Developments in Ecosystems, volume 1
Edited by M.H. Wong

Chapter 21

Wetland Ecosystems for Treatment of Stormwater in an Urban Environment

J. Gan

NSW Department of Public Works and Services, Sydney, Australia

Abstract. The drive towards urban consolidation has placed increased emphasis on development of innovative stormwater management solutions. This chapter describes management strategies undertaken by the NSW Department of Public Works & Services (DPWS) in utilising wetland ecosystems integrated into the general landscaping/streetscape for the treatment of urban stormwater. The strategies are based on formulating designs that incorporate multiple objectives and opportunities for integrating the following: urban design, landscape, aesthetics, engineering of subsurface ground conditions and stormwater runoff into the overall management strategy, so that a total water cycle management approach can be adopted, for an existing or new sub-division within an urban environment. It should be noted that the management strategies could also be combined to form a Universal Stormwater Treatment Train Model. The chapter also introduces the Victoria Park project in Sydney, Australia, which was constructed with these wetland ecosystems for site stormwater management.

21.1. Introduction

It is widely recognised that urban environments generate increased stormwater runoff and contaminants/pollutants, which can cause negative impacts on the aquatic ecosystem of receiving waters (Gan, 1998). The management of urban stormwater for water quantity and quality control/improvement, are now becoming standard considerations in urban design. This chapter describes the management strategies undertaken by the NSW Department of Public Works & Services (DPWS) in utilising wetland ecosystems integrated into the general landscaping/streetscape design for the control/treatment of urban stormwater (Gan, 2001a). The chapter also introduces the Victoria Park project in Sydney, Australia, which was constructed with wetland ecosystems for site stormwater management.

DOI: 10.1016/S1572-7785(04)01021-4

21.2. Stormwater Pollution

A number of pollutants are typically found in urban stormwater runoff. These pollutants originate from either point or non-point sources. Point sources are specific identifiable locations where stormwater pollution can occur, e.g. include illegal discharges of trade wastes and sewer overflows. Non-point sources or diffuse sources, are more general, and are comparatively difficult to identify and control, e.g. include litter, sediments, nutrients, oils and grease from road surfaces, toxic material, bacteria and organic material. Without appropriate stormwater treatment devices, the resulting impacts on receiving waters can be devastating, not only for aquatic ecosystems but also to community values such as aesthetics, recreation, economics and health of receiving water bodies.

Stormwater pollution can come from a variety of sources. Table 1 provides a summary of some of the land use activities and the likely pollutants that may have negative impacts on the environment. This information can be used to establish targeted strategies to reduce the pollutant loads on the environment, e.g. based on the catchment characteristics and the contaminants, so that a suite of treatment strategies can then be tailored to control/trap the specific contaminant.

Table 1: Relation of land-use to contaminants/pollutants generated (Gan, 1999).

Land uses	**Contaminant/Pollutants**						
	Litter	**Sediment**	**Nutrients**	**Oil and grease**	**Toxic material**	**Bacteria**	**Organic material**
Residential	x	x	x	x		x	x
Industrial/ Commercial	x	x		x	x	x	
Open space	x		x			x	x
Roads	x	x		x	x		
Raw sewer overflows			x	x	x	x	x
Construction activities	x	x		x			
Land fill	x	x	x		x	x	x
Septic tanks			x	x	x	x	x
Underground storage tanks				x	x		

Note: “x” denotes likely contaminants produced from the specified land use activities.

21.3. Management Options

The identification of stormwater pollutants, and likely source/s, will enable the selection of appropriate strategies for managing or trapping the pollutants generated from urban stormwater, and thus protect the water quality of the receiving waters.

