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Integrated multi-functional urban water systems: key findings from project C4.1

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Integrated multi-functional urban water systems: key findings from project C4.1
Integrated multi-functional urban water systems (Project C4.1)
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Table of contents

1 Introduction, aim and objectives

The traditional use of water in our cities severely distorts the natural water cycle, consuming potable water for purposes such as toilet flushing and irrigation, whilst discharging excessive volumes of stormwater runoff and wastewater. Water Sensitive Urban Design (WSUD) offers a new approach to urban water management, providing water treatment and harvest for reuse using green technologies such as constructed wetlands and biofiltration systems (bioretention or raingardens). In addition to waterway protection, these multifunctional systems also enhance the local microclimate, biodiversity, aesthetics and liveability of urban landscapes.

While the benefits of the existing technologies are well documented, particularly for stormwater treatment, there are multiple other polluted water streams in the urban environment. These include greywater, treated wastewater and polluted groundwater, whose characteristics differ substantially from stormwater (e.g. in composition, volume and frequency). In addition, pollutant removal performance, particularly for nutrients, may vary depending upon design, hydrological conditions and vegetation characteristics. In particular, prolonged dry periods between stormwater inflows presents a challenge for the adoption of biofiltration systems in dry climates. Instead, other wastewater sources could be treated in hybrid (or dual-mode) biofiltration systems to provide water treatment and prevent severe desiccation of the system during dry periods.

Uncertainty also surrounds the use of constructed wetlands in sandy environments interacting with high-nutrient shallow groundwater, such as the Coastal Plain in Perth, Western Australia. Further understanding of the processes and pathways of nutrient and contaminant assimilation, and how they respond to extremes in flow variability, is required to enable managers to further optimise wetland design and operation.

This project aimed to deliver hybrid systems capable of treating multiple water sources within urban landscapes. This was achieved by further optimising stormwater biofiltration technology and wetland systems, and developing new technologies. Two outcomes were key for the project – technology delivery and the development of adoption guidelines, addressed by the following objectives:

1. To understand and optimize wetland systems for treatment of urban stormwater to support protection of waterways, with the Coastal Plains of WA as a case study;

2. To optimise stormwater biofilters for treatment of (partially-treated) wastewater and/or polluted groundwater;

3. To develop hybrid biofilters that can treat wastewater and/or polluted groundwater during dry weather and capture and treat stormwater during wet weather and deliver improvements;

4. To develop adoption guidelines for this new generation of WSUD systems.

As multifunctional systems, the additional aesthetic, amenity and microclimate benefits provided by green water treatment infrastructure are critical to their adoption. This project also aimed to enhance these attributes by incorporating climbing plant species within biofiltration systems to create ‘living walls’, testing the performance of ornamental plant species and the development of green walls for greywater treatment. Green walls are increasingly popular in our dense urban environment, but in standard design they consume large volumes of potable water daily. Importantly, the fundamental design of these green wall systems differs substantially from biofiltration, and required the development of entirely different lightweight media, plant species and operational protocols.

The project involved multiple large-scale laboratory experiments testing design parameters and operational conditions, modelling simulation, and validation by the construction and monitoring of field systems. Experiments tested the performance of biofiltration systems treating greywater, hybrid biofiltration systems variously treating greywater and stormwater, and green walls treating greywater. Process-based studies were also conducted to better understand pollutant fate and inform system management. A wide range of design parameters were tested across these experiments including plant species, plant presence (i.e. using non-vegetated controls), the presence or absence of mycorrhizal fungi (which may enhance plant nutrient uptake), the use of a supplementary carbon source to support denitrification, green wall media, design configuration and inflow frequency.

At the field scale, biofiltration systems were constructed and monitored at the Eastern Innovation Business Centre (EIBC) in partnership with Monash City Council. Collaboration with industry has been paramount to the project and knowledge transferred through the creation of adoption guidelines, journal and conference papers, and presentations at conferences, seminars and training workshops. In particular, an industry advisory panel was set-up, comprising of stakeholders across different states to provide expert input during the review stage of the adoption guidelines.

The wetland study analysed data from ten years of monitoring within a Perth Coastal Plains wetland system. This was used to develop an ecohydrological model to simulate groundwater interactions, wetland metabolism, nutrient attenuation and flow dynamics, including response to prolonged no-flow periods. The high-resolution model integrates multiple aspects of wetland function to support design and maintenance. The findings on this project's component are being reported in a separate report prepared by the University of Western Australia.

The current report presents the outcomes resulting from the above research in line with the project's objectives. It is divided into four distinct sections, namely, green treatment technologies (which provides performance data from laboratory studies together with practical recommendations on the design, operation and maintenance of these systems); findings arising from field testing of the Monash City Council EIBC biofilter systems; an assessment of the cost-benefit analysis of the aforementioned systems and a review of the different technologies.

Figure 1: **Green water treatment infrastructure provides waterway protection, treated water for potential reuse, amenity, biodiversity, aesthetics and microclimate benefits. This project extended the application of existing technologies to new water sources, developed new technologies and improved our understanding for optimal design and operation to better provide these multiple ecosystem services in our urban landscape.**

2 Green treatment technologies

2.1 Biofilter optimisation of submerged zone for effective nitrogen removal from multiple water sources

Eight different carbon substrates (acetate, brewery waste, brewer's spent grain, cracked corn, rice hulls, cotton wool, softwood and hardwood) were tested for their ability to reduce nitrate concentrations for subsequent amendment in the submerged zone of biofilters. The rate of decrease of oxidised nitrogen concentrations in a pure nutrient solution, light greywater, secondary-treated wastewater and tertiary-treated wastewater was measured in batch scale laboratory studies. It was found that the choice of carbon substrates used can impact on overall nitrogen removal rates. For instance, rates varied by several folds between the most bioavailable (acetate, 48 mg N/L/d) and the least biodegradable substrate (hardwood, 0.3 mg N/L/d). The type of water source also had an effect on nitrogen removal, the extent of which was dependent on type of substrate. In fact, while substrates such as cotton, rice hulls and the woodchips experienced comparative rates between the pure nutrient solution, secondary-treated wastewater and tertiary-treated wastewater, this was not the case for brewery waste and spent grain. These substrates recorded lower removal rates in the two partially treated wastewaters. From these findings, we concluded that different substrates are not universally suitable for use to treat nitrate from different water sources.

