CHAPTER 2

CHAPTER 2

DEVELOPING STORMWATER MANAGEMENT STRATEGIES

2.1 INTRODUCTION

Traditional approaches to stormwater management are based on a single management objective that considers stormwater as a source of potential hazard to public safety. Stormwater management was essentially that of stormwater drainage using two general methods, ie. (i) conveyance of stormwater to receiving waters in an hydraulically efficient manner; and (ii) detention and retardation of stormwater. Recent developments involving the concept of major/minor drainage systems (Institution of Engineers, Australia, 1987) take into account an economic risk-based approach to stormwater drainage but stormwater management essentially remained a single objective exercise.

A growing public awareness of environmental issues in recent times has highlighted the importance of environmental management of urban stormwater. It is well documented that urban stormwater runoff are generally of poorer overall quality than runoff from a rural catchment. The impact of poor stormwater quality is becoming an increasing issue of concern amongst catchment managers. The impacts can include the deposition of suspended material, which can smother aquatic habitats, increased concentrations of nutrients, oxygen-demanding materials, micro-organism and toxic materials and the deposition of litter. Increase catchment runoff can lead to significant changes to the morphology of creeks and rivers leading to degradation of aquatic habitats. Stormwater contaminants causes dissolve oxygen depletion and increased toxicity levels with the consequential degradation of ecological health of the receiving waters.

The wide ranging impacts of urban stormwater have led to the implementation of urban stormwater management strategies that address multiple objectives. These objectives include stormwater drainage, managing stormwater as a resource, protection of receiving water quality, protection of downstream ecological health, etc. There have been a number of initiatives to change the conventional means by which urban stormwater is managed. One such initiative is the development of the Water Sensitive Urban Design Guidelines (WSUDG) under the auspices of a number of government departments in Western Australia (Whelans *et al*, 1994). The management of urban stormwater to meet these objectives can fundamentally be categorised into stormwater quantity and stormwater quality management.

In general terms a Best Management Practice (BMP) may be defined as the best practicable method of achieving management objectives. The concept of BMPs has been adopted from similar work overseas, particularly in the USA and Australia and had been adjusted to meet Malaysian conditions. The term "practicable" allows for considerations of cost and plausible contingency strategies, but is not intended to compromise the achievement of management objectives.

While the term BMP has been used in association with a range of disciplines, its reference in this document relates only to stormwater management. Stormwater management strategies need to address the issues of stormwater runoff quantity and quality in an integrated manner. This is particularly relevant in new "green field" developments, such as the Putrajaya development. While the concept of a stormwater treatment train has been widely appreciated, this concept has not been implemented well in practice. Common problems have often arisen from the inappropriate utilisation of BMPs; their positioning within the treatment train; prioritisation in their implementation in a staged program and lack of maintenance.

The practicalities of urban stormwater management often require that stormwater quantity management issues such as flood protection, public safety and drainage infrastructure economics are addressed. This should occur in the first instance before stormwater quality issues are considered. This does not suggest that these two fundamental issues are mutually exclusive. Many measures designed for stormwater quantity control have inherent water quality management functions while others can be retrofitted to serve the dual functions of stormwater quantity and quality management.

The BMPs discussed are essentially management tools to aid the developer, design engineer or planner to meet urban stormwater management objectives. Stormwater BMPs potentially involve the use of structural and non-structural changes to catchment management. This document concentrates primarily on the implementation of structural BMPs although issues of catchment planning are discussed in some detail.

2.2 EFFECTS OF CATCHMENT URBANISATION

2.2.1 Stormwater Quantity

A common measure that can be used to physically relate the degree of catchment urbanisation to changes in the catchment hydrology is the catchment imperviousness. This parameter measures the sum of roads, parking lots, pavements, roofs and other impervious areas associated with the urban landscape and is a convenient measure of the degree of urbanisation in the catchment. Of these components, transport-related imperviousness (eg. roads, car park, driveways etc) was found to comprise up to 70% of the total impervious cover in an urbanised catchment (Schuler, 1995).

In small urban catchments, the runoff coefficient used in applying the Rational Method of predicting peak discharges is often related directly to catchment imperviousness of the catchment as shown in Figure 2.1, which is based on a study by the USEPA on 44 small catchments in the United States.

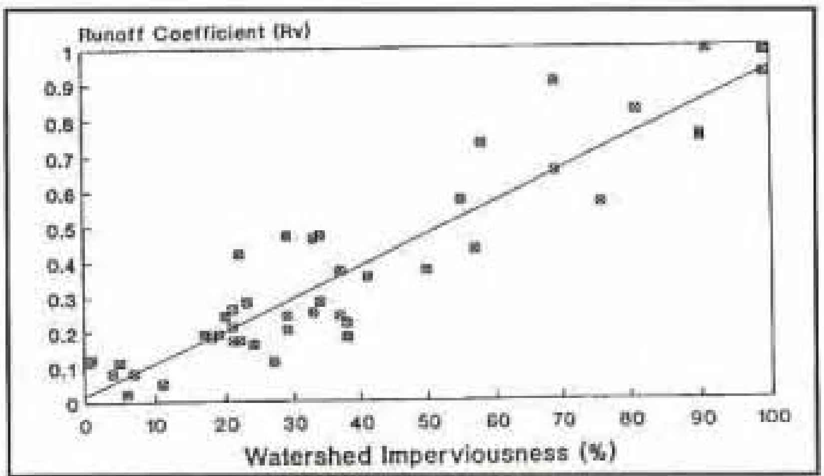

Figure 2.1 Data From 44 Small Catchment Areas in the United States (Schuler, 1987)

