WATER SENSITIVE URBAN DESIGN - A STORMWATER MANAGEMENT PERSPECTIVE

by

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Foreword

This Industry Report is one of a series prepared by the Cooperative Research Centre (CRC) for Catchment Hydrology to help provide agencies and consultants in the Australian land and water industry with improved ways of managing catchments. Since we published our first CRC Industry Report in 1997, the response has been overwhelming. It is clear that land and water managers appreciate material written specifically for them.

Through this series of reports and other forms of technology transfer, industry is able to benefit from the Centre's high-quality, comprehensive research programs:

- Predicting Catchment Behaviour
- Land-use Impacts on Rivers
- Sustainable Water Allocation
- Urban Stormwater Quality
- Climate Variability
- River Restoration

This particular Report presents key findings from Project 4.2 in the CRC's Urban Stormwater Quality Research Program: 'Stormwater Best Management Practices'.

The CRC welcomes feedback on the work reported here, and is keen to discuss opportunities for further collaboration with industry to expedite the process of getting research into practice.

Rob Vertessy
Director, CRC for Catchment Hydrology

Preface

In response to the need for reliable, cost-effective, environmentally-friendly, robust and aesthetically-pleasing stormwater treatment measures, the Cooperative Research Centre (CRC) for Catchment Hydrology undertook research to develop new, and refine existing stormwater quality improvement practices. The integration of these and other water conservation practices into urban design is referred to as Water Sensitive Urban Design (WSUD) and its principles can apply to individual houses, streetscapes and precincts or to whole catchments.

Fundamental to successfully applying WSUD principles to urban development is an understanding of the performance capabilities of structural stormwater management strategies, their life cycle costs and market acceptance. This report centres on the design process, construction activities and monitoring of environmental, social and economic performance indicators associated with the Lynbrook Estate Demonstration Project.

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- The Urban and Regional Land Corporation and in particular Bernie Porter
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Bio-filtration system along Lynbrook Boulevard at Lynbrook Estate, Victoria

Introduction

Urban catchments have a complicated water cycle involving water supply, wastewater disposal and stormwater drainage that are, in most Australian urban areas, managed as independent systems (Figure 1). High quality water is harvested from catchments often some distance away from urban areas, treated and delivered to meet domestic and industrial water demands. Wastewater generated from urban areas is conveyed to regional wastewater treatment facilities and then discharged to the environment (for example, to rivers or bays). Stormwater generated from urban areas is often conveyed efficiently to designated trunk stormwater drainage systems to reduce stormwater ponding and flooding.

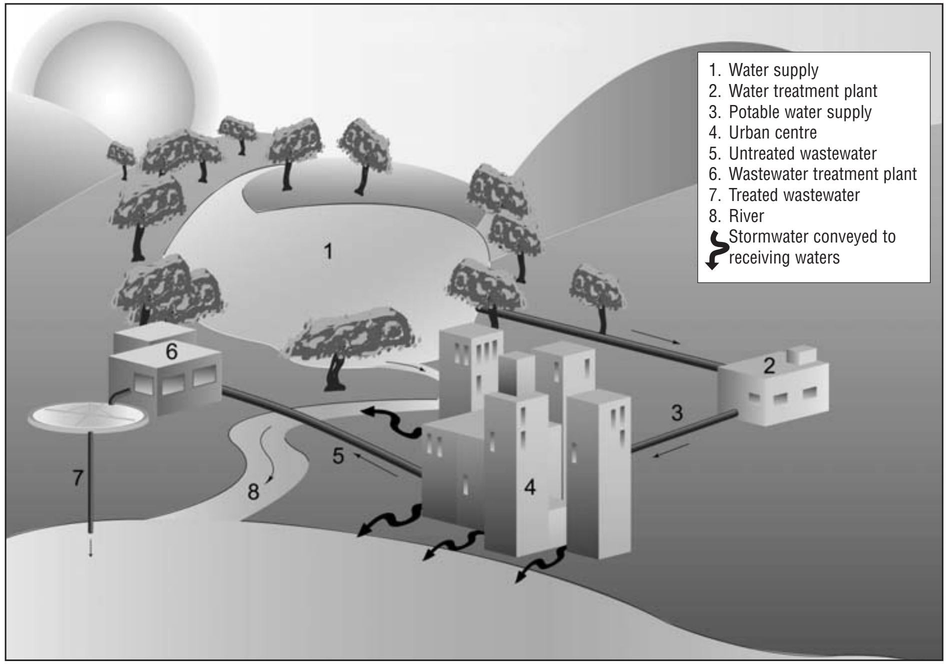


Figure 1. Important components of the urban water cycle

Increased pressures on the nation's water resources, and increasing awareness of the environmental impacts of stormwater and wastewater discharges on receiving water values has led to the water industry considering alternative approaches to manage the urban water cycle. Many opportunities are possible for reuse and more efficient use of water resources in urban areas if water quality considerations (matching availability with needs) are explicitly included in future water infrastructure design. These opportunities extend to measures to improve stormwater runoff quality into receiving waters (rivers, lakes, and bays) and are the primary focus of this report.

This report is divided into three sections.

The first addresses key issues of stormwater management in the context of an integrated urban water cycle.

The second uses the Lynbrook Estate Demonstration Project in Victoria to discuss issues associated with the implementation phase of a stormwater management scheme. Research findings are presented that quantify water quality improvements attributed to bio-filtration systems and the level of market acceptance and perceptions of changes in urban drainage using Water Sensitive Urban Design (WSUD).

The third section briefly discusses key barriers to widespread adoption of WSUD in Australia. The focus is on creating an effective planning framework and examining the performance of hypothetical structural stormwater management schemes and associated life cycle costs.

What is Water Sensitive Urban Design?

Water Sensitive Urban Design (WSUD) is a philosophical approach to urban planning and design that aims to minimise the hydrological impacts of urban development on the surrounding environment. Stormwater management is a subset of WSUD directed at providing flood control, flow management, water quality improvements and opportunities to harvest stormwater to supplement mains water for non-potable uses (that is, toilet flushing, garden irrigation etc.).

Key planning and design objectives encapsulated in 'Urban Stormwater: Best Practice Environmental Management Guidelines' (Victorian Stormwater Committee, 1999) are to:

- Protect and enhance natural water systems in urban developments
- Integrate stormwater treatment into the landscape by incorporating multiple use corridors that maximise the visual and recreational amenity of developments
- Protect water quality draining from urban development
- Reduce runoff and peak flows from urban developments by employing local detention measures and minimising impervious areas
- Add value while minimising drainage infrastructure development costs.

WSUD recognises that opportunities for urban design, landscape architecture and stormwater management infrastructure are intrinsically linked. The practices that promote long-term success of a stormwater management scheme are called Best Planning Practices (BPPs) and Best Management Practices (BMPs). They can apply to greenfield land development sites, redevelopment sites in built-up areas and, in some instances, to retrofits in fully urbanised catchments. The scale of application can range from individual houses, streetscapes and precincts, to whole catchments.

Developing a Stormwater Management Scheme

A broad approach to the development of a stormwater management scheme is outlined in 'Urban Stormwater: Best Practice Environmental Management Guidelines' (Victorian Stormwater Committee, 1999). These guidelines present strategies to meet stormwater management objectives involving integration of BPPs with catchment-wide use of non-structural BMPs and structural BMPs. Consideration of these strategies during the planning phase of a stormwater management scheme helps guide the decision-making process when selecting and designing BMPs to manage stormwater.

To support these guidelines the recently-released software package, Model for Urban Stormwater Improvement Conceptualisation (MUSIC) developed by the CRC for Catchment Hydrology, enables users to evaluate the merits of design concepts for a stormwater management scheme. MUSIC evaluates downstream flow control and water quality benefits achieved through applying structural BMPs.

The construction activities involved in translating a design concept for a stormwater management scheme into on-ground works will vary depending on what BMPs are included.

Figure 2 summarises the planning, design, assessment and implementation stages, and the associated activities involved in applying WSUD principles and practices to urban stormwater management. Planning, design and assessment issues are discussed in the remainder of this section. The implementation process of a stormwater management scheme is explored as part of the discussion of issues associated with the Lynbrook Estate Demonstration Project.

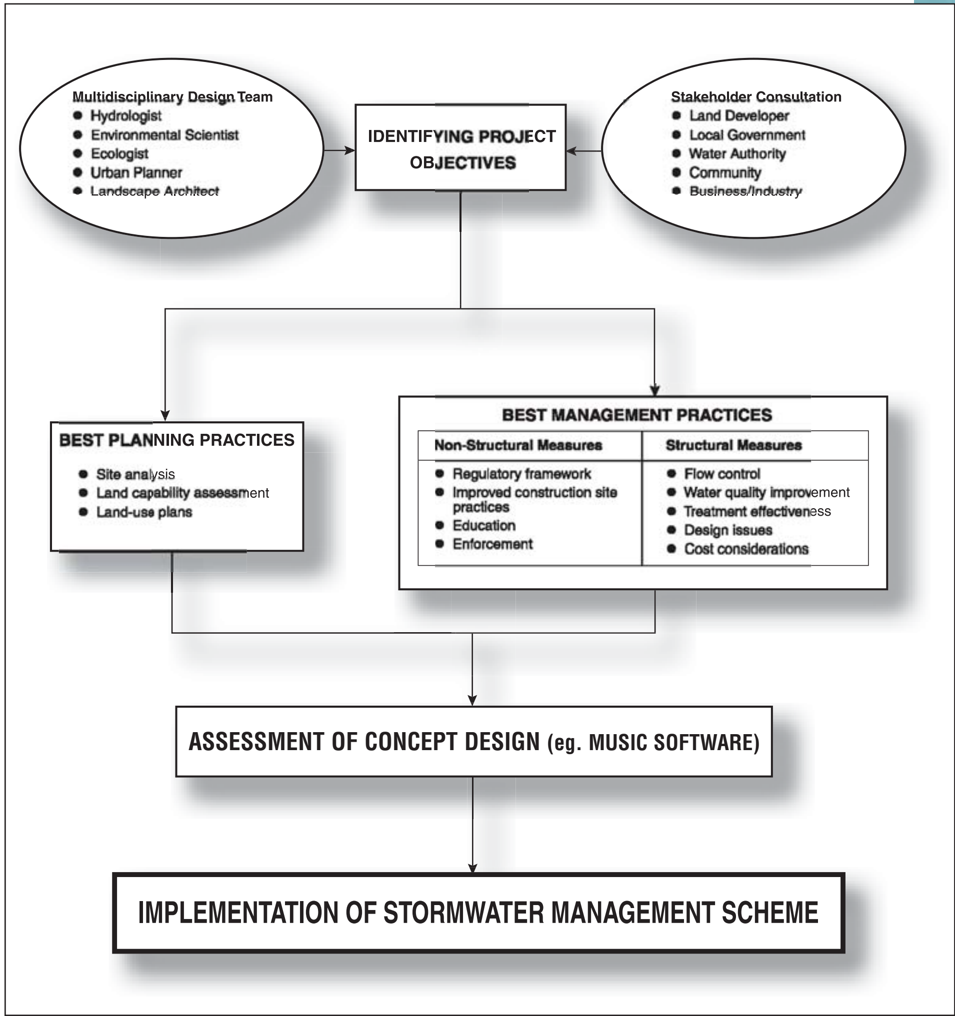


Figure 2. Key considerations in the planning, design and assessment of a stormwater management scheme

Identifying Project Objectives

Planning and design considerations for a stormwater management scheme should meet one or more of the following stormwater management objectives:

- Flood control
- Flow control for more frequent events (for example, up to the 1.5 year Average Recurrence Interval (ARI) event)
- Water quality control (for example, up to the three month ARI event)
- Use of stormwater as a resource.

In many cases, these objectives will need to be integrated with other water cycle management, urban design, landscape architectural and non-water related ecologically sustainable development objectives (for example, energy, material, socio-economic).

Multi-disciplinary Design Team

Defining project objectives and appropriate urban planning and design strategies are multi-disciplinary tasks, so WSUD requires inputs from a range of professions. Specialist skills in urban planning, landscape architecture, engineering hydrology and hydraulics, environmental science, aquatic ecology and water resource management are needed to support an integrated and holistic WSUD project. Fostering interaction between the professions that offer these skills is essential for WSUD to become a widely-adopted urban planning and design philosophy.

