The planning and construction of an urban stormwater management scheme

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Abstract Water Sensitive Urban Design (WSUD) offers a means to integrate stormwater best management practices into urban planning and design to achieve multiple objectives. Some of these objectives relate to stormwater drainage, water quality improvements, aquatic habitat protection, stormwater harvesting and use, and landscape amenity. The Lynbrook Estate, Australia, has incorporated bio-filtration systems and wetlands into the design of major roads, local access streets and parklands that attenuate and treat roof runoff and road runoff from a 32 ha, 270 allotment residential precinct. This paper outlines the process that enabled the concept of a stormwater drainage design to be translated into on-ground works. Details of the construction activities, costs and market acceptance highlight the potential for the adoption of similar practices elsewhere.

Keywords Bio-filtration system; source control; swale; urban stormwater; wetland

Introduction

Water Sensitive Urban Design (WSUD) is being promoted as a sustainable approach to the management of our urban water resources. It aims to minimise the impact of urban development on the natural water cycle. One component of WSUD relates to the management of stormwater and offers to achieve multiple outcomes including stormwater drainage, water quality improvements, aquatic habitat protection, stormwater harvesting and use, and landscape amenity. Five key objectives of WSUD for application to urban stormwater planning and design are listed in the Urban Stormwater: Best Practice Environmental Management Guidelines (CSIRO, 1999). They are:
1. Protect natural systems: protect and enhance natural water systems within urban developments
2. Integrate stormwater treatment into the landscape: use stormwater in the landscape by incorporating multiple use corridors that maximise the visual and recreational amenity of developments
3. Protect water quality: protect the water quality draining from urban development
4. Reduce run-off and peak flows: reduce peak flows from urban developments by local detention measures and minimising impervious areas
5. Add value while minimising development costs: minimise the drainage infrastructure cost of development

Fundamental to the application of the WSUD philosophy to urban water resource management is the adoption of best planning practices and best management practices. Best Planning Practices refer to the site assessment and planning component of WSUD. Best Management Practices (BMPs) refer to the structural and non-structural control measures that perform the prevention, collection, treatment, conveyance, storage or reuse functions of a water management scheme. This enables appropriate land-use requirements, including the layout and arrangement of a stormwater management scheme, to be matched to landscape characteristics.
Slow adoption of WSUD practices by the development industry is partly related to the general lack of understanding of the implementation strategies, field evidence on the life-cycle cost and community acceptance of structural BMPs. This paper describes the planning process and construction activities undertaken to implement a stormwater management strategy at the Lynbrook Estate, Melbourne, Australia. The drainage system consists of bio-filtration systems and wetlands designed to attenuate stormwater runoff and improve water quality by a combination of grass swale, infiltration and wetland treatment processes. The various challenges that were encountered in translating the concept design of the stormwater management scheme into on-ground works are discussed. Details of the construction activities, costs and market acceptance are documented.

**Background – a distributed approach to stormwater management**

The term “treatment train” refers to the sequencing of structural BMPs to achieve optimal flow management and pollutant removal for urban stormwater runoff. Since no single stormwater treatment measure can provide flow management and remove all pollutant types, a number of treatment measures targeting different stormwater management issues are required. The treatment train concept also espouses source control and promotes a distributed approach to the management of stormwater across a catchment. A distributed approach to the management of stormwater is highly desirable having the advantages of:

- a greater ability to attenuate flows and re-establish flow conditions similar to those prior to catchment development;
- the pollutants remain distributed across the catchment rather than accumulating in a single location, thereby reducing pollutant loads to downstream regional treatment facilities (such as wetlands);
- lower capital costs and, in many instances, maintenance costs;
- provision of aesthetically pleasing landscaping features within urban catchments.

There is growing concern about the accumulation of pollutants in the receiving waters, including waterways, bays, and wetland systems. These concerns primarily relate to the build-up of pollutants, such as metals, in the receiving waters and their subsequent entry into the food chain. In residential precincts the generation of pollutants is relatively low compared with other land uses such as industrial and commercial precincts or highway/freeway transportation routes (Livingston, 1997). Nevertheless, low pollutant levels generated across large catchments accumulating at a single downstream location can potentially lead to the deterioration of ecosystem health. Applying a distributed approach to the design of a stormwater management scheme means that the build-up of pollutants in the stormwater treatment measures remains low, since the area of contributing catchment is much smaller. In addition, if the treatment measures are designed with minimal habitat value (i.e. grass swale or grassed bio-filtration system) then the risk of pollutant entry into the food chain is greatly reduced.

