CRC for
Water Sensitive Cities

Adoption Guidelines for Green Treatment Technologies

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Adoption Guidelines for Green Treatment Technologies
Integrated multi-functional urban water systems (Project C4.1)
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Glossary

Living walls

Commonly known as green facades, they consist of vertically-growing climbers that are rooted in the ground or in containers at the base of the wall. Plants can be grown directly onto the building façade or on a separate structural system close or attached to the wall.

Dual-mode living wall treatment systems

They are living wall systems capable of treating both stormwater and greywater. They operate by switching between the two water sources (that is, daily greywater, stormwater during and immediately following rainfall, termed parallel mode) or in seasonal pulses (that is, greywater in dry months, stormwater in wet months, termed sequential mode)

Green walls

Plants grow in boxes or compartments mounted onto wall surfaces but held away from it, separated by a waterproof membrane with at least 5 cm space between the wall and the green wall frame.

Greywater

Also referred to as light greywater or light wastewater, comprises wastewater discharges from washing basins, baths and showers.

Effective plant species

Plant species showing superior pollutant removal performance when planted in biofiltration systems.

Chapter 1

Introduction

City of Adelaide Civic Centre Green Wall
Image courtesy of Water Sensitive SA

Cities and towns across Australia and the world are growing rapidly. The increase in urban development has brought with it multiple social, economic and environmental challenges. These include hotter weather conditions, higher flood risks, greater pressure on water resources and infrastructure and increasing air and water pollution. This is further complicated by a highly variable and unpredictable climate

To increase the resilience and liveability of cities and to maintain their productivity, green infrastructure is being highly viewed as a sustainable development strategy. Green infrastructure or technologies, essentially, represent a set of engineered elements providing multiple ecosystem services at building and urban scales. They aim to integrate local water management with urban greening. Examples include biofiltration systems (or raingardens), constructed wetlands, green roofs, vegetated swales and ponds, green walls and living walls (or green façade). In particular, the presence of green walls and facades within city precincts has grown tremendously in the recent decades since inception of the concept in the seventeenth and eighteen centuries. Initially designed as aesthetic features, their (additional) merits in terms of easing the urban island heat effect and improving the adjacent building energy efficiency are turning them into highly valued urban assets. The fact that they do not require large land areas and can be effectively used in dense urban centres is an added advantage.

Yet, green walls and façade systems have high irrigation needs. Currently, some systems consume 0.5 to 20 L/m^2/d of potable water while for others, a more sustainable source of water, greywater (in some cases stormwater), is provided to meet demand. From a water management perspective, re-using the greywater (or stormwater) locally after passing through the green wall or façade represents an important water recycling opportunity. For instance, it is estimated that if a green wall on one face of a building consumes approximately 40% of the greywater generated from a typical 6-8 storey building, the remaining 60% can be re-used within the building for toilet flushing as well as for other precinct-wide non-potable uses (CRC for Water Sensitive Cities, 2016).

This guide provides critical information on how to design, operate and maintain these green wall and façade systems to maximise their water treatment benefits to ultimately increase the sustainability and liveability of cities.

Important!

1. The present guideline focuses on living walls that are used to treat greywater and/or stormwater. It does not promote the use of these technologies above others that may be better suited to meet site-specific objectives.

2. These guidelines focus mainly on the biophysical aspects of living walls. Information relating to the design of the structural elements would be sought elsewhere.

1.1 What are these green technologies?

Green façades or **living walls** (as commonly referred to in this document) consist of vertically-growing climbers that are rooted in the ground or in containers at the base of the wall (Figure 1.1). They cover the wall through a self-clinging mechanism (plants grow directly onto the building façade, Figure 1.1a) or with the aid of physical supports adjacent or attached to the building façade (Figure 1.1b). Climbing and non-climbing plants are grown in a sand-based media which universally functions as a biofiltration system. This can be located either underground in the form of a trench (Figure 1.1a,b) or aboveground in a planter box (Figure1.1c).

Two types of treatment systems have been developed:

(1) Living wall systems for treatment of greywater

(2) Living wall systems for treatment of both stormwater and greywater within a single system; they are also referred to as **dual-mode living wall systems**

The concept of the technology for on-site greywater/stormwater treatment and re-use is illustrated in Figure 1.2. The two types of living wall systems share multiple common design features but essentially differ in terms of surface area required per treatment volume as well as in operation.

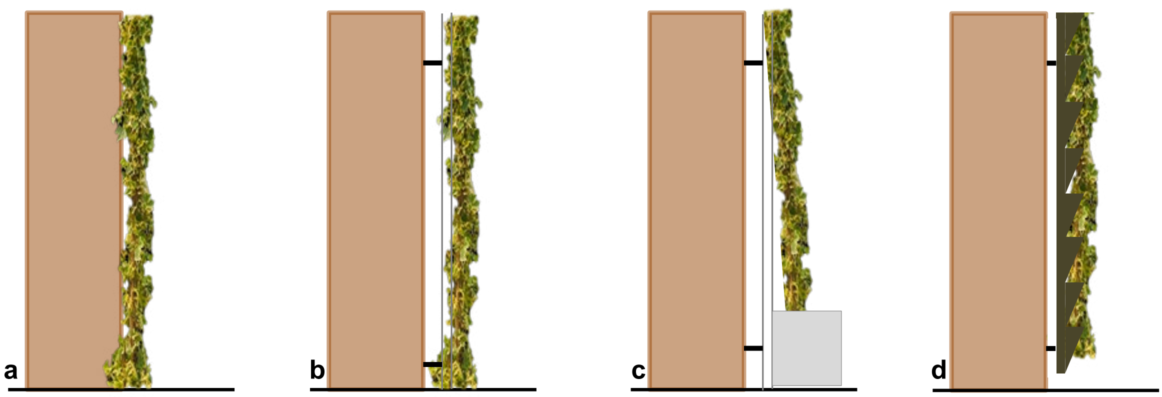

Figure 1.1 Schematic of different designs of green and living walls; a – direct living wall (façade), b – indirect living wall (façade) with plants grown from an underground trench, c - indirect living wall (façade) with plants grown from a planter box, d – green wall

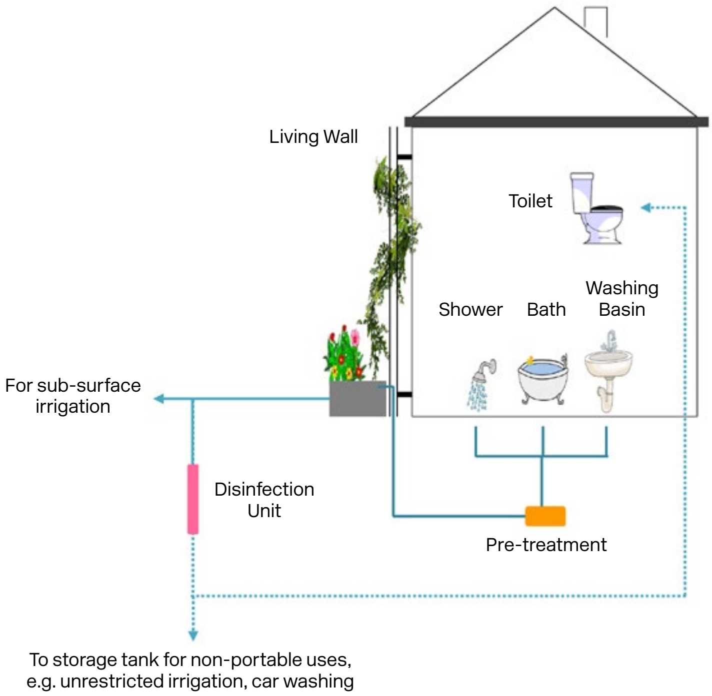

Figure 1.2a Concept of living walls for greywater recycling in domestic premises (adapted from Fowdar et al., 2017)

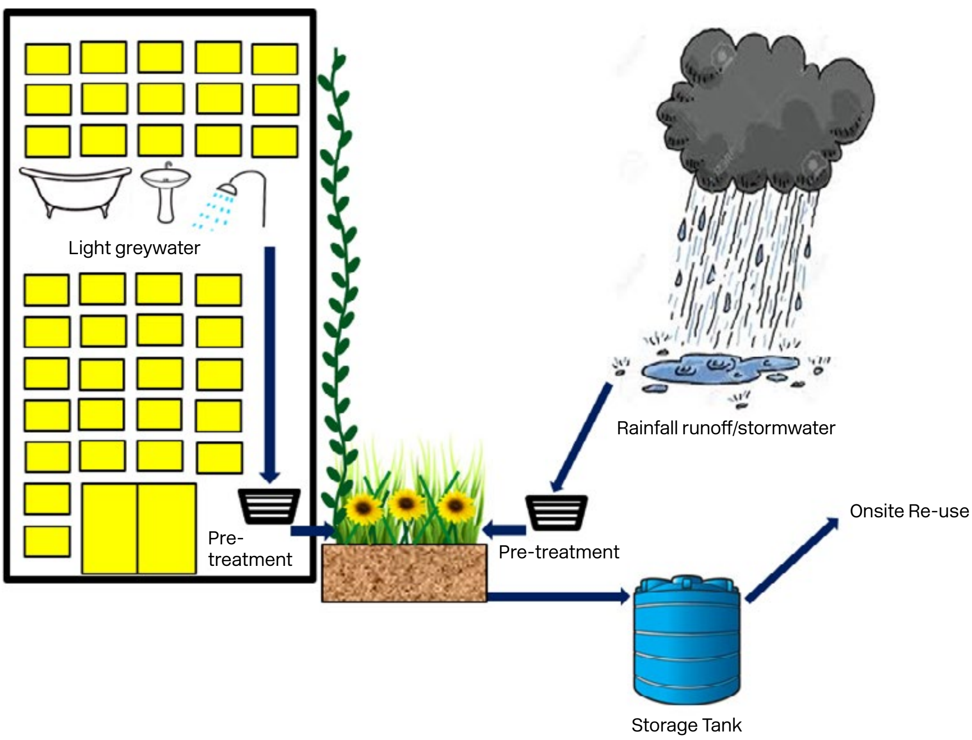

Figure 1.2b Concept of living walls for stormwater and greywater recycling in commercial premises (Barron et al., 2016)

These technologies are an extension of existing stormwater treatment systems. The present guidelines largely build upon the existing guidelines for stormwater biofilters (*Adoption guidelines for stormwater biofiltration systems*, Payne et al., 2015).

Stormwater biofiltration systems (also commonly known as raingardens, bioretention systems) are an example of Water Sensitive Urban Design (WSUD) technologies used to attenuate flows and mitigate aquatic pollution produced by storm runoff. Stormwater biofiltration systems are vegetated basins that collect and treat runoff through infiltration and detention processes for either discharge into receiving waterways or for harvesting purposes.

The fundamental difference between stormwater and greywater biofilters are the influent loading rate and influent composition. Greywater tends to have higher organic and nutrient concentrations, is generated daily and is likely to be received by the system in smaller volumes per inflow in contrast to stormwater systems. These have significant implications on system performance and hence on system design and operational conditions. Similarly, the greywater living wall differs from wastewater wetland systems in both their design and operation. For instance, the greywater/stormwater living walls will be less saturated than vertical flow wastewater wetlands and will operate only when greywater is generated or during a storm event.

Current development stage: These systems are experimental only. So far these systems have been tested at the laboratory scale. Pilot field-scale systems are in their early monitoring phase. Results collected will be amended as they become available. Nevertheless, it should be noted that since these systems are an extension of stormwater biofilters, many of the experiences can be successfully transferred which substantiate confidence in the laboratory findings presented here. For the dual-mode system, work pertaining to assessing the impact of different loadings on performance is ongoing to determine optimum operational conditions.

Figure 1.3 Traditional stormwater biofiltration systems (also known as raingardens, bioretention systems)

Figure 1.4a Living walls used as part of urban landscaping on Monash University Clayton Campus

Figure 1.4b Living wall at Stonnington Council Offices Glenferrie Road, Malvern (Image Source: Fytogreen)

Green walls are plants grown in boxes or compartments mounted onto wall surfaces but held away from it and separated from it by a waterproof membrane (Figure 1.1d). Please note that green walls in this document refer to external walls only. Novelty of green walls as a treatment system lies in the fact that new 'lightweight' media and a range of plant species have been tested that are able to effectively treat greywater to re-usable standards for non-potable use (following disinfection).

Current development stage: These systems have been trialled at the laboratory-scale and are still in the early stages of their development. The preparation of a separate report discussing the findings of the research conducted on the green walls and the associated practical implications is underway.

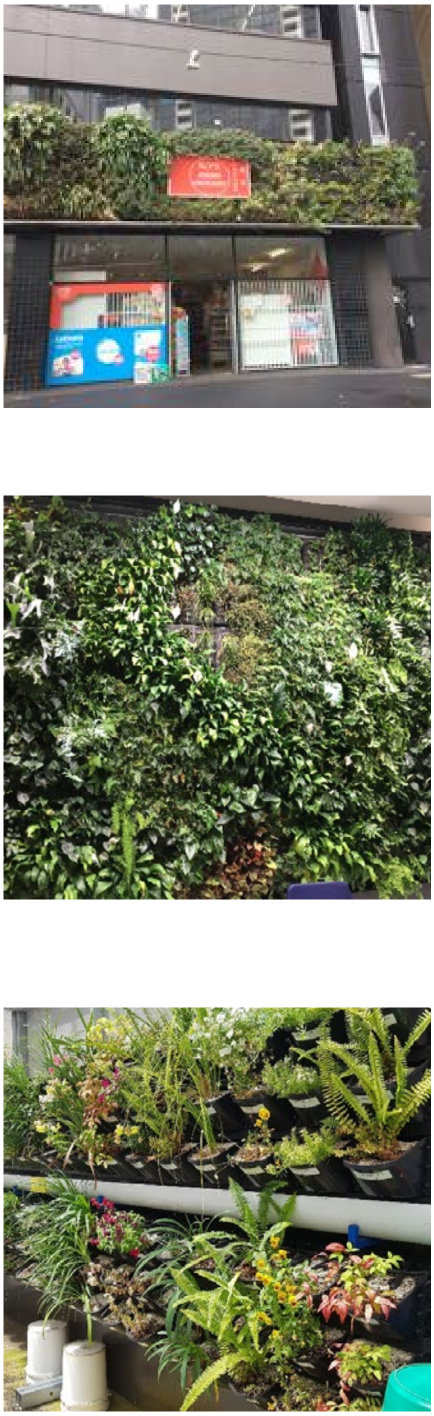

Figure 1.5 Green walls trial at Monash University

How do they work?