Cotton and rice hulls were found to be potentially promising substrates for use to augment nitrogen removal in biofilters as a result of their adequate oxidised nitrogen removal rates and lower level of leachable nutrients measured. They are recommended for testing under continuous flow conditions.

The results of this study have been published in the following journal paper:

- Fowdar, H. S., Hatt, B. E., Breen, P., Cook, P. L., & Deletic, A. (2015). Evaluation of sustainable electron donors for nitrate removal in different water media. *Water Research*, 85, 487-496.

2.2 Living walls for greywater treatment

Living walls, (also, commonly known as green façades), are vertically-growing climbers that grow alongside a building façade and are rooted in the ground or in containers at the base of the wall. The underground trench or aboveground planter box supporting the vegetation essentially functions as a biofiltration system. As such, these systems represent an extension of biofiltration systems previously developed for stormwater treatment. Laboratory based research was performed to develop living wall systems that could treat greywater and at the same time employ a larger variety of plant species (ornamental flowers, climbing plants, deciduous and evergreen species). A large scale laboratory column study was undertaken over a period of one year whereby the performance of different designs (plant species, submerged zone configurations) as well as operating conditions (hydraulic loading rate, dry period, high inflow concentrations) were tested. Preliminary results found that nitrogen and phosphorus removal to vary a lot across plant species. Two process-based studies were initiated to investigate the processes governing their removal in these systems:

1. ^{15}N tracer was used to quantify extent of nitrogen removal through denitrification;
2. A mass balance method and the ^{32}P radiotracer were used to quantify the fate of phosphorus in the different biofilter storages.

Figure 2: Living wall columns at Monash University greenhouse facility

The results of this research identified living walls incorporated within urban areas to be a promising technology for on-site greywater treatment. This work showed that high suspended solids and organics removal (>80% for total suspended solids (TSS) and >90% for biological oxygen demand (BOD)) can be achieved in these systems. High nitrogen removal (about 80%) can also be achieved dependant on plant selection. Phosphorus removal will vary to a larger extent and will be heavily reliant on effective plant selection. Based on the results, an operational loading rate of 55 mm/d (or less) is recommended for a temperate climate such as Melbourne. Depending on plant type, the system should be resilient to fluctuations in operating conditions (such as rest periods of up to 2 weeks depending on climate, loading rates, higher pollutant loads).

Nitrogen retention in biofiltration systems was found to be primarily driven by assimilation and adsorption processes. Regarding phosphorus retention, the mass balance study found that most of the phosphorus to be stored in the plants (about 60%) while the rest was found in the top layers of the filter media. Therefore, both filter media and plants are important for phosphorus removal in biofiltration systems. Media with sufficient adsorption capacity to retain phosphorus and plants with effective rooting system to scavenge the phosphorus adsorbed are some of the design recommendations for effective phosphorus removal in biofiltration systems. Moreover, since most of the phosphorus in the study was recovered in the *Carex appressa* shoots, pruning of the aboveground biomass could constitute an effective phosphorus management strategy within biofilters.

The implications of this work and practical guidance on the design, operation and maintenance of these systems have been collated in the form of a guideline document (CRCWSC Adoption Guidelines for Green Treatment Technologies). A summary of the guideline document is presented here.

Living wall treatment systems can satisfy multiple objectives, including reducing the urban island heat effect, increasing amenity value, improving human health and wellbeing and productivity and beautifying the surrounding environment. The system developed can effectively reduce wastewater flows and improve water quality for re-use purposes. Currently, these systems satisfy regulatory limits imposed for restricted non-potable urban uses. With a post-disinfection unit, re-use applications can be extended to other uses such as unrestricted irrigation and toilet flushing. System sizing will vary depending on household/building greywater flow and quality, filter media properties and local climate. Typical minimum sizing of the biofilter for a system in Melbourne is around 2 m^2 per 100 litres of greywater generated per day as per the laboratory results. A range of lower storey ornamentals and climbing plant species can potentially be suitable for use in these systems for greywater treatment and survival within the greywater treatment system. Examples of successful ornamental species studied include Canna lilies, *Lonicera japonica*, *Strelitzia nicolai*. Examples of successful climbing species studied include *Pandorea jasminoides* and *Vitis vinifera* (grape vine). However, a range of species could be applied to the living wall treatment system. More details about the characteristics and detailed suggestions for suitable species can be found in the Adoption Guidelines. A permanently submerged zone at the bottom of the biofilter is highly recommended to allow for a detention time of at least 24 hours for additional pollutant processing. If designed correctly, these systems will likely be resilient to minor fluctuations in operating conditions such as dry periods, varying influent greywater flow and loads. Further recommendations on operation and maintenance of these systems can be found in the adoption guidelines.

