assess given the lack of historical rainfall data for the area which is not discussed nor presented in the report.			
50% of qualifying storms should include the first 70% storm hydrograph coverage (p15-16)	Hydrographs have been provided.	Y		
Flow measurement at the inlet and outlet are recommended. Monitoring of bypass flows is optional, however, at a minimum the monitoring information should be sufficient to identify periods when device is operating in bypass (p17)	Bypass occurs when total flow is more than the treatment flow, except a very small part of the catchment contributes to the bypass without going to the treatment.	Y		
The QAPP should identify whether effluent characterization accounts for total storm flow, including bypass if it occurs (p17)	Sampled Prior to the inclusions of mixing with bypass.	Y		
Outlet flow should be sampled either prior to or after mixing with bypass flow and Claims identify the inclusions/exclusion of bypass flows (p17)	Sampling was conducted prior to mixing with bypass.	Y		
Make, model and procedures and schedule for calibration, inspection and cleaning shall be provided (p20)	Influent sampler: ISCO 730 Bubbler Weir module connected to an ISCO 6712 Portable Automated Sampler and installed within a pre-configured and calibrated 152mm	Y		

SQIDEP Requirement	Initial AWC comments	Complianc	Ocean Protect Response	Final AWC comments / compliance
	diameter Thel-Mar Weir for flow analysis of treated effluent and sample pacing ISCO 750 Area Velocity Flow Module with a Low Profile Area Velocity Flow Sensor connected to an ISCO 6712 Portable Automated Sampler for total flow analysis and effluent sample pacing. The bubblers are regularly checked for calibration by submersing the weir in water and setting the depth on the sampler with the bubbler module to the depth measured. The tables for the flow against height are provided by The-mar and input into the samplers This detail is now provide in report.			
Rainfall (p20)	The rain gauge is factory-calibrated and needs no further adjustment. Routine maintenance is required to check for debris and blockage, with details provided in the supporting documentation.	Y		
Flow proportional sampling requires at least 80% of the submitted events have at least 8 aliquots collected from both the rising and falling limbs of the hydrograph to form the composite sample (p21)	At least 8 aliquots were collected in 80% of storms with detail provided in Table B-3.	Y		Y
Sample blanks for field and analytical testing to	Provided	Y		

AWC

SQIDEP Requirement	Initial AWC comments	Complianc	Ocean Protect Response	Final AWC comments / compliance
be supplied (p21)				
COC documents identifying sample collection, collection agency, collection time, preservation used, laboratory receipt of sample and sample collection shall be provided (p21)	Provided	Y		
NATA accreditation (p21)	Evidence of NATA accreditation has been provided.	Y		
Method of analysis detailed (p21)	Analytical method stated in Table B-2	Y		
Non-detects (p23) Effluent sample results below the limit of detection (LOD) shall be set at 0.5 x LOD and must be accompanied by a sensitivity analysis showing impact on performance metrics of adopting both LOD and 0).	Limit of Readings are in the attached certificate of analysis. Sensitivity analysis undertaken (see spreadsheet sheet 'Table 3 - WSU Data')	Y		
Performance metrics (p25) Analysis should clearly indicate how treatment and bypass flows (either external or internal to the device) have been accounted for in the presentation of results.	Detail on how treatment and bypass flows have been accounted for is provided within Section	Y	The system is offline The treatment flow is collected prior to mixing with the bypass. The flows measured are the effluent flow pipe and the downstream total flow (effluent + bypass). This detail now provided in report.	Y
Average and Median Concentration Removal Efficiency (p25)	The results for the 17 events following the initial 12 months of monitoring (establishment period) are provided within the excel spreadsheet WSU Data	Y		
Event Mean Concentration and Mass Discharge (p30) The event mean	The required results including EMCs, mass discharge, and box and whisker plots are provided	Y		

SQIDEP Requirement	Initial AWC comments	Complianc	Ocean Protect Response	Final AWC comments / compliance
concentration and Mass Discharge variability are required to verify the ability of the device to manage large variability in EMCs and mass discharges. Box and whisker plots should be prepared for influent and effluent EMCs as well as mass loads (where presented). The number of EMCs and mass loads contributing to each distribution should be clearly indicated.	in figure B-7 and B-8 of the report and in the accompanying spreadsheet. The number of EMCs and mass loads contributing to each distribution have been indicated.			

Appendix G Cost Abatement Analyses for Filterra® Biofiltration Systems and Other Stormwater Treatment Asset Types

G.1 Preamble

This appendix describes the methodology and results of an assessment of the life cycle costs of Filterra® biofiltration systems and other stormwater quality asset types for an example 'typical' site.

G.2 Methodology

G.2.1 Software

The eWater CRC MUSIC software (Version 6) has been used in this assessment. This is the latest version of MUSIC (at the time of report writing). MUSIC was used to model the stormwater flows and pollutant loads generated from the example site and assess the treatment performance of the given stormwater treatment assets. The life cycle costing module within MUSIC was also used to analyse the life cycle costs of the assets and associated 'cost effectiveness' (given as an average 'equivalent annual payment' of pollution removed per year).

G.2.2 Source nodes

Within MUSIC, the user is required to specify source nodes. The source nodes represent the stormwater flow and pollutant generating areas of the site.

For the purposes of this assessment, a 'typical' development site was assumed. The assumed land usage was 'residential', with rainfall-runoff and pollutant export properties in accordance with Water By Design (2010). The site was assumed to be one hectare in area, which was separated into roof, road, and 'other' ground level areas (35%, 30% and 35% of the site respectively), with imperviousness values in accordance with Water By Design (2010) of 100, 70 and 30% respectively.