Green and living walls are engineered, nature-based systems that harness the natural functions of plants, media, and microbial communities to reduce pollutant concentrations in the incoming water. Pollutants carried by stormwater runoff and greywater differ, but generally include nutrients (excess levels of nitrogen and phosphorus), heavy metals, sediment, pathogens (bacteria, viruses, protozoa and parasites) and organic micropollutants (such as hydrocarbons, pesticides, herbicides, polyaromatic hydrocarbons (PAHs), phthalates and phenols). Greywater or stormwater directed onto the surface of these systems may temporarily pond (in the case of stormwater) before vertically infiltrating through the filter media. As water passes through, plant roots, media and microbial communities provide biological, chemical and physical processes to remove, transform and attenuate pollutants in the water as shown in Figure 1.6. The treated effluent can be safely discharged to the downstream environment (in the case of stormwater) or collected for reuse purposes.

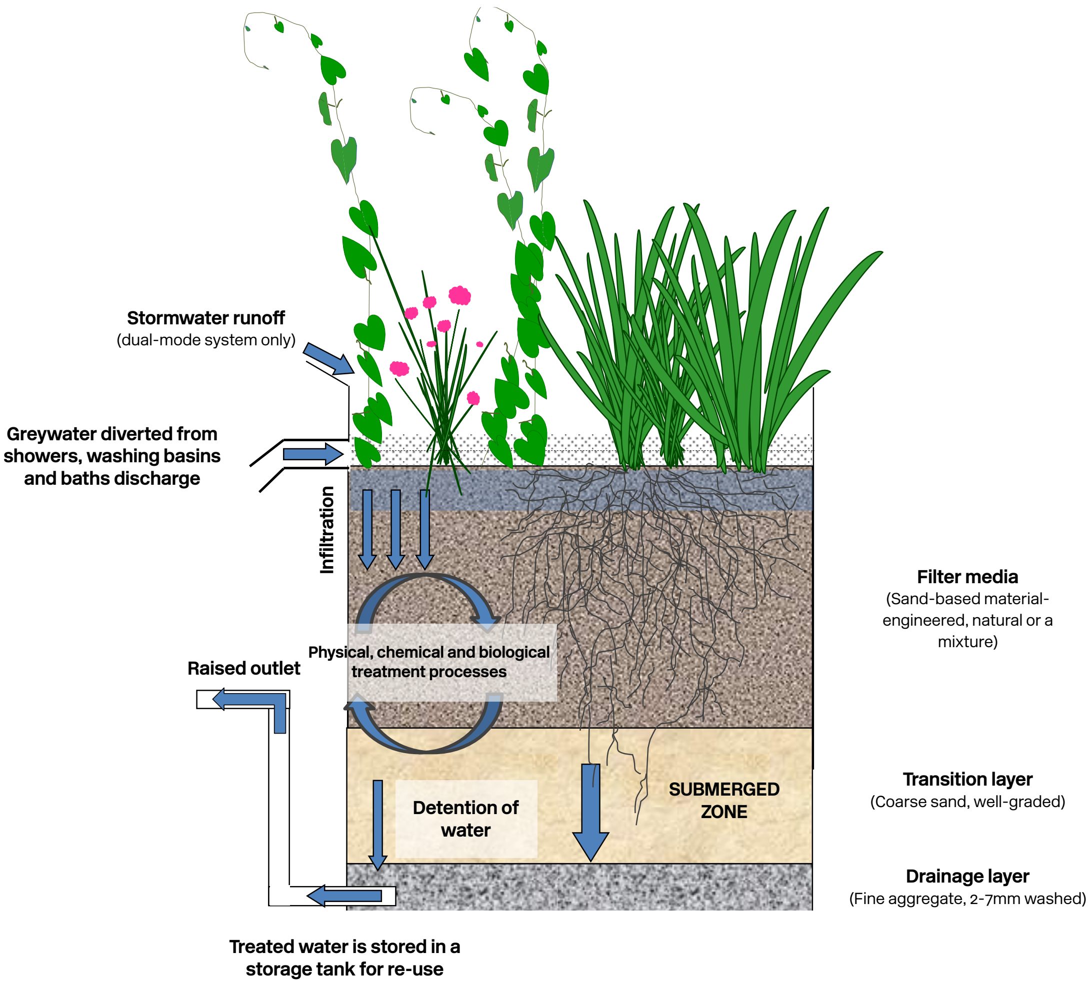

Figure 1.6 Key principles of biofiltration (living wall treatment system)

1.2 Why choose these technologies?

The green and living wall treatment systems are multi-functional systems. They demonstrate great potential in increasing the liveability and sustainability of urban cities. They:

- are able to treat greywater, or both greywater and stormwater within a single system (dual-mode systems). and in so doing, they help protect the receiving environment and reduce pressure on centralised wastewater treatment systems;
- minimise wastewater flows and thus reduce energy requirements of wastewater treatment plants;
- enable re-use of alternative water sources, thus reducing demand on limited freshwater sources;
- are self-watering systems;
- provide greenery in the urban environment, which enhances amenity and aesthetics of the surrounding landscape, supports improved human health and wellbeing and increased property values;
- are a relatively low-energy treatment option;
- are flexible in scale and application;
- provide enhanced urban biodiversity;
- are beneficial to the urban microclimate via the cooling effects of evapotranspiration and shading;
- deliver thermal insulation benefits of climbing plants or green wall structures alongside building walls and;
- enable increased community engagement with the urban environment and water cycle.

1.3 Purpose of the guidelines

These guidelines aim to facilitate the adoption of these multi-functional green technologies across the water community and deliver sustainable and liveable water-sensitive cities. They provide practical information on the design, operation and maintenance of living walls for treatment of stormwater and greywater.

More specifically, these guidelines focus on the:

- use of biofiltration for greywater treatment
- use of biofiltration for both greywater and stormwater treatment
- performance of climbing plant species and aesthetically-pleasing plant species in water treatment

These guidelines are intended for use by engineers, designers, planners, landscape architects, developers, commercial building suppliers, water regulatory authorities and other parties involved in urban design and water management.

These guidelines are presented as a series of chapters:

- Chapter 2 - Business case and regulations
- Chapter 3 - Objectives and performance of green technologies
- Chapter 4 - Living walls for stormwater and greywater treatment – design, installation and operation
- Chapter 5 - Maintenance and Monitoring
- Chapter 6 - Living wall case study

1.4 Research underpinning the design of these systems

These guidelines have been developed under Program C4.1 of the Cooperative Research Centre for Water Sensitive Cities (CRCWSC) with funding from the Australian Government and its industry partners (https://watersensitivecities.org.au/). They are based upon laboratory studies conducted at Monash University where multiple design options were trialled to quantify system performance and identify optimal design parameters. Pilot field-scale studies, namely at the Monash Council Eastern and Innovation Business Centre (EIBC), have been constructed and their performance are currently being tested and validated.

1.5 Additional resources

These guidelines are not intended to be a standalone document for the design and installation of the living and green wall treatment system. It is strongly recommended that the following references be consulted in conjunction with the present guidelines:

- *Adoption Guidelines for Stormwater Biofiltration Systems* (CRCWSC, 2015). Summary report or full document available online for free download.
- *Bioretention Technical Design Guidelines* (Water by Design, 2014)
- *Vegetation guidelines for stormwater biofilters in the south-west of Western Australia* (Monash Water for Liveability Centre, 2014)
- *Construction and establishment guidelines – swales, bioretention systems and wetlands (Water by Design, 2009a)*
- *Guide to the cost of maintaining bioretention systems* (Water by Design, 2015)
- *Stormwater harvesting guidelines* (Water by Design, 2009b)
- *A Business case for best practice urban stormwater management* (Water by Design, 2010)
- Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1 and Phase 2) (Environment Protection and Heritage Council, the National Health and Medical Research Council and the Natural Resource Management Ministerial Council, 2006 (Phase 1), 2008 (Phase 2))
- AS/NZS 1547:2012 On-site domestic wastewater managementCity of Melbourne (2008)
- *Risk management guidelines for Water Sensitive Urban Design* (City of Melbourne, 2008)
- *Growing Green Guide: A guide to green roofs, walls and facades in Melbourne and Victoria, Australia* (Department of Environment and Primary Industries, 2014)
- *Feasibility study: Living wall system for multi-storey buildings in the Adelaide climate* (Hopkins et al., 2010)
- Planting green roofs and living walls (Dunnett and Kingsbury, 2008)
- *202020 Vision: How to grow an urban forest* (City of Melbourne,2015)

Chapter 2

Business Case and Regulation

Adelaide Zoo green living wall
Image courtesy of Water Sensitive SA

2.1 Introduction

This chapter outlines the benefits, costs, challenges and risks of implementation that might help water practitioners make a business case for adoption of these technologies. It outlines regulations pertaining to reuse of greywater and stormwater and the need to establish a risk management framework. Finally, it presents information about the approvals and planning permits that are required when considering the implementation of these technologies.

2.2 Benefits of green technologies

Living and green wall treatment systems offer a number of benefits at both the building and urban scale. Developers, building owners and water managers can maximise these benefits through smart design and by following proper maintenance measures during the systems' lifespan. Below are summarised examples of these benefits. Evidence of research and quantification of the benefits are provided in more details in sections 3.3 and 3.4 in Chapter 3.

- Improvement in greywater and stormwater quality
- Water conservation
- Reduction in wastewater flows
- Decentralised, low energy treatment technology
- Urban cooling
- Improvement in building thermal performance
- Improvement in human health, social productivity
- Aesthetics and amenity value
- Increase in property values
- Urban biodiversity
- Improvement in air quality
- Improvement of stormwater run-off
- Reduction in noise
- Protection of building wall surface

2.3 Costs of green technologies

Installation costs for the growing base (underground trench or above ground planter box) of the living wall system will be more or less comparable to stormwater biofiltration systems (Adoption guidelines for Stormwater Biofiltration Systems, Payne et al., 2015). Total installation costs for the living wall system are estimated to be around $250 - $500/m^2. Please note that this value will vary depending on the type of support used.

For the green wall system, the total installation cost could amount to approximately $1,500/m^2.

Please note that these costs are indicative only and do not take into consideration maintenance costs. Please refer to the *Growing Green Guide* (Department of Environment and Primary Industries, 2014) for more details of the system costs as garnered from previous case studies. A green wall in Victoria covering 206 m^2 was recorded to cost $350,000 while a living wall (Victoria) spanning over an area of 122 m^2 had a cost of $230,000 (Department of Environment and Primary Industries, 2014).

2.4 Challenges, research needs and opportunities

Green and living wall treatment systems are relatively new technologies. There is still much to learn to make these systems as successful, cost effective and efficient as possible. Table 2.1 lists some of the challenges currently impeding implementation and identifies opportunities to drive implementation.

Table 2.1 Challenges impeding implementation of green treatment technologies and opportunities to drive implementation

Challenges	Opportunities
Relatively new systems. Limited research conducted so far to optimise design, e.g. suitable plant species to use under different climatic conditions.	Implementation of more pilot scale systems. State and regional policies and programs could be developed to encourage green infrastructure implementation that can then act as case studies. Lessons learnt from these will drive more widespread implementation.
High costs in some cases which may deter implementation. For e.g., standard maintenance costs of green walls can be 8.5% to 15% of installation cost annually.	Plan for long-term; investing in a quality product at the initial construction stage will reduce maintenance in the long term. Government incentive schemes (including financial incentives) would help to encourage use of green surfaces for stormwater management and greywater treatment. For instance, San Francisco's Green Building Ordinance sets minimum standards for carbon dioxide emissions (Wood et al., 2014)
More complex plumbing - separate pipes are required for blackwater, laundry and kitchen wastewater and bathroom wastewater; important to ensure cross-connections are avoided.	For new buildings, this should be taken into account at the building planning stage.
Health and safety represent a challenge from a public health perspective.	Systems should be strictly designed following appropriate water recycling standards. A robust risk management framework should be established. Clear signage and demarcation for public access should be in place.

2.5 Regulations for managing health and environmental risks

Like any water recycling scheme, use of green and living wall treatment systems presents with certain public health and environmental risks.

Collection, treatment and reuse of greywater

Greywater contains a wide array of microbial pathogens (e.g. bacteria, viruses, protozoa and parasites) which presents certain human health risks. On the other hand, the impacts of greywater re-use on the environment include increased salinity and sodicity of soils; increased nitrate and phosphorus loading to soil and eventual run-off into aquatic ecosystems; increased groundwater or surface water contamination in the event of unauthorised movement of greywater off-site.

The above public health and environmental risks can be minimised through proper planning, design and maintenance. A risk management approach should be established in the first place. Where there are relevant state and territory regulations, standards or guidelines (see below), they should be consulted to ensure that any local requirements are met and best practice management of the recycled water is followed. In particular, schemes that reuse treated greywater also require water authority consent, typically to increase the level of backflow protection. Designers must be aware of the relevant requirements. Examples of national and state standards and guidelines for consultation:

- National Water Quality Management Strategy, (2006) Australian Guidelines for Water Recycling: Managing Health and Environmental Risks: Environment Protection and Heritage Council, Natural Resource Management Ministerial Council, Australian Health Ministers' Conference.
- City of Melbourne (2008) Risk Management Guidelines for Water Sensitive Urban Design
- Victoria: EPA Victoria, (2016) Code of practice – onsite wastewater management, Guidelines for environmental management
- WA: Department of Health (2010) Code of practice for the reuse of greywater in Western Australia
- NSW: Department of Water and Energy, (2008) NSW Guidelines for greywater reuse in sewered, single household residential premises.
- Queensland: Department of Energy and Water Supply (2008) Water Quality guidelines for recycled water schemes,
- SA: Department of Human Services and EPA (1999) Reclaimed water guidelines: Treated effluent

Establishing Performance targets

Performance targets for each greywater living wall system needs to be identified in accordance with the above guidelines for the intended end use. Most greywater re-use applications are for restricted, non-potable uses. Concentration limits for greywater re-use are summarised in Table 2.2.

