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Royal Botanic Gardens Melbourne: Lessons Learnt in Transforming an Existing Garden Bed Feature into a Functioning Rain Garden

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Abstract

GHD, Melbourne Water Corporation (MWC), Royal Botanic Gardens Melbourne (RBG) and Ecodynamics have worked together to design and construct a rain garden that transformed an existing Canna Bed feature within the RBG into a functioning rain garden, providing stormwater treatment in accordance with Best Practice Environmental Management Guidelines (BPEMG).

A number of lessons were learnt from this collaborative approach. The project highlighted how important collaboration and leadership are in achieving sustainable project outcomes. One of the unique outcomes was how engineering and science can be used to achieve a successful living landscape feature. More specifically, the project found that the Canna Lily, an ornamental species, could thrive in a bioretention system, especially during dry conditions from variable and infrequent rainfall. The project has presented a number of future opportunities, including extending the existing monitoring regime to sample both a greater number of storm events and a larger suite of contaminants such as heavy metals and hydrocarbons. Furthermore, the installation of a gross pollutant trap (GPT) upstream of the rain garden has been identified as critical in maintaining acceptable levels of water quality and protecting the long-term viability of the rain garden. Overall, the project is a viable case study for any new WSUD project where retrofitting to existing infrastructure is being considered.

Introduction

The Royal Botanic Gardens Melbourne (RBG) and City of Melbourne (CoM) have considered a range of stormwater management options to address concerns of both drainage capacity and water quality for the Birdswood Avenue and Royal Botanic Gardens precinct of Melbourne. As a Water Sensitive Urban Design (WSUD) opportunity, the concept of a rain garden located above a drain within an existing Canna Bed feature in the RBG was identified.

GHD, Melbourne Water Corporation (MWC), RBG and Ecodynamics worked together to design and construct a rain garden that transformed an existing Canna Bed feature within the RBG into a functioning rain garden, providing stormwater treatment in accordance with Best Practice Environmental Management Guidelines (BPEMG).

Incorporating the WSUD feature within the site not only provides water quality treatment for stormwater discharging to the RBG lakes system, which experience regular blue-green algae blooms, it has provided an ornamental garden bed with a source of water that will reduce long-term maintenance and water requirements. In addition to the water harvesting and water quality benefits associated with the rain garden, one of the major project drivers for MWC was the educational opportunity presented by the high profile location and patronage to the RBG. Importantly for the RBG, the rain garden has maintained the ornamental species and heritage that the original garden bed offered.

Some of the lessons learnt from this project include:

- Importance of collaboration and knowledge transfer in achieving sustainable project outcomes;
- Need for leadership where infrastructure spans catchments of different land managers;
- Engineering and science can be used to achieve a horticultural outcome whilst maintaining heritage values;
- Successful use of an ornamental species in a bioretention system. Canna Lilies have been found to be reasonably drought tolerant, particularly considering the sandy soil profile;
- Reliance on regular maintenance and upstream sediment capture for bioretention system success;

- Interim monitoring indicates that the BPEMG are on average exceeded for the rain garden; and
- Significant increase in nutrient levels in the top 150 mm profile of the rain garden since amelioration.

Collaboration and Knowledge Transfer

The project has provided an opportunity to convert an existing garden bed into a functioning rain garden system as a demonstration project for WSUD. The project has presented some unique opportunities in terms of a WSUD retrofit project with the added benefit of dedicated RBG staff that can provide a closer level of maintenance without significant burden on their overall RBG maintenance workload. Undertaking an appropriate level of maintenance is crucial for the long-term viability of the rain garden treatment system and preservation of the aesthetics the garden bed offers as a landscape feature.

The project involved various key staff within RBG including management, landscape specialists and maintenance. At the concept stage, the project raised various concerns for the RBG staff, however due to the collaborative approach, these concerns could be addressed and alleviated in the design and implementation phases. Whether by open communication in round table forums or on site meetings discussing the project status, any issues or concerns were readily addressed through furnished explanations. Some of the key issues and requirements for RBG in the design included retaining the existing garden bed footprint, the Canna Lilies and associated colour schemes as well as the unique contoured edging of the surrounding manicured lawns.