G.2.3 Treatment scenarios & nodes

The following stormwater treatment scenarios were modelled:

- Jellyfish®, with OceanGuard™ for road areas
- StormFilter®, with OceanGuard™ for road areas
- Filterra® biofiltration tree pits
- Filterra® biofiltration basin
- 'Typical' biofiltration at-street tree pits
- 'Typical' biofiltration at-street 'garden beds'
- 'Typical' bioretention basin
- Constructed wetland

For each scenario, the assets were sized to achieve operational phase pollutant load removal targets in accordance with the *State planning policy* (DILGP 2017). These criteria are provided in Table G-1.

Table G-1 Operational Phase Performance Criteria

Pollutant	Criteria
Total Suspended Solids	80% reduction
Total Phosphorus	60% reduction
Total Nitrogen	45% reduction
Gross Pollutants (5mm or larger)	90% reduction

The properties of the treatment nodes for each scenario are summarised in Table G-2. An example layout of one of the MUSIC models used in the analyses is provided in Figure G-1.

Table G-2 Treatment node properties for modelled scenarios

Treatment scenario	Description
Jellyfish® with OceanGuard™	7 OceanGuards™ (treating ground and road runoff only). Modelled as a 'GPT' treatment node with high flow bypass of 0.14m^3/s. Performance determined by node transfer functions (approx. average annual TSS, TP, TN and GP load removals of 81%, 30%, 21% and 100%). Jellyfish® with 2250mm-diam. manhole (5 high flow, 1 drain down) 6 cartridges. Modelled as generic treatment node with flows (up to high flow bypass of 0.0275m^3/s) having reduced TSS, TP, TN and GP concentrations of 89, 65, 54, and 99% respectively.
StormFilter® with OceanGuard™	7 OceanGuards™ (treating ground and road runoff only). Modelled as a 'GPT' treatment node with high flow bypass of 0.14m^3/s. Performance determined by node transfer functions (approx. average annual TSS, TP, TN and GP load removals of 81%, 30%, 21% and 100%) 17 x 690 PSorb cartridges. Modelled as a 'detention' node and 'generic' node. Detention node with 5.2m^2 surface area, 0.77m extended detention depth, zero performance volume, zero exfiltration, 91mm equivalent pipe diam., 2m overflow width, and zero treatment (k = 1 for TSS, TP and TN). Generic node with high flow bypass of 0.0153m^3/s) with reduced TSS, TP, TN and GP concentrations of 99.6, 86, 56, and 100% respectively.
Filterra® biofiltration tree pits	Modelled as a bioretention node, 150mm extended detention depth, 30m^2 surface and filter area (0.3% of catchment), zero exfiltration, 3550mm/ hour saturated hydraulic conductivity, 0.53m filter depth, 500mg/kg total nitrogen, 1mg/kg ortho-phosphate concentration, vegetated with nutrient effective plants, 3m overflow width, under-drain present, no submerged zone.
Filterra® bioretention basin	
Typical bioretention tree pits	Modelled as a bioretention node, 100mm extended detention depth, 130m^2 surface and filter area (1.3% of catchment), zero exfiltration, 200mm/ hour saturated hydraulic conductivity, 0.5m filter depth, 400mg/kg total nitrogen, 30mg/kg ortho-phosphate concentration, vegetated with nutrient effective plants, 13m overflow width, under-drain present, no submerged zone.
Typical biofiltration 'rain gardens'	As per bioretention tree pits, but with 150mm extended detention depth.
Typical biofiltration basin	As per typical bioretention tree and rain gardens, but with 100m^2 surface and filter area (1.0% of catchment), and 300mm extended detention depth.
Wetland	Modelled as wetland treatment node. 100m^3 inlet pond volume, 1000m^2 surface area, 0.3m extended detention depth, 300m^3 permanent pool volume (and initial volume), zero exfiltration, and 48 hour detention time.