A variety of options are available for addressing the stormwater quality management issues (Gan, 2001a). The approach to water quality improvement adopted by DPWS has been undertaken in two separate approaches. The *first approach* looks at ways in which pollutants entering the stormwater system can be reduced, and the *second approach* looks at the pollutants once they have entered the stormwater system, and considers how can they be removed before they enter receiving waters. Clearly "prevention is better than cure" — not only is it better, i.e. more effective, it is also cheaper. The cost for removal of pollutants trapped is substantial and it is not only a one off capital cost — there are ongoing associated maintenance/cleaning costs that can be substantial. The options are:

- *Non-structural*. Potential non-structural options include:
    - educational measures (e.g. advertising in local papers, radio and TV media, school curriculum, etc.);
    - planning controls (e.g. council policies and strategies etc.);
    - site auditing;
    - review of management practices (e.g. council maintenance/cleaning activities, etc.);
    - studies and assessments;
    - others.
- *Structural*. Structural options (NSW DPWS, 2002) for stormwater management can be beneficial for targeting known "hotspot" locations within the catchment. These solutions typically address the immediate, and often visible, issues as opposed to addressing the source of the problem. Some structural options include:
    - at source controls:
        - litter traps, e.g. litter basket, litter booms, nets, trashracks;
        - pit inserts — from Enviropod, Dencal industries, Ecosol, Net Tech, etc.;
        - bank stabilisation, e.g. vegetation planting, gabions and reno mattress, etc.;
        - silt fences and sand filters;
        - buffer strips, grass swales, bio-retention/infiltration, wetlands;
        - universal stormwater treatment trains.

- At "in-line" or "end-of-pipe" controls:
  - gross pollution traps,
  - booms,
  - sediment traps,
  - constructed wetlands, and
  - universal stormwater treatment trains (i.e. a combination of the above).

21.4. Selection of Management Options

The first step in selection of a management option, is to decide what the target pollutants are. A wide variety of pollutants have been identified, as being washed off from urban catchment/s by the action of rainfall and stormwater runoff. Stormwater pollutants typically found in urban catchments include those listed in Table 1.

At present, it would be uneconomical to select a stormwater treatment device to capture all the stormwater pollutants listed in Table 1. So, the normal practice is to target only the gross pollutants. Gross pollutants can be defined as all the substances listed in Table 2. The table also lists the criteria and trapping requirements for gross pollutants (NSW EPA, 1996, 1998).

Table 2: Gross pollutants and capture requirements.

Gross pollutant	Description	Capture and trapping criteria
Litter	All anthropogenic material, e.g. cans, bottles, plastic bags, etc.	Capture 100% of average annual litter load greater than 5 mm
Coarse sediment	Coarse sand (particles between 5 and 0.5 mm)	Capture 90% of average annual load for particles 5–0.5 mm
Medium sediment	Medium-sized soil (particles between 0.5 and 0.062 mm)	Capture 75% of average annual load for particles 0.5–0.062 mm
Fine particles	Fine sand (particles smaller than 0.062 mm)	Capture 50% of average annual load for particles 0.062 mm or less
Nutrients	Total phosphorus and total nitrogen	Capture and retain 45% of average annual load
Cooking oil and grease	Free floating oils that do not emulsify in aqueous solutions	Capture 90% of average annual pollutant load with no visible discharge
Hydrocarbons, motor oils and grease	Antropogenic hydrocarbons that can emulsify	Capture 90% of average annual pollutant load

21.5. Issues and Causes

Table 3 provides a summary of the issues, potential negative impacts and possible causes on the environment based on the ecological, social and administrative concerns.

21.6. Design Terminology

Treatable flows are used and normally associated with flow hydraulics and the pollution capture effectiveness of a particular stormwater treatment device, i.e. if the stormwater treatment device is able to allow more treatable flows through the structure, the higher the level of pollutant removed and captured. The minimum treatable flow rate for a stormwater treatment device should be quoted for a three-month average recurrence interval (ARI) storm event or tied-in with the maintenance programme. However, in DPWS Contract 019, there has been an array of flows quoted by the different manufacturers. These flows should be re-defined, e.g. suggested definitions include:

- design flow — similar to as defined for treatable flow rate, i.e. design should be for a minimum of a three-month ARI storm event or tied-in with the cleaning programme;
- maximum flow — maximum flow that can pass through the stormwater treatment device, safety without causing any major damage to the structure, i.e. 100-year ARI storm event;
- hydraulic capacity — similar to as defined for maximum flow, i.e. that a 100-year ARI storm event can pass through the stormwater treatment device, safety without causing any major damage to the structure.