A recent series of field experiments investigating the pollutant removal effectiveness of a bio-filtration system, constructed as part of the stormwater management scheme at the Lynbrook Estate, found TSS removal rates of between 55% and 74% (Lloyd et al., 2001). The particle size distribution of TSS used in the experiments ranged from 0.4 μm (5 percentile) to 15 μm (95 percentile). The high proportion of pollutants, such as metals, transported in stormwater bound to finely graded particles suggests that the use of bio-filtration systems distributed across a catchment is an effective means to improve urban runoff. Bio-filtration systems integrated into the design of the streetscape are one method of keeping stormwater pollutants distributed across a catchment. In doing so, the rate of pollutant accumulation in the receiving waters is significantly reduced and the risk associated with bio-accumulation is minimised.
At the regional or precinct level, the use of constructed stormwater wetlands in the urban landscape has become common practice as an effective means of stormwater quality improvement in addition to their other environmental and landscape/passive recreational values. Stormwater wetland systems can be adopted to provide further improvement of stormwater by targeting those pollutants that have not been effectively removed by source control measures. The effectiveness of constructed wetlands in water quality improvement is well documented in the wastewater industry. The extension of this technology to stormwater management brings with it unique challenges and the proper design of these systems is not a straightforward task.

Research studies undertaken by a number of research organisations, including the Cooperative Research Centre for Catchment Hydrology have provided a sounder basis for sizing constructed wetlands for stormwater management and for its integration into landscape design. The development of technical guidelines has enabled landscape designers to achieve a balance between meeting their aesthetic and habitat provision objectives with those of stormwater quality improvement and many of the management issues related to the accumulation of contaminants within such systems. These guidelines include the compartmentalisation of various treatment functional elements within a wetland system (Wong et al., 1998), quantifying the relative significance of vegetation coverage on the performance of stormwater wetlands, (Wong et al., 2000) and establishing a quantitative measure of hydrodynamic conditions (i.e. hydraulic efficiency) in constructed wetlands and ponds and to relate wetland and pond shapes to hydraulic efficiency (Persson et al., 1999). Issues of bio-accumulation of pollutants such as metals in the food chain in wetland systems can be addressed by appropriately designing these systems.

**Lynbrook Estate**

Stages 12, 13 and 14 of the Lynbrook Estate incorporate WSUD objectives at the streetscape and sub-catchment scale of the greenfield development. The drainage scheme covers some 32 ha of land consisting of 270 allotments and parklands. Figure 1 shows the layout of the key stormwater management practices adopted at the Lynbrook Estate.

The stormwater management scheme consists of bio-filtration systems (grassed and vegetated swales which promote infiltration into the underlying gravel-filled trench) as the “primary” stormwater treatment measures. Both roof runoff and road runoff from the main entrance boulevard and local access streets are treated using bio-filtration systems.
Secondary treatment is provided by a series of wetland systems which discharges into an ornamental lake and subsequently into a regional floodway. The unique feature of the stormwater management scheme is not the design of the individual WSUD elements but rather the integrated and complimentary layout of the bio-filtration systems and wetland systems. The layout of the systems forms a treatment train providing attenuation to catchment flows and improvement to the quality of the runoff conveyed by the stormwater management scheme.

**The planning and construction process**

Four steps were integral in the development of the concept design for the Lynbrook Estate stormwater management scheme and the subsequent translation into on-ground works. Each step is described briefly below and is as follows:

1. Meeting of key stakeholder groups
2. Design and construction plans
3. Gaining development approval by local government
4. Implementing on-ground works

**Meeting of key stakeholder groups**

A collaborative approach was adopted between Melbourne Water Corporation (regional water authority), the Urban and Regional Land Corporation (land developers), KLM Development Consultants (engineers), Murphy Design Group (landscape architects), and the Cooperative Research Centre for Catchment Hydrology (scientific research organisation) to design, implement and monitor the WSUD demonstration project. The first step was to run a series of meetings between key stakeholder groups. The initial meeting provided background information to the project and a presentation on the broad WSUD principles and techniques. Staff members from local government (City of Casey) were also encouraged to attend the meetings as their support was critically important. Those who would be involved in the final decision in local government were personally invited to attend, so that the awareness of WSUD principals was promoted as early as possible. Other meetings were subsequently held and the level of discussion became more focused on the design, implementation and maintenance of WSUD infrastructure.