Table 2.2 Treatment standards and corresponding end-use application for residential premises and multi-dwelling/commercial premises as compiled from state greywater re-use regulations

Treatment	End-use application	
	Single domestic premises	**Multi-dwelling and commercial premises**
Treated greywater to a quality of 20 mg/L Biological Oxygen Demand (BOD_5), 30 mg/L Suspended Solids (SS), 6 – 9 pH	• Sub-surface irrigation (100-300 mm below ground level) Sub-soil irrigation (>300 mm below ground level)	
Treated and disinfected greywater to a quality of 20 mg/L Biological Oxygen Demand (BOD_5), 30 mg/L Suspended Solids (SS) and 10 cfu thermotolerant coliforms/100 mL, 6 – 9 pH	• Surface irrigation • Toilet flushing* • Laundry use* • Car washing*	• Subsurface irrigation • Surface irrigation by drip only

*Depending on local guidelines, there may be stricter limits for these end-uses

Appropriate nutrient removal targets for individual greywater living wall systems will be influenced by the greywater characteristics and site conditions, including distance between the end use and underlying groundwater, susceptibility of the soil to surface ponding (and thus generation of run-off) and proximity of the area to surface water bodies.

Collection, treatment and reuse or discharge of stormwater

Similarly, relevant policies and legislative requirements should be consulted to ensure reuse and discharge of stormwater minimise associated health and environmental risks.

Examples include:

For stormwater reuse:

- National Water Quality Management Strategy: Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2)

  — Stormwater harvesting and reuse (2009)

- For discharge of stormwater into the environment:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality

Performance targets

The primary performance target should be to maintain or restore runoff volumes and frequency to pre-development levels. Pollutant load reduction objectives are 80% of total suspended solids, 60% of total phosphorus and 45% of total nitrogen on the site shall be retained by the system (see *Adoption Guidelines for Stormwater Biofiltration Systems* for more details; Payne et al., 2015).

2.6 Importance of education

The need to educate households, building occupants and the community in general about the benefits, functions and operation of these green technologies is necessary for three distinct reasons:

- To better manage the health and environmental hazards associated with greywater and stormwater re-use on-site;
- To ensure system longevity through proper operation and maintenance over the system lifespan and hence maximise financial returns;
- To promote community acceptance and uptake of these green technologies and hence accelerate implementation of sustainable water management practices.

Simple strategies involve use of signage, clear marking and labelling of infrastructures (e.g. pipes, valves, etc.). For example, signage would:

- indicate that recycled water is being used on the property and is not suitable for drinking,
- indicate that tampering with filter surface is prohibited as it will damage system functioning,
- educate about the purpose and function of the system,
- inform on the importance of healthy plant growth.

For commercial places and multi-dwelling buildings, some or all of this information could also be provided in the form of brochures and leaflets distributed to local residents.

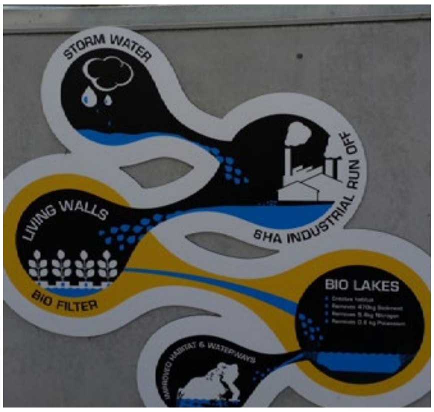

Figure 2.1 Examples of signage around green treatment infrastructure

Similarly, education and training programs for maintenance, inspection contractors or any other personnel directly or indirectly involved in the operation of these systems (e.g. external cleaning staff for building windows in commercial premises) are highly recommended.

It is also advisable to engage households and building occupants in the use of environmentally friendly products (see Chapter 4, Section 4.4.1).

2.7 Planning permits and approvals

The construction and use of the living and green wall treatment systems will need to be approved by the relevant state regulatory authority (e.g. EPA Victoria; Department of Health, Western Australia). Since a condition for approval is accreditation for use as an on-site greywater treatment system, it is highly recommended that the following guidelines be consulted in conjunction with the present guideline to achieve accreditation:

- AS/NZS 1546.3: On-site domestic wastewater treatment units – Aerated wastewater treatment systems
- AS/NZS 1546.4 – Greywater Treatment Systems or the most recent version of the NSW Health Accreditation Guidelines for Greywater Treatment Systems
- AS/NZS 4130: Polyethylene (PE) pipes for pressure applications
- AS/NZS 1319: Safety signs for the occupational environment
- AS/NZS 3500: Plumbing and drainage
- AS/NZS 1547: On-site domestic wastewater management

A planning permit and building permit to install the living and green wall will be issued in line with local building regulations. There is also a need to get approval from Wastewater Service providers if overflow connections enter their system. Designers and building owners should be aware of the relevant local jurisdictional legislative requirements at the early planning and design stage.

Chapter 3

Objectives and performance of green technologies

3.1 Introduction

This chapter provides guidance on how to choose between the three technologies (living walls for greywater treatment, dual-mode living walls for stormwater and greywater treatment and green walls for greywater treatment) based on design objectives, building type and other local site conditions. Further chapters detail the performance of the green technologies in terms of their pollutant removal and other deliverable benefits resulting from scientific research.

3.2 Matching design objectives to technology selection

Choice of technology for a particular site and application will depend on the performance objectives established in line with the client's requirements. Following selection of technology (in this case green or living walls), the performance objectives will further guide other design considerations, e.g. type of plants to use. An assessment of the local site will also inform design considerations as noted in more details in Chapter 4.

Green and living walls can be successfully implemented in a range of climates given careful plant selection, façade orientation and irrigation strategy. Building functions (commercial, hotel or residential), building size and envelope materials will all impact the selection of green technology type. For instance, direct living wall system (that is, plants that grow directly onto the building façade) is not recommended for damaged wall surfaces (e.g. walls with cracks). Table 3.1 provides on overview of how the choice of technology is influenced by the design objectives.

Table 3.1 Overview of how choice of green technology is influenced by design objectives

Design Objectives	Choice of technology
Low cost	• Direct living wall type (Figure 1.1a) has the lowest installation costs. • Indirect living wall type (Figure 1.1b) is the next suitable option if criteria for installing a direct façade are not satisfied. It should be noted that climbing plants require guidance to ensure they cover the entire surface which may slightly increase maintenance costs initially; however in later years of service, maintenance costs will still be lower than for green walls.
Aesthetics	• Green walls possess higher aesthetical potential as they make use of a variety of plants in contrast to living walls which have limitations in plant diversity. All the more, creative designs for green walls can add to aesthetics. • Use plant species that blend well with the surrounding landscape.
Simple and straightforward to install	• Living walls are simpler to install than vis-à-vis green walls which have a complex design, require more supporting materials and a more complex irrigation system.

Table 3.1 Cont.

Design Objectives	Choice of technology
Nutrient removal	• Research conducted so far at Monash University shows that N and P removal from living walls is higher than green walls. Opportunities to increase the nutrient removal performance of green walls, however, exist, subject to further study.
Provide biodiversity	• Both systems possess enormous potential when a variety of plant species are employed. In the case of living walls, include a more diverse range of understorey plants. • Consider use of insect hotels.
Provide thermal benefits in winter	• Use of deciduous plants in living wall systems will maximise heat absorption during colder months.
Cover unattractive surfaces	• Use green walls or living walls planted with evergreen species of high foliage density
Reduced stormwater flows	• Use dual-mode living walls
Provide for substantial potable water savings	• Install a disinfection unit (e.g. UV disinfection) after the living/green wall to enable re-use for a wider range of applications (e.g. toilet flushing and non-potable uses other than irrigation). Living walls are simpler to install than vis-à-vis green walls which have a complex design, require more supporting materials and a more complex irrigation system. • Consider use of the dual-mode living wall system for both greywater and stormwater harvesting.

Notes

One of the fundamental design difference between living and green walls is the type of plants employed in each of these systems which can have a significant influence on aesthetics.

Choice of living walls between single and dual-mode will depend on available land area, climate, stormwater management opportunities among other factors. In fact, a dual-mode system will be suitable for use in place of a stormwater biofiltration system in climates with long dry weather spells. Dual-mode systems will be more suitable for use in office buildings, commercial premises, apartment buildings; they will be used to treat stormwater from nearby roads, roofs and greywater from building.

3.3 Treatment performance

Living and green walls can reduce concentrations of several pollutants found in greywater and stormwater, including suspended solids, biological oxygen demand, organic pollutants, chemicals, heavy metals and pathogens and thus minimise ecological degradation and prevent drainage problems arising during re-use applications, namely irrigation. Pollutant removal performance will vary with design parameters, system operation, season and climate. System performance will equally depend on how well the system is maintained. Studies on green wall systems are ongoing, hence treatment performance data relating to greywater living wall systems and dual-mode living wall systems are presented in the following sections.

3.3.1 Greywater living walls

Table 3.2 provides useful information on the level of treatment that can be expected from a system receiving typical light greywater if designed and operated according to these guidelines (that is, based on results of the experimental studies conducted so far).

Table 3.2 Pollutant removal efficiency and critical design parameters influencing pollutant removal of greywater living walls

Pollutant	Critical design parameters	Expected concentration reduction for typical light greywater*
Biological oxygen demand (BOD)	Presence of aerobic conditions in the upper filter layer critical to removal.	>90%
Total organic carbon (TOC)	Presence of aerobic conditions in the upper filter layer desirable for removal.	>70%
Suspended solids (SS)	Adequate depth of transition layer (Figure 4.4) to prevent fine particles washing from the filter media and leaching from decomposition of plant roots. Concentrations of <10 mg/L can be achieved through careful plant selection.	>80%
Nitrogen (N)	Plant selection important. In the case where less effective plant species are selected (Section 4.2.6), ensure preferential flow paths are minimised. Preferential flow paths decrease water retention time within the system, leading to leaching of NOx. Extreme drying (>4 weeks) of the system should be avoided.	20 to >80% depending on plant selection
Phosphorus (P)	Plant selection important. Effective plants can help prolong the life span of the media and hence of the system and delay saturation of the media from exhaustion of its P sorption capacity (Section 4.2.6). Performance also benefits from inclusion of filter media layer with a high P sorption capacity.	20 to 90% depending on plant selection
Pathogen/ *E.coli*	Removal is influenced by plant species, retention time, temperature and media composition. Presence of submerged zone will facilitate *E.coli* reduction.	2 to 3 log reduction

*Compiled from the laboratory study conducted by Fowdar et al. (2017); *E.coli* removal results yet to be published

The electrical conductivity (EC) and pH of the greywater will be relatively unchanged after passing through the living wall. For this reason, it is important to encourage households to use products that are low in salts such as sodium, boron and chloride (see Section 4.4) as elevated salinity may be problematic for some end-uses e.g. if used for irrigation it can damage vegetation and soil structure. On the other hand, pH of light greywater is generally within the neutral range and therefore not likely to be an issue.

It should also be noted that turbidity levels in the effluent may be higher relative to the influent during the initial months of operation as a result of fine filter media wash-out. Choice of filter media (Section 4.2.5) as well as water detention time in the saturated zone (Section 4.2.7) will influence turbidity in the effluent.

Pending further studies, the behaviour of other pollutants present in light greywater can be inferred from observations of other similar systems. For example, removal of heavy metals exceeds 90% in stormwater biofiltration systems (Payne et al., 2015); removal occurs via adsorption processes and through plant uptake. Oil and grease removal from stormwater biofilters has been reported to be >95% (Hsieh and Davis, 2005). Biofilters possess the capacity to reduce concentrations of several organic micropollutants (present in detergents, cosmetics) to varying degrees (Zhang et al., 2014; Paredes et al., 2016; Zearley et al., 2012), although percentage reductions are yet to be quantified within the unique greywater biofilter environment. Removal of organic micropollutants will likely take place through biodegradation where sand is the filter medium but adsorption onto media can play an important role if the filter medium contains a higher percentage of carbon/organic matter.

3.3.2 Dual-mode living walls

Table 3.3 Pollutant removal efficiency and critical design parameters influencing pollutant removal of dual-mode living walls

Pollutant	Critical design parameters	Parallel Mode	Sequential mode	
		Expected concentration reduction for 50% urban stormwater, 50% light greywater	Expected concentration reduction for typical light greywater	Expected concentration reduction for typical urban stormwater
Biological oxygen demand[2] (BOD)	See table 3.2	>95%	>95%	-
Total organic carbon[2] (TOC)	See table 3.2	>70%	>90%	>30%
Suspended solids[1] (SS)	See table 3.2	>90%	>95%	>95%
Nitrogen[2] (N)	See table 3.2. Dry periods in excess of 2 weeks should be avoided.	>80%	>90%	>80%
Phosphorus[1] (P)	See table 3.2	>70%	>80%	>75%

Table 3.3 Cont.

Pollutant	Critical design parameters	Parallel Mode	Sequential mode	
		Expected concentration reduction for 50% urban stormwater, 50% light greywater	Expected concentration reduction for typical light greywater	Expected concentration reduction for typical urban stormwater
Heavy metals[1]	Organic matter binds metals, but note high content compromises nutrient removal and infiltration. High fraction bound to sediment.	>60%	-	>90%
Pathogen/ *E.coli*[3]	See table 3.2. Successive inflow events (back-to-back) lead to poor treatment. Consider use of a novel antimicrobial media (heat-treated copper coated Zeolite) to enhance pathogen removal.	-	99.9 (3.1 log)	96.8 (1.5 log reduction)

[1] Compiled from the laboratory study conducted by Barron et al (2017a)
[2] Compiled from the laboratory study conducted by Barron et al (2017b)
[3] Compiled from the laboratory study conducted by Jung et al (2017)

Notes

In **parallel** mode, the system receives stormwater and greywater on alternating days, that is, the system treats greywater on all days throughout the year except on wet days when stormwater is diverted into the system.

In **sequential** mode, the system receives stormwater during wet months and greywater during dry months. This is directly relevant to single-mode stormwater biofilters operating in climates with long dry weather spells. This is also the preferred operational mode as research showed that treatment performance is more stable in sequential mode than in parallel mode.

3.4 Other benefits

This section provides information on evidence-based benefits of the green technologies previously outlined in Chapter 2, Section 2.2.