Stakeholder Consultation

Achieving long-term support for a stormwater management scheme requires commitment to the project by key stakeholder groups such as local government, the local water authority and community. A discussion of project issues involving the design team and stakeholder groups may include:

- Broad concepts of WSUD
- Project objectives
- Site opportunities and constraints
- Potentially suitable BPPs and BMPs for inclusion in the stormwater management scheme
- Concerns related to functional design elements of BMPs (ie kerb inlet design, sediment pit/trap) and preference for final appearance in terms of landscaping and design element finishings
- Activities that would potentially impair the system's design performance/robustness
- Maintenance issues such as requirements, frequency, access and responsibility
- Capital cost and on-going maintenance costs
- Overall market appeal and commercial success of similar stormwater management schemes
- Potential strategies to protect BMPs during the construction of surrounding infrastructure
- The likely level of behavioural change, if any, that residents and others may have to accept to ensure system design performance is maintained
- Possible requirements for education/information transfer to raise resident and visitor awareness levels.

Best Planning Practices (BPPs)

Planning a stormwater management scheme involves undertaking a site analysis and land capability assessment, and developing a land-use plan. When the site layout is established, understanding the changes in catchment runoff characteristics and pollutant loads helps to identify, select and design appropriate non-structural and structural BMPs to achieve project objectives.

Site Analysis

Site analysis involves an audit of regional land-use zoning, climate and landscape characteristics. Important regional land-use zones may include green corridors and conservation areas. Identifying these regional land-use zones provides the opportunity to enhance, protect and/or create links between areas of regional significance.

At a more focused level, the following site characteristics are considered:

- Geology and soils
- Landforms
- Drainage patterns (including assessment of the 100 year ARI flood levels)
- Climate (including historical rainfall patterns and evaporation rates)
- Significant natural features (that is, remnant vegetation, habitat of threatened or endangered species, wetlands, etc.)
- Existing urban infrastructure (that is, underground gas lines or water supply mains)
- Historical/cultural features (that is, heritage buildings, archaeological sites, etc).

Land Capability Assessment

Land capability assessment involves matching the physical capability of landscape features identified as part of the site analysis to sustainable future land-uses once the site is fully developed. The use of a land capability matrix can help identify areas in the landscape most capable of sustaining specific land-use practices.

Land-use Plans

A land-use plan is one in which the layout, scale and arrangement of amenities at a site are drawn to scale. The outcomes of a site analysis and land capability assessment may suggest that different site layout options are possible. Preference should be given to the option providing greatest benefit to the downstream environment within the budgetary resources of the developer and organisation responsible for long-term maintenance of the stormwater management scheme. Minimising these costs is achieved by including planning provisions in the site layout. Examples of planning provisions that can improve overall effectiveness of the stormwater management scheme include:

- Whenever possible, orientate roads to run diagonally across the contour to achieve a grade of 4% or less to help incorporate BMPs into the streetscape
- Promote cluster lot arrangements around public open space to allow greater community access to, and regard for associated natural and landscaped water features forming the local stormwater management scheme
- Maintain and/or re-establish vegetation along waterways, and establish public open spaces down drainage lines to promote them as multi-use corridors linking public and private areas and community activity nodes.

Non-structural Best Management Practices (BMPs)

Non-structural BMPs include environmental and urban development policy, environmental considerations on construction sites and education and enforcement programs. It is likely that a combination of these non-structural BMPs will be required to encourage changes in behaviour and/or current practice across the community. Table 1 summarises five key non-structural BMPs.

The effectiveness of non-structural BMPs changing community behaviour and minimising the quantity and quality changes to stormwater attributed to urban development, is not well documented nor quantified. The CRC for Catchment Hydrology is undertaking research to develop an evaluation method to quantify improvements to stormwater resulting from implementation of non-structural BMPs.

Table 1. Examples of non-structural best management practices

Best Management Practices	Comments
Environmental and urban development policy	Environmental and urban development policy at the local, state and federal level is required to encourage widespread adoption of Ecologically Sustainable Development practices, including the incorporation of WSUD into the urban planning process.
Environmental considerations on construction sites	Poor planning and management of construction/building sites can severely deteriorate the quality of stormwater runoff. Site management plans are a useful strategy to minimise the generation of pollutants from land development and building activities.
Education and staff training • Local government • Industry • Business	Education programs including staff training should be directed at all staff levels to instigate effective changes in practice. Training should provide the necessary tools/techniques to enable staff to plan for future activities (ie. approval, construction, operation or maintenance activities).
Community education programs	Community education programs addressing stormwater management issues encourage change in social 'norms' and behaviours. Individual changes in behaviour may collectively contribute to reduce the impact of urban development on stormwater. However community awareness and understanding of issues related to stormwater pollution is not necessarily a precursor to changes in behaviour. Equally important is the concept that an informed community can place pressure on local government, industry and business to be responsible for their impact on stormwater.
Enforcement programs	Financial penalties are potentially an effective deterrent to reduce activities that result in the pollution of stormwater. Enforcement programs are largely the responsibility of the Environmental Protection Authority and local government. A number of studies are being conducted to measure the effectiveness of enforcement programs.

Structural Best Management Practices (BMPs)

Structural BMPs are stormwater treatment measures that collect, convey or detain stormwater to improve water quality and/or provide a reuse function. A treatment train approach is recommended, whereby BMPs are distributed across a catchment and their design may be modified for effective use at source or regional scales. Table 2 lists possible structural BMPs that can be included in the design of the allotment, streetscape or open-space networks.

This list will grow as more innovative BMPs are developed and integrated into urban design.

In built-up catchments, land availability often limits the type of structural BMP that can be used to manage stormwater. Nevertheless, with a little progressive thinking, opportunities in these catchments do exist. Some BMPs that have been successfully used include retarding basin retrofits with wetlands, green roofs and water recycling schemes for non-potable purposes.

Table 2. Opportunities for the placement of structural best management practices in urban catchments

Structural BMP	Allotment	Streetscape or precinct	Open Space networks or regional scale
Diversion of runoff to garden beds	✔		
Rainwater tank/reuse scheme (ie. garden watering, toilet flushing)	✔		
Sediment trap	✔		
Infiltration and collection system (bio-filtration system)	✔	✔	✔
Infiltration system	✔	✔	✔
Native vegetation, mulching, drip irrigation systems	✔	✔	✔
Porous pavement	✔	✔	✔
Buffer strip		✔	✔
Constructed wetland		✔	✔
Dry detention basin		✔	✔
Litter trap (side entry pit trap)		✔	
Pond and sediment trap		✔	✔
Swale		✔	✔
Lake			✔
Litter trap (gross pollutant trap)			✔
Rehabilitated waterway			✔
Reuse scheme (ie open space irrigation and toilet flushing)			✔
Urban forest			✔

The Treatment Train Approach

No single non-structural or structural BMP can effectively prevent or remove the full range of urban stormwater pollutants. Therefore, it is often necessary to use a number of BMPs to achieve the desired water quality outcomes. Pollutant removal mechanisms associated with BMPs involve physical, biological and chemical processes. Treatment methods based on physical processes are often the first to be used in a treatment train. Physical processes fundamentally involve trapping gross pollutants and coarse sediments and sedimentation of finer silts and clay sized particles. Once gross pollutants and coarse sediments are removed, other pollutant removal mechanisms involving biological and chemical processes can be effectively applied. The general approach to the sequencing of BMPs should be based on:

1. Avoiding pollution whenever possible through non-structural BMPs
2. Controlling and minimising pollution by means of structural BMPs located at the source of the runoff, in-transit or further downstream at the end-of-pipe if pollutant generation cannot be feasibly avoided
3. Managing the impacts of stormwater pollution on the receiving waters as a last resort.

Selecting Appropriate Structural Best Management Practices

Selection of structural BMPs to incorporate into a stormwater management scheme should be based on maximising flow control and/or water quality benefits relative to the costs incurred over the life of the asset(s). One approach to identify and select BMPs suitable to achieve the project objectives is to consider the following issues:

- Flow control
- Water quality improvement
- Treatment effectiveness
- Design issues
- Cost considerations.

Flow Control

Flow control provides the basis for all stormwater management schemes. The three flow control issues to consider are flood management, and for more frequently occurring runoff events, flow attenuation and runoff volume reduction. Table 3 summarises a number of BMPs effective at providing flow control.

Stormwater reuse schemes are an effective way to reduce urban runoff volume. However, it is important to harvest only the flows larger than those occurring before the catchment was developed to ensure environmental flows are maintained in receiving waterways.

Table 3. Flow control functions associated with structural best management practices

Best Management Practices	Primary Flow Control Function		
	Flood Management	Flow Attenuation*	Reduction in Volume*
Retarding basin	✔	✔	
Lake/pond	✔	✔	
Wetland		✔	
Rehabilitated waterway (pool and riffle system)		✔	
Vegetated swale		✔	
Buffer strip		✔	
Infiltration and collection system (bio-filtration system)		✔	✔
Infiltration system		✔	✔
Water reuse scheme		✔	✔

** Applies to frequent events*

Water Quality Improvement

One way to identify suitable BMPs for water quality improvement is to describe the target stormwater pollutant(s) to be removed. Pollutant particle size grading is a useful description of the pollutant characteristics. For instance, gross pollutants are often described as particulates larger than 5mm (or 5000 microns) while soluble pollutants are described as particles smaller than 0.45 microns. Classifying stormwater pollutants this way allows different pollutant types to be matched to BMPs that maximise their removal as shown in Figure 3.

Stormwater pollutants not easily described in terms of their particle size include petroleum by-products, that is oil, petrol and Polycyclic Aromatic Hydrocarbons (PAHs). These pollutants are most effectively removed from stormwater using infiltration systems.

Treatment Effectiveness

Estimating treatment effectiveness involves identifying the proportion of mean annual runoff volume that enters and flows through a BMP, as well as the pollutant removal efficiency of the BMP. Modelling tools such as the MUSIC software provide a simple means to rapidly assess the treatment effectiveness of BMPs.

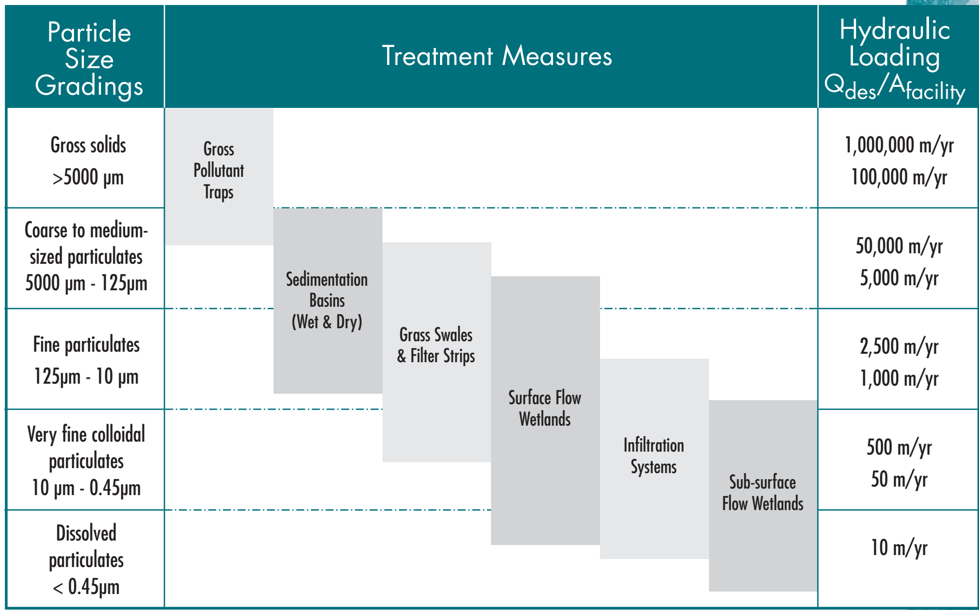
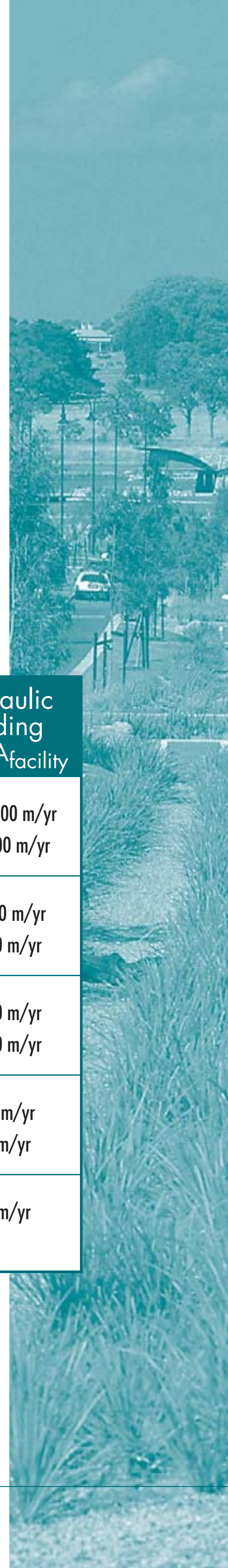


Figure 3. Best management practices, their target particle size range and operating hydraulic loading range (Wong 2000)



Design Issues

Details of a BMP design should be considered in the context of site opportunities and constraints, for example the landform and climate characteristics and the area of available land to construct/install a BMP. For instance, BMPs such as infiltration systems designed specifically for flow control require flows to be pre-treated prior to system entry to minimise potential for clogging and ensure their long-term sustainability. If land is not available upstream to adequately pre-treat flows entering the infiltration system, then the system should not be considered for inclusion in the stormwater management scheme.