Urbanisation causes changes to catchment behaviour due to an increase in the impervious area and the reduction in catchment storages as waterways become channeled and piped (Laurenson *et al*, 1985, Schueler, 1987). These effects can be summarised in terms of the following changes to the characteristics of runoff hydrographs generated from a developing catchment;

- increased peak discharges and runoff volume;
- decreased time of concentration;
- increased frequency and severity of flooding;
- characteristics of urban waterways altered from an ephemeral system to a perennial system.

Wong *et al.* (1998) found that urban development resulting in 20% of its area becoming impervious would be sufficient to cause significant increases in peak discharges and the frequency in which the bankfull discharge of the natural stream is exceeded. The consequential impact on stream degradation, alteration to habitat structure, water quality and biodiversity of the aquatic system is significant at this low level of catchment urbanisation. Figure 2.2 shows the computed flood frequency curves for a hypothetical catchment under rural conditions and for 20%, 40% and 60% catchment imperviousness. As evident in Figure 2.2, the peak discharge generated from an urbanised catchment can be as much as 35 times that generated from a rural catchment, with the relative difference between rural and urban conditions being most pronounced for frequent storm events. As a consequence the bankfull discharge of a rural upland creek which would normally be exceeded at an average recurrence interval of approximately 5 years would occur on average twice a year following catchment urbanisation with just 20% of its area becoming impervious.

Figure 2.2 also shows that the slope of the flood frequency curve corresponding to an urbanised catchment is flatter than that corresponding to a rural catchment suggesting a loss in peak flow variability for the range of event probabilities.

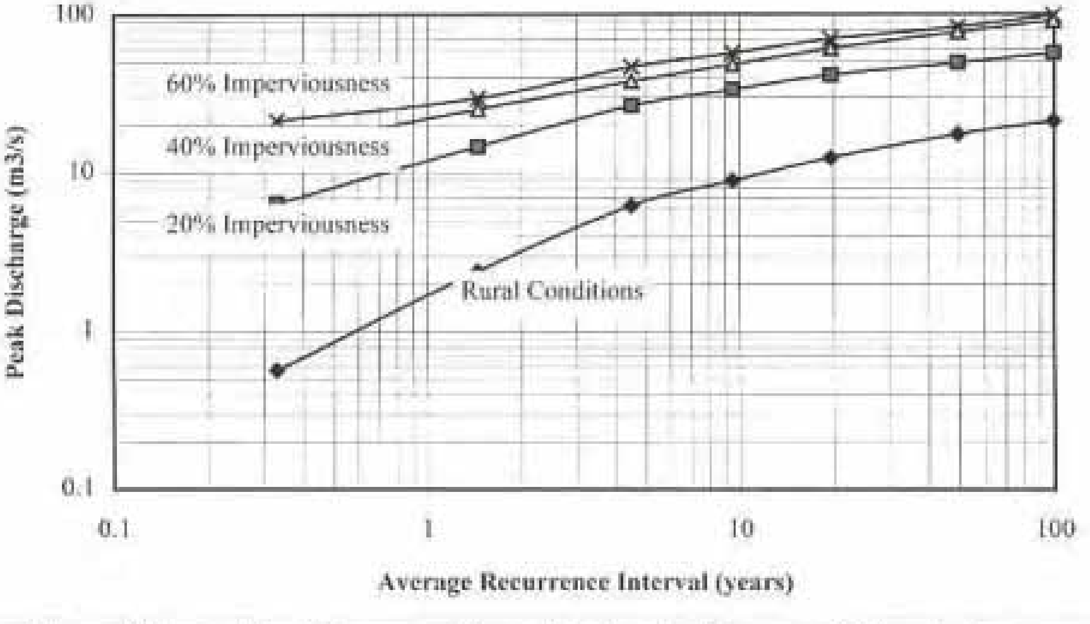

Figure 2.2 **Flood Frequency Curves for Varying Degrees of Urbanisation**

Figure 2.3 Urban waterways are often channelised and concreted to improve hydraulic efficiency

The increases in the magnitude of catchment discharges resulting from catchment urbanisation are attributed to two factors, ie. the increased in the impervious areas in the catchment and the increased hydraulic efficiencies by which the catchment runoff is conveyed to the receiving waters. An analysis on the relative contribution of these two factors by Wong *et al.* (1998) found the latter to account for up to 95% of the increase in peak discharge in an urbanised catchment. This is demonstrated in Figure 2.4 which shows the reduction in the magnitudes of probabilistic discharges for a catchment of 60% impervious areas with varying degree of waterway hydraulic efficiencies. The relative significance of channel modification reduces for more frequent flood events with improved hydraulic efficiency in watercourses accounting for 80% of the increase in peak discharge. It follows, from consideration of the results presented in Figure 2.4, that prioritisation of available stormwater management measures should consider first addressing the impact of increased hydraulic efficiency in the flow conveyance system of the catchment (ie. in-transit control) before source controls are implemented.