The following publications have resulted from the above research:

- Fowdar, H., Hatt, B.E., Breen, P., Cook, P.L.M., Deletic, A. (2017). Designing living walls for greywater treatment. *Water Research*, 110, 218-232.
- Fowdar, H. S., Hatt, B. E., Cresswell, T., Harrison, J. J., Cook, P. L. M., & Deletic, A. (2017). Phosphorus fate and dynamics in greywater biofiltration systems. *Environmental Science & Technology*, 51(4), 2280-2287.
- Fowdar, H.S., Deletic, A., Hatt, B.E. and Cook, P.L. (2018). Nitrogen Removal in Greywater Living Walls: Insights into the Governing Mechanisms. *Water*, 10(4), 527, doi: 10.3390/w10040527.

2.3 Hybrid living walls for stormwater and greywater treatment

Studies were conducted on the laboratory columns (Figure 2) in order to quantify the treatment performance of the living wall system when used in dual-mode, that is, for the treatment of both stormwater and greywater (hybrid living walls). Two operational modes were tested: (1) *Parallel mode* (i.e. the system treats greywater on all days throughout the year except on wet days when stormwater is diverted into the system); (2) *Sequential mode* (i.e. the system receives stormwater during wet months and greywater during dry months). This was simulated experimentally as follows: in parallel mode, the system received greywater and stormwater on alternative days (i.e. 2 days stormwater, 3 days greywater and 2 dry days during a given week). In sequential mode, the system received stormwater-only for about 4 months (autumn/winter) and greywater only for about 3 months (winter/spring).

Overall, pollutant removal performance in sequential mode was higher than in parallel mode. Variation in inflow volume and concentrations are heightened during parallel mode, resulting in a reduction in overall performance. This causes leaching in the presence of poor performing plants. In contrast, systems planted with effective plant species (i.e. those rendering high removal performances) were not significantly affected by operational mode. The most effective species were *Carex appressa* and Canna lilies. *Strelitzia nicolai*, *Lonicera japonica* and P*andorea jasminoides* will also deliver an acceptable performance. It is recommended to include at least 50% of effective species. When planted with effective species, removal efficiency for TSS, total nitrogen (TN) and total phosphorus (TP) will exceed 70% (sequential mode) and heavy metals removal is higher at >90%. Sizing of the biofilter will typically follow same principles as stormwater biofilters (Payne et al., 2015). If using the system for stormwater diversion during wet periods and greywater diversion during dry periods, it is recommended to leave a short rest period (e.g. 1 week) before switching between water sources otherwise pollutant removal will be compromised.

When compared with stormwater biofilters (biofilters that exclusively treat stormwater), the hybrid systems will produce a comparatively lower pollutant removal performance. These systems can however still be effective and meet removal targets, although, plant selection becomes more important particularly for nutrient removal.

In summary, hybrid living wall treatment systems can be a promising technology provided design parameters (plant species) and operational mode are carefully selected. More information can be found in the adoption guidelines (CRCWSC Adoption Guidelines for Green Technologies for Greywater and Stormwater Treatment). As an example, the hybrid living wall can be installed on the side of a commercial or office building for managing runoff generated from parking lots, roofs and other concrete pathways during wet periods and for treating greywater generated within the building during dry periods.

Two journal papers pertaining to this study are currently being drafted/under review:

- Can we expect more from urban biofilters? The impact of switching water sources and an extended dry period on treatment performance, *in preparation for submission to Water Research*

- Dual-mode stormwater-greywater biofilters: the influence of plant species and water source on treatment performance, *in preparation for submission to Ecological Engineering*

2.4 Green walls for greywater treatment

Green walls are plants growing in boxes or compartments mounted onto wall surfaces but held away from it and separated from the building wall by a waterproof membrane. Research was conducted in laboratory studies to optimise media and design of green walls for greywater treatment. The specific objectives of these studies were to:

- evaluate different lightweight substrates (media) for their hydraulic and pollutant removal performance;
- study performance of different green wall plants to guide species selection;
- study the influence of mycorrhizal fungi on pollutant removal performance and;
- optimise green wall design.

The seven lightweight substrates studied can be grouped into two distinct groups (hydraulically fast and hydraulically slow substrates). Hydraulically fast substrates tested included vermiculite, perlite, growstone, expended clay, and river sand as control. Hydraulically slow substrates comprised coir, rockwool and fyto-foam. Although displaying higher and more consistent pollutant removal performance, slow substrates were found to be prone to clogging. It was therefore concluded that the best media for use in green wall treatment systems would be a combination of both substrate types. Perlite as hydraulically fast and coir as hydraulically slow substrate were found to be the best performers in terms of their pollutant removal performance. Their performance as a mixed substrate in a 2:1 (coir: perlite) ratio was studied in a large scale laboratory experiment (which was more reflective of practice) (Figure 3). A number of design and operating parameters were also tested, including plant species, system configuration, mycorrhizal fungi design, dosing volume, inflow concentration, influent flow rates and rest period. The system was monitored for a total period of one-year for its hydraulic and pollutant removal performance. The system received 30 L of greywater per m^2 of green wall.

Figure 3: Green wall system set-up at Monash University greenhouse facility

Hydraulic performance of the system did not significantly decline over the experimental period, even though some surface clogging was observed. All configurations performed equally well for TSS and COD removal (98% and 95% respectively). TN removal was higher in vegetated columns (90-95%) in comparison to unvegetated columns (85%). *Carex appressa*, *Liriope*, *Nephrolepis* and *Myoporum* were the best performing species. TP removal performance was lower, achieving only around 50-60% removal in systems planted with *Carex appressa*, *Liriope* and *Nephrolepis*. In comparison, the un-vegetated configuration removed only 25% during normal operating conditions. Treatment of pathogens in the system was observed through *E. coli* removal. The green wall managed 1 log reduction of *E. coli*, which is consistent with other vegetated biofiltration systems (Chandrasena et al., 2014).