Cost Considerations

Assessment of capital and on-going maintenance costs is important to ensure adequate budgetary resources are provided by the organisation constructing the BMP (that is, the developer, water authority or local government) as well as the organisation responsible for maintaining the BMP over the life of the asset (that is, local government, water authority or body corporate). It is crucial to the stormwater management scheme's success that the organisation(s) responsible for meeting these costs be aware of the costs involved, especially in terms of on-going maintenance. One approach being developed to assess life cycle costs is outlined in Appendix A.

Assessment of Structural Stormwater Management Strategies: MUSIC software

There have been several major impediments to effective design, prioritisation and evaluation of urban stormwater management schemes. These stem from uncertainties about the likely water quality from catchments of different land-use, uncertainties about performance of BMPs, particularly when combined in parallel or series, and an inability to compare the performance, benefits and costs of different stormwater management strategies.

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC)[1] was developed by the CRC to provide urban catchment managers with the opportunity to assess performance of structural BMPs. MUSIC enables users to plan and evaluate conceptual designs of stormwater management schemes to meet specific water quality objectives, and to derive indicative sizes of structural BMPs.

Specifically, the software enables users to:

- Determine likely water quality emanating from urban catchments
- Predict the performance of specific structural BMPs in protecting receiving water quality
- Design an integrated stormwater management scheme
- Evaluate the success of structural BMPs, or a stormwater management scheme, against a range of water quality standards.

A particular feature of MUSIC is its capability to model urban stormwater management schemes at a range of spatial and temporal scales to cover structural BMPs at the individual allotment, streetscape, precinct and catchment scale, as illustrated in Figure 4.

[1] *http://www.catchment.crc.org.au/toolkit/music*

A scheme to allow developers (especially infill developers with limited treatment opportunities in built-up catchments) to contribute to regional and precinct WSUD schemes in lieu of some required on-site works would be consistent with an integrated catchment management philosophy in urban stormwater management. Investigation of the feasibility of a scheme for trading stormwater quality improvement credits or offsets for environmental management of urban stormwater is one of many efforts by Victorian local and state government departments to formulate a more integrated regulatory framework for WSUD. The modelling capability of MUSIC has provided the quantitative basis to underpin such a scheme by linking government policy to stormwater quality treatment technology.

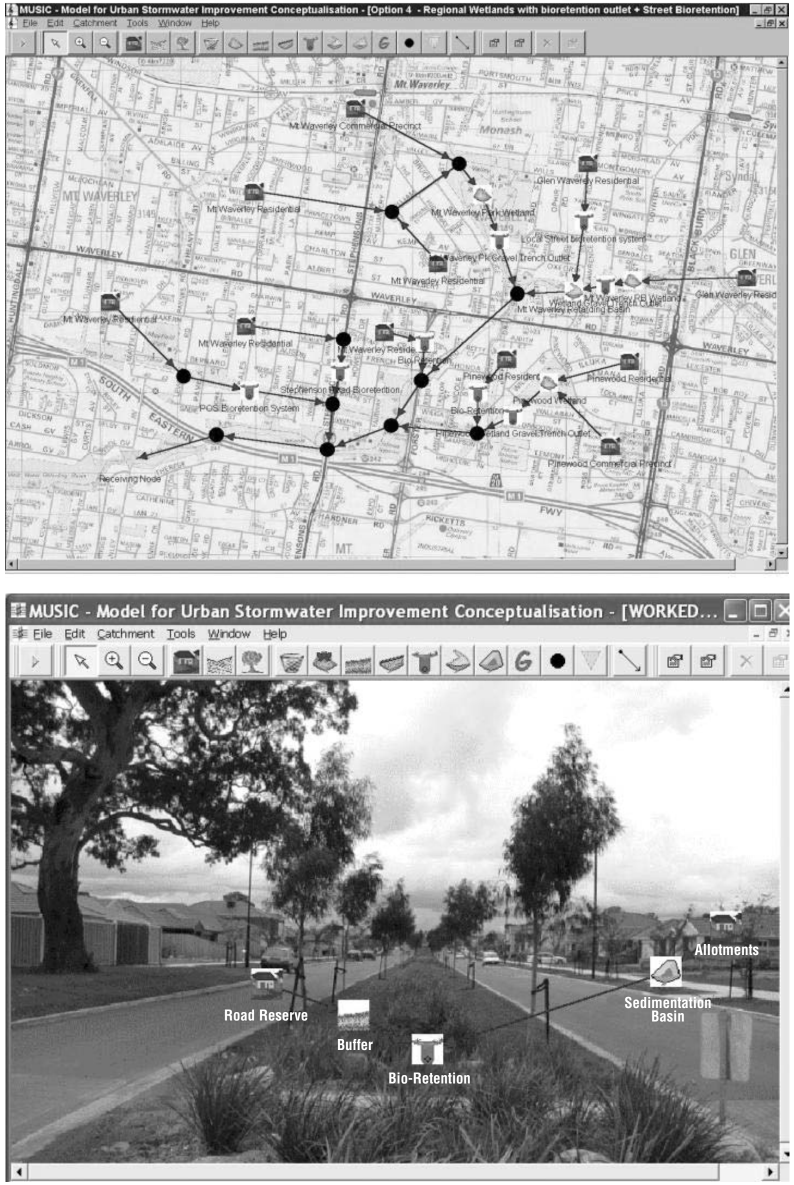


Figure 4. The application of MUSIC covers a range of spatial scales, from development of a regional stormwater quality treatment strategy (top) to modelling local streetscape systems (bottom).

Implementation of a Stormwater Management Scheme: The Lynbrook Estate Demonstration Project

In the past decade, industry has hesitated in adopting the principles and practices of WSUD. This is due, in part, to little evidence of the economic, social and environmental benefits associated with applying structural BMPs close to the source of runoff to manage urban stormwater. To address this issue, the Lynbrook Estate Demonstration Project was designed, constructed and monitored to provide an opportunity to evaluate the performance data of bio-filtration systems (also referred to as bioretention systems in published literature).

More specifically, information and/or performance data is being documented on the:

- Project planning and design process
- Role of, and negotiations between, key stakeholder groups
- Construction and landscaping activities associated with bio-filtration systems
- Effectiveness of a newly constructed bio-filtration system in treating pollutants commonly found in urban stormwater runoff
- Life cycle costs associated with integrating bio-filtration systems into the urban landscape
- Market acceptance of changes in residential design associated with applying WSUD practices
- Catchment flow and pollutant characteristics from a conventional street drainage scheme compared to a street drainage scheme using bio-filtration systems.

The level of documentation, monitoring and evaluation of performance data exceeds that of any other WSUD demonstration project worldwide. For further details on the design and implementation of the Lynbrook Estate Demonstration Project, refer to Lloyd *et al*., 2002.

Overview

The Lynbrook Estate Demonstration Project is a greenfield site residential development in the south-eastern growth corridor of Melbourne (~35 km from the CBD). The demonstration project incorporates some 32 hectares, consisting of 271 medium density allotments (average size 600 m^2) and parklands. Roof and road runoff are collected and treated using bio-filtration systems that form the street drainage system. These systems are grassed and landscaped swales which promote infiltration into the underlying gravel-filled trench. Subsequent treatment is provided by a series of constructed wetlands which discharge into an ornamental lake and then a regional floodway. Figure 5 shows a basic layout of the structural BMPs included in the estate.

A unique feature of the Lynbrook Estate Demonstration Project is the design simplicity of the stormwater management scheme. The estate's streetscapes appear conventional in design as parts of the bio-filtration systems are underground. In 2000, the innovative design of the Lynbrook Estate Demonstration Project was recognised nationally, with the project being awarded the prestigious Award for Excellence by the Urban Development Institute of Australia. The project's contribution to assisting industry adoption of WSUD principles and practices elsewhere in Australia was also recognised when the CRC for Catchment Hydrology received the Cooperative Research Centres Association Technology Transfer Award in 2001.

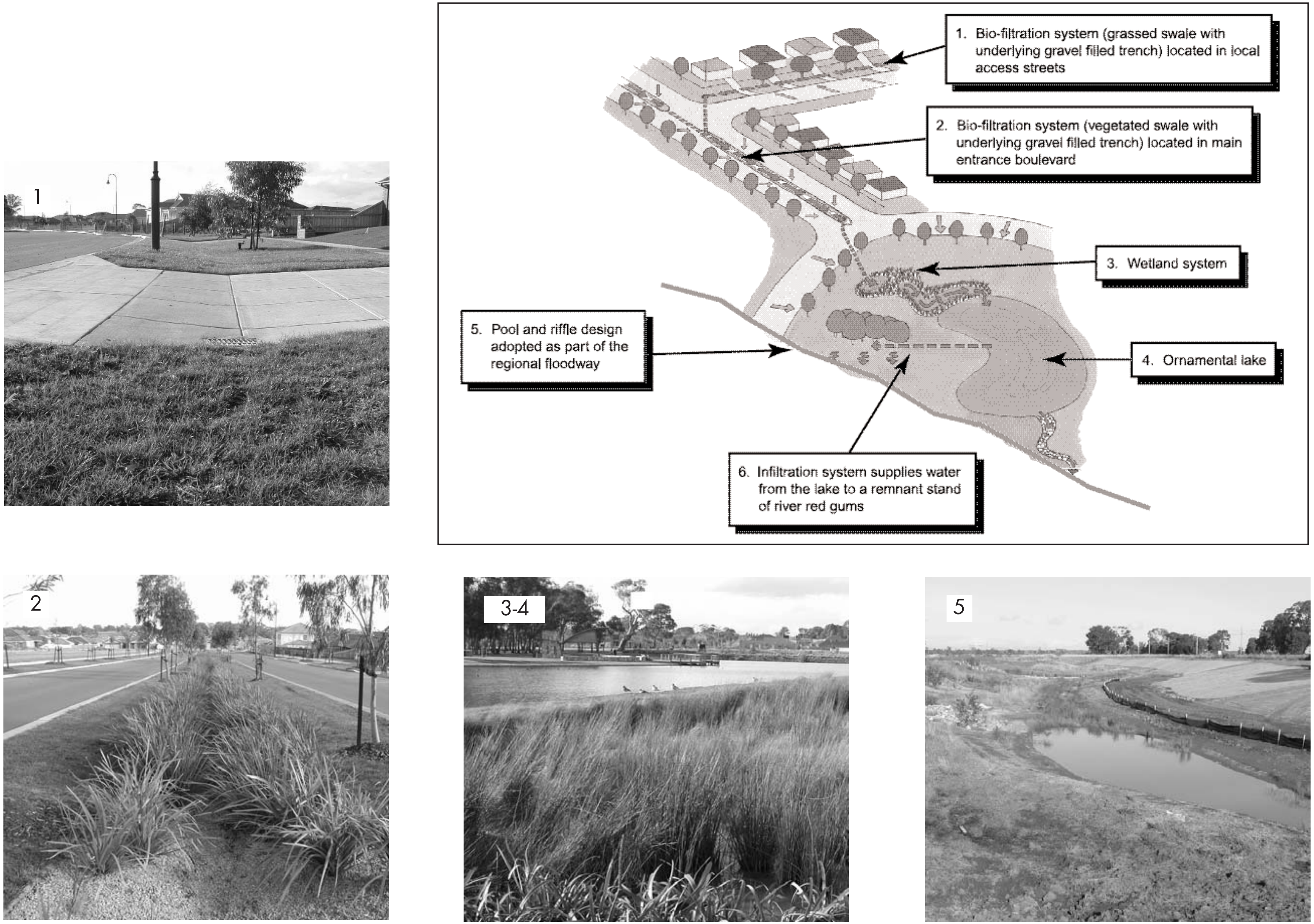


Figure 5. Layout of the best management practices incorporated into the Lynbrook Estate Demonstration Project

Engaging Stakeholders

Urban water resource management is complex, requiring input from many stakeholder groups. Stakeholders play an important role in identifying local opportunities and constraints in the context of broader regulatory, economic, environmental and social boundaries.

Stakeholders with little experience with WSUD commonly raise concerns over a range of design and operation issues. Examples of stakeholder concerns from the Lynbrook Estate Demonstration Project and brief descriptions of appropriate responses and/or actions are listed in Table 4.