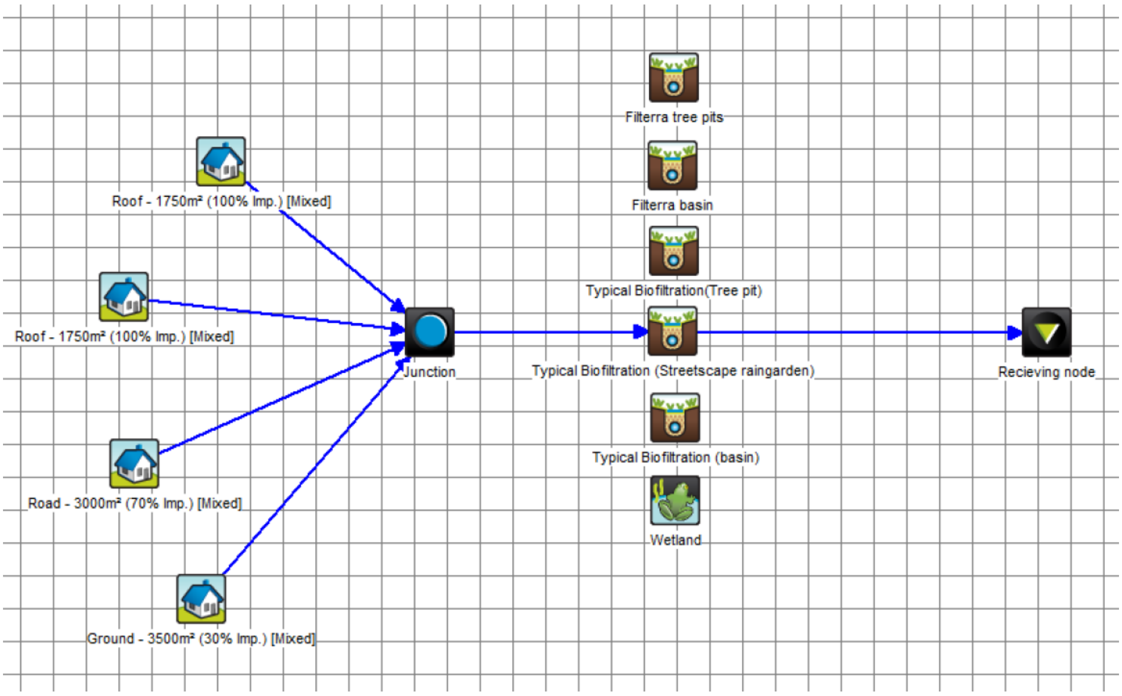

Figure G-1 Example layout of MUSIC model used in cost abatement analyses

G.2.4 Life cycle costing properties

The life cycle costing properties applied are summarised in Table G-3.

Table G-3 Applied life cycle costing properties

Parameter	Value	Comments
Real discount rate	1.8%	From Independent Pricing and Regulatory Tribunal (2017)
Annual inflation rate	2.5%	
Base year for costing	2019	Year at time of analysis
Span of analysis	50 years	In accordance with Water By Design (2010)

MUSIC requires values to be specified for acquisition, establishment, maintenance, renewal and decommissioning costs. Table G-4 provides a summary of the life cycle cost values for the modelled scenarios.

Table G-4 Summary of life cycle cost values for modelled scenarios

Scenario	Acquisition cost ($)	Annual maintenance cost ($/year)	Annualised renewal costs ($/year)	Annualised maintenance & renewal costs ($/year)	Lifespan (years)
Jellyfish® with OceanGuard™	58047 – 60949	4255	5495	9750	25
StormFilter® with OceanGuard™	53981	4239–8025	-	4239 – 8025	25
Filterra® biofiltration tree pits	191221	4147–27225	1089 – 2723	5236 – 29948	50
Filterra® bioretention basin	23100	1885–3770	990 – 2475	2875 – 6245	50
Typical bioretention tree pits	141700 – 1133600	14760–49201	2834 – 22672	17594 – 71873	50
Typical biofiltration ‘rain gardens’	70850 – 283400	1417–4251	1417 – 5668	2834 – 9919	50
Typical biofiltration basin	38150 – 109000	545	763 – 2180	1308 – 2725	50
Wetland	119900 – 179850	2398–11990	2398 – 3597	4796 – 15587	50

Costs for OceanGuard™, Jellyfish®, StormFillter®, and Filterra® biofiltration systems have been sourced from an extensive database of cost information for these assets collated by Ocean Protect. It is anticipated that these costs are accurate as they are based on real cost data for several thousand projects by Ocean Protect.

Unit cost information for ‘typical’ bioretention systems and wetlands was sourced from Melbourne Water (2013) and adjusted for inflation – with the exception of annualised renewal costs for these asset types (in the absence of values from Melbourne Water (2013), which was assumed to be equal to approximately 2% of total acquisition cost (as suggested by eWater (2014)). Decommissioning costs were assumed to be zero for all assets. It is anticipated that these costs are approximate only.

For each scenario, ‘low (typical)’ and high cost scenarios were applied. The ‘low (typical)’ cost values would be representative of ‘typical’ costs anticipated for these systems, recognising that these costs are likely to be ‘low’ within the normal range of costs required for these assets (and near the recommended minimum values for maintenance and renewal expenditure). The ‘high’ cost values would be anticipated to be ‘high’ within the normal range of costs required for these assets.

G.3 Results

The results of the life cycle cost analyses in terms of calculated acquisition, maintenance and renewal and equivalent annual payment (EAP) for TSS, TP and TN removal is summarised in Table G-5 and the figures below.

Table G-5 Summary of life cycle cost results for modelled scenarios

Scenario	Life cycle cost ($)	EAP ($/year)	EAP for TSS removal ($/kg/year)	EAP for TP removal ($/kg/year)	EAP for TN removal ($/kg/year)
Jellyfish® with OceanGuard™	391339 – 396099	7827 – 7922	6.0 – 6.0	4430 – 4484	987 – 999
StormFilter® with OceanGuard™	222924 – 343079	4458 – 6862	3.6 – 5.6	2331 – 3588	606 – 932
Filterra® biofiltration tree pits	359359 – 1386108	7187 – 27722	6.0 – 23.2	3154 – 12168	797 – 3073
Filterra® bioretention basin	107449 – 199719	2149 – 3994	1.8 – 3.7	943 – 1950	238 – 492
Typical bioretention tree pits	694462 – 3335443	13889 – 66709	12.4 – 59.5	6943 – 33347	1784 – 8567
Typical biofiltration ‘rain gardens’	69097 – 533004	1382 – 10660	1.2 – 9.3	671 – 5179	166 – 1304
Typical biofiltration basin	84160 – 164261	1683 – 3285	1.5 – 2.9	801 – 1596	203 – 395
Wetland	240715 – 685569	4814 – 13711	4.3 – 12.2	2378 – 6773	587 – 1672