Changes in inflow concentration and volume did not significantly affect removal, but drying did a have negative impact on overall performance. *Carex appressa*, *Liriope*, *Nephrolepis* and *Myoporum* showed the lowest drop in performance after drying.

Implications of this work: This study showed that green walls can be used effectively for water treatment from residential and office buildings, thereby adding value to these systems on top of their current multifunctional nature (used for temperature regulation and greening and vanity enhancement). The green wall laboratory system has shown that green walls can treat significant volumes of greywater (up to 60 L/m^2 of green wall was tested). Moreover, performance is not severely affected with a change in inflow volume. The robustness of the system was displayed in the effective buffering of sudden influxes of high concentration greywater (which had no significant effect on treatment performance).

Even though most pollutants (except for TP) are effectively removed during the watering of green wall systems, removal of pathogenic E. coli is still not sufficient to comply with greywater reuse standards for toilet flushing

(Table 1). It is therefore recommended that a small disinfection unit (UV or ozonisation) be placed prior to effluent storage for reuse purposes.

Table 1: Comparison of influent and effluent from the green wall to greywater reuse standard

Concentration (mg/L)	TSS	BOD	*E. coli*
INFLUENT	80	115	10^3 - 10^4
EFFLUENT	<2	<3	10^2 - 10^3
STANDARD FOR REUSE*	10	10	10
COMPLIANCE ACHIEVED	√	√	x

*EPA (2013)

Use of simple pre-treatment options, such as settling tanks is also recommended before greywater enters the green wall system. This will help with maintenance, and ensure long operating life of the system.

Colour of the outflow water was strong at the beginning of the experimental period due to inclusion of coco coir in the media mix, but it steadily declined over the period, stabilising at the potable water level within 9 months of the start of the experiment. It has been noted that use of higher inflow volumes (60 L/m^2) reduces the outflow colour, and eliminates the need for colour removal as a post-treatment process.

During the experiment, it was noted that plant selection is crucial for both performance of the system and reducing the cost of maintenance. Even though flowering and scented plants (such as violas) offer high amenity values, they require regular maintenance in order to achieve the highest yield and optimal removal performance. On the other hand, *Carex*, *Liriope* and *Nephrolepis* (ferns) require minimal maintenance over time, and achieve the highest pollutant performance.

This study used watercress (*Nasturtium officinale*) to assess the performance and suitability for use of vegetables in green wall treatment system. Watercress showed above average pollutant removal performance during this study, but as it is a fast growing vegetable, it requires frequent maintenance and pruning. Nevertheless, it shows that green wall treatment systems have the potential to be used for urban agriculture, a new emerging concept of growing food in the urban environment. Green walls can be placed on high residential buildings, providing easy access to pots for continual maintenance by the residents.

The following publications have resulted from the above research:

- Prodanovic, V., Hatt, B., McCarthy, D., Zhang, K. and Deletic, A. (2017). Green walls for greywater reuse: Understanding the role of media on pollutant removal. *Ecological Engineering*, 102, 625-635.
- Prodanovic, V., Zhang, K., Hatt, B., McCarthy, D. and Deletic, A. (2018). Optimisation of lightweight green wall media for greywater treatment and reuse. *Building and Environment*, 131, 99-107.

The following journal papers are proposed for publication:

- Prodanovic, V., Hatt, B., Mccarthy, D., Deletic, A. (in preparation). Designing green walls for greywater treatment: How plant choice and operational factors influence treatment performance. *Water Research*
- Prodanovic, V., Wang, A., Hatt, B., Mccarthy, D., Deletic, A. (in preparation). Assessing water retention and uptake of five plant species in greywater treating green walls used in Australian climate. *Journal of Hydrology*
- Prodanovic, V., Hatt, B., Mccarthy, D., Deletic, A. (in preparation). Optimising design of green walls for greywater treatment: What optimal system looks like and how tall it should be. *Building and Environment*

3 Demonstration and field testing of integrated systems

The CRCWSC has partnered with Monash City Council to conduct field testing at their Eastern Innovation Business Centre (EIBC), which is a complex incorporating multiple sustainable water and energy initiatives. The site (Figure 4) includes (1) a living wall/biofilter system that harvests and treats greywater from the building, and (2) a biofilter with novel filtering media that will treat harvested stormwater, which will then be re-used for passive irrigation. We have been involved in a consultative role throughout the design and construction phase. Knowledge already gained from the laboratory studies, testing optimal carbon sources and the performance of ornamental and climbing plant species has been applied to help design these field systems. Construction has been completed. Monitoring has been conducted for 5 events for the stormwater biofilter and 1 event for the greywater biofilter.

3.1 Stormwater biofilter system

The novel stormwater biofilter treatment system (Figure 4 bottom left) has been installed on the western side of the EIBC to treat stormwater runoff from nearby commercial properties. Stormwater is collected in a large pit and is pumped into the biofilter via an automatic float switch. This system comprises a number of plant species as well as washed sand and copper zeolite (a novel anti-microbial media) as filter media. The filter media trench is encased within a thick waterproof plastic liner and concrete walls. Following purification by the biofilter, treated stormwater flows into a small pond and is recirculated to maintain the ecological function of the on-site water feature. The biofilter has a total surface area of 30 m^2 and is 900 mm deep, consisting of 400 mm washed sand (amended with 100 mm of copper zeolite underlain by 50 mm raw zeolite) + 300 mm washed sand with carbon source + 100 mm coarse sand (transition layer) + 100 mm gravel (drainage layer).