Table 4. Typical concerns regarding implementation of WSUD and the response used during discussions with key stakeholders

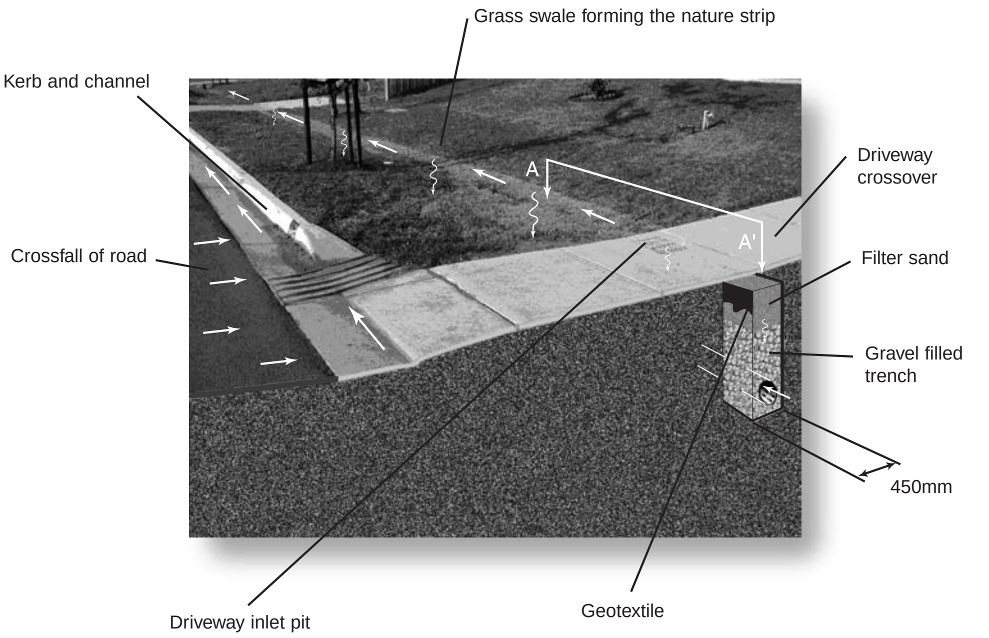
Issue	Concern	Response
Design of bio-filtration	• Level of flood protection and concern of increased flooding in extreme events	• Design standards are the same as for conventional drainage systems flooding in extreme events (ie. 5 year ARI event to be contained in the system, safe overland flow paths meeting depth and velocity requirements up to 100 year ARI event)
	• Council did not know how to assess the design as their standards and codes for approval did not easily allow for alternatives to conventional practice	• Key council staff were encouraged to participate in stakeholder group workshops, and additional meetings were held to ensure the detailed design document addressed their specific concerns. • Design team had to demonstrate how the concept design achieved urban development objectives (eg levels of flood protection)
	• Surface ponding of stormwater within the bio-filtration systems and concerns about public safety issues	• Compromises had to be made on the 'optimal' design from a stormwater treatment perspective (ie eliminating surface ponding led to a reduction in treatment effectiveness)
Ensuring system integrity	• Impact of housing construction phase on drainage system, particularly swales	• Swales were fenced off, geo-textile fabric placed in entry pits to gravel trench, warning signs erected to discourage inappropriate stockpiling, sediment fences and hay bales were used
	• Complete system failure	• The system is designed conservatively (ie the use of gravels in the system rather than fine sands to reduce the chance of clogging) • Melbourne Water Corporation committed to the replacement of the system with a conventional system if it failed within the first 5 years after construction
Maintenance requirements	• What maintenance is involved and how often is it required?	• The Urban and Regional Land Corporation had to extend their maintenance contract by 12 months to two years after completion of the bio-filtration systems, in order to provide local government with some assessment of these requirements
Community	• Market place acceptance	• The 3 stages of development enabled assessment of market place acceptance to be undertaken
	• Role, if any, the community must play in maintaining the system	• Community role is minimal, nevertheless an information pamphlet and video were distributed to each household to heighten their awareness of WSUD
Other	• Cost-effectiveness	• Assessment of cost-effectiveness is included as part of the monitoring program of the estate

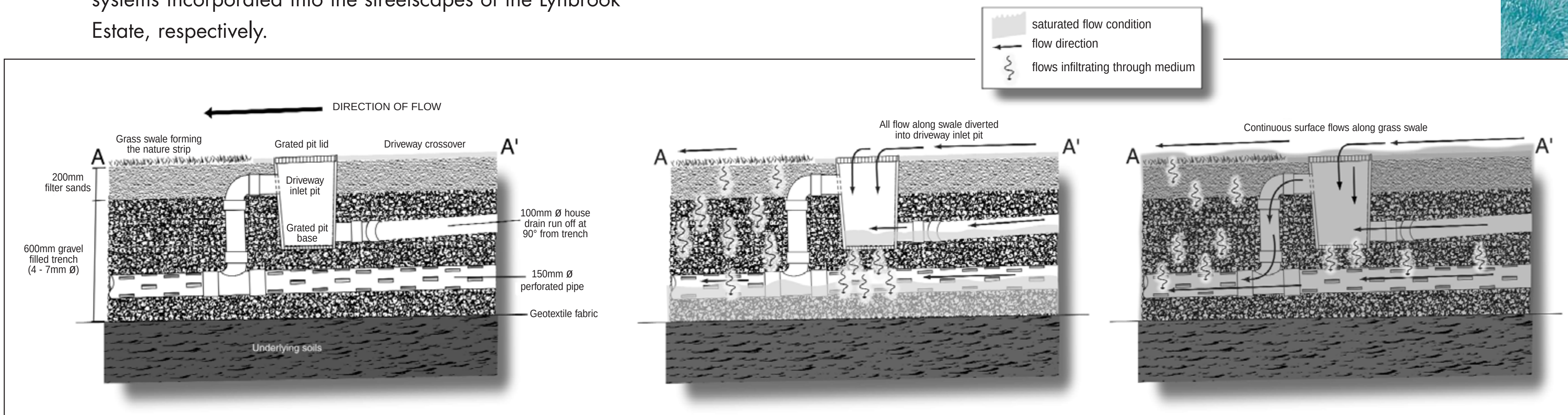
Design Details and Construction Activities Associated with the Bio-filtration Systems

The Lynbrook Estate Demonstration Project was constructed in three stages and was completed using conventional excavation methods and machinery. Appendix B explores construction issues involved in implementing a stormwater management scheme. It also includes a summary of barriers to the compliance of builders and contractors with local government initiatives that promote best practice measures on building sites in order to minimise pollutants entering the stormwater drainage system.

Figure 6 illustrates how the bio-filtration systems operate under different rainfall conditions. Figures 7 and 8 highlight key design details and construction activities associated with the landscaped bio-filtration systems and grassed bio-filtration systems incorporated into the streetscapes of the Lynbrook Estate, respectively.

Figure 6. Schematic representation of the bio-filtration system operating under different rainfall conditions





Longitudinal section of bio-filtration system

Flow pattern during low flow conditions (<4-5 month ARI storm event)

Flow pattern during high flow conditions (>4-5 month ARI storm event)

Laying of the geotextile fabric and 150mm diameter perforated pipe along the trench of the bio-filtration system. Root barriers are used where trees will be planted.

Roof runoff from the allotments located on the high side of the road drain to the gravel trench using a PVC pipe.

Geotextile fabric is temporarily used to protect the gravel trench from sediment in runoff during landscaping activities.

Early landscaping activities showing the gravel base of the swale that extends into the underlying trench.

The bio-filtration system forms the median strip with the road's cross fall sloping towards it.

No kerb and gutter system promotes an even distribution of flow from the road surface onto the grass filter strip for pre-treatment.

Thick tussock grass provides further treatment to road runoff prior to entering the gravel trench.

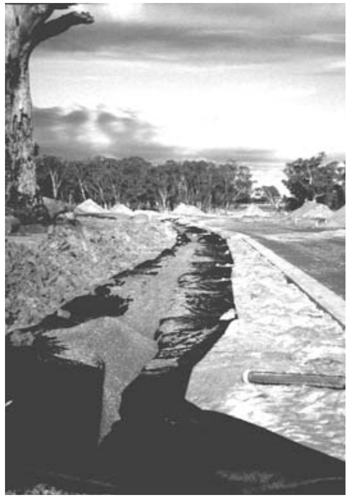
When the discharge capacity of the system is exceeded stormwater is conveyed as open channel flow. Culverts are used to convey these flows under vehicle turnings.

Figure 7. Construction and landscaping activities associated with the landscaped bio-filtration systems located in the main entrance boulevard

The general shape of the swale is graded using the kerb to guide the distance to the centre of the system.

Excavation of the trench component of the bio-filtration system.

Laying of the geotextile fabric and 150mm diameter perforated pipe.



Backfilling of the trench with gravel screenings 4-7mm in diameter.

Grass cover along the swale is established using rolled turf and hydroseeding. Hay bales are placed across the kerb chutes and driveway inlet pits are sealed to protect the system from sediment laden runoff during construction.

The grassed swale forms the nature strip. Road runoff is diverted onto the swale from the kerb and gutter system using kerb inlet chutes located on the downstream side of each driveway cross over.

Roof runoff is conveyed to driveway inlet pits, which are also used to discharge surface flows that exceed the infiltration capacity of the grass swale.

When the discharge capacity of the system is exceeded, stormwater is conveyed as open channel flow on the grassed swale to a grated entry pit at the downstream end of the system.

Figure 8. Construction and landscaping activities associated with the grassed bio-filtration systems located in the local access streets

The staged development approach applied at the Lynbrook Estate Demonstration Project proved extremely useful, allowing the design of the swale component to be refined in the later development stages. Figure 9 shows modifications to the kerb and gutter inlet chute designs and the cross-section form of the swale. This modification has helped reduce debris build-up at the concrete-grass interface. The slope of the cross section also increased from one in 13 to one in nine to help define a low flow path along the centre of the grass swale and more robust grass species have been used. These modifications did not alter the cost of the bio-filtration systems but have improved overall system efficiency in capturing runoff and treating pollutants conveyed in the stormwater.

Figure 9. Modifications made to the swale design of the bio-filtration systems

Capital Costs of Bio-filtration Systems

As part of the Lynbrook Estate Demonstration Project, capital costs of the bio-filtration systems were compared to a conventional design concrete pipe system. The bio-filtration cost calculation for stage 12 of the Lynbrook Estate included material and labour associated with the trench and swale earthworks, gravel fill, perforated pipe, turf, kerb and channel, pavement forming, and driveway crossover inlet pits. For the conventional concrete pipe system, costs included all pipe works, earthworks, side entry pits, house drainpipes to the street, driveway laybacks and kerb and channel.

The bio-filtration system capital costs in the demonstration project's first stage increased total drainage costs by about 5% over conventionally-designed concrete pipe system costs.

The stormwater drainage component of the total development cost is about 10%, resulting in an overall increase to the project budget of 0.5%. The increase in cost to the developer was mainly attributed to a 'safety margin' added by the drainage contractors because they had no experience with constructing bio-filtration systems.

Assessing the Effectiveness of Bio-filtration Systems for Stormwater Treatment

In January 2000, field experiments were undertaken to quantify the effectiveness of bio-filtration systems in removing common pollutants from urban stormwater runoff. The experiments were conducted along the grassed bio-filtration systems located in Lynbrook's local access streets. For details of the experimental design, refer to Lloyd *et al.*, 2001. Figure 10 indicates that bio-filtration systems are an effective structural BMP for removing sediments and associated pollutants from urban stormwater.

The bio-filtration system's effectiveness during steady state flow conditions for the eight experimental runs undertaken can be summarised as follows:

- A 60% reduction in Total Suspended Solids (TSS) load was measured. The removal of TSS is mainly attributed to enhanced sedimentation processes (through filtration and adhesion along the grass swale). Given the relatively fine nature of the sediments used in these experiments, it is expected higher rates of sediment removal can be achieved under actual storm conditions.

  A positive relationship was observed between an increased concentration in TSS dosed into the system and an increase in percentage removal of TSS by the bio-filtration system.

- A 47% reduction in Total Phosphorus (TP) was measured. The removal of TP is mainly due to the fraction of soluble phosphorus adsorbed to the sediments and then removed through sedimentation processes.

Laboratory studies conducted in the United States of America found bio-filtration systems to be effective not only at removing phosphorus from inflowing water, but also other stormwater pollutants closely associated with sediments such as metals commonly found in road runoff (Davis *et al.*, 2001).

- A 66% reduction in soluble phosphorus was measured. This result can be largely attributed to rapid attachment of soluble phosphorus to available binding sites of finely graded sediments.
- No net reduction in Total Nitrogen (TN) was measured.

  This finding suggests that organic nitrogen from fertilisers used to rapidly establish the grass at construction is flushed from the system shortly after establishment.
- A 29% reduction in soluble nitrogen was measured. The complex nature of the nitrogen cycle in the bio-filtration system is not well understood and further research is being conducted to gain greater insight into nitrogen removal processes.