The combination of the various stakeholders maintaining a long-term interest in the post implementation coupled with the level of attention that can be offered by RBG staff has provided an excellent opportunity to observe and monitor the progress of the plants and performance.

The following on-going monitoring activities have been undertaken by the RBG staff:

- Observation of actual events and recording of details such as surface flow, ponding characteristics, and damage to the rain garden;
- Continued visual monitoring of outflow into Fern Gully (visual sampling from inlet pit and outlet pits);
- Undertaking an event-based water sampling program for the rain garden using Auto-samplers; and
- Assessing the change in nutrients in the top 150 mm profile of the rain garden filter media.

The post implementation phase also presents an opportunity for a higher level of participation, with maintenance and monitoring activities undertaken by RBG staff, this was an ideal opportunity to capitalise on the potential educational benefits for the RBG.

Engineering and Science Achieve a Horticultural Outcome Whilst Maintaining Heritage Values

Integrating a rain garden into the Canna Bed required a number of unique engineering and horticultural issues to be resolved. The issues included:

- Use of an existing Canna display rather than conventional rain garden plants;
- Balancing of horticultural factors with functional requirements of a rain garden filter;
- Maintenance of hydraulic capacity and function; and
- Ensuring the rain garden maintained the heritage and aesthetic values of the Canna Bed by utilising the Canna Lilies in the design and maintaining the surrounding contouring of the manicured lawns.

To date all Australian guidelines and practice notes have recommended the use of indigenous native species in rain gardens. The use of Cannas in the garden bed was a key design outcome for the project, therefore, the project required the use of plants not recommended in current guidelines. However, there are examples where Cannas have been used in wastewater treatment applications, where they have demonstrated an ability to tolerate saturated soil conditions and achieve high levels of nutrient removal. Cannas were therefore considered suitable for the rain garden, although it is noted that they might require additional feeding and watering during their establishment period (i.e. initial 12 to 18 months).

Prior to the construction of the rain garden, the Canna Bed was comprised of a conventional landscape soil, which had achieved high levels of growth over a sustained period. The existing media could be characterised as slow draining (<10 mm/h) and fertile; these conditions ensured the plants could access moisture and nutrients readily. Rain garden soils are required to drain freely and therefore do not contain high proportions of fine materials (silts, clays and organic materials). Thus, rain garden soils have a tendency to have low water-holding capacity and be nutrient poor. These characteristics are offset by the high hydraulic and nutrient loading from the stormwater that the filter receives. Conventionally sized rain gardens are 1% of the upstream impervious area and therefore typically receive 100 times the hydrologic load and a significantly greater nutrient load than garden beds, which rely on direct rainfall alone.

The rain garden was configured in two layers:

- Filter layer—a selected sand medium which supported the Cannas; and
- Drainage layer—the base layer of 4–7 mm aggregate, which conveyed runoff from the filter to the outlet.

The filter profile does not contain a transition layer between the filter and drainage layers. This layer could be excluded by careful selection of the filter and drainage layer grading and was done to simplify construction methodologies. Figure 1 highlights the profile of the rain garden, with the filter and drainage layer located above the in-situ sodic clay subsoils that were compacted to form a clay liner.

The filter sand was a washed sand and selected to provide a hydraulic conductivity of at least 300 mm/h. The washing of the sand removes fines and their associated organic materials and nutrient matter. To compensate for this, the top 100 mm of the rain garden was ameliorated with organic material, trace elements and plant nutrients (Nitrogen and Phosphorous). The pH of the soil was also adjusted with lime as the sand material had a pH of 5.5 when delivered. Nutrient additions were required for the plant establishment period, with the stormwater runoff expected to meet the long-term fertility requirements.