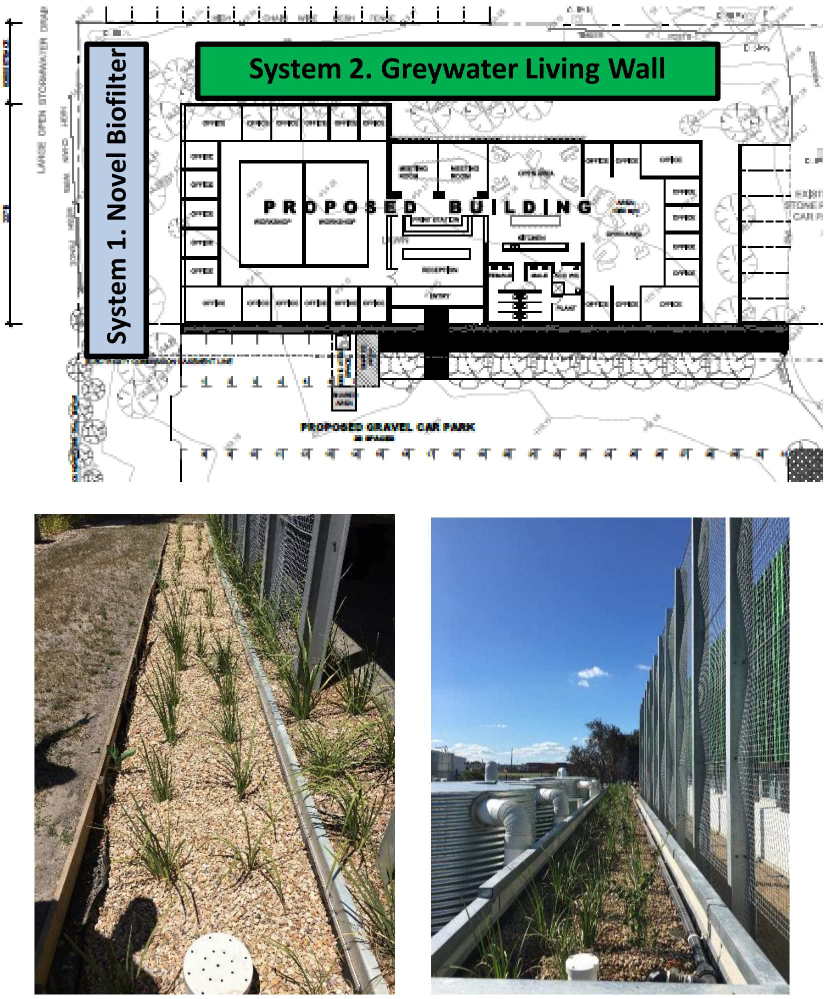

Figure 4: Monash City Council EIBC living wall treatment systems: system positioning within building complex (top); novel media stormwater biofilter (bottom left); greywater living wall (bottom right)

3.2 Greywater living wall

The greywater system (Figure 4 bottom right) is a small vegetated bay on the northern side of the EIBC building. It is fed by used potable water from the hand basins and showers within the building. The water runs into a small pit and is pumped into the greywater bed before it exits into the sewer system downstream. The system is planted with star jasmine, grape vine and wild iris. Media consists of washed sand and copper zeolite (filter media), coarse sand (drainage layer) and gravel (drainage layer). The system has a total surface area of 20 m^2 and is 1100 mm deep. For more details on the characteristics of the system, please see Chapter 6 of design guidelines (CRCWSC Adoption Guidelines for Green Technologies for Greywater and Stormwater Treatment).

Monitoring lessons and learnings: Monitoring was planned to start in November 2015, however, pump issues in the stormwater biofilter and blackwater intrusion in the greywater collection pipe stalled monitoring. Monash City Council addressed the issue after which the stormwater and greywater biofilters resumed normal operation. In May 2016, it was found that the stormwater biofilter was overflowing. As a result of the biofilter liner being too shallow and not properly sealed to sustain the volume of stormwater flowing into the system.

Several individual plants died during the summer of 2015/16, particularly when the pump systems were not operating efficiently. Upon fixing the pumps, all dried plants were replaced. Weeding from time to time has also been part of the system maintenance program.

3.3 Preliminary Results

Stormwater biofilter (Data collected from August 2016 – January 2017; 5 rainfall events)
Influent TSS concentrations ranged from 3.4 – 14 mg/L. Influent TP concentrations ranged from 0.04 – 0.08 mg/L and influent TN concentrations ranged from 0.68 – 1.7 mg/L. TSS removal was always high: in the order of 80-90%. TP removal was recorded in the first 4 rainfall events and achieved up to 50% removal. However, TN removal was compromised due to media leaching caused by the use of fertilisers for plant establishment (this was done without the council or project team recommendation or knowledge). The outflows of TN are improving as the systems are being established. These preliminary findings reinforce the importance of proper media and carbon source selection.

Greywater biofilter (data collected on 13th October 2016)
Influent concentrations were relatively quite low at 12 mg/L (TSS), 0.05 mg/L (TP) and 1.2 mg/L (TN). Small reductions in TSS and TN removal were recorded (8% and 20% respectively). In regards to TP removal, some leaching from the media/carbon source was observed. It is believed these preliminary results are not conclusive since the system encountered some operational issues, such as plant dry off and blackwater intrusion into the influent pipe. Monitoring of the system is ongoing and future results would be able to shed more light on the treatment performance of these living walls at the field scale.

4 Cost-benefit assessment of integrated systems

To assess the cost-benefit of the systems outlined in section 3, two life cycle costing (LCC) assessments were undertaken (1) a **traditional** approach and (2) a **total** approach. The traditional LCC evaluates all of the costs incurred by the system over its life cycle whilst the ‘total’ approach also incorporates the savings incurred from reducing the amount of main water uses and the savings associated with the pollution reduction of the stormwater or greywater. In the case of the greywater system, an additional approach including the savings incurred from reducing the amount of water disposed into sewer was also included (a Global LCC).