21.7. Pollutant Loading Rates

Table 4 shows the pollutant loading rates obtained from various sources including our on-going research and development.

21.8. Wetland Ecosystems for Treatment of Stormwater

As discussed, this chapter describes the management strategies undertaken by DPWS in utilising wetland ecosystems integrated into the general landscaping/streetscape design for the treatment of urban pollutants, e.g. buffer strip, grass swale, bio-retention/infiltration, wetland and the universal stormwater treatment train approach.

Table 3: Summary of the issues, potential negative impacts and possible causes (DPWS and DLWC, 1997).

Issue	Potential negative impact	Possible cause
Litter and debris	Reduces aesthetic appeal of waterways Can kill some marine aquatic life (e.g. fish, turtles, sea birds) Decay of some gross pollutants can decrease dissolved oxygen levels	Littering, e.g. bottles, plastic wrapping and caps, cigarette butts Overflowing rubbish bins Waste dumping Uncovered loads (e.g. trucks, trailers)
Sediment deposited in the bottom of receiving waters	Smothering of plants and animals that live on the bottom of receiving waters, ponds, lakes and streams	Erosion of sediment from building sites Erosion from bare earth areas, e.g. unsealed roads, driveways and car parks, poorly maintained lawns
Turbidity in waterways	Reduced aesthetic value (water looks “muddy”) Reduced aquatic plant growth Clogging of fish gills Hinders the ability of aquatic predators (e.g. certain fish species) to see their prey	Soil and sand piled on nature strips, footpaths, driveways and gutters Washing cars in the street Air pollution carried by rain into stormwater systems
Nutrient enrichment	Nitrogen and phosphorus stimulates the growth of algae and aquatic plants Decay of algae and plant matter reduces dissolved oxygen levels Excessive growth of algae and aquatic plants reduces waterway aesthetic values	Washing cars with detergent containing phosphorus. Excessive use of fertilisers, which is washed off lawns Decay of plant material Leaky or overflowing sewerage systems
Petrol, oils and grease	Reduces aesthetic appeal of waterways Can harm some aquatic life Decay of some hydrocarbons can decrease dissolved oxygen levels	Leaks from vehicles Car washing or maintenance Illegal dumping of waste; lubricating or food oils
Pesticides and herbicides	Harms aquatic plants and animals	Pesticides and herbicides (weed killers) used on gardens and nature strips and washed off during rain

(*continued*)

Table 3: Continued.

Issue	**Potential negative impact**	**Possible cause**
Trace metal pollution (heavy metals)	Stress on aquatic plants and animals Contamination of the food chain with trace metals	Runoff from roadways or car parks Deterioration of building surfaces (e.g. rusting galvanised iron roofs) Byproduct of burning fossil fuels Swimming pool water
Bacteria and other pathogens	Makes contact with water unsafe for humans Causes disease in aquatic organisms Contaminates shellfish	Animal (dog and cat) faeces Food wastes disposed improperly Leaky or overflowing sewerage systems
Vegetation washed into waterways	Oxygen dissolved in the water is used up when plant matter decays. Fish and other water life need this oxygen to live	Leaf drop from gardens and street trees, particularly when they fall onto paved surfaces Hosing or sweeping lawn clipping and leaves into gutters Mulch washed or blown from gardens
Loss of aquatic habitats and/or riparian vegetation	Weed infestation of urban bushland Nutrients in stormwater and the transport of weeds propagated from urban areas by stormwater Reduced fish population Water pollution due to loss of filter; strips adjacent to creeks Increased water temperature	Riparian vegetation cleared Changed flow characteristics resulting from change of land use Bank erosion Unrestricted access Creeks “channelised” or “piped”
High runoff rates	Increased pollutant loads Erosion of creek banks roads Changed pattern of water levels in wetlands, affecting aquatic flora and fauna Increased frequency of disturbance to aquatic ecosystems, reducing the diversity of aquatic life	Increased impervious surfaces (e.g. roofs, paved areas, footpaths) directly connected to the stormwater system