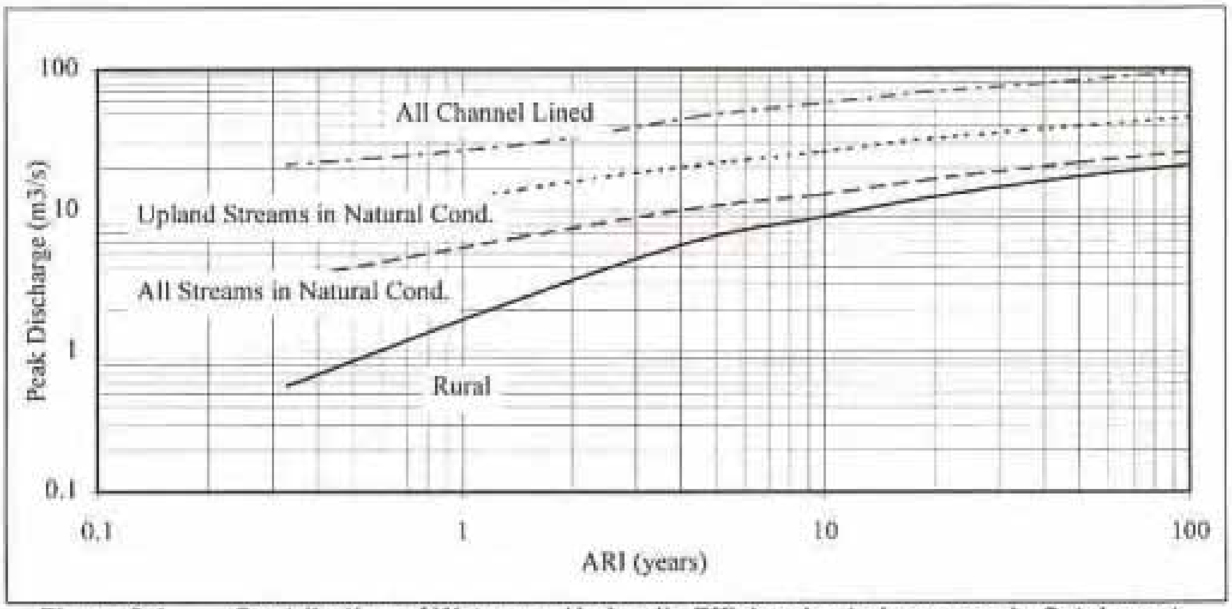

Figure 2.4 Contribution of Waterway Hydraulic Efficiencies to Increases in Catchment Discharge (Fraction Impervious = 0.6)

Table 2.1
Typical Urban Runoff Pollutant Sources

Pollutant Source	Solids	Nutrients	Pathogens	DO Demands	Metals	Oils	Synthetic Organics
Soil Erosion	✓	✓		✓	✓		
Cleared Land	✓	✓	✓				
Fertilisers		✓			✓		
Human Waste	✓	✓	✓	✓			
Animal Waste	✓	✓	✓	✓	✓		
Vehicle Fuels and Fluids	✓		✓	✓	✓		
Fuel Combustion		✓			✓	✓	
Vehicle Wear	✓				✓		
Industrial and Household Chemicals	✓	✓			✓	✓	✓
Industrial Processes	✓	✓			✓	✓	✓
Paint and Preservatives					✓	✓	
Pesticides					✓	✓	✓
Stormwater Facilities	✓	✓	✓	✓	✓		

2.2.2 Stormwater Quality

Stormwater pollutants from urban developments originate from a variety of sources in the catchment. Table 2.1 summarises the sources of some of the more common urban runoff pollutants as outlined by Brown and Wong (1995). Suspended solids, nutrients, BOD_5 and COD and micro-organisms are usually considered the most significant parameters in terms of ecological impacts. Oils and surfactants, and litter have aesthetic impacts which are more renowned for generating community concern and action. Organic load in stormwater originates mainly from leaves and garden litter. As a significant amount of inorganic pollutants is sediment bound, effective treatment of suspended solids is often a minimum criterion in stormwater quality management with the expectation that a significant amount of organic and inorganic pollutant will also be treated.

As described by Schueler (1995), as much as 70% of the impervious area is related to transport-related functions such as roads, driveway, car-parks etc. This component of the impervious areas in an urbanised catchment is identified as a prominent source of stormwater pollutants such as suspended solids and associated trace metals, polycyclic aromatic hydrocarbons and nutrients. Urban commercial activities have also been identified as the main source of litter generation.