Below are the assumptions made to determine the Traditional LCC and ‘Total’ LCC (which includes water savings and nitrogen removal savings) and Global LCC (including the reduction of sewage disposal) for the greywater system:

- A lifespan of 25 years period has been considered for all the systems;
- The inflation rate was set at a=2.9%, based upon average inflation between January 2010 and April 2017 as stated by the Reserve Bank of Australia;
- The nominal discount rate was set at d_n=10%, based on Taylor (2003) and is also the rate used in Brisbane City Council’s assessment of water related assets;
- The maintenance costs were not available and therefore were estimated using the Adoption Guidelines for Stormwater Biofiltration Systems (Parsons Brinckerhoff, 2013; Payne et al., 2015) assuming low maintenance requirements and taken as $16/m^2/yr;
- Decommissioning costs were unavailable. These costs have been estimated at 25% of the ‘Total Construction Cost’. This is due to the relative size of the cost and potential influence of an omission (present at a number of sites);
- The renewal costs are not available for any of the sites. They were estimated to be 25% of the ‘Total Construction Costs’ and it was assumed that renewal will occur mid-way through the life of the system (it was applied in year 13 from construction). This is a significant assumption and will impact on uncertainty of results. However there was no other way to estimate these costs, since information of renewal of these novel systems are non-existent;
- The residual value was estimated to be negligible;
- The default TN concentration of 2.1 g/kL was used and a saving cost of $13.95/kL has been applied for TN removal based on the stormwater offset rate of $6,645/kg (https://www.melbournewater.com.au/Planning-and-building/schemes/offset/Pages/Stormwater-offset-rate-review.aspx);
- The systems are still under monitoring phase and the water is not currently harvested, therefore the potential amount of water which could be harvested by the stormwater system was estimated using MUSIC and for the greywater system the value was provided by Design flow;
- All costs are in $AUD in 2016.

The results of the LCC analysis are presented in Table 2 and Table 3.

Table 2: Life cycle costing of Monash City Council EIBC stormwater treatment system

System name, location	Monash City Council – stormwater	Units
GENERAL		
Treatment Process	Biofiltration system, storage pond	
End usage	Stormwater harvesting and irrigation reuse (not currently in place until testing phase is over)	
Construction year	2015	
Catchment Size	5.89 ha (conveyed using low flow pumps)	ha
Catchment type	Residential and industrial	
Biofilter surface area	30	m^2
Storage Capacity	1200 (400m3 active storage for reuse)	m^3
Average Volume of Water Harvested Per Year	Potentially 2.21 ML/year	ML/year
COSTS		
Total Acquisition Cost	$198,718	$
Operation/Maintenance Cost	$480	$/year
Major maintenance cost (if available)	NA	
Decommissioning Cost	$49,680	$
SAVINGS		
Annual Mains Water Saving	$ 9,839 per year	$/year
Nitrogen Removal Saving	$ 42,422	$
TOTAL		
Traditional LCC	$ 231,149	$
'Total' LCC	$ 70,170	$
NA: not available		

Table 3: Life cycle costing of Monash City Council EIBC greywater treatment system

System name, location	Monash City Council – greywater	Units
GENERAL		
Treatment Process	Biofiltration system, living wall	
End usage	Greywater treatment and disposal	
Construction year	2015	
Catchment Size	NA – greywater is collected from all washing basins and showers of the premises (estimated volume = 205kL/year)	ha
Catchment type	Open space offices	
Biofilter surface area	20.8	m^2
Storage Capacity	NA	m^3
Average Volume of Water treated Per Year	Estimated at 205kL per year	kL/year
COSTS		
Total Acquisition Cost	$122,841	$
Operation/Maintenance Cost	$333	$/year
Major maintenance cost (if available)	NA	
Decommissioning Cost	$30,710	$
LCC		
SAVINGS		
Annual Mains Water Saving	$ 664 per year	$/year
Nitrogen Removal Saving	$ 2,861	$
Sewage Disposal Saving	$ 385	$/year
TOTAL		
Traditional LCC	$ 143,287	$
'Total' LCC	$ 132,432	$
'Total' LCC (including sewage disposal savings)	$ 127,787	$
NA: not available		

5 Assessment review of current and future technologies

A literature review and a survey of 30 water managers were conducted to study fit-for-purpose treatment technologies currently employed within Australia for both harvesting and/or treatment stages. The following work was undertaken in conjunction with project C1.3.

A total of 668 stormwater harvesting technologies implemented across QLD, SA, VIC, WA and NSW were reviewed. These included gross pollutant traps, UV disinfection, wetlands, engineered filters, sedimentation ponds/basins, biofilters, screen and trash racks, aquifer storage recovery, swales, infiltration systems, sand filters, porous pavement, ozone, microfiltration, sediment/oil separators, filter strips, sediment sump, reverse osmosis and electrolysis. The results of the review found that gross pollutant traps (39%), wetlands (21%) and UV disinfection (17%) were the most widely used technologies.

A further 84 stormwater harvesting schemes were studied through a stakeholder survey, consisting of 44 councils and 3 independent parties. The latter were asked a number of questions pertaining to the type of technologies used, the technologies end-use applications and the key factors influencing the successful implementation of (stormwater) harvesting schemes. These factors were grouped under nine major categories, namely, time to payback, maintenance, monitoring, design, policy and regulations, training/education, funding, scalability (that is, ability to respond to changing local conditions such as catchment land-use, population growth) and public perception.