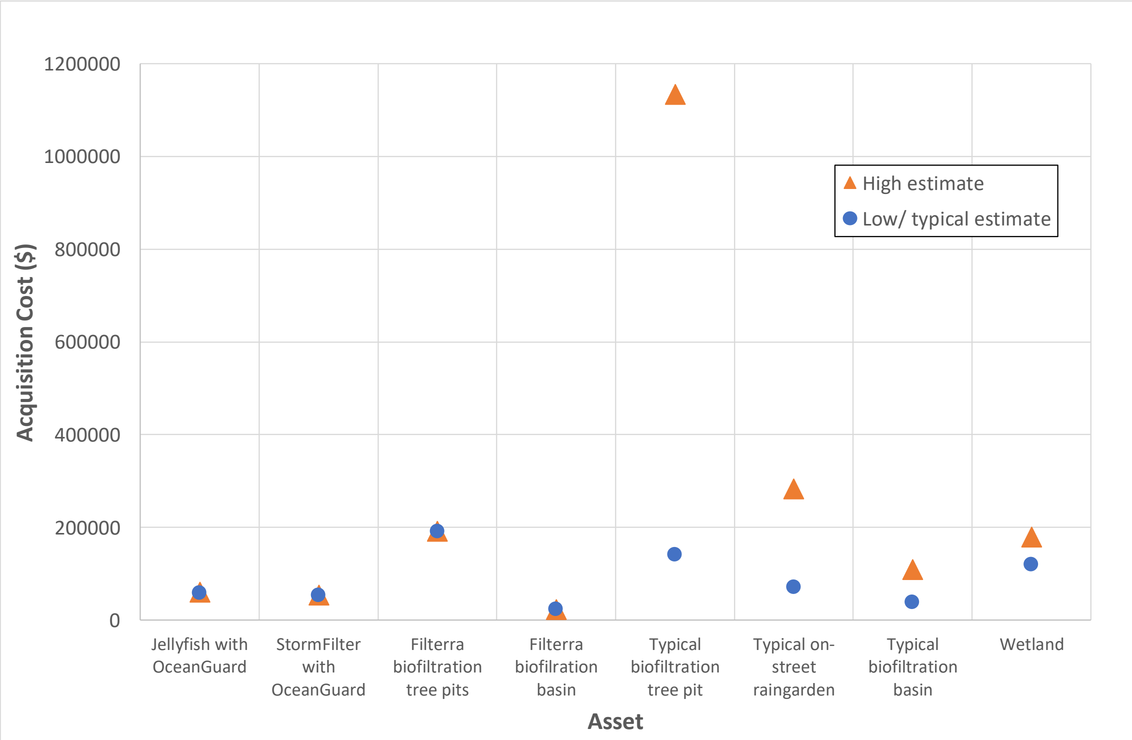

Figure G-2 Graph of calculated acquisition costs for modelled scenarios

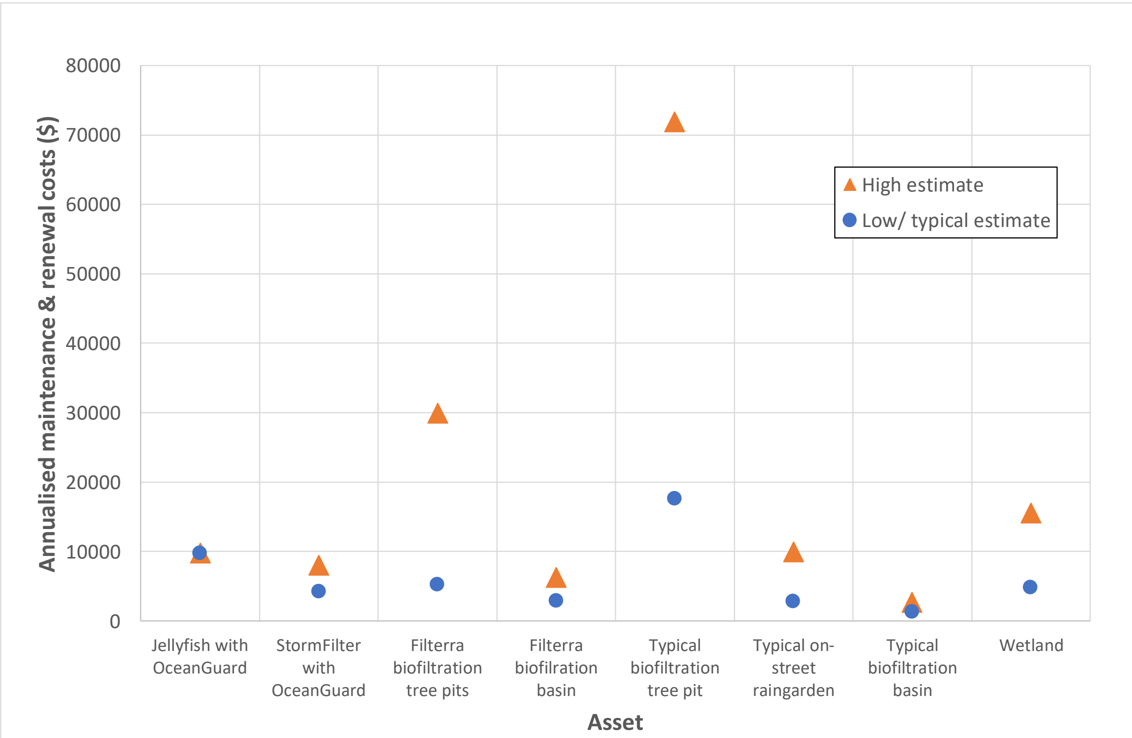

Figure G-3 Graph of calculated maintenance and renewal costs for modelled scenarios