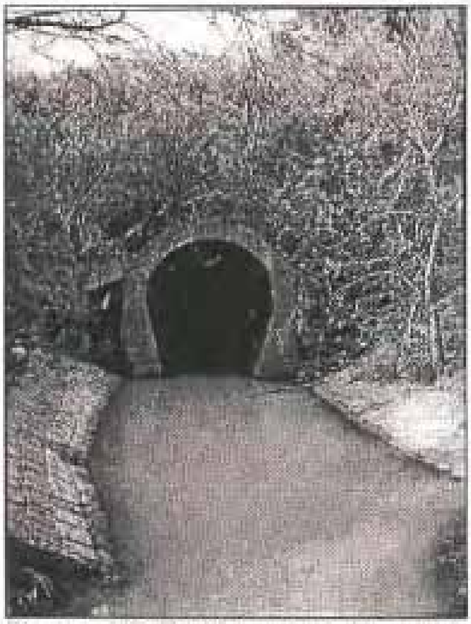

Figure 2.5 Turbid water in urban waterway reduces health of ecosystem

Suspended Solids

Suspended solids comprise of inorganic and organic materials. Sources of inorganic suspended solids include soil particles from erosion and land degradation, streets, households and buildings, and airborne particulate matter. Contributors to organic suspended solids are bacteria and microorganisms such as those found in sewage. The level of suspended solids in urban runoff is comparable to raw sewage and, inorganic soil particles are particularly of concern. Large amounts of inorganic soil particles are often associated with urban construction and the development of supporting services including roads, sewers and drainage systems. Levels of inorganic soil particles generated from these activities are at least two to six times, and can be up to several hundred times, pre-development levels.

Turbid waters often result from the presence of suspended solids. In general the community associates turbid waters with environmental pollution and degradation of the water's aesthetic value.

Nutrients and toxins such as phosphorus, heavy metals and organic chemicals utilise sediment as the medium for transportation in urban runoff. The deposition of sediments can result in the release of these toxins and nutrients at a later time when the ambient conditions related to the redox potential of the sediment and water column becomes favourable for their release. This mechanism provides the opportunity for pollutant re-mobilisation in later flow events enhancing the risk of further downstream degradation.

Suspended solids also reduce the penetration of light through water, and this adversely affects the feeding and respiration of aquatic plants.

Nutrients

Nutrients are fed into the water system through many different sources. These include sewerage, plant matter, organic wastes, fertilisers, kitchen wastes (including detergents), nitrous oxides produced from vehicles exhausts and ash from bushfires. Nutrients contain natural compounds consisting of nitrogen and phosphorus.

There are problems associated with high levels of nutrients in waterbodies. Nutrients promote growth of aquatic plant life including floating macrophytes, which if in large concentrations, produce algal blooms on the water surface. Algae are microscopic plants which occur naturally in waterways. With an increase in nutrients algal growth becomes excessive often resulting in a build up of toxins. Toxic algal blooms cause the closure of fisheries, water farming industries and public beaches.

Litter

Litter is generally the most noticeable indicator of water pollution to the community. Litter is also commonly thought of as the pollutant most detrimental to waterways because of its visibility. Pollution of the environment including the export of litter and gross pollutants has intensified over the last 30 years due to the production of easily disposable, non-biodegradable packaging and household and industrial items. The sources of litter are varied and they include dropping of

Figure 2.6 Commercial activities are a prominent source of litter

rubbish, overflows of rubbish containers and material blown away from tips and other rubbish sources as evident from Figure 2.6.

Metals

Analysis of contaminants associated with urban dust and dirt by Dempsey et al (1993) found highest concentrations of Cu, Zn and TP to be associated with particles in the 74 μm to 250 μm. The particle size range with high Pb association extends to 840 μm. One possible explanation for a higher contaminant concentration is the size range is the higher specific surface area (and thus contaminant binding sites) of particles in this range. For example, Sansalone and Buchberger (1997) found that specific surface area of solids transported from an urban roadway surface decrease with increasing particle size as is normally the case for spherical particles. With irregularly shaped particles, there is the general tendency for larger sized particles to have higher specific surface area than are normally expected.

Table 2.2 reproduces the table of particle sizes and associated pollutants presented by Dempsey et al (1993) for dust and dirt generated from road surfaces. The data presented in the Table 2.2 indicates that treatment measures with capability of settling particles of sizes down to 74 μm will be necessary to facilitate treatment of metals and nutrients in stormwater runoff generated from these areas. The particle size distribution of sediment transported in stormwater is dependent on the geology of the catchment and other studies (eg. Oliver et al (1993)) have found high concentrations of nutrients in colloidal particles which are much finer than 74 μm. Under such circumstances, treatment measures involving significant periods of detention and enhanced sedimentation, using wetland macrophytes, will be necessary (Lloyd, 1997).