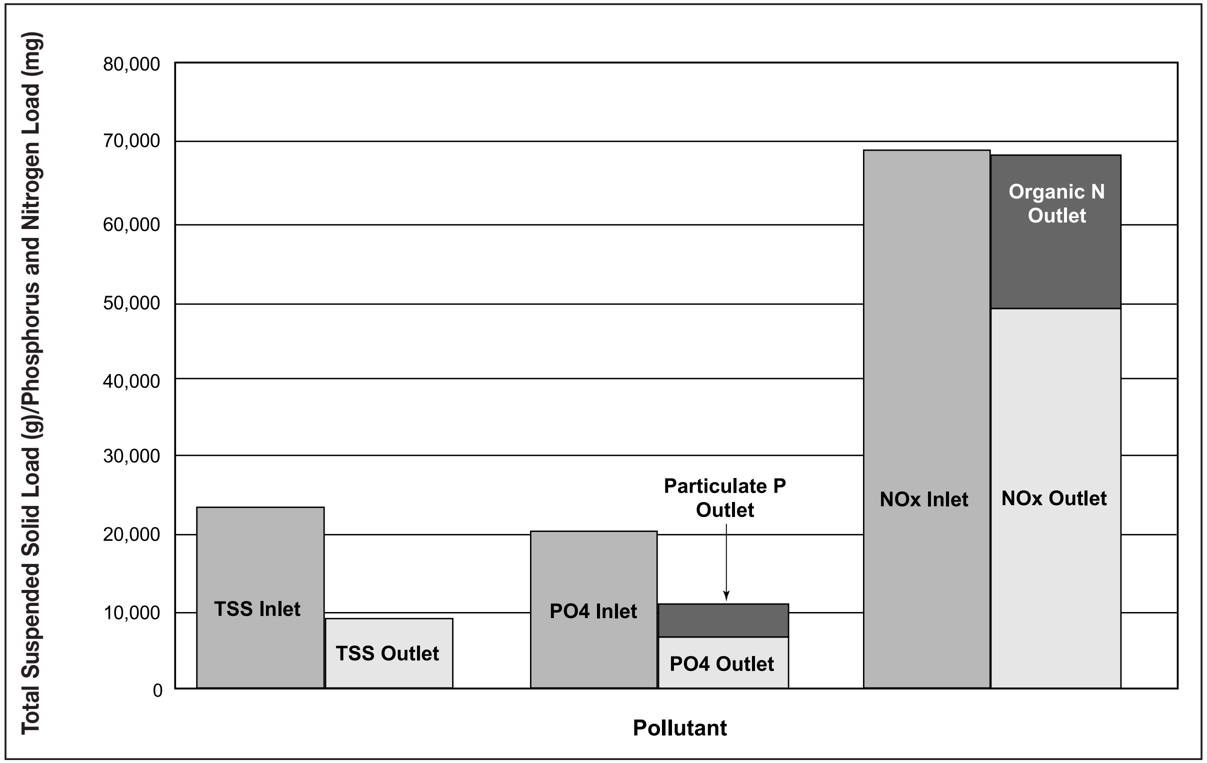


Figure 10. Pollutant removal performance associated with a newly constructed bio-filtration system

Flow Characteristics and Water Quality Improvements Associated with the Bio-filtration System during a Series of Small Storm Events

In order to assess the performance of the bio-filtration system under a range of storm event conditions, a paired catchment storm event monitoring program was implemented in adjacent sub-catchments at Lynbrook Estate. This enabled comparisons of stormwater runoff characteristics to be made between a conventional pipe system and a landscaped bio-filtration system.

The monitoring program quantifies changes in flow characteristics and water quality attributed to incorporation of bio-filtration systems into street drainage. Figures 11 and 12 show a reduction in total flow volume and pollutant loads for a series of small rainfall events (each small event is equal to or less than the one month ARI storm event). The findings indicate that pollutant removal results from a combination of treatment mechanisms promoted by flow reduction via infiltration into the underlying soils, and filtration of the flow in the bio-filtration system.

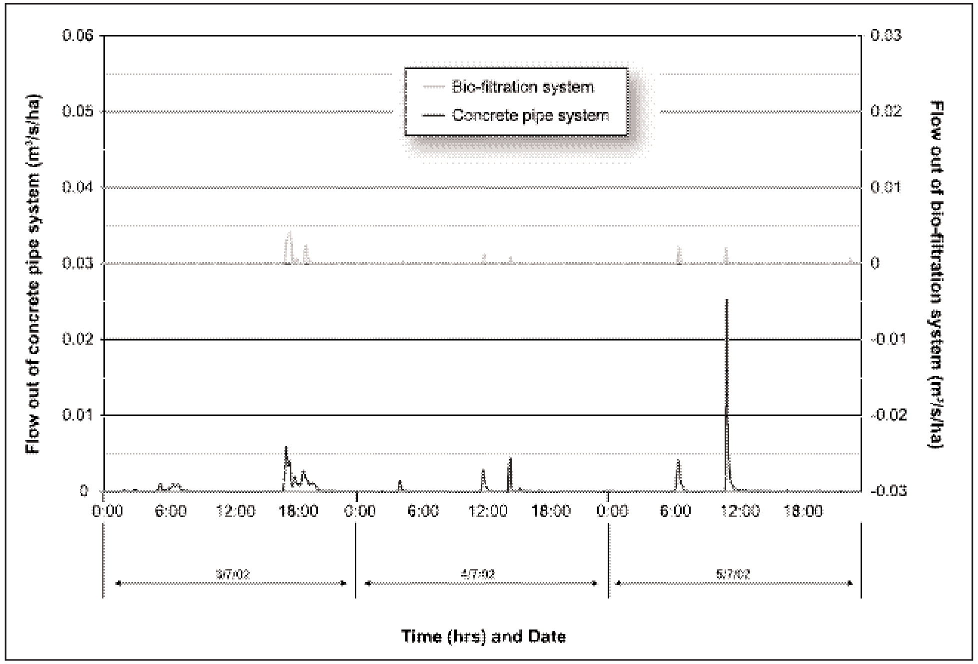


Figure 11. Comparison of flows discharged from a conventional pipe system and bio-filtration system for a series of small storm events

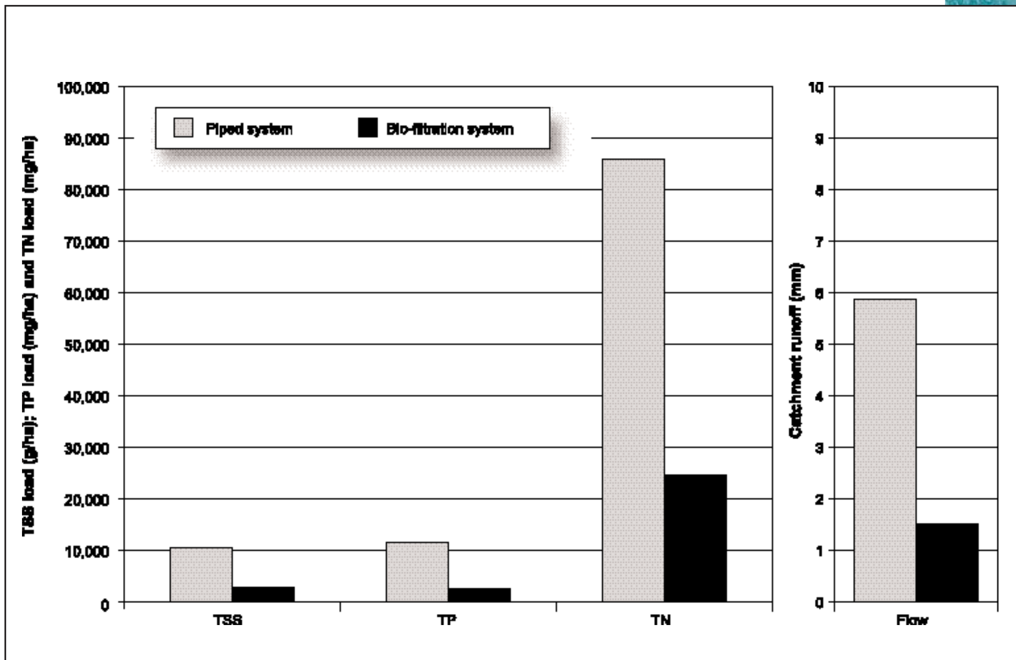
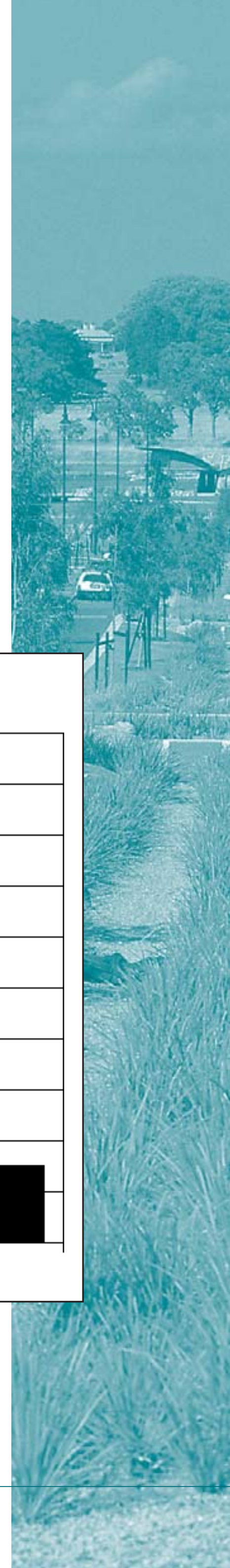


Figure 12. Flow reduction and water quality improvements attributed to a bio-filtration system for a series of small storm events



The results for this series of small storm events are summarised as:

Flow characteristics

- The runoff (flow volume discharged per catchment area) from the bio-filtration system catchment is between 51% and 100% less than the conventional piped system catchment
- Peak discharges from the bio-filtration system are consistently lower than from the piped system
- When stormwater is discharged from the bio-filtration system, a delay of up to 30 minutes occurs compared to stormwater discharged from the piped system (average delay is 10 minutes)
- The duration of stormwater discharged from the bio-filtration system is consistently shorter than the duration of stormwater discharged from the piped system.

Water quality characteristics

- Concentrations of Total Suspended Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN) discharged from the bio-filtration system are typically lower than pollutant concentrations discharged from the piped system

  One extreme outlier was observed for TSS, TP and TN concentrations discharged from the bio-filtration system where the concentration of each pollutant was significantly higher than the pollutant concentrations discharged from the piped system
- The loads of TSS, TP and TN are reduced by 73%, 77% and 70%, respectively. If the outlier pollutant concentration is ignored, the loads of TSS, TP and TN are reduced by 90%, 86% and 75% respectively.

Market Acceptance of Bio-filtration Systems

The level of market acceptance of bio-filtration systems was recently assessed as part of a broader study investigating the market viability of integrating structural BMPs into greenfield site developments. The research method involved qualitative and quantitative components.

300 property owners and prospective buyers drawn from four greenfield site developments located in Melbourne's major growth corridors were surveyed. Stimulus material was used to illustrate the nature of bio-filtration systems to survey participants. Participants were provided with a list of statements and asked to indicate which they believed applied to either the landscaped or grassed bio-filtration systems. Examples of bio-filtration systems from the Lynbrook Estate Demonstration Project were included in the study.

The study showed that more than 90% of respondents supported integration of landscaped and grassed bio-filtration systems into local streetscapes to address stormwater issues associated with new housing estates. Figure 13 summarises the positive perceptions held by respondents to bio-filtration systems. More than two thirds of the respondents saw the landscaped bio-filtration system as attractive, and believed its design could potentially contribute to making an entire estate look better and would improve local habitat. Interestingly about 70% of respondents believed bio-filtration systems would result in the bay being less polluted but did not associate these systems with improved water quality in local lakes and ponds. This suggests a low level of community understanding as to how elements within a drainage scheme relate to one another.

Figure 14 shows that the concerns held by respondents mainly related to uncertainty about the systems' purpose and maintenance issues. This suggests that these issues could be addressed through education and information programs.

The survey findings are reinforced by land sale records of allotments next to the bio-filtration systems at the Lynbrook Estate. During the release of each stage of the development that incorporated bio-filtration systems into the street drainage, the rate of land sales and prices at the Lynbrook Estate reflected the high end of the property market across Melbourne's greenfield site developments. For further details of the market acceptance study refer to ResearchWise (2002).