Urban cooling
Living and green walls act to cool their surrounding environment and hence contribute towards reducing the urban island heat effect. They provide cooling through shading, evapotranspiration, modifying airflow and by absorbing solar irradiance. Human thermal comfort can be considerably improved by installing a living and green wall canopy. Increasing vegetation cover will increase evapotranspiration. High foliage density and healthy growth of the living and green wall system will maximise urban cooling. • Research conducted in the Sydney Basin has shown that every 10% increase in tree cover can reduce land surface temperatures by more than 1°C (State of NSW and Office of Environment and Heritage, 2015). • A modelling study undertaken by Alexandri and Jones, 2008 on an urban canyon of 5 m height and 10 m width showed that a decrease in air temperature between 2.5°C and 4°C can be achieved by incorporating green walls. An average temperature reduction of 7°C was achieved for buildings with both green wall and green roof. The reduction in canyon air temperature was found to be more significant in hotter climates.

Reduction in building temperature
A study found that of the sunlight falling on the leaves, 5-30% is reflected, 5-20% is used for photosynthesis, 10-50% is transformed into heat, 20-40% is used for evapotranspiration and only 5-30% passes through the leaves (Feng and Hewage, 2014). Living and green walls can help reduce summer heat into the building and hence reduce the need for cooling. In particular, the air layer between the building walls and living/green wall has an insulating effect, which makes the latter as an extra insulator for the building envelope. For this reason, green walls may generate higher savings compared to living walls in terms of energy required to cool (or heat) buildings. The level of energy savings depends on climate, plant type, wall orientation, foliage thickness among others. • A study using artificial wall sections to simulate outdoor environmental conditions found that all surface temperatures behind plants were 10°C cooler than bare walls (Cameron et al., 2014). In fact, the amount of temperature decrease of the wall depends on the percentage of canopy cover over the wall; the greater the plant coverage, the higher the surface wall temperature reduction. • Coma et al. (2017) conducted a review of various such studies across the world and found that possible external wall surface temperature reduction of 1 to 15°C can be expected (but can go up to 30°C) depending on climate (season), plant type, wall orientation and foliage thickness. Higher reductions were usually obtained in summer and with green walls. • An experimental study found that green walls can provide a delay of about 2 hours before reaching the outside air temperature. Subsequent average energy savings ranged between 31 – 59% for the green walls and 5 to 34% for the green façade tested. The green walls reduced the energy consumption about 23% for every 1000 Wh/m^2 of incident daily vertical solar irradiation; The green façade provided a reduction of about 19% (Coma et al., 2017). • Energy saving for heating can amount to 1.2% - 6.3%, depending on wall type in a temperate climate according to Perini and Ottele, (2012).

Reduction in noise

While hard surfaces of urban areas tend to reflect sound rather than absorb it, green and living walls can absorb sound. Both the filter media and plants can help reduce noise levels with plant absorption coefficient likely increasing with leaf area density and coverage.
Thus, the level of noise reduction will depend on system design and materials used (Azkorra et al., 2015). Other factors important to improve the acoustic insulation capacity of green walls are mass (thickness and composition of substrate and vegetation layers), impenetrability (sealing joints between modules) and structural insulation (support structure) (Perez et al., 2016).

- A thin layer of vegetation (20-30 cm) can provide an increase in sound insulation of 1 dB for traffic noise and an insulation increase between 2 dB (Green wall) to 3 dB (green façade) for a pink noise according to Perez et al. (2016).

Improvement in air quality

Living/green wall plants have the capacity to improve the surrounding air quality by capturing both gaseous and particulate airborne pollutants. This varies with type of plants and the use of allergenic plants not recommended. Gases are removed from the air via several mechanisms, notably, direct uptake by leaf stomata, absorption through leaf surfaces and adherence to plant surfaces. On the other hand, particulate matter removal occurs through deposition on leaves and other plant surfaces and rain-wash (Coutts and Micah, 2015).

- A study that modelled the effect of vegetation in London street canyons estimated a reduction of 15-40% for nitrogen oxide and 23-60% for particulate matter concentrations, with the adoption of green walls in an urban canyon that was as wide as it was high (Pugh et al., 2012).
- In the southern US cities of Houston and Atlanta, with similar tree coverage, annual removal of particulates by trees was 4.7 and 3.2 tons per square mile respectively (Coutts and Hahn, 2015).

Aesthetics and amenity value

Living and green walls can enhance the visual landscape and bring enhanced public amenity within dense urban areas.

Increase in property value

Building owners and developers can benefit from increased property values.

- The placement of streetscape raingardens in Sydney have caused increasing property values by around 6% (AU$54,000) for houses within 50 m and 4% (AU$36, 000) up to 100 m away (Payne et al., 2015).
- A 10% increase in tree canopy coverage on the street verge can increase property price by about AU$14,500 (Payne et al., 2015).

Urban biodiversity
Living/green walls can improve urban biodiversity by providing a habitat for insects and birds. Green walls may be important for promoting the conservation of bird species declining in abundance as observed by a study measuring bird abundance on 27 green walls (4 times greater) as compared to a bare wall (Chiquet et al., 2012). Flowering species can influence the composition of invertebrates active above the ground. Hence, plants with a higher number of flowering plants will attract a more diverse species assemblage (Kazemi et al., 2011). Additionally, insect hotels could be integrated with these systems to enhance biodiversity.

Water conservation and reduction in wastewater flows
Increasing urban population coupled with uncertain climatic conditions are placing enormous stress on limited freshwater resources. Readily available alternative water sources such as stormwater and greywater can support non-potable water demand. By implementing living and green walls near a building, greywater produced within the building can be used to irrigate and maintain the green wall system whilst also purifying the water for subsequent re-use for lawn irrigation, toilet flushing and cooling. A study conducted in Southern Italy found that reusing light greywater (from washing basins) for toilet flushing could lead to water savings of approximately 10-30% of domestic water demand (Campisano and Modica, 2010). Living and green walls can help reduce wastewater flows and hence alleviate pressure on centralised wastewater treatment plants, including energy required for wastewater transport. A simulation study conducted under Israeli conditions found that light greywater reused for toilet flushing and garden irrigation could reduce wastewater flows by about 40-60% (in the morning) and about 30-40% (in the evening) (Penn et al., 2012).

Reduction of stormwater run-off (Dual-mode living wall system)
To minimise flood risks and protect urban water streams, living walls can be used to slow down and reduce stormwater flows. This is accomplished through infiltration through the filter media, evapotranspiration and storage within the lower submerged zone. The volume of stormwater retained and attenuated will depend on system design, notably, filter area, depth, evapotranspiration rate, water holding capacity of media, ponding depth and inclusion of submerged zone (Payne et al., 2015). Biofilters are able to reduce peak flow rates from 37 – 96% (Payne et al., 2015).

Protection of building wall surface
Building walls experience structural decay over time from exposure to UV rays, temperature changes, acid rain and air pollution. Living walls supported by an external structure and more significantly green walls (as long as the waterproof barrier remains intact) have the potential to act as a protective barrier and delay this degradation process. Building owners will certainly benefit from less frequent need for façade renovation.

Increase in human health and wellbeing, leading to increased productivity
The presence of green spaces has positive effects on the psychological and physiological health of people. Several studies indicate noticeable improvements in productivity and a reduction in illness-related work absences among occupants due to the presence of greenery (Wood et al., 2014). A study of the environment within the Pasona Headquarters in Tokyo Japan has shown a 12% productivity improvement among employees as well as a 23% symptom improvement for discomfort and ailments, along with reduction of absenteeism and staff turnover costs (https://www.dezeen.com/2013/09/12/pasona-urban-farm-by-kono-designs/, September 2013)

Chapter 4

Living walls for greywater and stormwater treatment – their design, installation and operation

4.1 Introduction

In the following sections, guidance relating to the design of the greywater and dual-mode living wall treatment system is presented. Where design deviates between the two systems, it is provided separately. This is followed by further guidance and recommendations pertaining to the operation of these systems. At this point, it is important to note that many principles of stormwater biofilters, including pollutant treatment processes and the role and importance of each biofilter component, are transferrable to the design of the living wall treatment system (*Adoption Guidelines for Stormwater Biofiltration Systems*; Payne et al., 2015). However, as discussed in Chapter 1, greywater living walls will typically receive more frequent but lower inflows than stormwater biofilters. The characteristics of greywater are also different from those of stormwater. For instance, greywater contains higher levels of organics which can be an important cause of system clogging (biological clogging) and can negatively influence other pollutant removal processes and hence system performance.

Figure 4.1 Examples of living walls designs

4.2 Technical design

4.2.1 Overview of key design parameters

Careful design is fundamental for the successful long-term operation of the living wall system and will reduce system maintenance as well as extend the life span of the system. Design of the living wall treatment system will depend on water quality requirements for the intended end use(s) (table 2.2) as well as local conditions (Figure 4.2). For example, a glass-curtain wall system is perhaps best suited to a mesh or cable system held away from the wall in contrast to a denser planting system that needs to be closer to the wall for support (Wood et al., 2014). Similarly, an underground trench (Figure 1.1b) would be better suited to support the root system of climbers growing on taller buildings in contrast to planter box systems (Figure 1.1c). **This section mainly deals with the technical design of the biophysical aspects of the system**; guidance on the structural aspects should be sought elsewhere (e.g. references outlined in section 1.5).

Site Conditions

Greywater flows and quality generated at the building scale

Climate

- Rainfall
- Solar radiation
- Temperature
- Humidity
- Evaporation rate
- Wind speed and direction
- Shading and sunlight orientation

DUAL-MODE SYSTEMS

Stormwater flows

- Minor storm event (5 year ARI for temperate climates; 2 year ARI for tropical climates)
- Major storm event (100 year ARI for temperate climates; 50 year ARI for tropical climates

Site characteristics

- Geology of surrounding soils
- Groundwater proximity
- Set back distances from dwelling
- Paths/hard surfaces
- Swimming pools
- Natural waterways

Building characteristics

- Orientation for shading and sunlight
- Height
- Envelope material
- Maintenance access

Surrounding landscape and existing greenery

Figure 4.2 Aspects to consider during the initial site survey

The first step in the design process will constitute a site assessment/survey. Opportunities for connection to existing greenery, including trees or surrounding site should be maximised.

Figure 4.3 Examples of living wall design (Image Source: above - Ronstan Tensile Architecture, below – Fytogreen)

Key system components controlling greywater/stormwater treatment efficiency include filter surface area, filter media depth and characteristics, vegetation and submerged zone (created by elevating the outlet pipe) (Figure 4.4). These should be specified first, prior to the design of the inflow and outflow structures. Each of these design elements has particular functions and importance leading to effective performance, summarised in Table 4.1. Details relating to each of these parameters for effective greywater/stormwater treatment by living wall plants are outlined in the following sub-sections.

It is important to make sure that there is interdisciplinary discussion at the start of the design. For the successful implementation of the technology on-site, several people will need to be involved (landscape architect, structural engineer, builder, horticulturalist, green wall provider, plumber, maintenance manager). It is important that a specialist or experienced living and green wall designer is engaged right at the beginning during the consultation phase. In a high-rise building, it is recommended that designers also consult with fire protection engineers as well as structural engineers.

Table 4.1 Key design parameters of living wall treatment systems and their respective functions (adapted from Payne et al., 2015)

Key parameter	Function	Design details found in section
Inflow structure	Delivers greywater/stormwater into biofilter.	4.2.4
Overflow structure	Allows high flows (e.g. in the event of an oversupply) to bypass to sewerage system and avoid damage to system.	4.2.4
Pre-treatment	Collects coarse particles and other gross pollutants, helping to protect the biofilter from premature clogging and blockages and facilitating maintenance.	4.2.2
¥Ponding (or detention zone)	Increase treatment capacity by allowing stormwater to pond before infiltration.	4.2.4
Vegetation	Serves multiple roles in water treatment via uptake, transformation of organic forms, carbon provision to microbes, transpiration, stabilising media surface, helping maintain infiltration rates. Also, provides cooling, amenity and aesthetics to surrounding environment.	4.2.6
Living wall support structure	Supports vegetation growth and allows establishment of plant cover across entire façade.	4.2.8
Filter media	Provides physical filtration of particulates, provides physicochemical pollutant removal processes such as adsorption, fixation, precipitation, supports vegetation growth and microbial community and enables infiltration of greywater/stormwater. In the case of stormwater, it reduces the magnitude of the outflow hydrograph.	4.2.3. 4.2.5
Transition layer	Provides a bridging layer to prevent migration of fine particles from the upper filter media to the gravel drainage layer.	4.2.5
Drainage layer)	Allows the system to drain, also provides higher porosity to temporarily store stormwater/greywater between pores.	4.2.5
Collection pipe)	Underdrain formed with slotted pipe and used to drain and collect effluent from the system.	4.2.4
Raised outlet, creates submerged zone	Allows storage in the lower portion of the biofilter, increasing moisture availability for plants and prolonging water retention time for enhanced pollutant removal. Recommended in systems likely to be non-operational (that is, not receiving inflows) for long time periods and for hot climates. Is adjustable to allow system to drain for maintenance.	4.2.7
Liner	Prevents exfiltration of water to surrounding soils	4.2.4