The concepts presented were new to most attending the meeting. With the diverse backgrounds of the key stakeholder groups many misinformed, but commonly raised, concerns were discussed. Some of these concerns have been listed in Table 1 with a brief description of the response given.

Compromise on an “optimal” design of the stormwater management scheme had to be accepted in order to satisfy all key stakeholder groups. For instance, the surface ponding of stormwater to increase detention times in the bio-filtration systems and therefore improve treatment processes was rejected due to perceived public safety. It is important to remember that radical changes will not occur overnight and the gradual acceptance of changes to the standard design are important milestones to the eventual widespread acceptance of change in the land development industry.

**Design and construction plans**

The development of design and construction plans involved numerous smaller meetings between particular stakeholders (e.g. engineers and local government). This enabled specific design issues to be discussed in detail and different stages of the concept design plan to be reviewed. The initial concept design took into account the site opportunities and constraints as well as the limitations placed on the design by local government. The review process continually kept local government informed and up to date so that when the project
sought local government approval there were no unfamiliar design elements or issues before them.

The greatest challenge faced by the design team was in the transfer of the drainage design concepts to their sub-consultants (e.g. drainage contractors). Raising sub-consultants’ and contractors’ awareness levels of the change in design intent before construction activities begin are important for the success of WSUD projects. Education and awareness raising will enable the industry to adapt construction practices to minimise the risk of on-ground construction problems and embrace the incorporation of WSUD practices into residential drainage schemes. Work by others who have developed and constructed stormwater management schemes based on the WSUD philosophy suggest that, until contractors are more familiar with the concepts and practices, design documentation standards need to surpass those normally accepted (Argue, 1996).

**Gaining development approval by local government**

A poor level of internal awareness within local government, regarding the design and
performance of the proposed stormwater management scheme was a major impediment to the project. Local government has a number of standards for drainage system design which developers are required to conform to. These standards are based on a conventional engineering practice and some variation from these standards was necessary for the approval for the WSUD demonstration project to proceed.

It was evident from the Lynbrook Estate demonstration project that different levels of local government have different concerns with the adoption of WSUD practices. Therefore it is important that awareness raising and education of local government employees needs to occur at a number of levels. The areas of local government that need to be targeted to facilitate a change in practice are as follows:

1. Senior levels of management – how WSUD fits into policy.
2. Middle management – broad issues of WSUD such as costs of maintenance, public safety; visual quality, level of protection against flooding.
3. City planners, assessment officers etc. – how and what to assess a submitted design against as current codes of practice do not enable the assessment process to occur easily.

In general, the councillors in the City of Casey were all very supportive but concerns regarding long-term maintenance could not be overcome without some form of documented evidence. To get the project off the ground, Melbourne Water had to underwrite the re-establishment of a conventional drainage system should the design of the bio-filtration systems prove to be unsuccessful. Similarly the Urban and Regional Land Corporation had to manage the maintenance of the bio-filtration system for the first two years. The success of the Lynbrook Estate stormwater management strategy has resulted in similar WSUD practices being approved elsewhere without such conditions being placed on the design team.

Implementing on-ground works

The design of the main entrance boulevard (Lynbrook Boulevard see Figures 2 and 3) is a divided road with the cross-fall towards the median strip, which includes a bio-filtration system. No kerb and gutter system exists thereby promoting the even distribution of road runoff into the bio-filtration system. Road runoff is pre-treated by a grassed filter strip on either side of the bio-filtration system extending to the road verge. The runoff is then infiltrated through the base of the swale and into an 800 mm deep gravel trench. A 150 mm diameter perforated pipe runs along the trench close to the base to collect and convey the infiltrated runoff downstream to the wetland system.