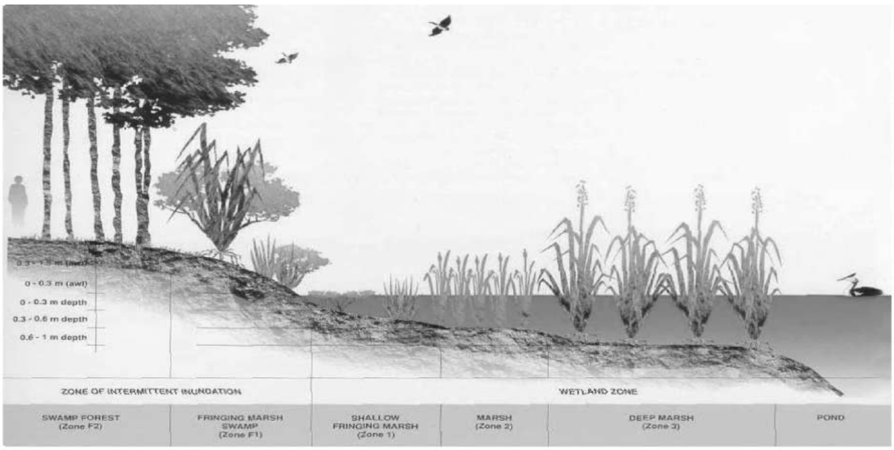
Table 4: Pollutant loading rates (kg/ha/yr).

Pollutant	**USEPA (1983)**	**CSIRO (1991)**	**Water Board (1992)**	**Willing & Partners (1993)**	**CRC (1996)**	**EPA (1997)**	**Sydney Water (1998)**	**DPWS (2002)**
Sediment					750		230	1200
Suspended solids	1731	120	200	500–600	200	500		500
BOD	72.3		25	32–40	40			30
TN	14.63	9.3	9.3	9.5–12	8.5	12		10
TP	2.85	1.2	1.2	0.76–0.97	0.85	1.65		3
Lead	0.424		0.4					0.5
FC (cfu/ha/yr)*	0.41×10^{12}*		3×10^{12}*	0.22×10^{12}*	0.75×10^{12}*	2.15×10^{12}*		0.5×10^{12}*
Gross solids or litter (m^3/ha/yr)*							0.11*	0.33*
Organic material (m^3/ha/yr)*							0.32*	2.04*
Hydrocarbons								5

*Denotes pollutant loading rates as stated.

21.8.1. Buffer Strip

Fig. 1 shows the buffer strip. These are vegetated areas that treat overland (sheet) flow, and commonly used as a source control measure, particularly adjacent to water courses or management of road runoff. They are effective in the removal of coarse to medium-sized sediments and can be used as an effective pre-treatment measure.

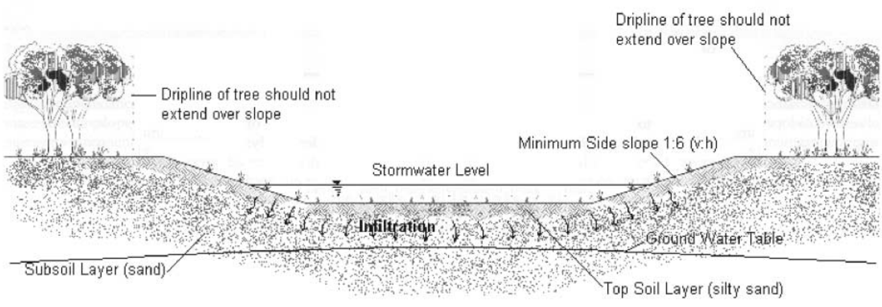


Pollutant	*Trapping efficiency*	*Pollutant*	*Trapping efficiency*
Litter	L-M	Oil & grease	H
Oxygen demanding material	L	Nutrients	M
Sediment	H	Bacteria	H

Figure 1: Buffer strips.

21.8.2. Grass Swale

Fig. 2 shows the grass swales. These are vegetated open channel systems, which utilise the grass to aid the removal of sediment and suspended solids. These systems are a subjected to fairly high hydraulic loading and the removal efficiency is highly dependent on the density and height of the grass.