Studies of constructed rain gardens (Somes *et al.* 2007), have shown that achievement of the desired hydraulic conductivity within the soil media is difficult as minor variations in filter materials, i.e. grading, can alter drainage rates significantly. To overcome this the use of hydraulic structures to control discharge rates has been used on several large rain gardens (Somes & Moore 2007). This approach is similar to that used in constructed wetlands, where a riser plate is used to set the discharge rate. The desired hydraulic conductivity of the reconstructed Canna Bed was 120 mm/h, which was controlled by a riser plate. The initial drainage rate of the filter media was typically 300 –500 mm/h. The initial high hydraulic conductivity of the filter was adopted to provide a buffer against blockage from fines and organic material from the catchment. The use of the riser plate also allowed the depth of the saturated anoxic zone to be varied. This anoxic zone was applied to increase pollutant removal (i.e. removal of nitrogen through denitrification). The use of the riser plate also presented the RBG with the ability to raise the water table in the Canna Bed to provide a water source to promote and support growth within the bed and compensate for its potentially low water holding capacity.

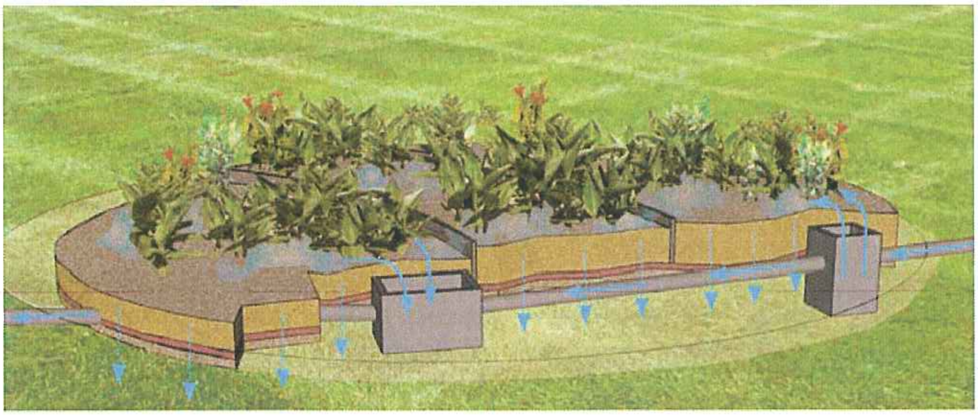

Figure 1. Profile of the Rain Garden

One of the important outcomes of the project for the RBG was to ensure that the resulting rain garden maintained the heritage and aesthetic values of the former Canna Bed by utilising the Cannas in the design and maintaining the surrounding contouring of the manicured lawns.

Use of an Ornamental Species in a Bioretention System

Management of Australian heritage gardens to maintain cultural values is often challenged by vexing contemporary issues such as managing the gradual replacement of over-mature trees, ensuring public safety, and dealing with resource limitations like water scarcity. Many of these legacy gardens, like the over 150-year-old RBG, had their origins from a time when the community was seeking to replicate European approaches to agriculture, land management, and indeed, gardens. Current environmental responsibilities to reduce the use of natural resources and protect habitats can be a dilemma when faced with also seeking to maintain the intrinsic qualities of a Botanic Garden.

The use of the Canna Bed to develop a rain garden is one example where environmental engineering has combined with a traditional garden to improve water quality and still obtain amenity horticultural outcomes. In the 1900's, this original site was used as a tip for the disposal of waste. However, in 1906, the then Gardens Director, William Guilfoyle changed this to a bed incorporating a subtropical landscape style with plants such as Cannas. Subtropical landscaping was popular around that time, and the evidence of this in the Gardens is still enjoyed by visitors from all over the world today.