The survey revealed that 66% of treated water was currently being applied for irrigation purposes, 13% for toilet flushing at public facilities, 4% for provision of public amenities (ponds/lakes/wetlands within parklands) and 3% for vehicle washing, park wash down, community and industrial uses respectively. It is believed that state water reuse guidelines were responsible for this division in the different end-uses. The use of UV disinfection as treatment measure was found to be popular in order to meet strict pathogen removal standards imposed by the local water reuse regulations. To facilitate TSS and turbidity management (in order to increase efficiency of the disinfection step), gross pollutant traps were also popularly adopted in the treatment train. In fact, it was found that in most cases, choice of technology depended on the local legislative requirements as well as the ease (cost-effectiveness, etc.) to validate the system according to existing frameworks. Similarly, a lack of clear guidance and validation frameworks associated with the technologies prevented the effective monitoring of many systems. The need for maintenance (and thereof lack of sufficient budget allocated to this component) and lack of information pertaining to maintenance and renewal requirements were found to be factors deterring selection of particular technologies (e.g. 25% of respondents identified this as a concern). Additionally, poor design often leads to increased operations and maintenance issues in the long term. The failure of planners to effectively communicate maintenance requirements for their designs, resulting in unexpected costs to asset managers, was also reported as a significant impediment to the effective implementation of these schemes. Stakeholders also indicated a perception that there are decreasing economic advantages to the installation of harvesting systems within Australia. This highlights the need to shift to installing technologies that are able to meet multiple objectives. This could thereby impact positively on the cost benefit ratio of these systems.

A number of endeavours could help drive the uptake of these technologies. For instance, more data on the removal performance of other pollutants (such as micropollutants) found in stormwater that can be a concern for re-use schemes will help to inform guidelines which will in turn drive the uptake of other technologies (that are also able to simultaneously meet other project objectives). Both maintenance and operations staff need to be involved right at the start during the planning and design stage. Further, more informed staff, increased operational knowledge and correct installation will decrease maintenance costs. Contractors installing WSUD systems should be more informed about WSUD principles while a higher level of control should be exerted to ensure that systems are constructed according to design. Finally, there is a need to set-up a national database to provide useful resources for water managers who are considering implementation and maintenance of these schemes (e.g. capital, operational, maintenance costs, operational knowledge, maintenance requirements and guidance, pollutant removal performances). This would play a key role in driving uptake of WSUD technologies across states, metropolitan and regional councils alike.

A paper reporting on the results of this study is currently under review, namely:

- Fit-for-purpose water re-use technologies: A review of stormwater treatment systems adoption in Australia

6 Summary

This research project focused on further development and optimisation of biofiltration systems to better protect our waterways and cool our cities. It delivered multi-functional hybrid WSUD systems capable of treating multiple water sources (stormwater, greywater, partially treated wastewater) within urban landscapes, namely green wall technology and hybrid biofilters planted with ornamental vegetation. A key outcome of the project was the development of adoption guidelines for these green treatment technologies, providing guidance on the design, operation and maintenance of these systems (a report providing design guidance on green walls for greywater treatment).

The key findings of this research projects are summarised below:

- Living walls (a form of biofilter) incorporated within urban areas were found to be a promising technology for on-site greywater treatment. A living wall biofilter sized at around 2 m^2 per 100 L of greywater generated per day can successfully treat greywater to a standard that satisfies regulatory limits for restricted non-potable water re-use. With installation of a disinfection unit post biofilter treatment, the water can be successfully used for unrestricted re-use applications such as unrestricted irrigation and toilet flushing.

- Plants were found to be the key design parameter for nutrient removal in greywater living walls.

- A range of ornamental species (including deciduous species) can be used in stormwater and greywater biofilters for effective water treatment. Examples include Canna lilies, *Vitis vinifera*, *Lonicera japonica*.

- Hybrid systems (capable of treating both stormwater and greywater) can be a promising technology provided design parameters (plant species) and operational mode are carefully selected. Current research reveals that the best operational regime is to use the systems for stormwater treatment during wet period and for greywater purification only during dry periods.

- Research shows that green walls can successfully treat significant volumes of greywater (up to 60 L/m^2 of green wall was tested) depending on their engineering design. Similar to living walls, installing a small disinfection unit (UV or ozonisation) prior to outflow storage for unrestricted non-potable reuse purposes such as toilet flushing, is highly recommended.

- Preliminary results from the monitoring of two field scale living wall biofilters (Monash City Council EIBC) revealed that media and carbon source should be carefully selected in order to prevent nutrient leaching which compromises the treatment capability of the system.

- A review of 668 stormwater harvesting technologies implemented across QLD, SA, VIC, WA and NSW revealed that gross pollutant traps (39%), wetlands (21%) and UV disinfection (17%) were the most widely used technologies in Australia.

- A stakeholder survey comprising 44 councils and 3 independent parties identified that the key factors influencing the implementation of stormwater harvesting schemes are time to payback, maintenance, monitoring, design, policy and regulations, training/education, funding, scalability (that is, ability to respond to changing local conditions such as catchment land-use, population growth) and public perception. It was concluded that a national database providing resources useful to water managers who are considering implementation and maintenance of these schemes (e.g. capital, operational, maintenance costs, operational knowledge, maintenance requirements and guidance, pollutant removal performances) would play a key role in driving uptake of WSUD technologies across states, metropolitan and regional councils alike.

References

Chandrasena, G. I., Pham, T., Payne, E. G., Deletic, A. and McCarthy, D. T. (2014). E. coli removal in laboratory scale stormwater biofilters: Influence of vegetation and submerged zone. *Journal of Hydrology* 519(PA): 814-822.