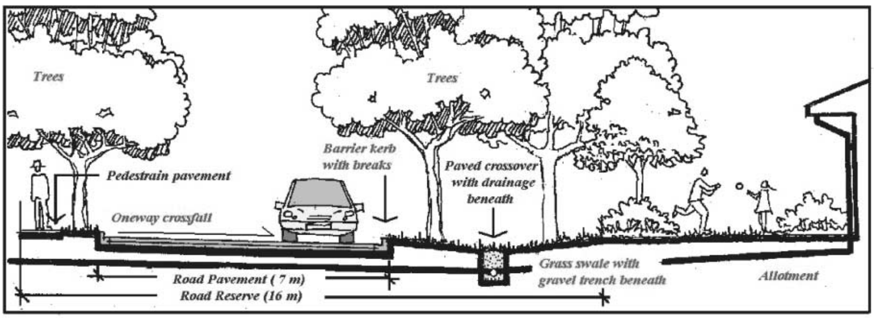


Pollutant	Trapping efficiency	Pollutant	Trapping efficiency
Litter	M	Oil & grease	H
Oxygen demanding material	L	Nutrients	M
Sediment	H	Bacteria	H

Figure 2: Grass swale.

21.8.3. Bio-retention/Infiltration System

Fig. 3 shows the bio-retention/infiltration systems. These systems promote the removal of particulate and soluble contaminants by passing stormwater through vegetation and filter medium. The type of vegetation and filter medium determines the effectiveness of pollutant removal, with the vegetation and material of lower hydraulic conductivity providing the most efficient pollutant removal (owing to longer detention time). Typical filter material ranges from gravel ($\sim$10 mm) to fine sand ($\sim$0.1 mm).

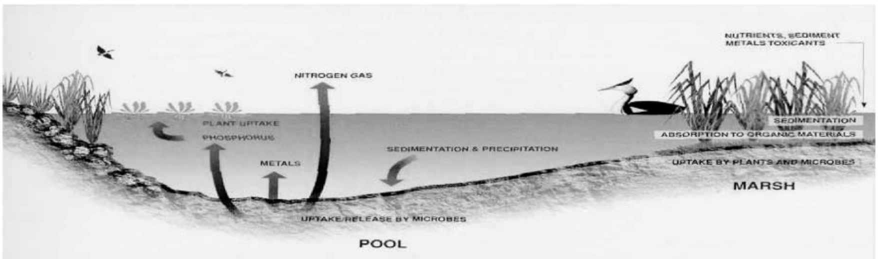


Pollutant	Trapping efficiency	Pollutant	Trapping efficiency
Litter	N-L	Oil & grease	H
Oxygen demanding material	H	Nutrients	M
Sediment	H	Bacteria	H

Figure 3: Bio-retention/infiltration system.

21.8.4. Wetland

Fig. 4 shows the wetlands. These are an effective stormwater treatment measure for the removal of fine suspended solids and associated contaminants, as well as soluble contaminants. These systems utilise a combination of physical, chemical and biological processes in removing stormwater pollutants. They are used as "end-of-pipe" or at "source control measures" (DLWC, 1998).



Pollutant	*Trapping efficiency*	*Pollutant*	*Trapping efficiency*
Litter	L	Oil & grease	H
Oxygen demanding material	M-H	Nutrients	M
Sediment	H	Bacteria	H

Figure 4: Wetland.

21.8.5. Universal Stormwater Treatment Train

These can be defined as the integration of best management practices (BMP) to achieve management objectives. The objectives may include:

- water quantity control — avoidance of flooding;
- water quality improvement — all water discharges to have no impact on receiving waters;
- conservation — optimise the use of rain that falls (i.e. apply reuse strategies);
- protection and enhancement of natural water systems — preserve natural drainage eco-systems;
- improving aesthetic, incorporating social and ecological objectives — provide an opportunity for the community to gain an enhanced appreciation of water as essential element of the urban environment.

Typical examples of BMP are as follows:

- for water quantity control — grass swales, adsorption pits, bio-retention/infiltration systems, detention and retention basins;

- for water quality improvement — gross pollutant traps, bio-retention/infiltration systems, oil and grit separators, water pollution control ponds, sediment traps, wetlands;
- for conservation — rainwater tanks, water re-use;
- for protection and enhancement of natural water systems — trashracks, bio-retention/infiltration systems, constructed wetlands;
- for improving aesthetic, incorporating social and ecological objectives — grass swales, bio-retention/infiltration systems, constructed wetlands.