In Victoria, rain gardens and other WSUD landscapes often seem to incorporate the use of indigenous plant taxa, especially sedges such as *Carex* sp and *Juncus* sp. Many of these species appear to adapt readily to the low nutrient-holding capacity of the underlying sand medium, transitional water logging and periods of drought. The question remains whether a rain garden relying on these species may become nutrient-saturated (especially phosphorous) and subsequently less effective to treat stormwater over time. Cannas may exhibit greater potential for removing nutrients from the system as they are fast growing and produce copious amounts of foliage (biomass), which can then be harvested and used elsewhere. In the Botanic Gardens, the Canna foliage is removed in winter, aerobically composted and used as mulch in the landscape. An ideal plant selection for a rain garden would incorporate the attributes of drought tolerance, water logging tolerance, adaptability to both low and high nutrient regimes, production of biomass for the uptake of nutrients and not in the least, ornamental quality to improve the amenity of urban areas. It is considered that Cannas meet these criteria, and when they are established; demonstrate fair to reasonable drought tolerance. However, after the rain garden transformation in June 2007, the growth rates and amenity of the Cannas were well below what had previously been observed. This was probably due to the disturbance from the drastic division of the plants to obtain the numbers required, and the very low fertility of the sand filter media. A tension needed to be overcome between treating stormwater flows to a high quality, whilst maintaining plant amenity. There was a risk that improving the nutrient status of the sand media would also increase the risk of nutrients leaching into the treated stormwater. During September to November 2008, a limited fertilising program was undertaken to improve the growth of the Cannas. This does not appear to have significantly affected the treated water quality and there have been acceptable growth rates of Cannas to date.

On 5 September 2008, about 2.5 kg of a low-P formulation fertilizer (NPK 22:1:6) was applied directly to the Canna Bed. On 16 September 2008, 13 October 2008, 3 November 2008 and 17 November 2008, a seaweed product (NPK 14:1.7:8) was applied on respective occasions as a foliar fertiliser at the rate of 3 ml/L in 15 L of solution. In total, it is calculated that 725 grams of actual Nitrogen, 25g of actual Phosphorous and 150g of actual Potassium was applied to the Canna Bed. The addition of trace elements from the seaweed-based fertiliser was considered not significant as the total Zinc applied is calculated to be 0.003g over the entire area.

Whilst utilising existing Cannas was considered to be an appropriate planting regime on the basis that the root structure would provide the water quality function within the filter media, their use in rain gardens is unprecedented. Belmont & Metcalfe (2003) found that Cannas are effective at reducing the total suspended solids, chemical oxygen demand and nitrogen in artificial wastewater. Wolverton (1989) reported that four ornamental species including the Canna Lily planted in a rock filter used to treat septic tank effluents were able to add oxygen and increase biological activity in the septic bed. Belmont *et al* (2004) found that Cannas were much hardier than Cattails (Typha spp.). Both the Canna and Cattail were equally efficient for treating domestic sewage, with the root zone of both species extending 0.5 m below the surface.

Whilst Belmont & Metcalfe (2003) highlighted that Cannas flourish in a wet/water-logging environment like a wetland, there was uncertainty as to how the Cannas would fair in a sand filter media during periods of drought. Despite the recent dry conditions, the growth of the Cannas has improved significantly since September 2008, as a result of the documented nutrient applications above and continued accumulation of nutrients in the sand filter media from catchment inflows. It was interesting to note in the 12 months proceeding the Canna Bed transformation, the significant difference in the growth rates of Cannas in the sand filter media inside the rain garden as compared to those in fertile landscape soil around the perimeter of the rain garden. This outcome was as expected, due to the fact the nutrient levels in the sand filter media were much lower than nutrient rich soils the Cannas have traditionally grown in. Figure 2 highlights that 18-months after construction, the Cannas are performing satisfactorily in their new environment.

The new Canna Bed design incorporated three different tiered terrace levels as a result of the site topography and need to maintain the contouring of the manicured lawns that border the Canna Bed. The different relative level of each terrace has resulted in different Canna root-zones relative to the water table below. Thus, some reduced growth has been observed in the higher terrace, presumably due to a less reliable access to subsurface water. Future designs may be improved in taking a more 'tanked' approach to ensure that all the plants have similar access to subsurface water and thus achieve more uniform growth rates.

In summary, the project has found that an ornamental species like Cannas are suitable for WSUD applications due to their high growth rates, potential nutrient removal and ability to survive in both phases of wet and dry conditions.