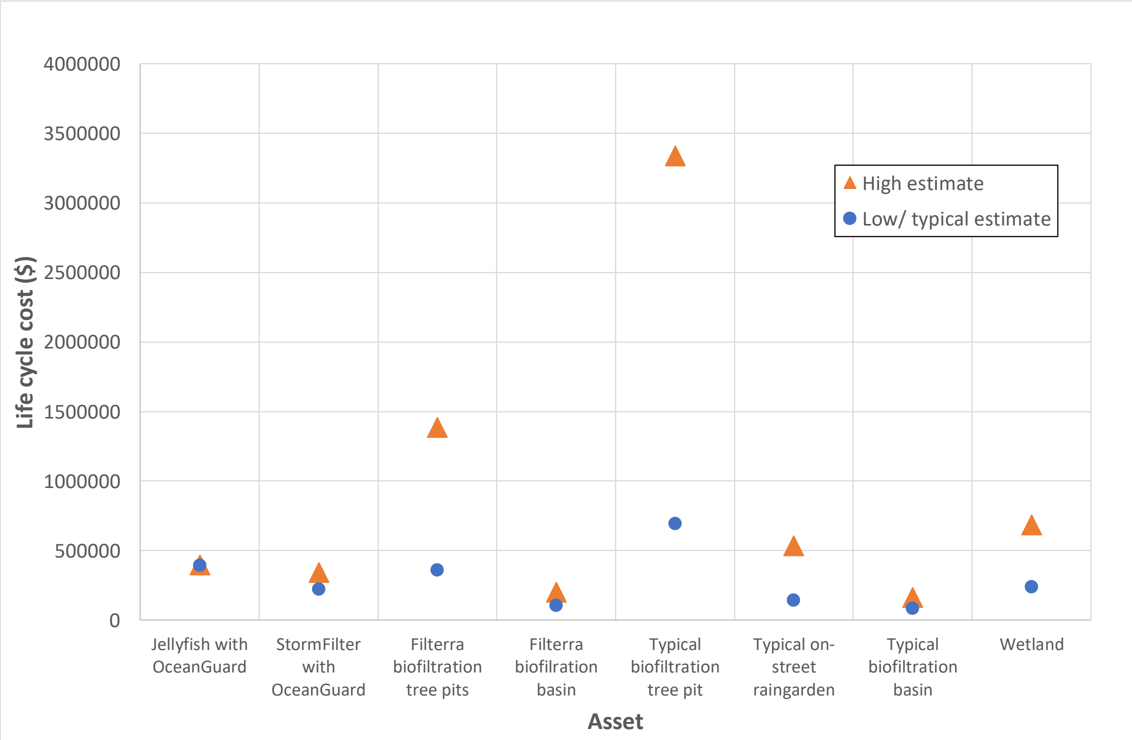

Figure G-4 Graph of calculated life cycle costs for modelled scenarios

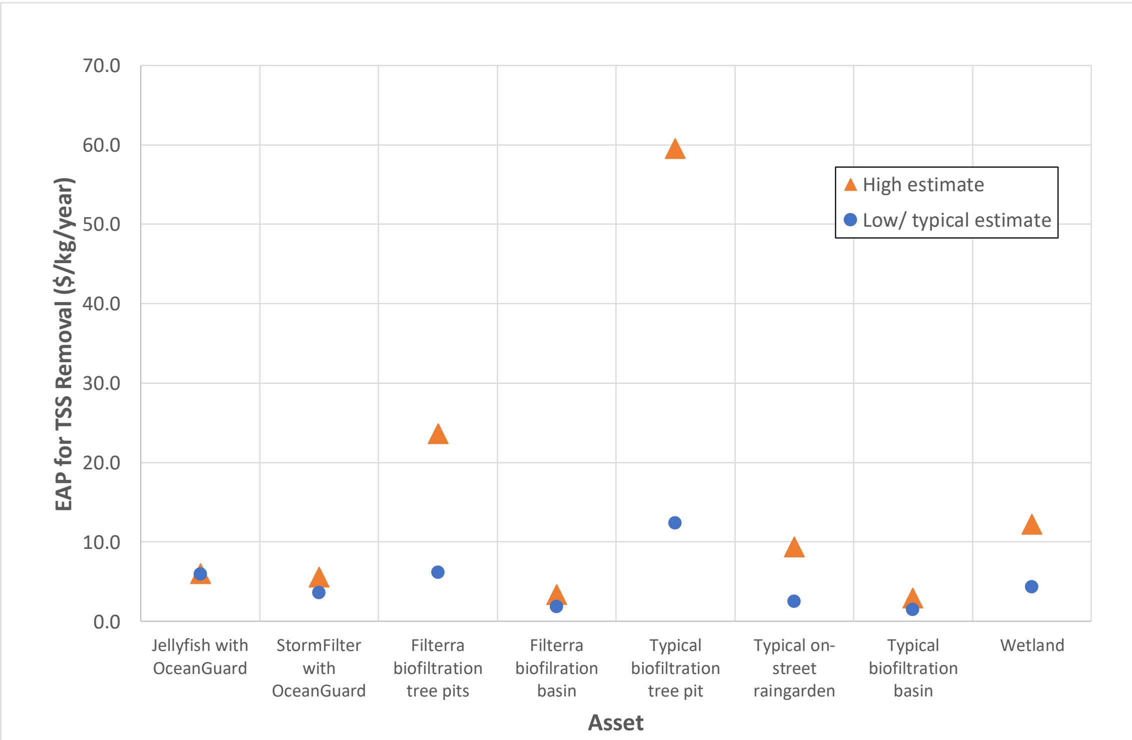

Figure G-5 Graph of calculated EAP for TSS removal for modelled scenarios

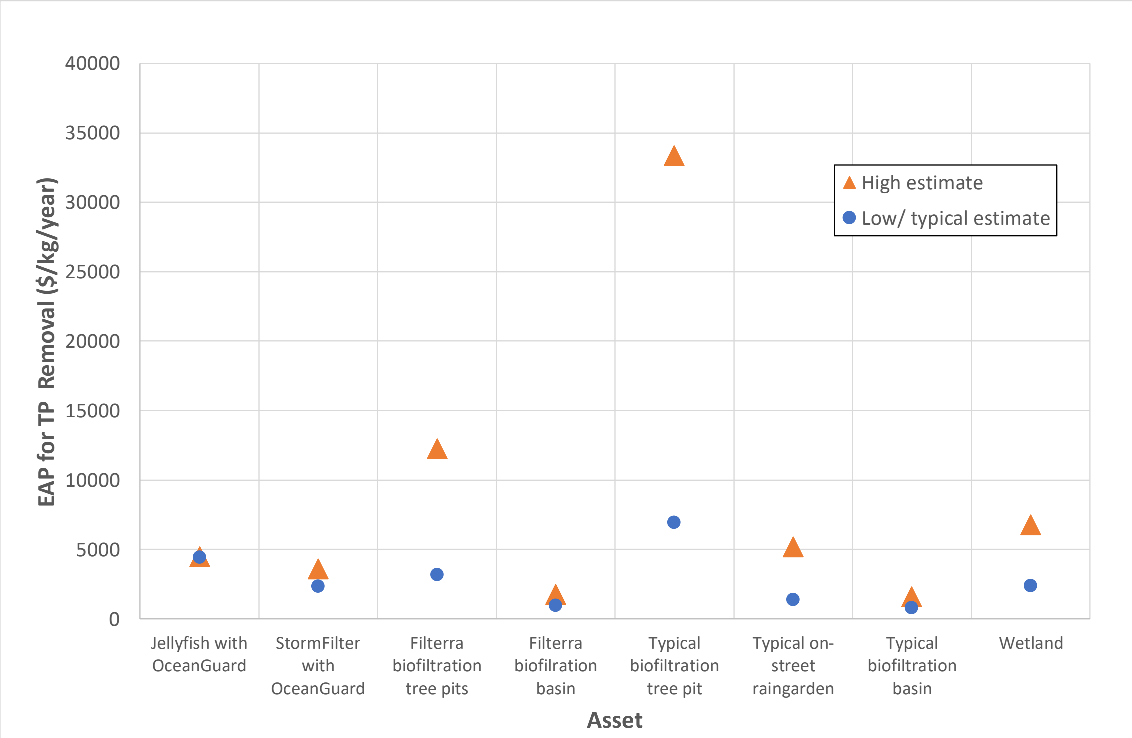