Table 2.2
Pollutants Associated with Urban Dust and Dirt (mg/g per mg/L)
(ref. Dempsey et al, 1993)

	Particle Size Range					
Contaminant	**<74 μm**	**74-105 μm**	**105-250 μm**	**250-840 μm**	**840-2000 μm**	**>2000 μm**
Cu	7,100	12,000	66,000	5,900	1,600	344
Zn	28,000	41,000	31,000	11,000	4,100	371
Pd	37,000	55,000	62,000	86,000	19,000	15,000
Total P	3,000	4,800	5,400	2,500	3,000	3,900

2.2.3 Receiving Waters Geomorphology and Ecology

Changes to the rainfall-runoff regime in a catchment as it becomes urbanised have a direct effect on the stream geomorphology due to the increased frequency of flow events which cause bank erosion and entrainment of bed sediments. Typically, catchment urbanisation can lead to an increase in the frequency of the bankfull discharge of small streams from 5 years ARI to 0.5 years ARI. The effects of this include the following:-

- increased frequency of disturbance of benthic habitat;
- possible changes in substrate characteristics as the result of the removal of the more easily eroded materials;
- increased rates of bed and bank erosion;
- higher sediment transport rates.

The geomorpholgical impacts listed above lead to alteration to habitat (substratum particle size and density), and consequently, lead to a reduction in the diversity of physical habitat, stream organisms and the pre-dominance of those aquatic species which can tolerate the increased frequency of physical disturbance to their habitat. Urban stream communities could be expected to consist of a predominance of forms adapted to large cobbles, hard surfaces and mobile sediments with few burrowers and with few species adapted to burrowing (Wong *et al*, 1998).

2.3 MANAGING STORMWATER FOR MULTIPLE OBJECTIVES

As with most multi-objectives exercises, the management of urban stormwater will involve the consideration of a range of measures that can appear to be mutually exclusive. For example, the rapid conveyance of stormwater requires hydraulically efficient systems which is contrary to conditions conducive to the effective removal of oil, grit and grease in stormwater. The practicalities of urban stormwater management often require stormwater quantity management issues of flood protection, public safety and drainage economics to be addressed in the first instance before consideration of stormwater quality improvements. Meeting the objectives of stormwater quantity and quality management is however not always mutually exclusive, especially if stormwater management strategies are formulated at the early stages of catchment development as part of the planning phase. These strategies involve the catchment-wide utilisation of a combination of structural and non-structural measures in series or concurrently in an integrated treatment train approach. Fundamental to the success of this holistic approach to stormwater management is the prioritisation and positioning of appropriate stormwater management measures (Wong, 1997). Table 2.3 lists the stormwater management objectives and design considerations of structural measures to meet these objectives.

The rapid conveyance of stormwater is not the only means of meeting stormwater drainage objectives and the utilisation of flow retardation methods often has beneficial water quality outcomes. Almost all measures aimed at improving stormwater quality involve some degree of stormwater quantity management. Many water quality management and ecological protection strategies require a combination of water quantity and quality control measures. For example, the protection of ecological health of urban waterways requires both water quantity and quality issues to be addressed with the former often the main causal factor of diminished ecosystem health in urban waterways. The increased magnitudes in stormwater discharges influence the frequency of ecosystem disturbance, which in turn influence the types and diversity of fauna in the ecosystem.

Many measures designed for stormwater quantity control have inherent water quality management functions while others can be retrofitted to serve the dual functions of stormwater quantity and quality management. Treatment processes in many of these management measures involve a combination of physical, biological and chemical processes. Physical processes fundamentally involve the trapping of gross solids and coarse material, and sedimentation of finer materials. The effectiveness of these physical processes is largely dependent on appropriate stormwater quantity control. Treatment methods based principally on physical processes are often the first category of treatment processes to be utilised in a treatment train. The removal of gross solids and coarse sediment is often a required pre-treatment of stormwater before other treatment methods involving biological and chemical processes can be effectively applied.

Table 2.3
Stormwater Management Objectives and Associated Design Considerations of Required Structural Measures

Stormwater Management Objectives	Design Considerations
Stormwater drainage	• cost-effective means of stormwater conveyance system (a risk-based approach in selecting appropriate design standards for the minor and major drainage system); • prevention of nuisance flooding (minor drainage system); • safe conveyance of overland flow through the use of designated floodways and retarding basins (major drainage system); • structural measures to prevent the blockage of the drainage system by urban litter and flood debris.
Stormwater as a resource	• removal of gross pollutants to facilitate the utilisation of stormwater to sustain urban features such as lakes and urban streams; • re-use of stormwater as a source of non-potable water supply • environmental management of construction sites
Protection of receiving water quality	• removal of gross pollutants to facilitate further treatment of stormwater; • flow detention to facilitate sedimentation of coarse and medium sized particles • removal or reduction of stormwater pollutants to achieve water quality standards by a combination of source and in-transit control measures • environmental management of construction sites
Protection of downstream aquatic habitats	• flow detention and in-stream retardation to prevent excessive physical disturbance of aquatic habitat by stormwater runoff • removal or reduction of stormwater pollutants to achieve water quality standards by a combination of source and in-transit control measures • environmental management of construction sites

2.4 FORMULATING A STORMWATER MANAGEMENT STRATEGY

2.4.1 General

Structural and non-structural stormwater management measures take many forms and can often be directed at addressing specific problems. In most instances, a number of management measures can be implemented in series or concurrently forming a treatment train approach to stormwater management. Figure 2.7 shows the various types of treatment works within an overall regional management flow chart, which could form an integrated catchment management strategy.