Canna Bed Before the Rain Garden Transformation

Canna Bed 18 Months After the Rain Garden Transformation

Figure 2. Canna Bed—Before and After the Rain Garden Transformation

Need for Leadership

One of the significant learnings of this project has been the need for leadership where infrastructure spans catchments of different land managers. The RBG has been incorporating the elements of WSUD in all its projects where possible. More recently, the decision to transform the unique Canna Bed into a functioning rain garden has provided a focus for treating local urban water quality issues and providing visitor education. The RBG with the assistance of MWC has also recognised the water harvesting and water quality opportunities presented by the rain garden. Importantly, the rain garden will assist in reducing the amount of nutrients entering the lakes system, which presently experience regular blue-green algae blooms.

Furthermore, the long-term viability of the Canna Bed rain garden is expected to be reliant on the effective management of sediment loads coming from CoM land, which is outside the RBG managed catchment. This garden bed forms part of a wider stormwater management system that requires collaborative leadership from both the RBG and CoM to address drainage issues and water quality challenges associated with the Birdswood Avenue precinct.

Life Cycle of Rain Garden and Reliance on Maintenance and Sediment Capture Upstream

Managing the amount of sediment entering a rain garden is critical in maintaining the life cycle of such an important asset. Limiting the amount of sediment entering the rain garden reduces the maintenance requirement to remove accumulated sediment from the surface of the rain garden media and minimise the risk of the filter clogging.

The Canna Bed rain garden forms part of a wider stormwater management study. Whilst sumps have been built into the existing stormwater infrastructure to minimise the amount of sediment entering the rain garden, this is not satisfactory for stormwater best practice, and is highly reliant on very regular maintenance. An important part of the solution has been identifying the source of the sediment and working with CoM to establish infrastructure that manages upstream sediment loads.

Effectiveness to Treat Stormwater to BPEMG: Interim-Monitoring Results

Interim monitoring of the Canna Bed rain garden has been undertaken to assess the effectiveness of the Canna Bed rain garden in meeting Best Practice objectives. Using two ISCO 3700 Compact Auto-samplers, the RBG has undertaken monitoring of five separate storm events over the past 12 months. The sample analysis indicates that the rain garden is meeting Best Practice for both nitrogen and phosphorous removal. The interim monitoring results are tabulated in Table 1 below.

Average reductions in Total Phosphorous were measured from 23%–68% for individual rainfall events with an overall average reduction of 56%. Total Nitrogen was reduced by 19%–63% with an overall average reduction of 49%. Total Suspended Solids was not measured, however the rain garden intercepted notable amounts of sediment. It has been identified that a Gross Pollutant Trap is required upstream to optimise the treatment train effectiveness and extend the life of the bioretention system.

With further financial support, the RBG would like to undertake additional monitoring to assess the range of contaminants entering the Botanic Gardens from the upstream catchment and the effectiveness of the rain garden in removing these contaminants from the stormwater. Strategically, the RBG is committed to harvesting additional stormwater as part of an integrated alternative water supply for the long-term health of the landscape and the lake system. Monitoring of current stormwater quality and the effectiveness of treatment choices is important to inform current and future initiatives.

Table 1. Analysis Results from ISCO Auto-Samplers

Date	Precipitation Aggregate over the Sampling Period (mm)	Average TP (mg/L) Birdwood Avenue Surcharge	Average TP (mg/L) Canna Bed Discharge	TP % reduction	Average TN (mg/L) Birdwood Avenue Surcharge	Average TN (mg/L) Canna Bed Discharge	TN % reduction
28-Feb-08	2.4	0.56	NA	NA	2.65	NA	NA
27-Mar-08	35.0	0.35	0.27	23%	3.8	1.4	63%
8-Jul-08	6.0	0.31	0.21	32%	2.68	2.18	19%
21-Aug-08	6.0	0.65	0.21	68%	3.23	1.94	40%
9-Dec-09	3.80	0.69	0.25	64%	3.23	1.43	56%
Average		**0.55**	**0.24**	56%	**3.26**	**1.67**	49%
BPEMG				45%			45%