¥Applies to dual-mode living wall system only

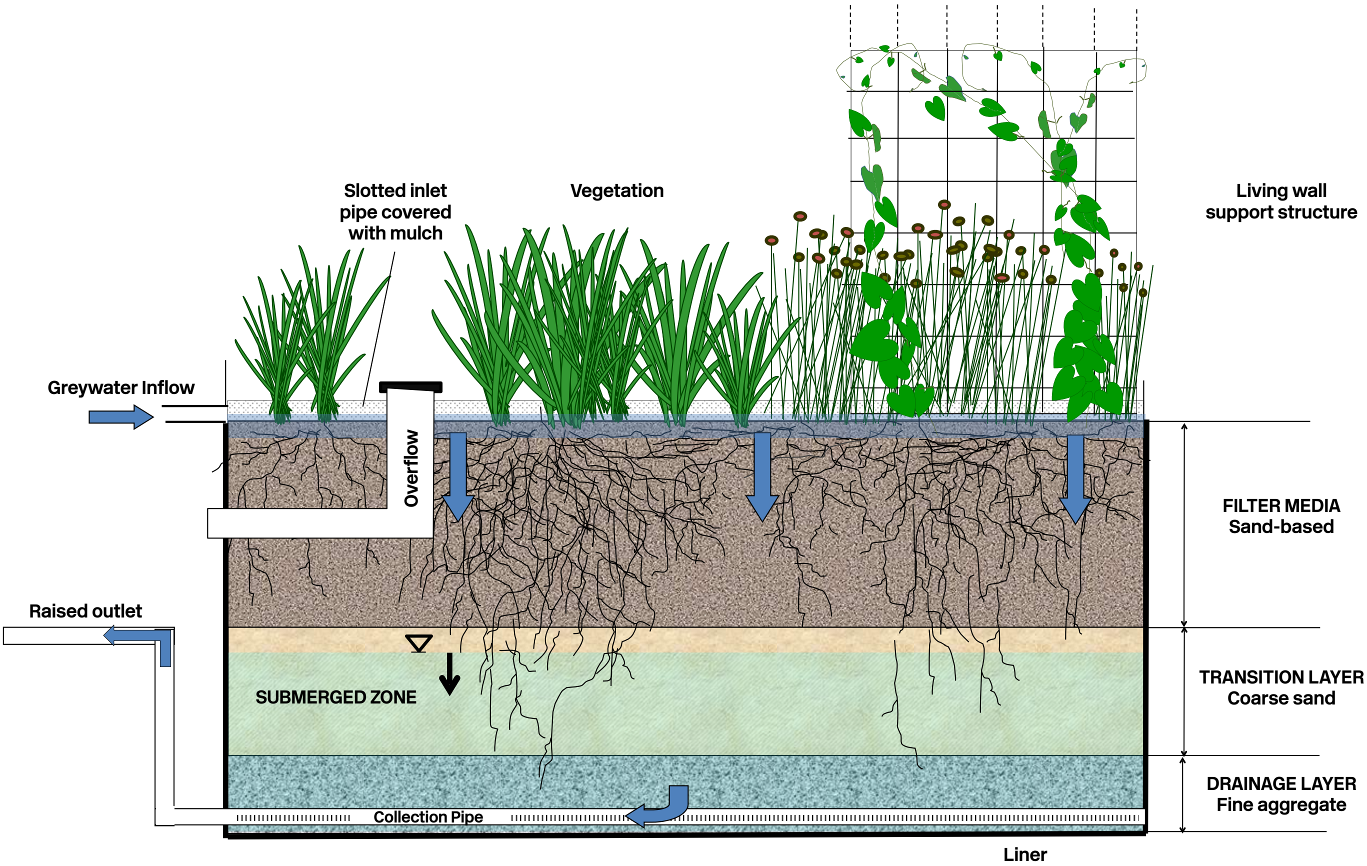

Figure 4.4 Key living wall design parameters. A dual-mode system will also feature an inlet for stormwater flow into the system.

Figure 4.5 Overview of the design process for greywater living wall systems after the system has been found to meet site-specific objectives

4.2.2 Pre-treatment

Pre-treatment is essential to screen out coarse particles (e.g. hairs) before entry of the greywater into the biofilter. This is important to avoid pre-mature system failure as a result of filter media clogging. Therefore, pre-treatment will prolong biofilter lifespan and facilitate maintenance. Examples of suitable pre-treatment devices are 0.3-1 mm square shaped mesh, plaster/solid traps under washing basins and hair traps. Their design should allow for periodic cleaning.

Dual-mode system

The dual-mode system will include two distinct pre-treatment devices for stormwater and greywater respectively. Pre-treatment of stormwater prior to entry into the biofilter could be facilitated by a grassed buffer strip, sediment forebay, sedimentation pond or sedimentation pit/tank.

4.2.3 Filter media area

Sizing of the living wall biofiltration system is intrinsically linked to the design hydraulic loading rate. This is, in turn, to a large extent dictated by the infiltration capacity of the system. Sizing will vary depending on local conditions (Figure 4.2). Proper sizing will avoid premature system failure as a result of clogging, poor plant growth and extend the lifespan of the system where filter media saturation due to pollutant accumulation is concerned. The required size for the greywater treatment system could be determined using the following principles:

1. Determine volume of light greywater generated by the household/commercial building and amount of greywater required to be treated for on-site reuse (metered water usage data collected at the site or estimated using table below).

Estimation of design flows for domestic premises

Design flows per person = 50 L/person/day[1] Total greywater flows per household are estimated based on number of bedrooms: 2 persons for first bedroom 1 person per additional bedroom

[1]AS/NSZ 1547:2012

Estimation of design flows for other premises (commercial buildings - office, business, schools, hotels, etc)

Source	Design flow rates (L/person/day)[2]
Offices, day training centres, medical centres	20
School	20
Premises with showers and toilets • Golf clubs, gyms, pools, etc	50
Motels/hotels/guesthouse • Per resident guest and staff with out-sourced laundry	100

Notes:

These flow rates are indicative only as they apply to total wastewater flows; hence represent an overestimation of actual greywater flows.

In a household, bathroom greywater comprise about 45% of total wastewater flow.

[2]Code of practice – onsite wastewater management, EPA Vic

2. Determine inlet greywater pollutant concentrations.

Table below represents estimates.

Parameter	Concentration (mg/L)[1]
Biological oxygen demand, BOD	76 – 200 mg/L
Total suspended solids, TSS	48 – 120 mg/L

[1]Based on data from 4 'typical' Melbourne Homes reported in Christova-Boal et al., 1996

3. Determine system infiltration capacity.

   a. A filter media infiltration capacity of 200 – 400 mm/h is recommended to support plant growth and ensure the system drains at a sufficient rate to enable re-oxygenation of the media, important to prevent clogging.

   b. Please note that vegetation type will have a slight influence on the influent infiltration rate (Fowdar et al., 2017; Monash Water for Liveability, 2014)

4. Select the hydraulic loading rate.

   a. A hydraulic loading rate (HLR) ranging between 5 – 10 cm/d is recommended. For a temperate climate, the selected HLR would be on the lower end of this range to prevent system failure as a result of clogging. Alternatively, for a tropical climate with more elevated temperatures, the selected HLR would likely be on the upper end.

5. Determine the surface area of the system based on

   a. Design hydraulic loading rate according to the following equation:

$$A = \frac{Qi}{q}$$

where: A = surface area of biofilter, m^2
Qi = greywater inflow, m^3/d
q = hydraulic loading rate (HLR), m/d

   b. Recommended BOD and TSS loading rates according to the following equation:

$$A = \frac{Cin \times Qi}{LR}$$

where: A = surface area of biofilter, m^2
Qi = greywater inflow, m^3/d
LR = BOD/TSS loading rate[¥], $g/m^2/d$
Cin = inflow BOD/TSS concentration, g/m^3

[¥]Based on experimental results (Fowdar et al., 2017),
BOD LR = 12 g $BOD/m^2/d$
TSS LR = 8 g $TSS/m^2/d$

As an example:

Estimated GW inflow per person = 50 L/p/d

Using a HLR of 5 cm/d, influent BOD of 200 mg/L, influent TSS of 120 mg/L, Table 4.2 summarises typical sizing for different dwelling types.

Table 4.2 Typical sizing for greywater living wall system for households

Number of bedrooms	Design flow (L/day)	Required system's surface area (m^2)			Recommended design surface area (m^2)
		Calculation based on HLR	Calculation based on L_{BOD}	Calculation based on L_{TSS}	
1 bedroom (2 persons)	100	2.0	1.6	1.5	2.0
2 bedrooms (3 persons)	150	3.0	2.5	2.2	3.0
3 bedrooms (4 persons)	200	4.0	3.3	3.0	4.0
4 bedrooms (5 persons)	250	5.0	4.1	3.7	5.0
5 bedrooms (6 persons)	300	6.0	4.9	4.5	6.0

Notes

Recommended BOD and TSS loading rates are based on data measured in a temperate climate (Melbourne), with influent concentrations of 110 mg/L and 73 mg/L respectively at a hydraulic loading of 11 cm/d using triple washed sand as filter media and total filter media depth of 100 cm to produce effluent concentrations of < 5 mg/L and <10 mg/L respectively.

Future tests will enable design refinements and allow for a performance based design to be set-up. This will allow prediction of system performance across different hydraulic and temperature regimes.

Dual-mode system

The dual-mode system will be sized as a typical stormwater biofiltration system. Readers are directed to the *Adoption Guidelines for Stormwater Biofiltration Systems* (Payne et al., 2015) for detailed guidance. Key points are summarised below:

- Design flows are used to estimate the dual-mode biofilter size and the following should be estimated:
  - The minor storm event (5 year average reoccurrence interval (ARI) for temperate climates, 2 year ARI for tropical climates, or according to local regulations), to size the inlet zone and overflow structure, and to check scouring velocities;
  - The major storm event (100 year ARI for temperate climates, 50 year ARI for tropical climates, or according to local regulations), if larger storms will enter the biofilter (i.e., are not diverted upstream of the system), to check that erosion, scour or vegetation damage will not occur; and
  - The maximum infiltration rate through the filter media, to size the underdrain. For small systems (contributing catchment area < 50 ha), use the Rational Method to estimate minor and major flows. For large systems (contributing catchment area > 50 ha), use runoff routing to estimate minor and major flows.
- Performance curves, such as those provided in the Water Sensitive Urban Design Technical Design Guidelines for South East Queensland (BCC and WBWCP, 2006), where the surface area can be selected according to the ponding depth and desired pollutant removal performance. The hydraulic conductivity of the filter media should also be considered.
- As a starting point, a dual-mode biofiltration system with a surface area that is 2% of the area of the contributing impervious catchment, a ponding depth of 100 to 300 mm and a hydraulic conductivity of 100 to 300 mm/hr would be a fairly typical design in order to meet regulatory load reduction targets for a temperate climate. Hydraulic conductivity may need to be higher in tropical regions.
- This preliminary design should be refined and adjusted as necessary using a continuous simulation model, such as the Model for Urban Stormwater Improvement Conceptualisation (MUSIC).

It is recommended to verify the above design with that of the greywater system. The final design should be selected based on the most optimum between the two designs.

4.2.4 Hydraulics

Greywater inflows

It is important that greywater inflows to the biofilter are via sub-surface:

- to avoid exposure of the inlet and outlet structures to the atmosphere and thus limit mosquito breeding;
- to better manage human access and;
- to limit algae growth on the filter surface.

Distributed inflows across the system's surface area are preferred to minimise short-circuiting, 'deadzones' and ensure maximum treatment efficiency. Covering the perforated inlet pipe with mulch (e.g. gravel) following its installation over and across the filter surface will help prevent subsurface inlets blockage by plant roots. The greywater discharge pipe (from the household) can be directly diverted to the biofiltration system (after passing through a pre-treatment mechanism) or alternatively captured in a holding tank which discharges into the biofilter either every 20-24 hours or when it reaches a specified threshold (maximum holding time of 24 hours) before 'controlled' discharge into the system.

Please note that untreated greywater cannot be stored for more than 24 hours as it will promote fouling and pose greater health risks as a result of microorganisms growth. Discharge of untreated greywater stored for more than 24 hours into the sewerage system requires council approval.

Dual-mode system

Stormwater inflows to the dual-mode biofilter may be concentrated (via a piped or kerb and channel system) or distributed (surface flow). It is important to deliver inflows so that they are uniformly distributed over the entire surface area and in a way that minimises flow velocity (i.e., avoids scour and erosion, and maximises contact with the system for enhanced treatment). To enhance flow distribution across the surface area, multiple inlet points should be used wherever possible. Critically, all inflow points should be located a maximum distance from the outflow point/s. This prevents short circuiting of the system and ensures maximum treatment efficiency. Comprehensive design procedures for inlet zones are given in Water by Design (2014). However, also refer to local guidelines for design procedures and local council policies to ensure that their requirements for flow widths, etc. are met.

Determination of ponding zone depth

Sufficient temporary storage of stormwater should be provided to meet performance objectives and ensure public safety. The recommended maximum ponding depth above the filter surface is 300 mm to prevent damage to plants and prevent overloading of the filter media (Water by Design, 2014).

High flow bypass

A high flow bypass device to the sewerage system is necessary to prevent overflows and excessive ponding in the event of an oversupply (that is, the household producing excessive amounts of greywater) and during periods of wet weather. High flows can cause problems such as filter media erosion and movement of untreated greywater off-site. An automatic diversion of untreated greywater to sewer must thus be provided in case the system fails as a result of a malfunction.

Dual-mode system

The provision of an extendable/adjustable overflow pipe is recommended. This is because of the different ponding volumes required for stormwater versus greywater (no surface ponding). Stormwater is encouraged to pond on the surface, while greywater should be delivered to the sub-surface with no surface ponding. It is important to remember that an overflow pipe that satisfies the stormwater requirements may be set too high for the greywater requirements.

Treated effluent collection and re-use

Perforated underdrains can be used to facilitate drainage of the system. Slotted PVC pipes are preferable to flexible perforated Ag pipes as they are easier to inspect and clean as outlined in the Adoption Guidelines for Stormwater Biofiltration Systems.

For biofilter lining requirements, a heavy duty flexible membrane such as high-density polyethylene (HDPE) can be used for lining the base and sides of the biofilter (Payne et al., 2015).

The effluent is collected in a raised outlet pipe. An adjustable riser pipe is recommended to enable the water level within the biofilter to be controlled and thereby facilitate maintenance (e.g when complete drainage is required).

The treated greywater can be stored up to 7 days for reuse purposes (irrigation or upon further disinfection for other non-potable uses such as toilet flushing and car washing). A deeper drainage layer could be used in lieu of a separate storage tank if irrigation is the only end use. The marking, labelling and signage of the treatment system (including greywater outlets) and associated irrigation system must be in accordance with standards outlined in section 2.7.

Dual-mode system

As above.

4.2.5 Media

The biofilter filter media is a key design element for reliable system functioning. It has multiple functions, including physically straining of coarse particles from the influent water, supporting plant growth and microbial communities central to biological processes, adsorbing pollutants and maintaining an acceptable infiltration capacity. An engineered media, developed to accomplish the aforementioned functions, comprises three distinct layers (Figure 4.6):

1. The filter media or top layer (sand-based, 600 – 1000 mm or deeper)
2. Transition layer (well-graded coarse sand, ≥ =100 mm deep)
3. Drainage layer (2-7 mm washed screenings, ≥ =50 mm cover over the underdrainage pipe).

The transition layer must have a hydraulic conductivity higher than the overlying filter media while the drainage layer must have the highest hydraulic conductivity for the system to drain properly.