The construction of the bio-filtration system was surprisingly fast with only minor construction issues that were quickly resolved. The entire system was constructed using conventional excavation methods and machinery. Once the base of the road was established the general shape of the swale component of the bio-filtration system was graded. The trench was excavated and root barriers were placed along the sections of the trench where Eucalypts would subsequently be planted to minimise the risk of root penetration of the gravel trench component of the bio-filtration system (shown in the foreground of Figure 2A). The discharge point of the roof runoff flows directly into the gravel trench via an underground PVC pipe from each dwelling and can be seen in the mid-section of Figure 2A. As shown in Figure 2B the geotexile fabric lining is simply rolled out along the length of the trench and then backfilled with 2–7 mm gravel screening (Figure 2C).

To protect the trench from excessive sediment loads during the landscaping phase of the swale component of the bio-filtration system, the geotexile was temporarily held in place over the gravel trench as shown in Figure 3A. The geotexile fabric was later laid back and 10 mm gravels were used to top-up the trench to create the base of the swale. Figure 3B
shows the landscaping of the base of the swale designed as a dry gravel channel fringed by tussock grasses, Eucalypts and hardy turf grass.

Figure 4 shows the final result; a magnificent looking entrance feature forming the median strip along the boulevard leading to the wetlands and lake system. The design standards of the bio-filtration system remain the same as for conventional drainage systems. The underlying gravel trench component is designed to convey storm runoff up to the 6-month ARI event while the bio-filtration system (i.e. trench and swale) are designed to carry the 5-year ARI flow. Stormwater runoff in excess of the 5-year ARI event and up to the 100-year ARI event is conveyed within the roadway.
Protecting the integrity of the system during construction activities

One major risk to the integrity of stormwater management schemes is the generation of sediment during the house construction phase of the development, resulting in highly turbid runoff during rainfall events. To inform and raise general awareness of individuals visiting, working or living at the Lynbrook Estate, billboards were erected adjacent to elements of the stormwater management scheme illustrating the design of the new street drainage system using simplistic diagrams.

Adoption of best practice on construction sites to control sediment-laden runoff is imperative to ensure the integrity of WSUD elements. Hydroseeding, sediment fences and hay bales to protect the bio-filtration system during the house construction phase were used. Direct damage to the swale components of the bio-filtration systems during house construction was also a concern. A variety of techniques were adopted to deter vehicle access and stockpiling of building materials on the swales. Fencing off the swale using temporary fencing and the use of signs located in front of each allotment that read “WARNING Infiltration Trenches Below: no vehicles, building materials or excavation on this nature strip” was found to be an effective method.

In addition a local by-law passed by the City of Casey as part of their attempt to minimise the impact of construction activities on the environment, requires every builder to provide a rubbish container, portable toilet and adequate sediment controls on each allotment. Failure to do so incurs a penalty notice and fine for committing the offence. Re-offenders or failure to pay the penalty notice can be prosecuted in the Magistrates Court for up to $2000.

Cost analysis

Table 2 summarises the costs of the stormwater management scheme adopted at the Lynbrook Estate and compares the costs to those based on a conventional drainage system. The tabulated costs include road and drainage works, as this is the only component that differed with the implementation of the WSUD at the Lynbrook Estate. Comparison of costs between implementing a WSUD stormwater management scheme and a conventionally designed stormwater drainage system shows only a minor increase of 5% to the cost of the drainage component of the development. Considering the drainage works component represents only 10% of the overall cost, the incorporation of WSUD into the stormwater management system at the Lynbrook Estate increased the total budget by approximately 0.5%.

It is expected that in the future cost neutral outcomes will predominantly occur as contractors become more familiar with the construction of WSUD infrastructure and remove the extra costs associated with a “safety margin” included into their project budget. The use of off-the-shelf construction components minimises the costs associated with contractors adding exorbitant safety margins into their project budget.