The correct utilisation of the various components of the treatment train is a vital design consideration and requires a holistic approach to their performance specifications and positions in the treatment train. An overview of common elements of the stormwater treatment train may be summarised as follows:-

Source Controls

- Community awareness
- Land use planning and regulation
- Permissible discharge
- Street cleaning
- Sewer overflow management
- Isolation of high pollutant source areas
- Construction site management
- Landfill management
- Litter traps
- On-site detention basins
- Stormwater infiltration systems
- Buffer strips

In-transit Controls

- Gross pollutant traps
- Swale drains
- Detention basins
- Ponds and wetlands

End-of-pipe Controls

- Gross pollutant traps
- Lakes
- Floating booms
- Ponds and wetlands
- Receiving water management

The list of stormwater management measures is by no means exhaustive and they serve to outline common techniques currently used in the industry.

The proper utilisation of the various components of the treatment train should be based on the general philosophy of:-

1. avoiding pollution whenever possible through source control measures;
2. controlling and minimising pollution by means of in-transit and end-of-pipe control methods where pollutant generation cannot be feasibly avoided; and
3. managing the impacts of stormwater pollution by managing receiving waters and their appropriate utilisation as a last resort.

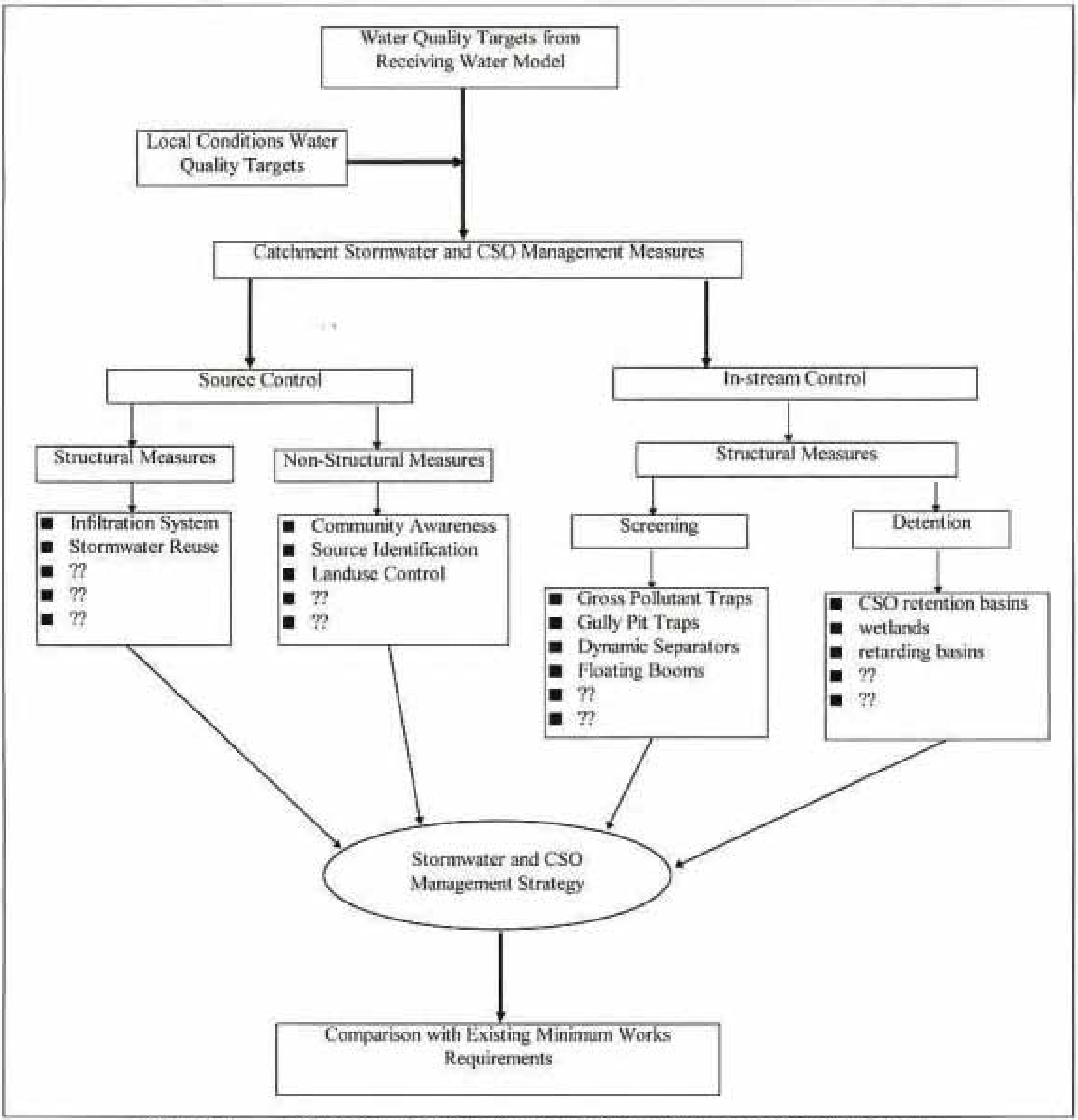

Figure 2.7 Structural and Non-structural Stormwater Management Measures

2.4.2 Major/Minor Drainage System

The concept of providing two levels of service in stormwater drainage is now common practice. This concept is often referred to as the Major/Minor Drainage concept. Major drainage should not be confused with trunk drainage. The terms major and minor refer to the magnitude or the probability of exceedence of the event being served by the two component of the system. Provision of well-engineered underground stormwater drainage system is expensive. If designed to convey stormwater runoff for the full range of storm events up to the 100 year ARI event, these systems becomes very cost-ineffective. An economic risk analysis approach is now commonly adopted to define the right balance between capital expenditure on underground drainage and the likely economic and social impacts of flooding due to exceedence of the discharge capacity of the minor drainage system.