EPA (2013). *Code of Practice Onsite Wastewater Management*. Victoria, Australia, EPA Victoria.

Payne, E.G.I., Hatt, B.E., Deletic, A., Dobbie, M.F., McCarthy, D.T. and Chandrasena, G.I. (2015). *Adoption Guidelines for Stormwater Biofiltration Systems*. Melbourne, Australia: Cooperative Research Centre for Water Sensitive Cities.

Appendix 1 – Cost-benefit assessment of green technologies

Using the terminology primarily derived from the Australian Standard for Life-Cycle Costing (Australian Standard, 1999; Taylor, 2003), the costs involved in developing a stormwater or greywater recycling system are:

- **Total acquisition costs** - the cost of design, approval and construction (often called capital costs);
- **Typical annual maintenance costs** - costs including maintenance and energy requirements;
- **Renewal/adaptation costs** - costs associated with infrequent and irregular maintenance activities that involve the redesign or addition of system elements;
- **Decommissioning costs** - costs associated with decommissioning the asset at the end of its life-cycle/span;
- **Life-cycle costs** - a sum of all costs over the life-cycle of the asset after these costs have been adjusted for inflation and discounted using an appropriate nominal discount rate;
- **Equivalent annual payment costs** - the life-cycle cost divided by the life- cycle/span of the asset (in years); and
- **User price** - may apply where recycled stormwater is provided as a user-pays service by a central agency (this may be higher or lower than the actual cost).

The benefits included in this LCC analysis were:

- Provision of water supply and/or reduced demand for potable water (particularly peak flows), which offers savings through the reduced need to develop other water resources or expand water supply infrastructure;
- Reduction in stormwater pollution, which may lead to protection/enhancement of downstream waterways as well as savings resulting from the reduced need for downstream pollution mitigation measures; and
- Reduction in the volume of greywater disposed into sewer.

Traditional Life Cycle Costing

The life cycle cost of an asset can be expressed by the simple formula:

LCC = capital cost + life-time operating costs + life-time maintenance costs + life-time renewal costs + life-time disposal cost – residual value (1)

The costs are collected and adjusted (according to inflation if it was a cost incurred in the past) to a present ‘base’ cost date. To account for the costs that will occur throughout the life cycle of a project, adjustments can be shown by an inflation factor and an industry specific nominal discount rate to account for the variance in value which will occur during this time period using the following equations:

Inflation factor: $f = (1 + a)^{y}$ (2)

Discount factor: $f = 1 / (1 + dn)^{y}$ (3)

Where f = the costs,

a = the annual inflation

d_n = the annual depreciation rate

y = the number of years between the base date and the occurrence of the cost

n = the number of years

The costs can then be added to give a total life cycle cost (in present day worth) and an annual equivalent payment ($/year) (Standards Australia, 1999). Price of water in $/kL can then be calculated by dividing this value by total volume of water harvested per year.

Community costs based on LCC approach

An attempt was made to quantify the benefits of the stormwater harvesting systems to the environment. The analysis was limited to costing the following benefits:

- Potable water savings,
- Nitrogen removal costs, and
- Sewage disposal savings in the case of the greywater system.

The potable water savings per year were calculated by multiplying the volume of harvested water per year with the current costs of mains water:

Water Savings = Volume x Mains Water Cost (4)

Main water price was taken as $3.2366 per kilolitre (http://southeastwater.com.au/Residential/Pages/WaterPricesCharges.aspx).

The nitrogen removal costs were based on existing Melbourne Water stormwater offsets program that has been running in Victoria for a number of years. They are estimated at:

Nitrogen Savings = Volume x Conc (TN) x TN fee (5)

Where Volume = volume of harvested stormwater [ML/year]
Conc (TN) = TN concentration in untreated stormwater [mg/L] or [kg/ML]
TN fee = fee that Melbourne Water charges developers per 1 kg of TN discharged per year = $6,645 per each kg of discharged TN per year and TN concentration derived from MUSIC = 2.1 mg/L

When both Water and Nitrogen savings are calculated (the first being per year and the second as upfront saving) they were used in LCC to estimate Community Life Cycle Costs:

Community LCC = capital cost + lifetime operating costs + lifetime maintenance costs + lifetime renewal costs + lifetime disposal cost – residual value – lifetime water savings – lifetime nitrogen savings (6)

Finally the sewage disposal savings were calculated by multiplying the volume of greywater harvested per year with the current cost of sewage disposal as follows:

Sewage Disposal Savings = Volume x Sewage disposal cost (7)

The sewage disposal price has been taken as $1.8803 per kilolitre (http://southeastwater.com.au/Business/Pages/Water-prices-and-charges.aspx).

As in standard LCC the Community LCC was subject to inflation and discounted rate. The final costs were simply divided by total volume of water harvested over the life span of the system to calculate Community price of water in $/kL.

The systems characteristics are summarised in Table 2 and Table 3, and the different life cycle costs (LCC) of the systems were evaluated. The capital costs and characteristics of both systems were kindly provided by the City of Monash and Design Flow.

References

Australian Standards (1999). *AS/NZS 4536:1999 Life Cycle Costing – An Application Guide*. Standards Australia, Homebush, New South Wales.

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

Payne, E.G.I., Hatt, B.E., Deletic, A., Dobbie, M.F., McCarthy, D.T. and Chandrasena, G.I. (2015). *Adoption Guidelines for Stormwater Biofiltration Systems*. Melbourne, Australia: Cooperative Research Centre for Water Sensitive Cities.

Taylor, A. (2003*). An Introduction to Life cycle Costing Involving Structural Stormwater Quality Management Measures*. Cooperative Research Centre for Catchment Hydrology, Melbourne, Victoria.

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