21.9. Victoria Park Project in Sydney, Australia

21.9.1. Project Description

The Victoria Park site occupies an area of 24 ha. The site drains into the Shea's Creek–Victoria Branch drain just beyond the south-western corner of the site in Joynton Avenue. Flooding has been reported at the low point along South Dowling Street near the Winkurra Street intersection and at the low point along Joynton Avenue south of Elizabeth Street. Flooding appears to be due to the limited capacity of the Victoria Branch drain, which crosses Joynton Avenue at the low point, the limited inlet capacity of the street entry structures and the high ground water table. Fig. 5 shows the proposed re-development and the site drainage conveyance/treatment system.

The proposed drainage infrastructure has been designed to cater for all flows, i.e. the off-site and on-site stormwater runoff flows into and out of the development site, designed to cater for the 100-year ARI storm event and also to treat the stormwater pollution to meet ANZECC standards (ANZECC, 1992). In general the drainage infrastructure will consist of the following elements:

- a series of trashracks to trap rubbish and litter;
- gross pollutant traps to trap litter, grease, oils and coarse sediments;
- a series of buffer strips and grass swales;
- a series of bio-retention/infiltration system that provide drainage conveyance and stormwater;
- a piped drainage conveyance system to cater for major flows up to the 100-year ARI;
- an 8,000 m^3 storage onsite detention basin to cater for all flows, i.e. the off-site and on-site stormwater flows;
- water control appurtenant structures consisting of pits, grates, valves, etc;
- a water recycling system consisting of pumps and mains for the on-site water reuse and irrigation system.

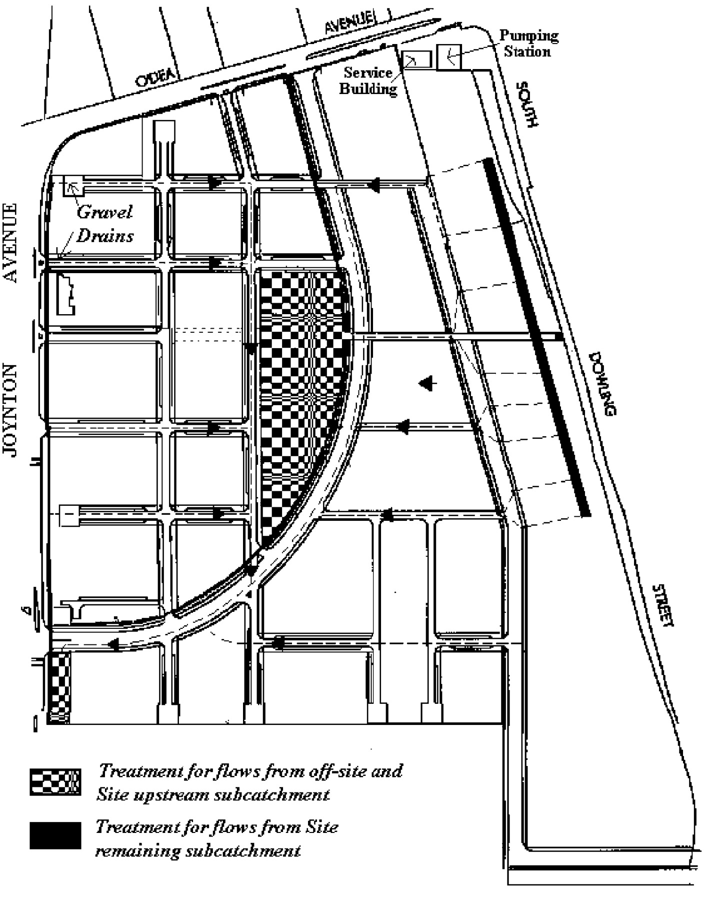


Figure 5: Site drainage conveyance and treatment system.

21.9.2. Purpose

The objective is to construct an overall drainage system that will integrate the planning, landscaping and stormwater objectives for the site re-development. Figs. 3 and 6 show a typical section of this multi-purpose integration for the local streets.