Change in Nutrient Levels in the Top 150 mm Profile of the Rain Garden Since Initial Amelioration

Total Carbon (TC) content has increased since non-detectable levels to 0.5g/100g or an estimated organic matter content of 1.1%. Discernible increases in Phosphorous are not significant at this time. However, along with other parameters such as TC, it is approximately double the concentration in the top 50 mm of the sand profile (as compared to elsewhere in the sand profile)—or the zone of sediment accumulation, where it is likely the fate of any particulate-borne Phosphorus would probably reside. The existing levels of Phosphorous are still considered to be deficient for healthy plant growth. Potassium has also risen from non-detection to 0.1 meq/100g, which is also at deficient levels. Potassium is prone to being readily leached and in these sandy soils may require regular light applications.

It is perhaps of significance that Zinc has increased from 0.7 ppm to 4.8 ppm in the top 150 mm of the sand profile. Whilst this result is within the ideal range for plant growth, the level of Zinc in the top 50 mm of the sand profile is reaching more toxic levels (12 ppm). This may also be explained by the urban nature of the stormwater runoff from Birdwood Avenue (atmospheric fallout, rubber from car tyres etc).

One of the lessons learnt from the monitoring regime is that soil sampling needs to be taken at multiple levels within the profile. Desirable materials and also pollutants will accumulate and concentrate at the interface of the sand surface. As the build-up of fine particles tend to clog the sand over time, this effect will increase. A composite of a minimum 20 samples using a soil core removal tool should be collected and tested at each respective depth. This project has found that three distinct depth zones, namely of 0 to 25 mm, 0 to 50 mm and 0 to 150 mm are probably the ideal layers to test. Another important observation with respect to the filter profile is the heterogeneous nature of the hydraulic conductivity of the sand profile. Whilst the sand filter may continue to have the capability to drain at 100–200 mm per hour at depth, it can become compromised at the surface, with significant reductions in hydraulic conductivity caused by sediment clogging the sand filter at the surface. Comparative hydraulic conductivity results can be analysed in the laboratory from collected composite samples, but from experience this does not reflect the actual hydraulic conductivity in the field. It is recommended that the hydraulic conductivity of the sand filter should be evaluated in-situ using a recognised infiltrometer.

Conclusions—Outcomes and Opportunities

The transformation of an existing Canna Bed feature within the RBG into a functioning rain garden not only provides water quality treatment for stormwater discharging to the RBG lakes system, which experience regular blue-green algae blooms, it has provided an ornamental garden bed with a source of water that will reduce long-term maintenance and water requirements.

Some of the key lessons learnt from this project include:

- Importance of collaboration and knowledge transfer in achieving sustainable project outcomes;
- Need for frontline leadership where infrastructure and or catchment cross different organisations and land management responsibilities;
- Engineering and science can be used to achieve a horticultural outcome whilst maintaining heritage values;
- Successful use of an ornamental species in a bioretention system;
- Reliance on regular maintenance and upstream sediment capture to bioretention system success;
- Interim monitoring indicates that the BPEMG for the rain garden are on average exceeded;
- Significant increase in nutrient levels in the top 150 mm profile of the rain garden since amelioration;
- Installation of GPT should be seen as essential to the success of rain gardens where upstream sediment loads are high;
- Growth rates of plant species may be low in first 18 months and education is needed to manage people's expectations; and
- The terrace design to manage varying stormwater flows resulted in media levels (and root-zones of the Cannas) at increasing heights above the water table. Some reduced growth was noted in the Cannas on the upper terrace presumably due to a reduced access to subsurface water.

There are a number of future opportunities presented by this project, including:

- Extend monitoring regime and sample for heavy metals and hydrocarbons;
- Installation of GPT has been identified as critical in protecting the long-term viability of the rain garden;
- Viable case study for new WSUD projects where retrofitting to existing infrastructure is being considered; and
- The RBG is an ideal site for urban water treatment research, including future student research projects.

Acknowledgements

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