Chapter 2: The Business Case for Biofiltration

2.1 Introduction

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

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

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

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

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

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

- The **amenity value of streetscape raingardens** in Sydney is realised in residential house prices, **increasing property values by around 6% ($54,000 AUD) for houses within 50 m and 4% ($36,000 AUD) up to 100 m away.** This demonstrates that raingardens are valued by the community, and a typical raingarden installation at a street intersection can generate around $1.5 million increase in residential value (Polyakov et al., 2015).

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

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

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

- The **cost of effective maintenance for WSUD systems is outweighed by the value gained by higher performance and prolonged lifespan** (Browne et al., 2013).

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

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

2.2 Elements of a business case

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

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

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

2.3 Stakeholders

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

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

Figure 5. Common stakeholders in WSUD projects

Table 2. Details of stakeholder perspectives and possible engagement needs

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

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Table 2. Continued

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

2.4 Biofilter performance for water treatment

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

2.4.1 Pollutant removal performance

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

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

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

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Table 3. Continued

<table>
<tr><th>Pollutant</th><th>Removal and critical design aspects</th><th>Expected concentration reduction if well designed and for ‘typical’ stormwater*</th></tr>
<tr><td colspan="3">Organic micropollutants</td></tr>
<tr><td>Hydrocarbons (TPHs)</td><td rowspan="4">Micropollutants incorporate a wide range of compounds, with varied chemical properties. Limited data on micropollutant processing is available. Many micropollutants can be retained by adsorption to the media during storm events and subsequently broken down over time by microbial respiration processes. However, the tendency for sorption and complexity of decomposition varies between compounds. In addition, the lighter hydrocarbons can volatilise.

Removal can benefit from increased soil organic matter content (but this will compromise nutrient removal) and drying – even prolonged drying. Back-to-back storm events do not benefit removal as there is limited opportunity for decomposition and some adsorbed contaminants can be flushed.

Removal of herbicides, chloroform and phenols can be particularly challenging with breakthrough possible (Zhang et al., 2014b).

It must be noted that biofilters cannot treat large oil spills, but can treat small quantities of hydrocarbons effectively.</td><td>> 99% Hydrocarbons</td></tr>
<tr><td>PAHs (Pyrene and Naphthalene)</td><td>> 80% PAHs</td></tr>
<tr><td>Pesticides and Herbicides (Glyphosate, Atrazine, Simazine, Prometryn)</td><td>> 80% glyphosate

<20 up to 50% atrazine & simazine</td></tr>
<tr><td>Other organic chemicals –

Phthalates (DBP, DEHP),

THMs (Chloroform),

Phenols (PCP, Phenol)</td><td>< 80% TPHs and phthalates

> 80% DBP and DEHP

20-50% Chloroform

50 to > 80 % Phenols

(Zhang et al., 2014b)</td></tr>
</table>

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

2.4.2 Hydraulic and hydrological performance

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

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

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

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

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

2.5 Benefits

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

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

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

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

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Table 5. Continued

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

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Table 5. Continued

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

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Table 5. Continued

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

2.6 Misconceptions

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

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

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

2.7 Cost-benefit analysis

2.7.1 Framework

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

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

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

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

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

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

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

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

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

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

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

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

2.7.2 Evidence

Costs vs. Benefits

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

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

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

Cont.

Table 7. Continued

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

Cont.

Table 7. Continued

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

Life-cycle costs

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

System size– the benefit of economies of scale for larger systems is evident in the capital costs expressed per unit area (Table 8). Moreover, a cost review undertaken by Knights et al. (2010) found greater cost variation for the construction of small streetscape systems (<50 m², $500 - $2000/m²), yet more consistency for the cost of larger systems (> 100 m²; $500-$750/m²). This was attributed to a higher ratio of edge to media area for small systems - as the edge requires varying construction techniques from concrete to earthen walls - and to the higher standard expected of visible streetscape systems.