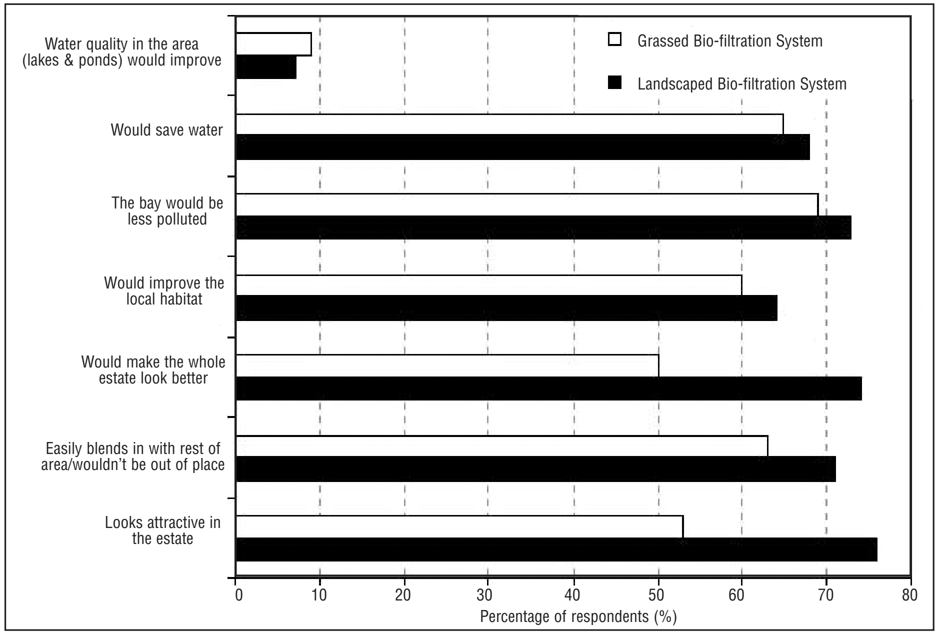


Figure 13. Positive perceptions of bio-filtration systems held by survey participants

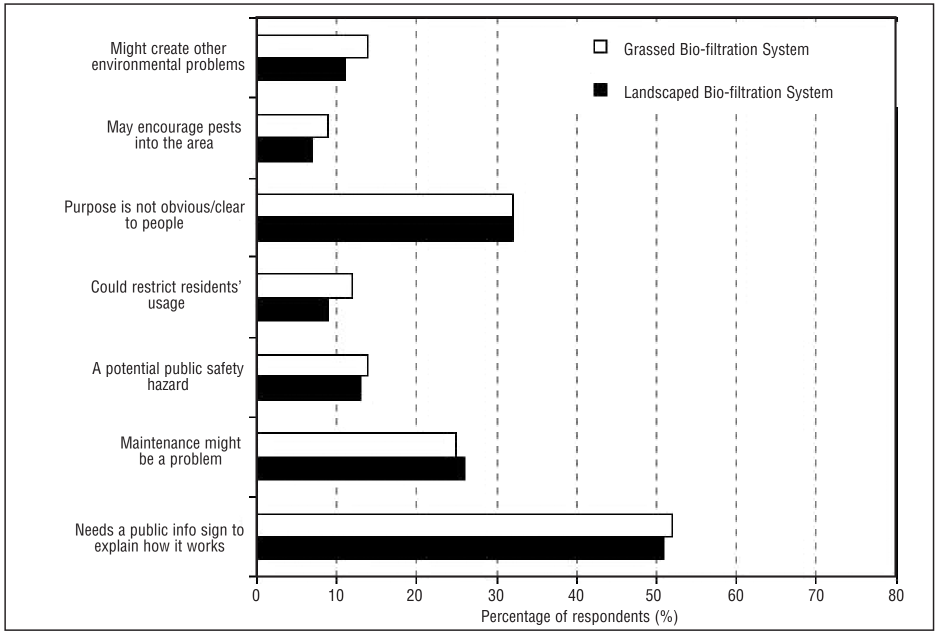


Figure 14. Negative perceptions of bio-filtration systems held by survey participants

On-Going Research

Research activities associated with the Lynbrook Estate Demonstration Project are continuing. They include:

- A paired catchment stormwater monitoring program to quantify changes in flow characteristics and water quality parameters discharged from the residential development with bio-filtration systems integrated into the street drainage networks, and the residential development with conventional underground concrete pipes forming the street drainage networks
- Research into market viability of integrating structural BMPs into greenfield site developments. The final report is due for completion in early 2003
- Assessment of maintenance costs and requirements over the life of the project
- Further field experiments to increase understanding of pollutant removal mechanisms associated with bio-filtration systems. The focus will be to better understand nitrogen transformations and/or removal processes.

The Current Status of Water Sensitive Urban Design in Australia

During 2000, the first WSUD conference was held in Melbourne to identify opportunities and barriers to the widespread adoption of WSUD in Australia (refer to Lloyd, 2001 for further information). Four major issues categories that support or impede adoption of WSUD principles and practices are summarised in Figure 15. They are the regulatory framework, assessment and costing, technology and design, and marketing and acceptance.

Table 5 lists eight potential barriers to widespread adoption of WSUD across Australia associated with the four issues categories identified in Figure 15. Table 5 also presents a summary of the perceived level of importance each barrier represents to stormwater industry stakeholders recently surveyed in Perth, Western Australia. The respondents of the survey considered seven of the eight listed to be of a high or very high level of importance (Andre Taylor Pers. Comm. 2002).

Figure 15. Key components to successfully integrate WSUD into urban development projects

Table 5. Potential barriers to the implementation of WSUD

Potential Barriers to the Implementation of WSUD	Perceived Level of Importance*
• An effective regulatory and operating environment does not yet exist at the State or local government level.	**Highest** 76%
• There is limited quantitative data on the long term performance of best planning practices and best management practices in WSUD.	75%
• Insufficient information on the operation and maintenance of structural best management practices in WSUD leads to local government concerns about their long-term viability.	70%
• Institutional fragmentation of responsibilities in the urban development and approval process creates difficulties in working across administrative boundaries and impedes collaboration between organisations.	67%
• The current culture and technical skills within local governments and water corporations do not yet support the changes required for the assessment, approval, construction and maintenance of development schemes based on the principles of WSUD.	52%
• The assessment of project costs requires an examination of externality costs (e.g. costs/benefits associated with environmental impacts) and currently there is no established procedure to guide this aspect of life cycle cost analyses.	52%
• The market acceptance of residential properties with WSUD needs defining.	52%
• Poor construction site management practices lead to reduced effectiveness or failure of best management practices.	39% **Lowest**

** This column contains the percentage of stormwater industry respondents that ranked the potential barrier to the implementation of WSUD as either 'high' or 'very high' in terms of perceived level of importance (Andre Taylor Pers. Comm, 2002)*

Creating an Effective Planning Framework

The early history of urban drainage in most Australian cities was dominated by a lack of resources to meet the demands of the community and local government, disagreement about standards of protection, and little data to support planning and design. There was also disagreement about responsibilities and priorities for expenditure and a reactive approach to major flooding or pollution problems as they arose, rather than avoiding or minimising problems by appropriate planning and servicing of new urban areas as they were developed.

These issues took years to address through legislative requirements relating to drainage and subdivision. However, improved development controls now exist and developers are required to provide water, sewerage and drainage services in new urban areas.

Most states also established environment protection agencies in the 1970s and 1980s which regulated point sources of pollution such as industrial discharges. Work began on establishing water quality objectives for receiving waters and major sewering programs were initiated with massive State and Federal funding to reduce the backlog of unsewered properties (by then more than 170,000 in Melbourne).

The result is that pollutant loads from many sources are now significantly less than they were 30 years ago, yet Australian urban communities have become increasingly concerned about water quality in our waterways and coastal waters. Urban areas in particular provide a concentrated source of contaminants to be carried into our waterways by runoff. As a result, urban stormwater management is as much about protecting and enhancing environmental values and improving urban amenity and sustainability as it is about flood protection. However, in achieving these goals, many old challenges remain: overlapping jurisdictions, uncertain responsibilities, limited resources, lack of agreed standards and limited environmental data on which to base standards and designs.

Most Australian states have planning frameworks which allow WSUD to be specified as a development requirement. In fact, for nearly a decade the Australian Model Code of Residential Development (AMCORD, 1992) and some state codes (for example, VicCode 1) have had provisions encouraging measures to protect environmental values of waterways from urban runoff. Yet the process of change to more sustainable urban water management through adoption of WSUD has been slow. The reasons for this have been discussed earlier in this report.

Knowledge and understanding of WSUD is developing in government, industry and research organisations with technology transfer and capacity building activities occurring Australia-wide. Increasingly it is our lack of a consistent planning and policy framework with clear requirements for environmental performance that limits progress.

Traditionally, local government has used prescriptive standards as the basis for controlling development and building. Where local planning policies have been introduced to encourage WSUD, there has often been conflict with existing development standards. These policies may not have specified how the WSUD requirements can be met or how development proposals will be assessed. This leaves a lot of scope for uncertainty and potential for delays in approvals and conflicts between approval authorities.

Fragmented jurisdictions are a fact of life. To move forward more effectively, we need more consistent policy and planning requirements related to the environmental performance of urban development and WSUD.

Such a framework should be capable of being applied across entire regions or states to create greater consistency across jurisdictions and certainty for industry. It should also allow performance standards or targets to be set locally to take account of specific circumstances (community expectations, economic climate, development types) and characteristics of the environment (environmental values, climate, topography, soils). It should also have the flexibility to deal with scales from single lot infill developments to major greenfield subdivisions, and be supported by common or agreed planning, design and assessment tools used by industry as well as government.

Attempts have been made to put forward such an integrated framework (for example, Lawrence 2001), but adoption has been piecemeal. The key elements of an integrated planning framework to support WSUD should include:

- Adoption of statewide environmental performance objectives for stormwater management
- Incorporation of objectives into state planning policy
- Model provisions developed for incorporation of objectives into local government planning schemes
- Development of planning, design and assessment tools (such as MUSIC) to guide selection of appropriate structural BMPs for various urban sites, conditions and development scenarios.

The success of a planning framework such as this may be limited without appropriate regional management arrangements. Local governments need to be free to adopt locally-specific WSUD performance requirements. Where on-site strategies fall short of environmental performance objectives required to achieve environmental outcomes at the catchment level, a mechanism is required to provide for offset strategies at the local, precinct or catchment scale. The regional catchment manager has an important role to play in ensuring a balance of on-site, local precinct and regional BMPs is implemented to achieve overall objectives in a way that is equitable, transparent and economically and administratively efficient.

Cost-benefit Assessment of Stormwater Management Schemes

To date no well-established procedures exist that enable alternative approaches to stormwater management to be assessed in terms of life cycle costs and associated downstream benefits. The following hypothetical cost-benefit analyses demonstrate the potential application of the capital and maintenance costs provided in Appendix A. The aim of the analyses is to determine the costs associated with providing stormwater treatment and relate these costs to downstream benefits achieved when adopting different approaches to urban drainage.

The three urban drainage designs included in this cost-benefit assessment are:

1. **A CONVENTIONAL APPROACH**
Underground concrete pipes convey stormwater runoff from the catchment and discharge it directly to the receiving waters.

2. **A DOWNSTREAM TREATMENT APPROACH**
Underground concrete pipes convey stormwater runoff from the catchment and discharge it to a stormwater treatment wetland system that includes a litter trap, an inlet zone and vegetated zone. Treated flows are then discharged to the receiving waters.

3. **A DISTRIBUTED TREATMENT APPROACH**
Bio-filtration systems convey stormwater runoff from the catchment and discharge it to a stormwater treatment wetland system (only a vegetated zone is required). Treated flows are subsequently discharged to the receiving waters.

The first drainage approach assessed considers a conventionally-designed stormwater piped system, which provides a baseline scenario that can be used to assess the cost-benefit associated with providing stormwater quality treatment before discharging to the receiving waters (approaches two and three).

It is assumed that the catchment area for all three approaches is 27 hectares and the land-use is mainly residential development (~470 lots). The design of the litter traps, wetland systems and bio-filtration systems are based on best practice principles assuming 850 mm of annual rainfall. BMPs are sized to treat discharges equivalent to the 3 month ARI flow event or meet the Victorian stormwater quality performance objectives: a 70% reduction in annual litter load; an 80% reduction in annual TSS load; and a 45% reduction in annual TP and TN load (Victorian Stormwater Committee, 1999). Pollutant loads conveyed to each BMP and the receiving waters are modelled using MUSIC (20 years of rainfall data is used for each simulation).

In addition to the capital cost and maintenance costs defined in Appendix A, the costs associated with the concrete pipe drainage and bio-filtration systems are based on the costs incurred for the Lynbrook Estate Demonstration Project (refer to Lloyd *et al*., 2002 for further details). The costs associated with dredging the wetland's inlet zone every ten years are based on the volume of material captured (generated using MUSIC) and the associated costs to remove the captured material as shown in Figure A2. The dredging and re-establishment of the wetland system's vegetation is assumed to be half the capital cost and required every 30 years. Consideration is also given to the unknown replacement costs of the bio-filtration system. A worst case scenario is assumed whereby the entire system requires replacement 60 years after establishment at a cost equal to the total capital cost of the system.