Other purposes included:

- to function as a drainage conveyance system for offsite and site stormwater;
- to function as stormwater retarding system with the aim to reduce stormwater contribution to the downstream stormwater conveyance system during large storm events;

Figure 6: Photo of a local street.

- to function as a water quality control system that will detain and filter pollutants from the stormwater. Controlling and trapping stormwater pollutants at their source has their advantages of reduced hydraulic loading, attenuate flows, reduce pollutant loads to downstream treatment facilities (i.e. drainage pipe, wetlands) and, in may cases lower capital costs;
- the bio-retention/infiltration system and wetlands with immediate/adjacent planting, will function as, habitat creation, aesthetics and create an environmental friendly environment.

21.9.3. Bio-retention/Infiltration System Details

Figs. 7–9 show the bio-retention/infiltration system details.

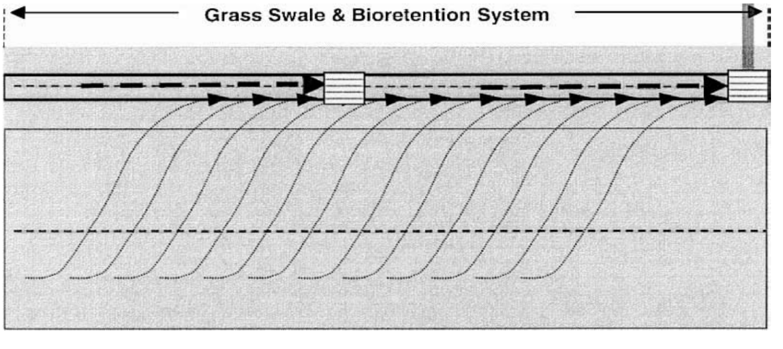


Figure 7: Plan view.

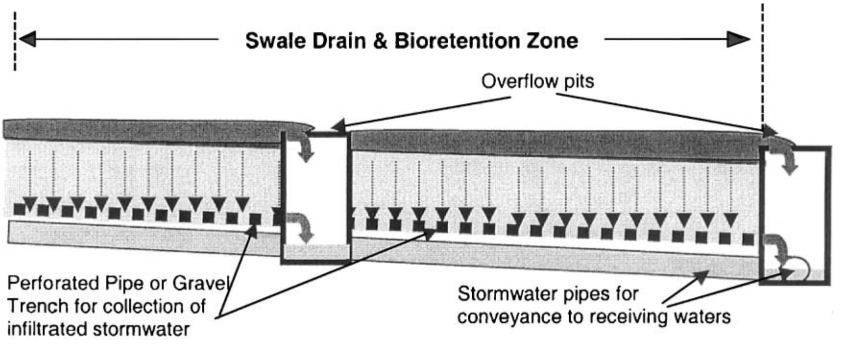


Figure 8: Section view.

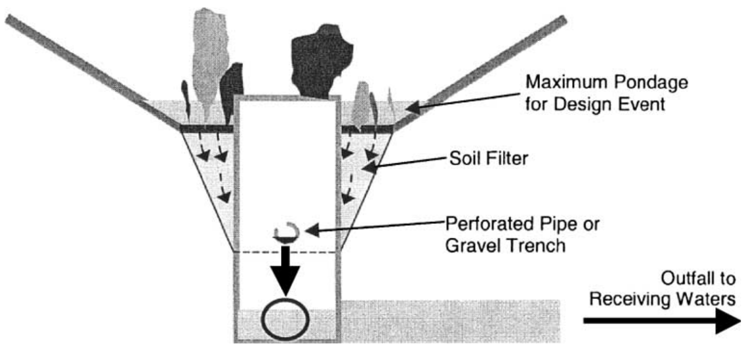


Figure 9: Cross-sectional view.

21.9.4. Bio-retention/Infiltration Variations

Figs. 10–12 show other variations of the bio-retention/infiltration system used by DPWS.