The minor drainage system is that component of the drainage system which is designed to convey the higher frequency events without causing disruption to urban activities. The design objective is to prevent "nuisance" flooding of the urban catchment. The appropriate design standard for the minor system is dependent on the landuse. Typical design standards are between the 5 year ARI and the 10 year ARI events. For high profile and high valued areas, it is sometimes necessary to select a design standard of 50 year ARI to 100 years ARI.

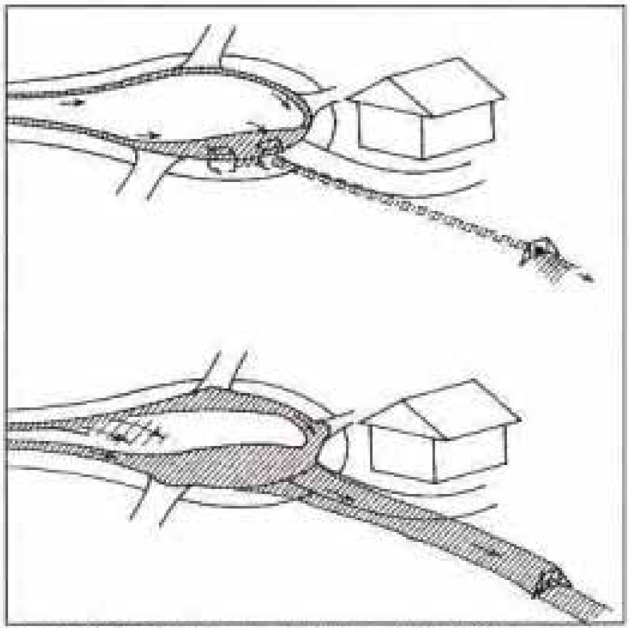

Figure 2.8 **Drainage system behaviour during minor and major storms (ref. Inst. of Engrs., Aust.,1987)**

While overland stormwater flow is tolerated, as long as their occurrence is sufficient infrequent, it is necessary to ensure that the overland flow path is well defined and engineering computation carried out to ensure that property damage is mitigated or avoided altogether. This can often be overlooked in design to the detriment of the overall stormwater drainage strategy. Designated floodways, roads and detention basins form the components of the major drainage system. It is not uncommon to utilise streets as part of the major drainage system as illustrated in Figure 2.9. The routes of minor drainage systems may often differ from the natural drainage path, to conform with the urban design. The major drainage system however generally follows the natural terrain of the catchment. Major system calculations can be complex when overflows do not follow the same paths as the underground or open drain minor system. Nevertheless, it is important that the flow paths of major events are identified and provision made for the safe conveyance of the stormwater during storm events which are larger than the design event for the minor drainage system.

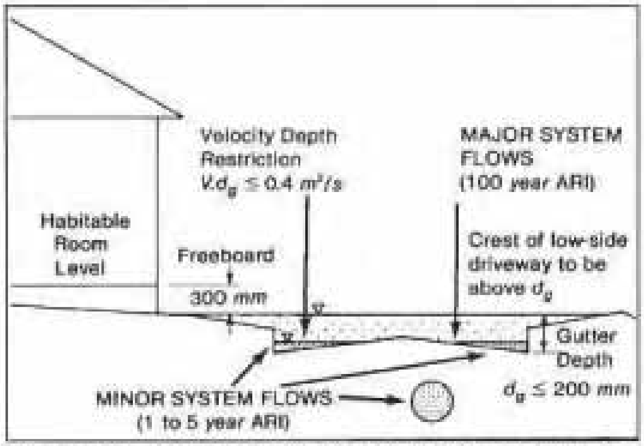

Figure 2.9 **Components of a Major/MinorDrainage Systemref. Inst. of Engrs., Aust, (1987)**

2.4.3 BMP Selection

Selection of the appropriate BMPs can be based on a rational approach that considers the individual characteristics of the site, the desired performance objectives, and any impacts of the measure adopted. The basis for the appropriate selection of the management measures is the matching of the various stormwater management objectives and their relative priorities.