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

- **System complexity** – systems with more sophisticated hydraulics and engineered structures (e.g. underdrain, pits and pipes), or those with highly novel configurations, will require additional design, construction and maintenance costs relative to simpler systems.
- **Site characteristics** – the slope, access, subgrade and other aspects of the site will influence the design requirements and construction techniques employed, all of which can significantly influence the cost (Knights et al., 2010). For example,
    - In particular, **features at the perimeter of the system** (batters, walls, rock, drainage) demand a high fraction of the cost.
    - **Steep sites** require more cut and fill and higher retaining walls.
    - If **site access** crosses through steep terrain greater sediment control is required. Consider access requirements and costs during the initial feasibility assessment of the project.
    - **Online systems** can cost more than offline systems due to interruptions during wet weather, and higher sediment and litter loads. Construction of a bypass is critical for online systems.
    - The **cost of excavation** will depend upon site geology, depending upon the characteristics of underlying sand, clay or rock material. However, rocky sites are not necessarily more expensive, particularly in soft rock such as sandstone. Excavation may be a cheaper option than wall construction with less excavation.
    - **Earthworks and drainage** require a sizeable portion of the cost, generally comprising 10-30% and 15-25% respectively.
    - **Wall construction**, if required for large and steep sites, can comprise 10-15% of the total cost, and **rock excavation and roadworks** can cost up to 20% of the total cost. However, Knights et al. (2010) also found that biofiltration systems can still be constructed on steep or challenging sites without deviating from the same general cost relationship applicable to other sites.
- **Disposal of excavated soil** – can also be a significant cost driver and depends upon the quality of the material, with contaminated or weedy soils more costly to dispose. Take care to factor this in to the total cost. Before the project proceeds, conduct preliminary site investigation and soil testing if feasible, particularly if soil contamination is likely. If appropriate, the cheapest option is on-site re-use but if spread across the surrounding area a capping layer of topsoil is recommended, to limit the maintenance costs of weed management and re-establishing vegetation (Knights et al., 2010).
- **Presence of a canopy layer** – Biofilters have lower maintenance costs when a canopy layer of trees is present (<$1/m² filter media/year), relative to those with understorey plants alone ($5/m² filter media/year). This has been anecdotally reported and confirmed with an analysis of maintenance data by Water by Design (2015). It was attributed to the shading effect of trees and their litter in reducing weed invasion (Water by Design, 2015). Trees may also help to prevent severe drying of the biofilter surface and drought effects on understorey plants. Water by Design (2015) provides examples of resilient neighbourhood-scale systems with canopy layers that have lacked regular maintenance for many years.
- **Grouping or isolation of biofilter** – Another trend quantified by Water by Design (2015), streetscape biofilters may cost half as much to maintain if grouped within the same street, rather than separately located systems.
- **Level of service provided by council or the asset owner** – this will be influenced by the level expected for the community and may be higher for systems in highly visible public places (City of Melbourne, 2009).
- **Catchment characteristics** – some sites will experience high sediment or plant litter loads, which will require more frequent inspection and maintenance, particularly those with a high level of construction in the catchment.

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

Table 8. Life cycle cost estimates for biofiltration

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

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

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

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

Cont.

Table 8. Continued

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

Comparison against the base-case

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

- **Landscaping costs** – biofilters provide landscape amenity and are largely self-watering and self-fertilising gardens. In many cases traditional civic landscaping would be otherwise be developed in place of a biofilter. Landscaping Victoria suggests an average project cost of $150-$350/m^2 (data from May 2009, assumes 60% soft landscaping and 40% hard landscaping works) (Landscaping Victoria website). Lower cost estimates were used in a biofiltration business case analysis by Water by Design (2010a). Garden bed landscape design and construction was estimated at $55/m^2 and maintenance costs $2.50/m^2/year (using guidance from landscape architects), while turf areas were estimated to cost $15/m^2 in design and construction and $1/m^2/yr for maintenance.
- **Traditional drainage network capital costs** – these costs are considerable. Quick reference to several Stormwater Asset Management Plans from city councils indicate replacement costs for the stormwater pipe network can be in the order of $185,000/km (CT Management Group, 2011, Moreland City Council, 2006), and in other cases up to $430,000/km (City of West Torrens, 2012, Adelaide City Council, 2008). Replacement costs increase further if other stormwater infrastructure such as pits, junctions, culverts and gross pollutant traps are included (e.g. ~$240,000/km of pipe network (Moreland City Council, 2006), $280,000/km (CT Management Group, 2011, City of Playford, 2012), $570,000 (Adelaide City Council, 2008, City of West Torrens, 2012).
- **Sediment and litter removal from conventional drainage network** – the council Stormwater Asset Management Plans also indicate the high cost of maintaining the traditional drainage network. Pipe cleaning and inspection can cost in the order of $1,000/km of pipe network, or $1,850/km if general maintenance, inspection and cleaning of pits are included (please note this figure is based on one council report only; (CT Management Group, 2011)).

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

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

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

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

- Seeking **input from the maintenance team early in design** and throughout the project to ensure maintenance issues are addressed and well planned (e.g. access, ease of checking and cleaning pits and pipes).
- **Clearly distinguishing routine maintenance activities from rectification** works. The City of Port Phillip has clearly defined the distinction and this facilitates planning and budgeting, with funds sourced from separate council budgets (E2DesignLab, 2014b).
- In addition, **maintenance during the establishment period should also be differentiated** in terms of planning and requirements – maintenance needs will be higher during this period, while tasks and frequency of maintenance must be tailored accordingly. However, this **early investment in system establishment will lead to reduced long-term costs** for maintenance and rectification works.
- **Allocating sufficient budget early** in the project, as the total budget is scoped, to support a high level of maintenance during establishment and ongoing routine maintenance.
- Implementation of **good design, construction and establishment procedures.** This avoids costly rectification works in the majority of cases, leaving only relatively minor and inexpensive routine maintenance tasks (E2DesignLab, 2014b, a). Hence, a greater upfront commitment of funds to develop a functioning system can be more than offset by savings from reduced long-term maintenance and rectification.
- Undertaking **timely and regular maintenance** allows any issues to be identified early and corrected before the problem escalates to require more costly rectification works. This approach has been demonstrated to be

significantly more cost-effective than no or infrequent maintenance by Browne et al. (2013) and Mullaly (2012). For example, if blocked outlets or overflow structures are discovered and cleaned before the system experiences prolonged flooding, the cost of replanting can be avoided.

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

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