A 4% and 10% discount rate is used to calculate the life cycle cost and the range in values is presented for each drainage approach considered. Life cycle cost calculations are based on the costs associated with a 60-year life cycle. Tables 6 and 7 present the findings of this case study.

Meeting the stormwater quality performance objectives in our hypothetical urban catchment using a distributed treatment approach would involve an estimated 22% increase in capital expenditure on infrastructure, and using a downstream approach, an estimated 47% increase. The 25% difference between the two approaches is consistent with costings undertaken by Melbourne Water.

To achieve the environmental benefits associated with a downstream or distributed approach, there is an associated increase in the annual maintenance costs. The annual cost per household to maintain conventional stormwater infrastructure is $2 to $4. This is generally regarded as low and may be a reflection of a lower level of maintenance activities undertaken by local government responsible for relatively new drainage infrastructure. A distributed or downstream approach involves increasing the annual maintenance cost per household from $4 to $14 to allow for the range of maintenance activities outlined earlier.

The cost of removing different pollutant types from urban stormwater varies significantly. This is mainly due to the rate at which each pollutant is generated in the urban catchment and each BMP's effectiveness at removing a specific pollutant type. Assuming a distributed approach to treat stormwater is adopted, the cost to remove 1 kg of TSS is about $1.35, to remove 1 kg of TP, about $625 and 1 kg of TN, about $145.

Table 6. The capital costs and annualised maintenance cost of alternative approaches to urban drainage

Approach to Urban Drainage	Capital Cost	Annualised Maintenance Cost
Conventional	$1,370,000	$737-$1,672 ($2-$4 per household)
Downstream	$2,016,000	$2,336-$6,371 ($5-$14 per household)
Distributed	$1,664,000	$1,723-$6,512 ($4-$14 per household)

Table 7. The costs associated with improving water quality to meet downstream water quality standards

Approach to Urban Drainage	Annual Load of Pollutant Conveyed to Receiving Waters (kg/yr)				Cost to Remove 1kg of Pollutant[1] ($/kg/yr)			
	Gross Pollutants	TSS	TP	TN	Gross Pollutants	TSS	TP	TN
Conventional	1240	7330	15	107				
Downstream	109 (91%)[2]	1090 (85%)[2]	5.22 (65%)[2]	60.1 (44%)[2]	$11– $14/kg	$2– $2.50/kg	$1,270– $1,580/kg	$265– $330/kg
Distributed	0 (100%)[2]	1550 (80%)[2]	5.13 (66%)[2]	53.3 (50%)[2]	$5– $8/kg	$1– $1.70/kg	$600– $650/kg	$110– $180/kg

[1] The cost to remove 1kg of pollutant is calculated by subtracting the annualised life cycle cost of Approach 2 or 3 from the annualised life cycle cost for implementing a conventionally designed system (Approach 1) divided by the annual load of pollutant removed

[2] Percent reduction in annual pollutant load

CRC for Catchment Hydrology Research Activities

Since January 2000, the CRC for Catchment Hydrology has embarked on research activities directed at improving urban stormwater management. These activities include the development of the MUSIC software, training material and fundamental research activities associated with field monitoring, experiments and theory development. Fundamental research based on field, laboratory and literature studies remains the main activity of the urban stormwater quality research program.

The construction of BMPs in Brisbane and Melbourne has provided the research group with the opportunity to conduct field-scale water quality treatment experiments. The facilities are also demonstration sites to describe the design, construction and operation of stormwater treatment methods.

Targeted field studies, PhD projects and associated projects provided the necessary scientific underpinning for the MUSIC software and associated training material. Research conducted in the past two years and future research activities are directed at achieving a better understanding of the following issues:

- Pollutant generation from differing land-uses and catchment characteristics
- Performance of structural BMPs, and how performance may vary with different design specifications
- Long-term performance of structural BMPs against water quality standards
- Resultant impacts on receiving ecosystems, before and after implementation of the proposed stormwater strategy.

The research has provided substantial insights into these issues. The issue relating ecosystem responses to catchment urbanisation remains an important knowledge gap and is the subject of collaborative research between the CRCs for Catchment Hydrology and Freshwater Ecology.

Summary

Recent practice and research has shown that WSUD is a well conceived planning and design concept that is an important component of achieving more sustainable urban development. The technologies are well developed and reliable and have been employed in a variety of urban settings with strong acceptance by the community.

WSUD projects, including the Lynbrook Estate Demonstration Project in Victoria have helped to overcome some perceptions that WSUD technology is difficult to construct and costly to operate, and would be resisted by the community. This has led to greater acceptance and more widespread adoption of WSUD by the development industry and local government, and accelerated changes in industry practice.

WSUD incorporating streetscape measures is a more cost effective way to manage stormwater quality than the more traditional downstream (end-of-pipe) approach to treatment.

There is a sound research base underpinning the further development of WSUD practice. Future research needs to confirm the long-term performance of BMPs and the associated costs of operation and maintenance but there is sufficient knowledge now to be confident of the technology. There is still, however, the widespread problem of drainage design standards conflicting with WSUD principles. Standards should encourage rather than inhibit WSUD.

There are programs in place that will help to overcome many of the impediments to adoption of WSUD. Research and experience has increased our knowledge of the technology. Technology transfer is accelerating through the production of guidelines, training and development of new tools such as MUSIC. Market acceptance of WSUD appears to be strong and even a positive factor in the commercial success of developments. Industry is becoming more positive about WSUD and environmental sustainability in general.

The most significant constraint to adoption appears to be the lack of an appropriate planning and regulatory framework. A number of local governments have recognised WSUD as an important part of their sustainability agendas and innovative models for specifying and assessing WSUD measures as part of local planning requirements are emerging. The CRC for Catchment Hydrology will support these innovations as part of its ongoing technology transfer role.

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Glossary

Best Management Practice (BMP) - Structural and non-structural measures used to reduce the impact of development on the urban water cycle.

Best Planning Practice (BPP) - Actions undertaken as part of developing a concept design plan that defines and matches site characteristics to the layout and final design of infrastructure to reduce the impact of development on the urban water cycle.

Bio-filtration (bioretention) system - A grassed or landscaped swale or basin promoting infiltration into the underlying medium. A perforated pipe collects the infiltrated water and conveys it downstream.

Constructed wetland - An artificially-created system often consisting of an inlet zone and vegetated zone that promotes physical, biological and chemical treatment mechanisms for water quality improvement.

Life cycle cost (LCC) - The total cost incurred to construct, operate, maintain and replace an asset over a given time frame.

MUSIC - The acronym used for the Model for Urban Stormwater Improvement Conceptualisation software developed by the CRC for Catchment Hydrology to model urban stormwater management schemes.

Stakeholder - An individual or organisation with a vested interest in the long-term success of a project.

Stormwater management scheme - A holistic approach to managing urban stormwater that incorporates some or all of the following considerations; stormwater drainage, water quality improvements, aquatic habitat protection, stormwater harvesting and use, and landscape amenity.

Treatment train - The sequencing of structural Best Management Practices to achieve optimal flow management and pollutant removal from urban stormwater.

Water Sensitive Urban Design (WSUD) - A philosophical approach to urban planning and design that aims to minimise the hydrological impact of urban development on the surrounding environment.

Appendix A: Life Cycle Cost Assessment

Economic considerations, including capital cost and maintenance costs associated with structural BMPs, strongly influence future directions in urban planning. Assessments of life cycle costs are made difficult because records of capital cost, maintenance costs and performance data for BMPs are scant and distributed amongst different organisations. Extensive work has been undertaken to collate data and develop an approach to calculate life cycle costs of BMPs. This approach is presented below.

Litter and Sediment Traps

Figures A1 and A2 provide a basis for estimating capital costs and annual maintenance costs of litter and/or sediment traps. When applying these cost estimates, consideration of site characteristics and catchment landuse practice helps to define if the capital cost and maintenance cost of a trap are likely to be considered typical or high/low relative to the catchment area. Analyses of capital and maintenance cost data indicate the following:

- There is a clear trend of increasing capital cost with catchment area. The scatter about this trendline may be attributed to other factors such as site conditions, type of trap, etc.
- There is a trend of increasing maintenance cost with volume of material captured. The scatter about this trendline may be attributed to such factors as method of clean out, access to the trap, etc.
- The cost to remove accumulated material is about $310 per m^3. This costs decreases slightly as the volume of material trapped annually increases.

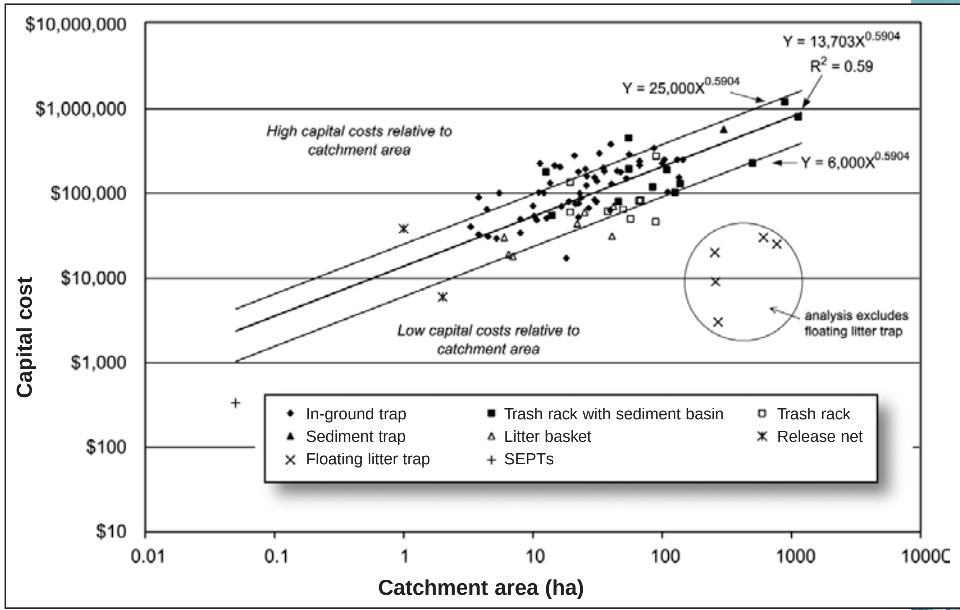


Figure A1. Capital costs associated with litter and sediment traps

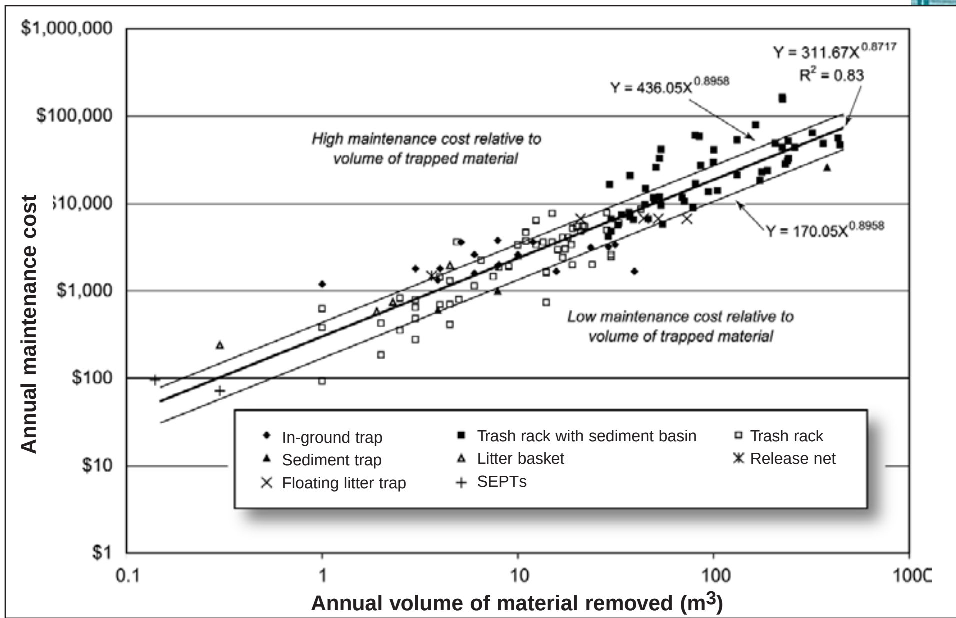
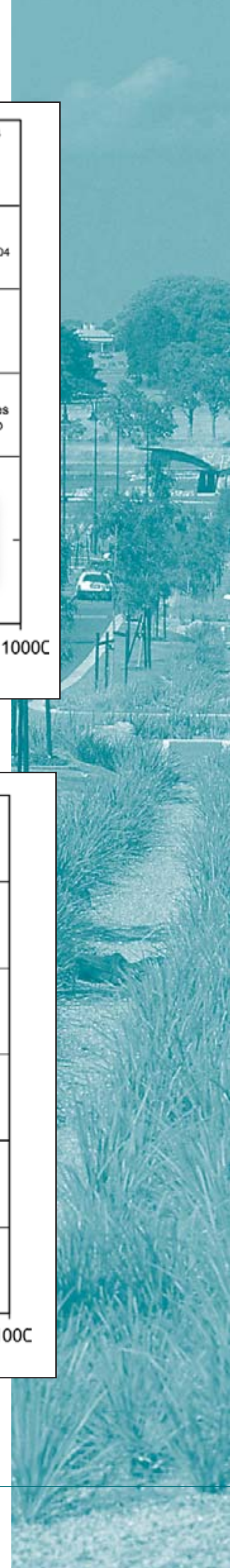


Figure A2. Annual maintenance costs associated with litter and sediment traps



Figures A1 and A2 should be used with caution to assess life cycle costs when the associated benefits to the receiving waters are not considered. Locating traps at source or in-transit on relatively small sized catchments (<60ha) compared to locating a single trap further downstream has the advantages of;

- Targeting areas within the urban landscape that generate higher pollutant loads per hectare of catchment area (that is, commercial, industrial and high-to-medium density residential precincts)
- Treating a greater proportion of the mean annual runoff volume, and often a higher pollutant trap efficiency.