Table 4.3 Recommended media properties

Filter media (top layer)	
Material	Either an engineered material - a washed, well-graded sand - or naturally occurring sand, possibly a mixture
Clay & silt content	< 3% (w/w)
Grading of particles	Smooth grading – all particle size classes should be represented across sieve sizes from the 0.05mm to the 3.4mm sieve (as per ASTM F1632-03 2010)
Nutrient content	Low nutrient content Total Nitrogen (TN) < 1000 mg/kg Available phosphate (Colwell) < 80 mg/kg
Organic matter content	Minimum content ≤ 5% to support vegetation.
pH	5.5 – 7.5 – as specified for 'natural soils and soil blends' in AS4419 – 2003 (pH 1:5 in water)
Electrical conductivity	< 1.2 dS/m - as specified for 'natural soils and soil blends' in AS4419 – 2003
Particle size distribution (PSD)	Note that it is most critical for plant survival to ensure the fine fractions are included. Filter media do not need to comply with this PSD to be suitable for use. (%w/w) Retained Clay & silt < 3% (< 0.05mm) Very fine sand 5-30% (0.05- 0.15mm) Fine sand 10-30% (0.15- 0.25mm) Medium sand 40-60% (0.25- 0.5mm) Coarse sand < 25% (0.5- 1.0mm) Very coarse sand 0-10% (1.0- 2.0mm) Fine gravel < 3% (2.0- 3.4mm)
Depth	600-1000 mm or deeper
Transition layer	
Material	Clean well-graded sand e.g. A2 Filter sand
Fine particle content	< 2%
Particle size distribution	Bridging criteria – the smallest 15% of sand particles must bridge with the largest 15% of filter media particles: D15 (transition layer) ≤ 5 x D85 (filter media) where: D15 (transition layer) is the 15th percentile particle size in the transition layer material (i.e.,15% of the sand is smaller than D15 mm), and D85 (filter media) is the 85th percentile particle size in the filter media. The best way to compare this is by plotting the particle size distributions for the two materials on the same soil grading graphs and extracting the relevant diameters.
Depth	≥ 100 mm

Table 4.3 Cont.

Drainage layer	
Material	Clean, fine aggregate - 2-7 mm washed Screenings
Particle size distribution	Bridging criteria D15 (drainage layer) ≤ 5 x D85 (transition media) where: D15 (drainage layer) - 15th percentile particle size in the drainage layer material (i.e., 15% of the aggregate is smaller than D15 mm), and D85 (transition layer) - 85th percentile particle size in the transition layer material.
Perforations in underdrain	Perforations must be small enough relative to the drainage layer material. Check: D85 (drainage layer) > diameter underdrain pipe perforation.
Depth	Minimum 50 mm cover over underdrainage pipe

Readers are directed to the Adoption Guidelines for Stormwater Biofiltration Systems (Payne et al., 2015), particularly Appendix C: Guidelines for filter media in stormwater biofiltration systems, for more detailed specifications of the filter media.

Notes

- Correct specification is vital for the system's longevity.
- It is important to ensure that the media complies with design specifications. Avoid over-compaction and ensure media is homogenous to prevent short-circuiting which could otherwise compromise nitrogen removal.
- A transition layer of at least 100 mm is vital to prevent migrating fines from the filter media and plant roots.

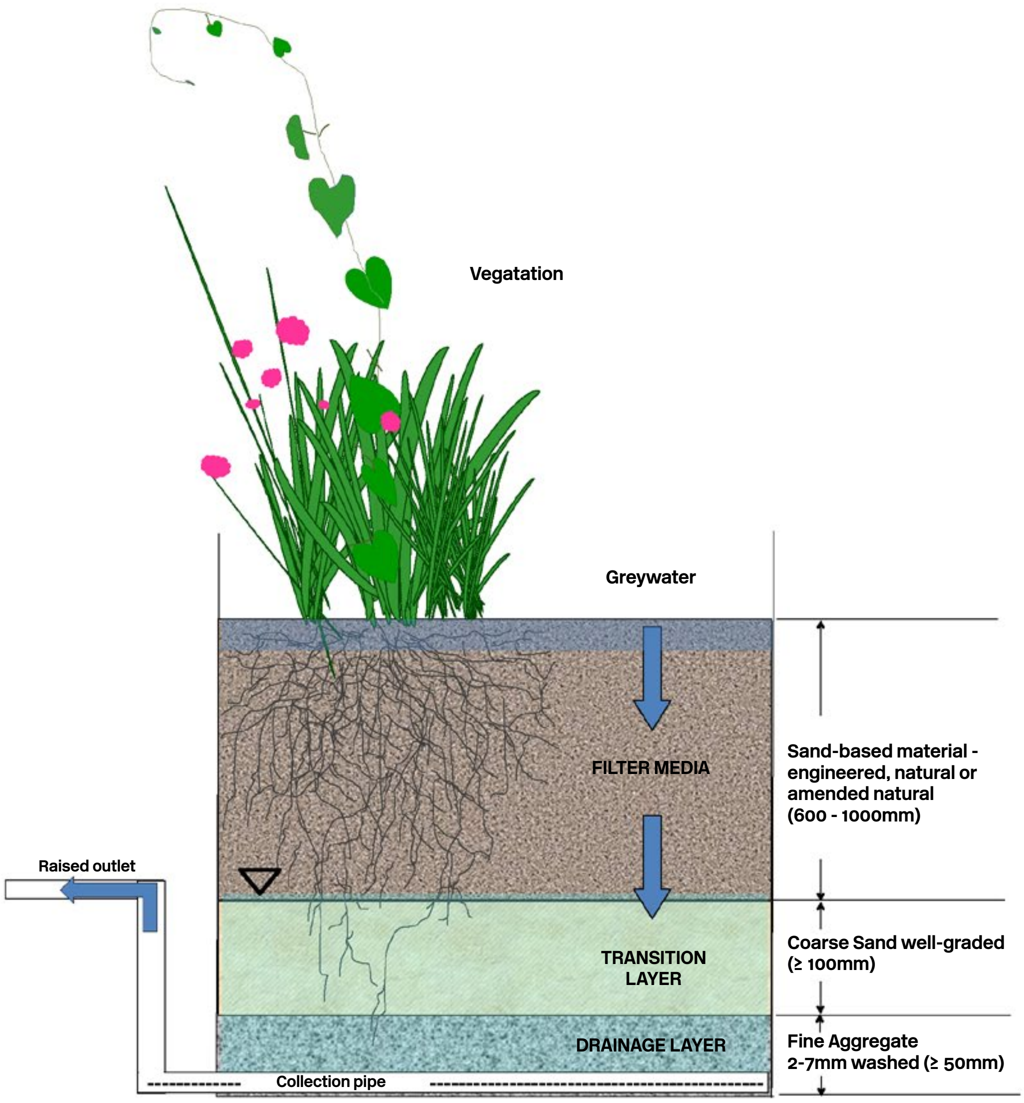

Figure 4.6 Different media layers for living wall system

Dual-mode system
As above.

4.2.6 Vegetation

Plants are a key component of these systems. Their importance in water treatment is already well established (for example, refer to *Vegetation guidelines for stormwater biofilters in the south-west of Western Australia*, Monash Water for Liveability Centre, 2014). In greywater living wall biofiltration systems, plants play a key role in pollutant (in particular, nitrogen and phosphorus) removal as well as in influencing the infiltration capacity of the system (Fowdar et al., 2017). However, plant species differ in their performance. In addition to improving nutrient removal, planting with *effective* species will ensure stable performance and system resilience against fluctuations in loadings and dry periods in the early years of system operation. Plant species selection is guided by the design objectives and local climate.

Table 4.4 provides a list of effective, average performers and non-effective species that have been studied for greywater treatment at the laboratory scale.

Table 4.4 (a) List of plant species studied for their treatment ability under Victorian climate (Fowdar et al., 2017) and (b) Type of climber (evergreen, deciduous, twining or self-clinging)

Objective	Effective	Average performers	Less Effective
Nitrogen removal	*Carex appressa* Canna lilies *Lonicera japonica* *Pandorea jasminoides* (**cl**) *Parthenocissus tricuspidata* (**cl**) *Strelitzia nicolai* *Vitis vinifera* (**cl**)	*Phormium spp.*	*Billardiera scandens* (**cl**) *Phragmatis australis* *Strelitzia reginae*
Phosphorus removal	*Carex appressa* Canna lilies *Lonicera japonica*	*Pandorea jasminoides* (**cl**) *Parthenocissus tricuspidata* (**cl**) *Strelitzia nicolai* *Vitis vinifera* (**cl**)	*Billardiera scandens* (**cl**) *Phormium spp.* *Phragmatis australis* *Strelitzia reginae*
Infiltration capacity	Canna lilies *Vitis vinifera* (**cl**)		
Pathogen removal	*Phormium spp.* *Lonicera japonica* *Vitis vinifera* (**cl**)		

Type of plants		Type of climbers		
Evergreen species	**Deciduous species**	**Twining**	**Self-clinging**	**Tendril**
• *Billardiera scandens* • *Carex appressa* • Canna lilies • *Pandorea jasminoides* • *Phragmatis australis* • *Phormium spp.* *Strelitzia nicolai* • *Strelitzia reginae*	• *Lonicera japonica* (semi-deciduous) • *Parthenocissus tricuspidata* • *Vitis vinifera*	• *Billardiera scandens* • *Pandorea jasminoides*	• *Parthenocissus tricuspidata*	• *Vitis vinifera*

Twining, self-clinging and tendril refer to the ways in which climbers attach themselves to a surface or structure. Climbing plants can be self-supporting, attaching themselves to the vertical surface (self-clinging) or be supported by a structure where they can hold though different mechanisms (e.g. twining, tendril). Tendril climbers attach themselves by means of tendrils on the younger stems; they are climbers with specialised leaves for attachment.

Canna lilies

Lonicera japonica

Pandorea jasminoides

Vitis vinifera in late October

Vitis vinifera in February

Figure 4.7 Examples of effective ornamental species (that is, contributing to biofilter performance) for use in living wall treatment systems

Suggestions for plant species that could be employed in systems in Western Australia include:

- *Hardenbergia comptoniana* – Native Wisteria (WA native species)
- *Kennedia nigricans* – Black coral pea (WA native species)
- *Hibbertia scandens*- Snake Vine
- *Pandorea jasminoides*
- *Trachelospermum jasminoides* – Star Jasmine

The guiding principles for selecting successful plants in greywater treatment system include:

- Using species capable of growing well in sandy soils and under elevated saline environments;
- Using species that have a preference for wet and damp soil environments;
- Using species that tolerate a high nutrient environment;
- Using species that establish quickly and display a moderate to high growth rate;
- Selecting species (applies largely to ornamental plant selection) that are resistant to damage from insects and disease;
- Preferably, selecting species that have fine and extensive root systems (high total length of roots, surface area). They usually are more capable at removing nutrients. More information on desirable plant traits for nutrient and pathogen removal can be found in the *Vegetation guidelines for stormwater biofilters in the South West of Western Australia* (Monash Water for Liveability Centre, 2014) and
- Selecting species that are able to adapt to or are already suitable to the local climate, taking into close consideration the local temperature, wind direction and speed, humidity and evapotranspiration rate. Please note that wind speed will be more of a consideration with vegetation at height.

In addition to the above, plant selection should meet the criteria for successful 'living wall' plants. For example, the following points should be considered when selecting climbing plants:

- Type of support structure, linked to the project objectives (see section 4.2.8);
- The desired height of the living wall structure will govern choice of plant (plants have individualistic maximum height they can reach);
- Aesthetic factors;
- Orientation of the living wall (that is, sunlight, shade conditions preferred by the plant); and
- Preferably select species that are non-invasive to facilitate management and to prevent strangulation of other co-existing species.
- Avoid use of allergenic species.

Climbing plant species ideal for screening will also have the following features (Growing Green Guide - Victorian Guidelines for Green Roofs and Walls, State of Victoria through the Department of Environment and Primary Industries, 2014):

- Retention of lower foliage
- High shoot density
- Pendulous leading shoots
- Tolerance of and recovery from severe pruning (rejuvenation)
- Longevity
- Reliable growth rate

Expectations for overall aesthetics, the speed of coverage and initial growth are important factors to be considered. It is important to bear in mind that some façade systems will require several years' growth before achieving the desired visual impact.

Both evergreen and deciduous species are suitable for use in the living wall treatment system (Table 4.4). Deciduous species have a strong visual change along the year (see Figure 4.7, *Vitis vinifera* – Grape vine). Use of deciduous species has both its merits and drawbacks (Table 4.5) and their inclusion in the living wall system should align with performance objectives. Deciduous species may entail less maintenance in terms of amount of pruning required in a year. Use of deciduous species is not particularly recommended in regions where they can easily be washed into stormwater drains and waterways.

Table 4.5 Considerations for use of deciduous species in living walls

Planting with deciduous species	
Merits	**Drawbacks**
Can contribute to energy-savings due to their ability to shield against the sun in warmer months and allow sunlight/heat into the building during colder months.	May not be visually appealing during winter when they lose foliage – hence not recommended for use near unattractive walls or where purpose is to hide unattractive surfaces/structures. Choice of support systems, e.g. wire arrangement may provide aesthetical appeal in winter when species lose their leaves.
Does not affect treatment efficiency[1]	Increased maintenance to manage leaf litter which could otherwise contribute to organic loading of the system.

[1]Pollutant removal efficiency was not affected during the first year of service (Fowdar et al., 2017)

Botanical name	Common name
Carex appressa	Tall sedge
Canna lilies	Canna lily
Lonicera japonica	Japanese honeysuckle
Pandorea jasminoides	Bower of Beauty, Bower Vine or Bower Climber
Parthenocissus tricuspidata	Boston Ivy
Strelitzia nicolai	Giant white bird of paradise
Strelitzia reginae	Bird of paradise
Vitis vinifera	Ornamental grape vine
Phormium spp.	New Zealand flax
Billardiera scandens	Apple berry
Phragmatis australis	Common reed

Dual-mode system

Effective species for nitrogen removal include *Carex appressa, Strelitzia nicolai,* Canna lilies, *Lonicera japonica* and *Pandorea jasminoides.*

Effective species for phosphorus removal include *Carex appressa, Strelitzia nicolai,* Canna lilies, *Lonicera japonica* and *Pandorea jasminoides.*

4.2.7 Submerged zone

The incorporation of a submerged zone, created by elevating the outlet pipe,

1. ensures there is sufficient moisture in the filter layers to support plants and microbial activities beneficial for water treatment;
2. increases the detention time of water in the system, which improves pollutant removal and;
3. provides water for plant survival during dry (non-operational) periods.