Figure G-6 Graph of calculated EAP for TP removal for modelled scenarios

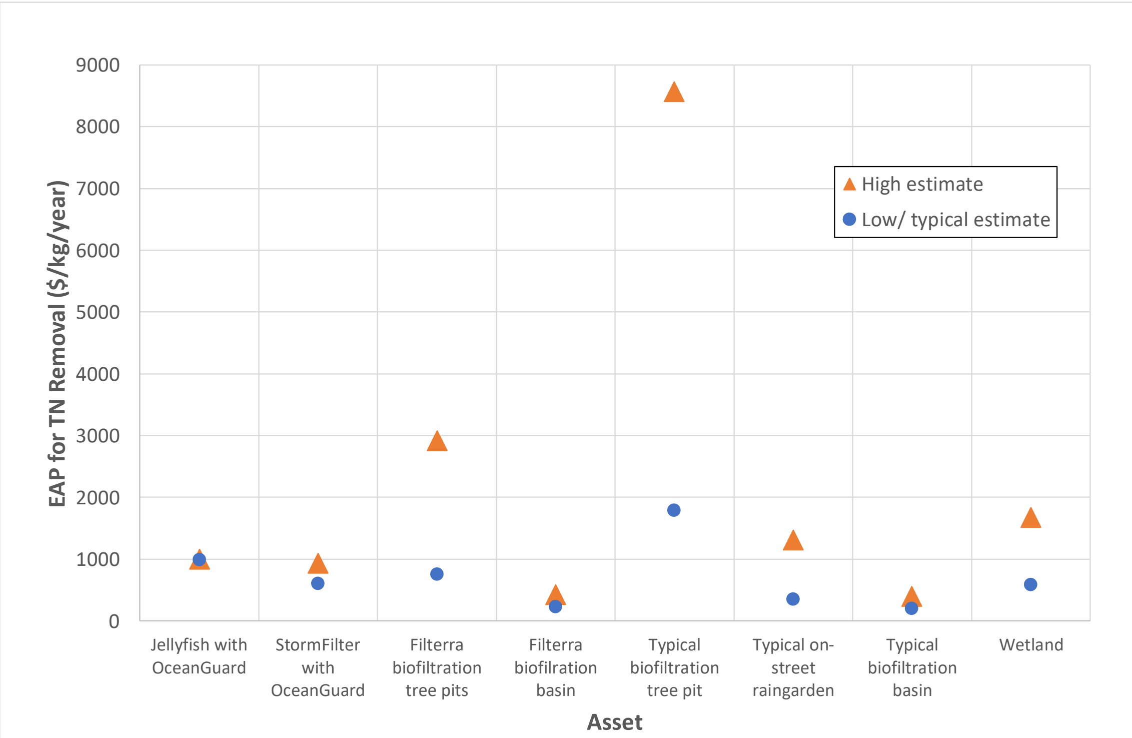

Figure G-7 Graph of calculated EAP for TN removal for modelled scenarios

Key findings from the above results for the modelled scenarios include the following:

- Filterra® biofiltration basins likely have the lowest acquisition costs, whilst tree pits (Filterra® and conventional biofiltration tree pits) have the highest.
- Conventional biofiltration basins likely have the lowest maintenance and renewal costs, whilst conventional tree pits have the highest maintenance and renewal costs
- Conventional biofiltration basins likely have the lowest EAP for pollutant removal, whist conventional tree pits likely have the highest.
- Filterra® biofiltration basins likely have the second lowest EAP for pollutant removal, and second lowest maintenance and renewal costs.
- Wetlands likely have an acquisition cost lower only than the tree pit options, and likely have a higher EAP for pollutant removal (and maintenance and renewal cost) than the StormFilter® and OceanGuard™ scenario.

G.4 Discussion

It should be noted that the above analysis has the following limitations:

- One climate (Brisbane, 1980 to 1989) and land usage (residential) scenario has been modelled
- Land costs have been excluded from the analysis. This is particularly relevant for stormwater treatment assets (particularly wetlands and conventional biofiltration systems) that require significant land area to be appropriately integrated
- Costs for typical biofiltration and wetland asset types should be considered approximate only.

Nevertheless, the above analysis shows that Filterra® biofiltration basins was likely the second most cost-effective stormwater treatment scenario (noting that land costs for assets are excluded from the analysis) – and only requires more maintenance and renewal expenditure than a conventional bioretention basins. This indicates that Filterra® biofiltration basins may be a preferred asset type – particularly when space is constrained.

Traditionally, proprietary stormwater treatment asset types (such as StormFilter® and OceanGuard™) are not accepted in public owned land by local government in Australia due to perceived higher operational (e.g. maintenance and renewal) costs than other ‘natural’ stormwater treatment assets, such as biofiltration and wetlands. The aforementioned analysis shows, however, that estimated maintenance and renewal costs for wetlands are relatively high – higher than the modelled StormFilter® and OceanGuard™ scenario. This indicates that the perception of proprietary stormwater treatment assets being a larger maintenance burden is likely erroneous (at least for some asset types).

Appendix H Results of Filterra® filter media sampling & analyses

This appendix provides the laboratory results of Filterra® filter media testing, as summarised in Table 2-4.

H.1 Sample collection & analysis

Table H-1 provides a summary of the Samples of Filterra® filter media have been collected and analysed from the following locations:

Table H-1 Summary of locations for Filterra® filter media sampling and analyses

Site location	Date of installation	Date of sampling	Comments
Supply from Ocean Protect	N/A	13 February 2019	Filter media had not been used. Two samples collected and analysed.
Western Sydney University, Kingswood	April 2018	1 March 2019 14 February 2020	See Table 2-2, Table 2-3 and Appendix B and for further information about site. Samples collected from one location in March 2019 and two locations in February 2020 within system, from the top, middle and bottom of the Filterra® filter media.
Warwick Farm racecourse, Sydney, NSW	November 2017	12 August 2019	Samples collected at four locations across the system shown in top photo of Figure 2-1 (approximately evenly distributed across the system). Samples collected from the top, middle and bottom of the Filterra® filter media.

Samples were collected by Ocean Protect staff and delivered to ALS on ice (<4^{o} C) and accompanied by chain-of-custody documentation and analysis was carried out in accordance with Table B-2.

Table H-2 Water quality analytical parameters and methods for the site

Parameter	Abbreviation	Analytical method	Limit of Reporting
Electrical Conductivity (1:5)	EC	EA010	1 µS/cm
Moisture content	MC	EA055	0.1%
Nitrite and Nitrate as N (NOx) – Soluble by Discrete Analyser	NOx	EK059G	0.1 mg/kg
TKN as N By Discrete Analyser	TKN	EK061G	20 mg/kg
Total Nitrogen as N (TKN + NOx) By Discrete Analyser	TN	EG062G	20 mg/kg
Reactive Phosphorus as P-Soluble By Discrete Analyser	RP	EK071G	0.1 mg/kg

H.2 Results & Discussion

Table H-3 provides a summary of the results from the Filterra® sampling and analyses.