Wetlands and Vegetated Swales

Data on the capital and on-going maintenance costs associated with wetlands and vegetated swales is limited. Nevertheless, Figures A3 and A4 provide a basis for estimating these costs according to the surface area of the system. The maintenance costs for wetlands presented only considers the landscaping component. When calculating the life cycle cost for a wetland system, an assessment of the additional costs incurred to remove the sediments accumulated in the inlet zones every five to10 years can be estimated using Figure A2. In addition, the cost associated with cleaning out and re-establishing the macrophyte zone every 30-50 years should be considered. Typically this clean out and re-establishment cost is assumed to be half the capital cost of the system.

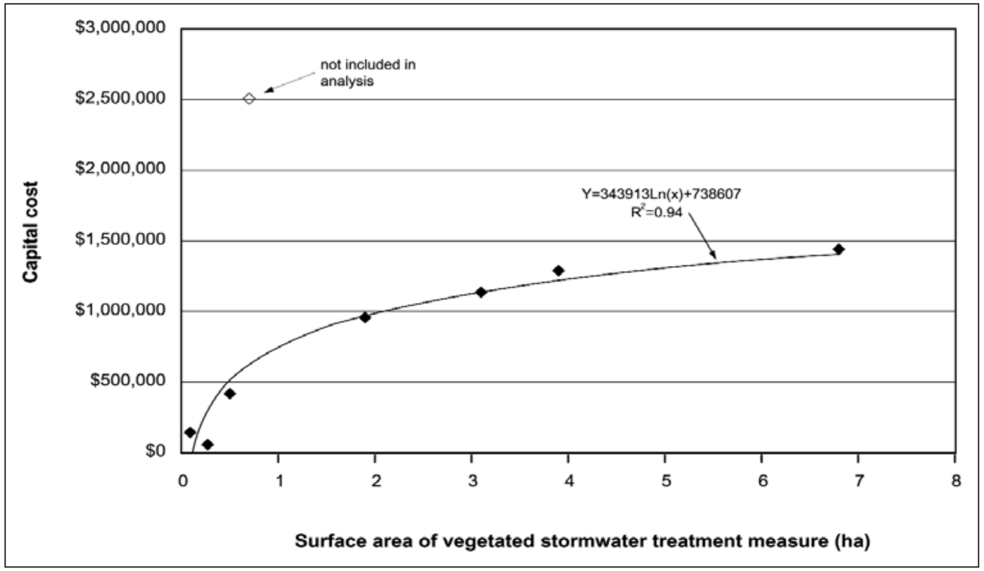


Figure A3. Capital costs associated with the construction of wetlands and vegetated swales

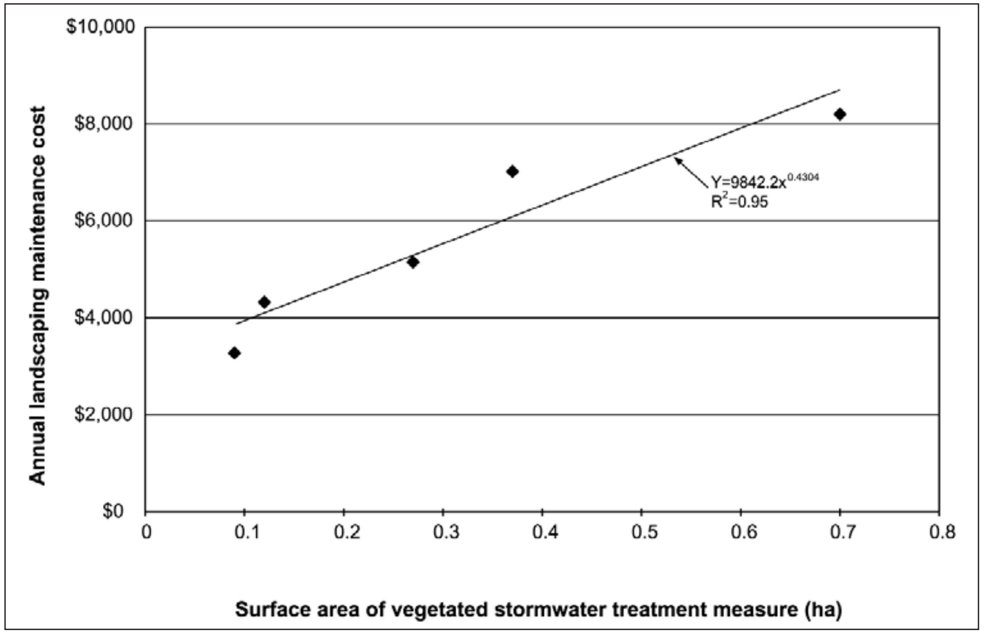


Figure A4. Annual landscaping maintenance costs associated with wetlands and vegetated swales

Temporal Changes in Maintenance Costs

Examination of detailed maintenance cost records kept for a landscaped swale in a residential estate in Melbourne shows the annual cost decreasing significantly as the system matures, as shown in Figure A5. Once the system became well established and development activities within the catchment were completed, maintenance costs associated with the vegetated swale decreased from about $9.00 per m^2/yr down to $1.50 per m^2/yr. A similar pattern in cost reduction over time is expected for the vegetated zone of a wetland system.

The maintenance costs associated with grassed swales remain relatively constant over time at $2.50 per m^2/yr (based on figures provided by VicRoads). However, when the grassed swale forms part of a nature strip, residents in adjacent properties maintain the grass just as they do with conventionally designed nature strips.

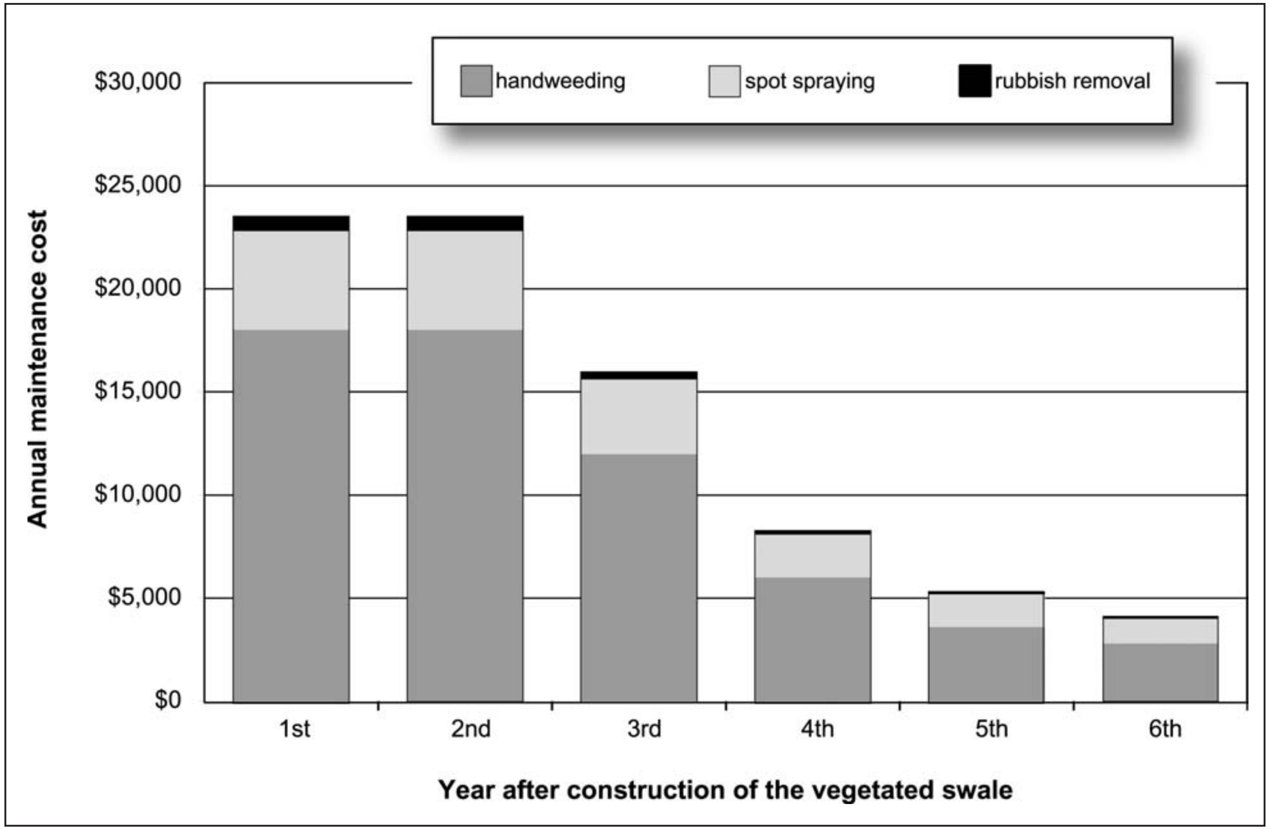


Figure A5. Decrease in maintenance costs over time associated with vegetated swales located at the Kinfauns Estate, Victoria (Sourced: Indigenous Gardens Pty Ltd. 2002)

APPENDIX B: Construction Issues

Successfully translating a stormwater management scheme into on-ground works involves two stages; the subdivision stage and the building stage. At the subdivision stage, the developer is responsible for constructing and installing all subdivision infrastructure and services, including drainage. In the case of a stormwater management scheme, this involves construction or installation of various collection, conveyance, treatment and/or reuse BMPs.

The construction or installation of BMPs generally presents few problems to drainage contractors, as they are often familiar with the techniques involved. Many BMPs such as swales, gravel trenches, water tanks and ponds form part of drainage systems in rural areas and along highways. In most instances conventional excavation methods and machinery can be used.

Once subdivision is complete, the building stage begins and the number of individuals who work on-site increases dramatically. During building, the greatest concern is protecting the integrity of BMPs from pollutants generated by building sites. Building sites are recognised as a major source of stormwater pollution and inadequate provision of runoff and pollution controls can impact on the design performance of BMPs. This could lead to failure of the stormwater management scheme.

Local Government Initiatives

The Southern Sydney Regional Organisation of Councils ran an education campaign for builders and contractors called 'Do it right onsite'. The campaign sought to inform builders and contractors about practices considered appropriate to minimise pollutants entering the stormwater drainage system. The project outcomes indicated an increase in rate of use of best-practice treatment measures on building sites.

A subsequent study was undertaken to identify the major barriers to compliance (SSROC, 2000). Those identified by local government representatives involved in the 'Do it right onsite' campaign include:

- Unclear responsibility in local government as to who should enforce builders and contractors to comply with prescribed pollution control practices on building sites. Generally responsibility went to building officers, many of whom felt they did not have the time nor resources to properly enforce compliance.
- No statewide database existed to identify who had committed building site offences. This resulted in builders committing multiple offences over time and across different local government boundaries. Multiple offences did not result in increased fines or further action.
- Lack of notification to local government about when building site work commenced resulted in sites not being checked for appropriate use of pollution control measures. In some instances, building officers only became aware of poor practice when complaints were made.
- Building officers were not offered training and support on how to deal with offenders (ie conflict resolution).
- Difficulty with managing building materials' supplier breaches of pollution control practices on building sites (ie inappropriately locating stockpiles).