The submerged zone could prevent excess salt accumulation in the root zone which could otherwise occur as the roots dry out during extended non-operational periods.

For the above reasons, a submerged zone is recommended in systems that are likely to be non-operational (that is, not receive greywater) for long time periods (>4 weeks) as well as in oversized systems. The presence of a submerged zone may also be beneficial for pathogen removal in these systems as was observed in stormwater biofilters. The submerged zone is also recommended in warm/hot climates where high evapotranspiration rates and resulting faster drying of the filter media could impact the living wall system and pollutant removal.

A carbon source is potentially not required in this layer as is the case for stormwater biofilters since the greywater biofilters are more organically rich and nitrogen removal will likely be predominantly occurring in the upper filter layers (Fowdar et al., 2017).

Depth of the SZ can be determined from the following equation:

$$dsz = \frac{Qi \times t}{A \times \eta}$$

where: d_{sz} = depth of submerged zone, m
Qi = design flow, m^3/d
T = detention time, d
A = filter surface area, m^2
η = porosity of media

A detention time of 48 hours within the submerged zone is recommended particularly for nutrient removal. At bare minimum, allow for a detention of 24 hours. Higher depths can be recommended for systems which are likely to be non-operational for long periods of time (> 4 weeks).

Dual-mode system

Similar to stormwater biofilters, the provision of a carbon source (e.g. woodchips, 5% by volume) in the submerged zone is recommended. The carbon source is mixed throughout the media within the submerged zone. A submerged zone depth of 450-500 mm is recommended for optimal performance.

4.2.8 Support structure for the living wall

Plants can be grown directly onto the building façade or on a structural system that can be either attached to or separate from the building façade (Figure 1.1 and 4.8). The selection of either option (direct versus indirect façade) will depend on performance objectives (section 3.2) and building envelope characteristics. For instance, a particularly porous or layered exterior surface is not recommended for use with direct climbing vines unless they are well supervised and well-trained; some climbers and woody plants can penetrate through building envelopes, causing cracks and leaks (Wood et al., 2014) in which case an external support system is the most viable option.

The design of the support system is indirectly related to the performance of the living wall system in that firstly, the support system influences plant growth and hence pollutant removal (section 4.2.6) and the system's cooling effect. Secondly, the lifespan of the living wall system is to a certain extent dictated by it. The support structure plays a crucial role in increasing the living wall system resistance to environmental actions such as wind and rain.

Different types of support systems are available such as cables, wires or trellis made of galvanised, or stainless steel or trellis made of wood (timber), plastic or glass fibre products. Each of the above materials will change the aesthetical and functional properties of the living wall structure due to their different weight, profile thickness, durability and cost. **The choice of living wall support structure will depend on plant selection (that is, the growth habit of plant species; see Table 4.4(b)), the intended life span of the system and the spacing and offset from the wall.** For instance, steel structures and tensile cables will be the preferred support structure to hold climbing plants with denser foliage and to support their weight.

To design for weight loading of the support structure (or load-bearing capacity of the building if no support is used), the loading of the climbing plants (at plant maturity) should be considered. This varies across plant species. For instance, Jasmine carries a weight loading of 6-12 kg/m^2 while ornamental grape vine bears a higher loading of 12-26 kg/m^2 (Department of Environment and Primary Industries, 2014).

The design of the support system (including wall fixing) for heights greater than two storeys will follow conventional structural engineering design which should be verified by a structural engineer. Structural materials should be carefully selected to avoid corrosion and resulting adverse effects on plant health (Wood et al., 2014). Cross-wires could be a viable option when use of deciduous species is considered to maintain the aesthetic appeal of the system during seasonal senescence (loss of leaves) in winter.

Fundamentally, the choice of support system will affect maintenance (replacement) costs. It is pertinent that supports are installed to appropriate size for the species used, are of sufficient strength, are adequately fixed to the building and allowances are made for plant development (Dunnett and Kingsbury, 2008). Installation of the living wall structure should also consider access for maintenance.

While the present guidelines are not intended to provide advice on the design of structural elements, readers are referred to the living wall references outlined in Chapter 1.

a) Single cable

b) Stainless steel/metal trellis

Figure 4.8 Examples of support systems for climbing plants

Dual-mode system

As above.

4.3 Installation and establishment

Ensuring good construction and establishment practices are important to reduce maintenance requirements and eventual system costs as well as to promote the biofilter life-span. Effective and reliable greywater and stormwater treatment performance will also be heavily reliant on constructing as per the specified design.

These guidelines are not intended to provide detailed construction protocols or drawings. Readers should refer to the Adoption guidelines for stormwater *biofiltration systems* (2015) and the Water by Design *Construction and Establishment guidelines* (2009) for practical advice for construction of the biofilter as well as the *Urban Green cover in NSW Technical guidelines*, Office of Environment and Heritage (2015), the Growing Green Guide and Planting green roofs and living walls by Dunnett and Kingsbury 2008 for guidance on installation of the living wall structure.

Good construction protocols will encompass

- careful vegetation planting and establishment (following the guidance of a horticulturist),
- filling with layers of filter media as per design specifications;
- avoid the use of filter media material that is high in organics and nutrients (will have a higher incidence of leaching and will negate pollutant removal performance);
- correct installation of the support system for the plants;
- correct installation of the biofilter liner;
- ensure installation of pipes complies with plumbing codes (for example, materials used in plumbing for greywater treatment and diversion systems must comply with AS/NZS 3500;
- ensure proper interpretative and warning signage for the greywater system.

When installing on a new building, it is good practice to design the project so that the green wall is installed in the final stages of construction to prevent any damage to the system.

For retrofit applications, be sure to clean the wall, provide clear access to site and check the structural integrity of the wall before installation.

Planting and establishment

Given that establishment of a healthy plant cover across the biofilter is vital for effective long-term performance, below are some tips to promote plant growth:

- Use high quality planting stock.
- When planting, consider seasonal conditions (for example, it is best to plant between autumn and early spring) which could otherwise lead to more difficulty in plant growth.
- Supplement the upper 100 cm layer with fertiliser if necessary to support plant growth during the initial establishment phase (see Adoption guidelines for *biofiltration systems*, Appendix C: Guidelines for filter media in stormwater biofiltration systems).
- Irrigate with tap water or recycled water during the initial plant establishment phase. Aim for a minimum establishment irrigation period of 6 months to avoid moisture stress and to promote plant growth across the site during this time and ensure plants are watered frequently.
- Implement a maintenance schedule consisting of timely weed control.
- Ensure a minimum establishment period of 6 months before commencing irrigation with greywater.

4.4 System operation

For effective and reliable long-term performance, it is strongly recommended that the living wall treatment system is operated intermittently, that is, allowance be made for small rest periods between greywater applications. Doing so will ensure re-oxygenation of the upper filter layer, vital for enabling aerobic degradation of organic matter, averting system (biological) clogging and preventing odours. While this should not be an issue in typical households where the greywater flow and frequency varies over the day, in instances where greywater is generated continuously over the whole day, it is recommended to pre-store greywater in a tank (that can easily be purchased off the shelf) for ‘controlled’ discharge into the living wall treatment system. The untreated greywater can only be stored for up to 24 hours.

Following treatment, it is recommended to store the greywater in a tank that is not completely air sealed. This is important to re-stabilise the oxygen levels in the treated water to atmospheric level.

The treatment system would be resilient (that is, performance will not be significantly affected) if it does not operate (for e.g. while building occupants are away) for a total period of 2 weeks depending on plant species (section 4.2.6) and with inclusion of a lower submerged zone. However, longer non-operational timeframes may affect plant health, dry out the filter media, and consequently impair pollutant removal. The first flush of water after re-wetting would not be suitable for reuse and should then be diverted to the sewer. Where this is likely to be frequent, an alternative method of irrigation should be provided. Diverting stormwater in the system may be considered.

The system is robust to fluctuations in influent greywater concentrations depending on planted species (see section 4.2.6) in the early years of system operation. For subsequent years of service, this needs to be confirmed by further investigations from field-scale systems.

To lengthen the lifespan of the system, Table 4.6 provides recommendations of products that are best avoided when the treatment system is directly connected to the bathroom drain (or the system is on line). It should be noted that although these systems will work with conventional products, it is highly recommended to use environmental friendly products (including detergents). When using drain unblockers, make sure to flush with plenty of water. The use of an oxidation/reduction probe (ORP) could be used to detect oxidising disinfectants to automatically divert to sewer.

Table 4.6 List of household products that should be used minimally to ensure successful long-term performance of the treatment system

Products	Risks	Recommendations for diversion into greywater treatment system
Bleaches (including hair dyes)	Chemicals will affect the soil's ability to assimilate nutrients or water leading to vegetation loss. Excessive levels of salt will degrade the media's structure, permeability and pH leading to vegetation loss.	Not recommended Flush with ample water if used
Detergents (containing boron, borax, chlorine, sodium perborate, and sodium trypochlorite (salts), sodium tripolyphosphates (STPP), acids)		Recommended to use garden-friendly detergents (that is, easily biodegradable products – always check label before use). Choose detergents that comply with the Australian Industry Standard of < 7.8 mg/L of P.
Products used to clean drains		Not recommended Divert flow to sewer if used
Paints		Not recommended
Automotive oils and greases		Not recommended
Chemicals in general		Not recommended
Pharmaceuticals		Not recommended

Dual-mode system

To date, two operational modes for the dual-mode systems have been tested at Monash University: *Parallel Mode* and *Sequential Mode*.

In **parallel mode**, the system receives stormwater and greywater on alternating days, that is, the system treats greywater on all days throughout the year except on wet days when stormwater is diverted into the system.

In **sequential mode**, the system receives stormwater during wet months and greywater during dry months. This is directly relevant to single-mode stormwater biofilters operating in climates with long dry weather spells. This is also the preferred operational mode as research showed that treatment performance is more stable in sequential mode than in parallel mode.

In parallel mode, rest periods will need to be tightly controlled to ensure the system is not overloaded and to cope with the change in source water (i.e. impact of switching between stormwater and greywater). Based on the climate and stormwater inflows, rest days should be incorporated into the weekly flow regime to allow the system to recover. A minimum of two days per week of no water treatment is recommended. A combined storage tank would be appropriate to store the treated water for re-use purposes as it would be difficult to differentiate between treated stormwater and treated greywater.

In sequential mode, rest periods may occur more organically with stormwater inflows (i.e. stormwater enters the system passively). Rest periods, for example for a week, before switching to greywater and then back to stormwater are recommended. Depending on space constraints, either separate or combined storage tanks can be used for storing the treated water.

Chapter 5

Maintenance and Monitoring

5.1 Maintenance

Routine maintenance of a living wall treatment system will ensure the system functions effectively both in the short and long term. Effective inspection and maintenance programs can reduce system costs by minimising expensive rectification works (due to the system under-performing) as well as system failure (Payne et al., 2015). A maintenance plan must be considered at the design stage when planning and budgeting. It is critical to include access for maintenance works (namely, weeding, replanting and regular inspections) in the maintenance plan. For example, for buildings taller than 10 m, provision of a stable area of paving for vehicle access near the base of the wall to deliver and remove lifting device should be considered.

In cases where the maintenance of the connecting façade or windows will be undertaken by an external agent, ensure adequate signage and training about the purpose and operation of the living/green wall treatment system, is in place to guide maintenance contractors (for example, as to which precautions to take and products to use to prevent interference with the treatment system; see sections 2.6 and 4.4). It is recommended that living or green wall maintenance services be undertaken by the same company that installed the system.

Examples of typical inspection and maintenance tasks and frequencies are outlined in Table 5.1.

Table 5.1 Examples of typical inspection and maintenance tasks and their frequencies

Horticultural tasks
Plant health Ensuring healthy plant growth is key to both the success of the treatment system and for aesthetics purposes. Inspect plants for signs of pests or disease and treat as needed using environmentally sustainable techniques. Inspect plants after severe weather events (e.g. wind, heat) to look for signs of stress. Control weeds by manually removing, avoiding the use of herbicides. If needed, use environmentally sustainable herbicides. When pulling woody or deep rooted weeds, minimise disturbance to filter media. **Frequency – 3 MONTHLY OR AS DESIRED FOR AESTHETICS AND AFTER SEVERE WEATHER EVENTS (WIND, HEAT ETC.)**
Removal of dead/dry vegetation Plant debris/litter may add nutrients to the system upon decomposition (especially in the case of deciduous species) and block drains. Check for and remove as necessary. **Frequency – 3 MONTHLY OR AS DESIRED FOR AESTHETICS AND DURING AUTUMN**
Pruning Pruning is essential to promote new plant growth and ensure plant coverage across the entire wall surface. Pruning also promotes transpiration. Tangled plant growth can lead to masses of stems which can cause overloading with additional wind pressure. Inspect and prune plants to prevent tangled growth, self-strangulation and unattractive growth as well as growth into window fittings or into gutters, or where they should not be going. Cut back shoots that are near sites where they could penetrate between materials in the building and damage wall structures. Note that deciduous species will require less pruning over a year. **Frequency – EVERY SECOND MONTH OR AS NECESSARY DEPENDING ON PLANT TYPE, AGE AND WALL ORIENTATION**

Horticultural tasks
Training of young climbers onto support Inspect young climbers to monitor their growth and train plants onto support where necessary. **Frequency – ONCE IN 2 YEARS**

Filter media tasks
Check for unusual odours, surface ponding and runoff, fine sheet of clay (from surfactants deposition) covering surface, waterlogging. Waterlogging could be accompanied by mosquito breeding which is highly undesired. Rectify by making sure infiltration through the filter media is not obstructed and the diversion to sewer mechanism (overflow) is working. Manually remove fine sheet of clay on surface or scarify the surface between plants. **Frequency – 3 MONTHLY**
Check for suspended solids and litter accumulation on the media surface. Remove litter to ensure infiltration capacity of the system is not compromised. Check whether the upper layer drains completely between greywater applications. This may otherwise cause clogging and minor algae growth at the surface (as the water is nutrient rich). **Frequency – 3 MONTHLY**

Drainage tasks
Ensure that the inlet pipe, underdrain, outlet pipe and overflow bypass are clear of debris. Check for blockage of underdrain pipes to ensure system is draining as designed. Waterlogging will affect plant growth. **Frequency – 6 MONTHLY**

Other tasks
Pre-treatment filter Clean pre-treatment filter regularly otherwise blockage will result. Replace filter as recommended by manufacturer. **Frequency – AS REQUIRED AND RECOMMENDED BY MANUFACTURER**
Inlet/outlet/storage tank Inspect inlets, outlets, tanks for the presence of mosquito breeding. **Frequency – 3 MONTHLY**

Other tasks
Living wall structural support system Check the supports and fixings of the living wall system to ensure they are in good working condition and comply with the structural engineer requirements. **Frequency – 6 MONTHLY TO ONCE A YEAR DEPENDING ON USE AND LOCATION OF BUILDING**
Building façade Inspect building wall for any damage from water (green wall system) and plants (indirect living wall). It is important to ensure that the building façade is free of moisture and condensation for its structural integrity as per the requirement of the structural engineer. Ideally, a water resistant material would be used on the building surface, e.g. plywood backing in which case the air gap between the support structure and plywood should be inspected monthly for any obstruction and debris). **Frequency – ONCE A YEAR TO CHECK FOR STRUCTURAL INTEGRITY**

Maintenance during establishment period (initial two years after installation)

The environmental benefits of a living wall treatment system will be influenced by plant health. Encouraging plants to develop a thicker canopy may prove effective in enhancing the cooling effects of the building façade (section 2.2) as well as in pollutant removal (section 4.2.6).