Table H-3 Summary of Filterra® biofiltration system filter media test results

Site	Date of sampling	Location ID	Depth	EC (µS/cm)	MC (%)	NOx (mg/kg)	TKN (mg/kg)	TN (mg/kg)	DP (mg/kg)
Supply from Ocean Protect	13 Feb 2019	A	N/A	28	0.3	1.7	160	160	<0.1
		B		34	0.3	1.7	200	200	<0.1
		Average		**31**	**0.3**	**1.7**	**180**	**180**	**<0.1**
Western Sydney University, Kingswood	1 Mar 2019	-	Top	14	2.3	0.9	620	620	0.2
		-	Middle	13	2.2	0.5	330	330	0.1
		-	Bottom	14	2.0	1	370	370	<0.1
		Average		**13.7**	**2.2**	**0.8**	**440**	**440**	**0.1**
	14 Feb 2020	A	Top	41	4.5	8.8	450	460	0.1
		A	Middle	21	4.2	6.0	270	280	<0.1
		A	Bottom	22	4.5	5.2	380	380	<0.1
		B	Top	26	4.5	8.7	390	400	0.2
		B	Middle	24	4.7	6.2	300	310	<0.1
		B	Bottom	21	3.4	5.6	300	300	<0.1
		Average		**25.8**	**4.3**	**6.8**	**348**	**355**	**<0.1**
Warwick Farm race course, Sydney, NSW	12 Aug 2019	A	Top	22	2.5	1.2	270	270	0.6
		A	Middle	12	2.9	0.6	220	220	0.3
		A	Bottom	10	4	0.5	200	200	0.3
		B	Top	18	2.4	0.9	280	280	1.4
		B	Middle	13	3.1	1	180	180	0.8
		B	Bottom	13	3.7	1	200	200	0.6
		C	Top	24	5.2	1.8	490	490	1.4
		C	Middle	15	1.6	0.6	300	300	0.6
		C	Bottom	17	1.1	0.2	200	200	0.5
		D	Top	22	3.6	2.8	300	300	0.8
		D	Middle	15	1.5	0.6	140	140	0.3
		D	Bottom	17	1.3	0.5	200	200	0.4
		Average for top		21.5	3.4	1.7	335	335	1.05
		Average for middle		13.8	2.3	0.7	210	210	0.50
		Average for bottom		14.3	2.5	0.6	200	200	0.45
		Average		**16.5**	**2.7**	**1**	**248**	**248**	**0.7**

Key findings from the above results are:

- Moisture content and nutrient concentrations within the operating Filterra® biofiltration systems is typically higher at the top and lower at the bottom. This would be anticipated given that incoming stormflows (and direct rainfall) enter the system at the surface.
- Nutrient concentration within the operating Filterrra® biofiltration systems are higher than that present within the un-used filter media. This is anticipated given that the media would accumulate some nutrients over time due to incoming nutrient loads (from stormwater) and possible leaching of nutrients from the vegetation and mulch layer.
- The nutrient concentrations within the filter media at the Western Sydney University site did not increase between the March 2019 and February 2020 sampling events. Instead, TKN, TN and DP concentrations decreased between the sampling.
- The nutrient concentrations within the filter media at the Warwick Farm system is significantly lower than that observed in the Western Sydney University system.

Appendix I Filterra® filter media nutrient concentrations for MUSIC Modelling

As outlined in Section 3, MUSIC is the preferred tool for demonstrating the performance of stormwater quality treatment systems and it is recommended that the MUSIC bioretention node be applied in assessing the performance of Filterra® biofiltration systems.

The MUSIC bioretention node allows the model user to specify values for parameters known to have significant influence on the performance of biofiltration systems, including filter media properties. The predicted performance of biofiltration systems (as predicted by MUSIC) is sensitive to the total nitrogen and orthophosphate concentration of the filter media of biofiltration systems (Healthy Land and Water 2018), including Filterra® biofiltration systems.

Healthy Land and Water (2018) states that, when modelling to demonstrate compliance with stormwater treatment objectives, the user should assume TN and orthophosphate concentrations of 400 and 30mg/kg respectively, or the actual value of orthophosphate in the filter media as established through testing of the supplied filter media.

Initial nitrogen and orthophosphate concentrations from other commercially available biofiltration filter media is known to be well below the aforementioned values recommended by Healthy Land and Water (2018). It is, however, anticipated that some increase in filter media TN and orthophosphate concentrations would occur over time, due to a combination of incoming stormwater flows, direct rainfall and vegetation and mulch leaching – although minimal information is available in relation to the likely long-term change in TN and orthophosphate concentrations within bioretention filter media.

Glaister et al (2013)'s paper "*Long-Term Phosphorus Accumulation in Stormwater Biofiltration Systems at the Field Scale*" described the investigations (and associated results). Glaister et al (2013) measured the filter media ortho-phosphate concentrations within six bioretention systems in Brisbane and Melbourne, that had been operating from between five and twelve years, with homogenised samples measured at the following depth intervals: 0-10mm; 10-20mm; 20-40mm; 40-80mm; 80-120mm; 150-200mm and; 300-350mm. The results showed that:

- ortho-phosphate concentrations were typically very low (between approximately 5 and 20mg/kg) at depths greater than approximately 150mm (from the filter media surface).
- Higher concentrations were typically observed at the inlet of the assed bioretention systems and/ or within the top 100mm of the filter media (although it should be noted that none of the devices have any form of stormwater pre-treatment).
- No clear signs of phosphorus "breakthrough" were observed, offering positive reinforcement that current biofilter design specifications are producing systems which function well (and continue to remove phosphorus) in the long-term.

As shown by the analyses of Filterra® biofiltration systems (described in Appendix H), nutrient concentration within operating Filterra® biofiltration systems was observed to be higher than that present within the un-used (supplied) filter media. Based on the results obtained to date (described in Appendix H), it is recommended that Filterra® biofiltration systems modelled in MUSIC using a bioretention node to demonstrate performance with stormwater management objectives assume TN and orthophosphate concentrations of 500 and 1mg/kg respectively.