21.10. Management

To maximise pollutant capture/treatment, wetland ecosystems will need regular maintenance. The essential operation and management elements required for wetland ecosystems include: *a description of the management strategy* (detailing its objectives, functions and the relationship between the physical structures and

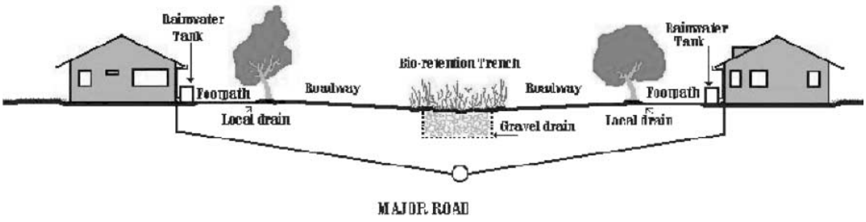


Figure 10: Major Road.

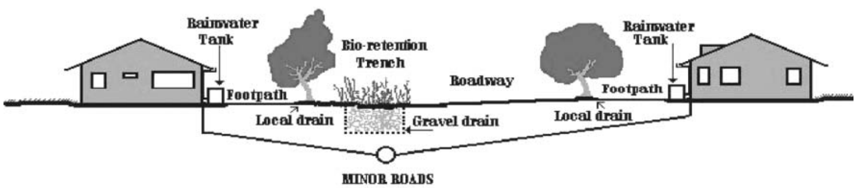


Figure 11: Minor Road.

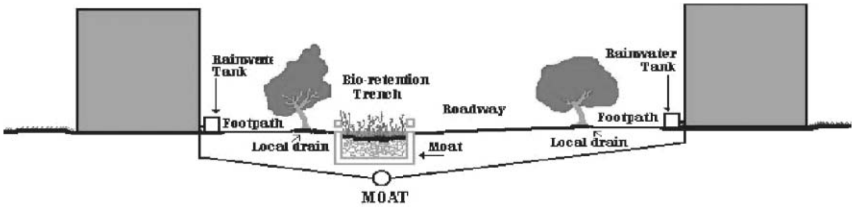


Figure 12: Moat.

the biological components); *a list of tasks or management activities*; *a management calendar* (to ensure that programmed maintenance activities are carried out); *monitoring activities* (with inspection checklists to ascertain that all components in a wetland cell are functioning properly); *safety measures* (to ensure that the wetlands are safe to visit and to work in); and *timelines* so that all the operation/works must be carried out on the specified time and within the period provided (Gan, 2001b; Gan and Beharrell, 2000).

Acknowledgements

I wish to thank DPWS and our Clients for permission to use the information presented in this chapter.

References

ANZECC (1992). *Australian water quality guidelines for fresh and marine waters*. Australian & New Zealand Environment & Conservation Council, Canberra, Australia.

DLWC (1998). *The constructed wetlands manual, volumes 1 and 2*. Department of Land & Water Conservation of New South Wales, Sydney, Australia.

DPWS and DLWC (1997). *The managers guide to sediment, nutrient and gross pollutant control*. Sydney, Australia.

Gan, J. (1998). *Managing stormwater*. Paper presented at IMEA-NSW Conference, Sydney, Australia.

Gan, J. (1999). *Managing urban stormwater quality in the blue mountains*. Paper presented at SIA conference, Sydney, Australia.

Gan, J. (2001a). *Stormwater management strategies undertaken in water sensitive urban designs (WSUD).* Paper presented at SIA Conference on WSUD, Sydney, Australia.

Gan, J. (2001b). *Good practices in wetland management and conservation*. Paper presented at Asia Wetlands Symposium, Malaysia.

Gan, J., & Beharrell, M. (2000). *The design, construction and planting of Putrajaya wetlands*. Paper presented at SIA Conference on Wetlands, Sydney, Australia.

NSW Department of Public Works & Services. (2002). *Government Contract 019, for supply of stormwater treatment devices*. New South Wales Government, Sydney, Australia.

NSW EPA (Environmental Protection Authority). (1996). *Managing stormwater, 3 volumes*. New South Wales Government, Sydney, Australia.

NSW EPA (Environmental Protection Agency). (1998). *Managing urban stormwater, treatment techniques*. New South Wales Government, Sydney, Australia.