Market acceptance

The first 93 lots of the Lynbrook WSUD precinct were put on the market in February, 2000. The market at the time was buoyant and prior to this release, the Lynbrook Estate was regarded as “middle of the range” selling to mainly first home buyers at an average of around 12 lots per month. Lots were selling at an average price of AUS$56,000. Early in the marketing of stage 12, there were concerns raised by potential buyers about perceived issues of flooding of allotments, as there was no “proper” drainage system. There was also resistance at first to the swale drains with some purchasers, unsure of what the swales would look like, preferring to buy on the side of the street without the swale. All resistance to the swales faded as construction of the stage neared completion and people could see the end product. Stage 12 sold quickly at an average price of AUS$60,000 with releases of Stage 13 (106 lots) following in July, 2000 and stage 14 (72 lots) in February, 2001.
The inclusion of water features, preservation of remnant vegetation and an emphasis on environmental issues tends to make developments more desirable and marketable and consequently the market now perceives Lynbrook as an “upmarket development”. Second and subsequent home buyers are now in the majority of consumers and house size has increased accordingly. Sales rates today are around 30 per month in a still buoyant market.

**Conclusion**

The Lynbrook Estate demonstration project presented various challenges that were readily overcome by adopting a collaborative key stakeholder groups approach to the design of the stormwater management scheme. Gaining local government approval was one of the more challenging tasks; raising the level of awareness of WSUD, open communication and the acceptance of a compromise on the design of the scheme were vital to the project’s success. The challenges associated with gaining local government approval will diminish as the principles and practices of WSUD become more widely adopted.

Construction of the stormwater management scheme was no more difficult than for conventionally designed stormwater drainage systems. However, protecting the integrity of a stormwater management scheme during the construction phase of the surrounding houses is vital. The by-law passed by local government (City of Casey) and the use of best practice construction site measures such as hydroseeding, sediment fencing and hay bales reduced the incidence of sediment laden runoff to the bio-filtration and wetland systems.

Analysis of the capital costs of the bio-filtration systems showed only a 0.5% increase to the developer. This small increase in cost was offset by the increased marketability of the estate to the consumer. The success of the project has been widely acknowledged and the Lynbrook Estate demonstration project has helped to encourage the adoption of WSUD principles and practice by others elsewhere in Australia.

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**Table 2** Comparison between WSUD and conventionally designed drainage work costs at the Lynbrook Estate (based on a typical 160 m length of road covering 7 lots)

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<thead>
<tr>
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<th>Conventional design</th>
<th>Water sensitive urban design</th>
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<tbody>
<tr>
<td>1. 5 x side entry pits</td>
<td>@ $929.46/pit = $ 4,647.30</td>
<td>@ $1400.00/pit = $ 1,400.00</td>
</tr>
<tr>
<td>2. 76 x 1 m: 300 diameter drainage pipe</td>
<td>@ $45.87/1m = $ 3,486.12</td>
<td>@ $45.87/1 m = $ 1,100.88</td>
</tr>
<tr>
<td>3. 60 x 1 m: 375 diameter drainage pipe</td>
<td>@ $61.21/1m = $ 3,672.60</td>
<td>@ $766.50/hd&amp;pit = $ 5,365.50</td>
</tr>
<tr>
<td>4. 24 x 1 m: 450 diameter drainage pipe</td>
<td>@ $71.39/1m = $ 1,713.36</td>
<td>@ $26.09/1 m = $ 4,174.40</td>
</tr>
<tr>
<td>5. 7 x standard house drain to pipe</td>
<td>@ $227.11/hd = $ 1,589.77</td>
<td>@ $21.71/1m = $ 3,473.60</td>
</tr>
<tr>
<td>6. 160 x 1m kerb and channel</td>
<td>@ $26.74/1m = $ 4,278.40</td>
<td>@ $159.25/lay back = $ 1,114.75</td>
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<tr>
<td>7. 7 x driveway lay backs</td>
<td>@ $141.94/lay back = $ 993.58</td>
<td>@ $4.90/m² = $ 3,616.20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>AUS$20,381.13</td>
<td>AUS$21,410.77</td>
</tr>
</tbody>
</table>
References


Livingston, E.H. (1997). Water quality considerations in the design of wet detention and wetland stormwater management schemes. *Stormwater BMPs; The Good, the Bad, the Ugly*, Florida Department of Environmental Protection and Watershed Management Institute, Inc. 7.41p.