Some typical maintenance tasks to ensure plant survival and establishment of a healthy cover during the first two years of operation include:

- Closely monitoring plant health through regular visual inspections;
- Regular maintenance tasks such as weeding on a more frequent basis, pruning as required;
- Training of plants and tying onto supports as required – monthly during the initial growth period then 6 monthly to annually depending on age;
- Checking for plant stress – water stress – ensure a regular supply of water.

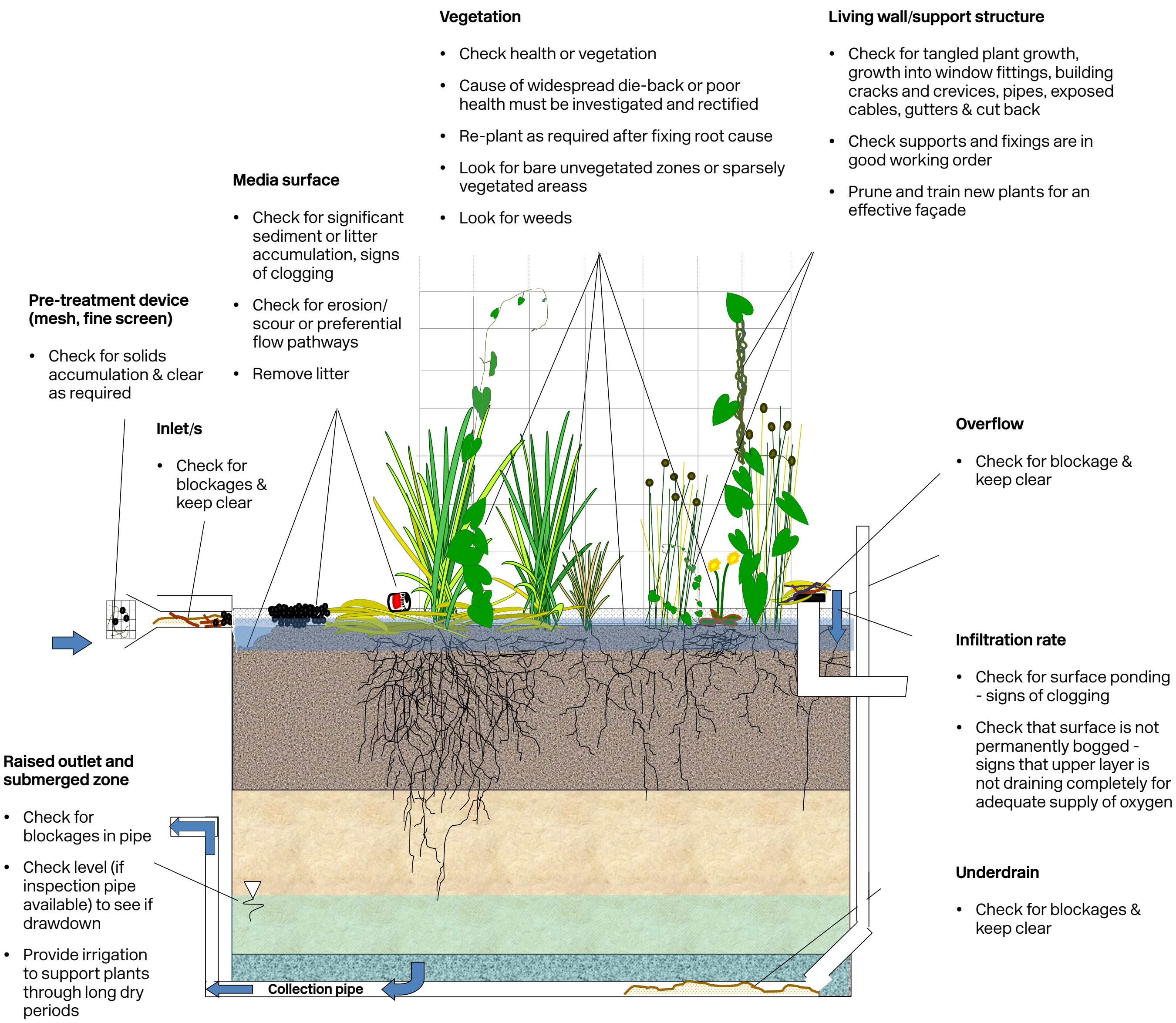

Figure 5.1 – Example of critical checks and tasks as part of a maintenance program for the living wall system

5.2 Monitoring

Monitoring is an important operational tool that:

- Helps identify technical problems;
- Ensures compliance with regulatory requirements, thereby minimising health and environmental risks;
- Provides data for improving treatment performance;
- Enables management of potentially toxic substances before they reach unsustainable levels.

The implementation of a monitoring program is, therefore, desirable. The performance of the living wall can be assessed as follows:

- Qualitative monitoring: regular visual inspections of the system (e.g plant health) during routine maintenance.
- Monitoring soil pH, EC and moisture level as these can affect plant growth. Moisture sensors represent an easy way to determine early on if there are any issues associated with 'deadzones' within the system.
- Measuring the hydraulic conductivity of the filter media (as per Appendix I of *Adoption guidelines for stormwater biofiltration systems*; Payne et al., 2015) to assess the hydraulic performance of the system.
- Collecting water samples to analyse for (1) TSS, BOD and E.coli (inflow and outflow concentrations) and verify that water reuse guidelines are being met and (2) TN, TP and heavy metals to ensure whether targets set during design are being met in line with regulatory standards.
- Conduct soil tests to test the filter media for accumulation of contaminants such as heavy metals.

Chapter 4 of the *Adoption Guidelines for Stormwater Biofiltration Systems* provides additional details for a comprehensive monitoring protocol.

Notes

Monitoring protocol level of detail will vary across systems. If systems are installed and maintained according to best practice, the likelihood of meeting designed targets will significantly increase which may preclude the need for detailed monitoring. Monitoring for compliance with the limitations of the discharge permit (as outlined in section 2.5) represents the minimum sampling and analysis requirements.

Chapter 6

Greywater living wall case study

Eastern Innovation Business Centre Greywater Living Wall
Mulgrave, Victoria

Location: 5a Hartnett Cl, Mulgrave VIC 3170

Completion Date: 2015

Biofilter (trench) area: 20 m²

Background

The Eastern Innovation Business Centre (EIBC) was designed to support new businesses particularly science, technology and research-based businesses. Its business facilities and environmental assets feature innovative technologies and incorporate a number of sustainable energy and water initiatives. Such initiatives include a roof-runoff harvesting scheme which captures roof runoff in several rainwater tanks for indoor non-potable reuses, including toilet flushing, irrigation of an indoor green wall system and for building cooling. A stormwater living wall biofilter harvests and treats stormwater generated on-site which is stored in a lake for on-site irrigation and for maintaining an ornamental water feature. The greywater living wall treats all greywater generated within the building from washing basins and showers. The total volume of greywater to be treated annually is estimated at 205 KL. The Integrated Water Cycle Management (IWCM) system was designed to act as a 'demonstration project' within an urban light industrial context to benefit knowledge capital in IWCM.

The project is a partnership between the Australian Government (through the Regional Development Australia fund), the City of Monash, the Victorian Government, Monash Enterprise Centre, the CRC for Water Sensitive Cities, Melbourne Water, and the Melbourne South East Group of Councils.

Living wall design features

The greywater living wall was constructed on the northern side of the EIBC building. A below-ground trench supports plants that climb up a trellis separate from the building façade.

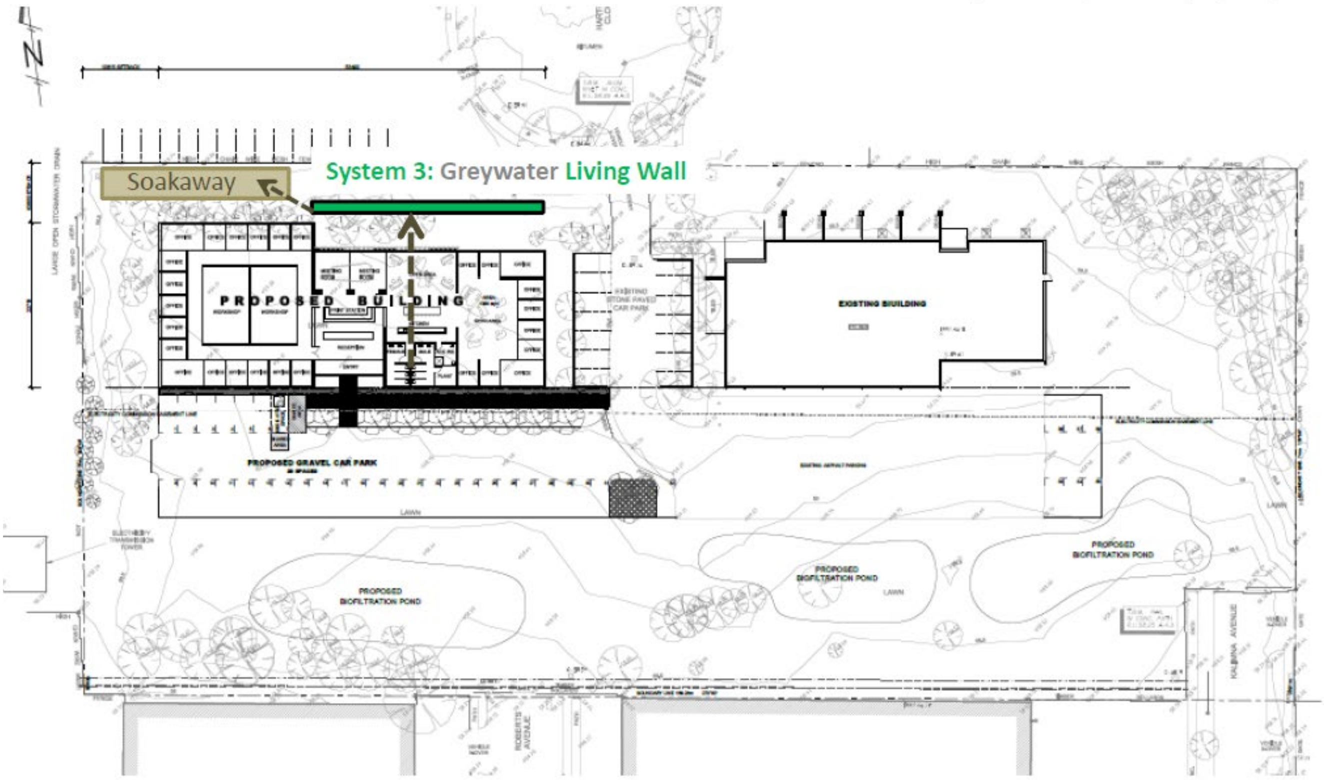

Figure 6.1 Location and design of the greywater living wall at EIBC building in Mulgrave Victoria (Design credit: DesignFlow with input from Monash University)

The greywater living wall has the following design features:

- The size of the trench (biofilter) is approximately 0.4 m in width and 52 m in length.
- The upper 500 mm filter media consists of washed sand and copper zeolite. Copper zeolite was used to improve the pathogen removal capacity of the treatment system. The 600 mm saturated bottom layer comprises washed sand mixed with woodchips. The transition layer (coarse sand) and drainage layer (2 mm gravel) are each 100 mm deep.
- Deciduous vines have been planted to create a living wall for thermal isolation and microclimate improvements. The system is expected to provide shading in summer and allow natural light to enter the building during winter.
- When generated, greywater enters a greywater diversion unit and a monitoring pit before being pumped into the biofilter via a slotted PVC pipe placed directly on the filter surface and covered with 50 mm thick mulch. The system has a slotted underdrainage pipe and is currently designed to discharge all effluent into the sewerage system.
- A protective liner extends across the floor and up the sides of the retaining structure.

Plant species

Trachelospermum jasminoides (Star Jasmine)
Vitis vinifera (Ornamental Grape vine)
Dietes (Wild Iris, Butterfly grass)

Trachelospermum jasminoides

Vitis vinifera

Dietes

Figure 6.2 Plants species used to create the living wall on the EIBC building in Mulgrave (Source for Trachelospermum: Luca Camellini, source for Vitis: Jon Sullivan)

Maintenance

Since the system is currently not receiving the designed volume of greywater (as the centre has not reached full occupancy), it is irrigated with tap water from time to time, particularly during the summer months.

A pump malfunction in October 2015 resulted in substantial plant die-off during the summer of 2015/16. Following plant replacement, the system has since recovered with healthy vegetation growth. Weed removal has also been part of system maintenance.

Analysis

The systems are currently being monitored for E.coli, nutrients and heavy metals. Preliminary results are inconclusive as inflow E.coli concentrations are currently low. More performance data would be available in the near future as monitoring continues.

Figure 6.3 Living wall at the EIBC building

Figure 6.4 Climbing plants forming part of the living wall at the EIBC building

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Appendices

Appendix 1 - Research underpinning the green treatment technologies guidelines

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Notes

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