The 'treatment train' approach to integrated stormwater management improves the overall performance of a drainage and stormwater treatment system, leading to a sustainable strategy which can overcome site factors that limit the effectiveness of a single measure. Generally, the more BMPs incorporated into the system, the better the performance and the more likely it is that water quality objectives will be achieved without compromising the drainage function of the system. This approach also provides a catchment-wide approach to stormwater management, the benefits of which are well understood.

Opportunities for structural works are often limited in existing highly urbanised catchments. Stormwater management strategies in such circumstances are often based on non-structural measures and end-of-pipe controls in the short term. Longer term strategies involve the progressive implementation of structural in-transit and source control measures when opportunities for retrofiting existing infrastructure present themselves.

Solutions to problems caused by urban stormwater need to be ecologically and economically sustainable. A common oversight in many stormwater management strategies is the issue of maintenance and rehabilitation of these stormwater pollution control facilities. The life cycle of stormwater management options are often not taken into consideration when assessing the merits of individual management measures.

Chapters 6 to 9 of this document outline the procedures for designing the various components of an integrated stormwater management systems to allow a developer to consider a range of alternative BMPs. The selection of BMPs is likely to vary largely from site to site. No two environments are exactly the same, so no hard, and fast prescriptive assessment can be applied. The most appropriate BMPs must be determined after assessing the characteristics of individual elements.

2.4.4 Best Planning Practice

The layout of the combination of BMPs included within a 'treatment train' may be viewed as Best Planning Practice (BPP), although the two are not mutually exclusive as indicated by Figure 2.10. The selection of appropriate BMPs to include within a treatment train involves an assessment made within a variety of disciplines in order to account for site specific characteristic and limitations. This procedure is illustrated in Figures 2.11 and 2.12.

Stormwater characteristics are highly varied and the effectiveness of individual BMPs and the treatment train as a whole will differ from one event to another. A statistical approach is probably the most appropriate method of evaluating the performance of the treatment train. A number of approaches can be adopted in evaluating the effectiveness of the stormwater management strategy ranging from detailed continuous model simulations to simplified flow frequency/mean event pollutant concentrations.

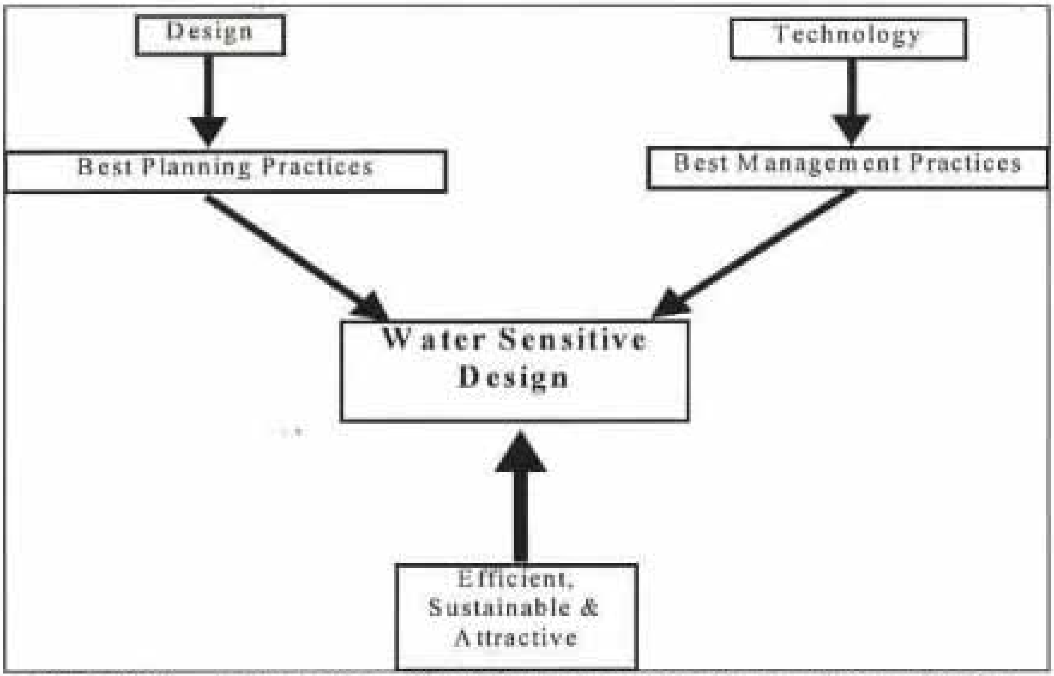

Figure 2.10 Incorporation of Best Management Practices and Best Planning Practices in Water Sensitive Urban Design

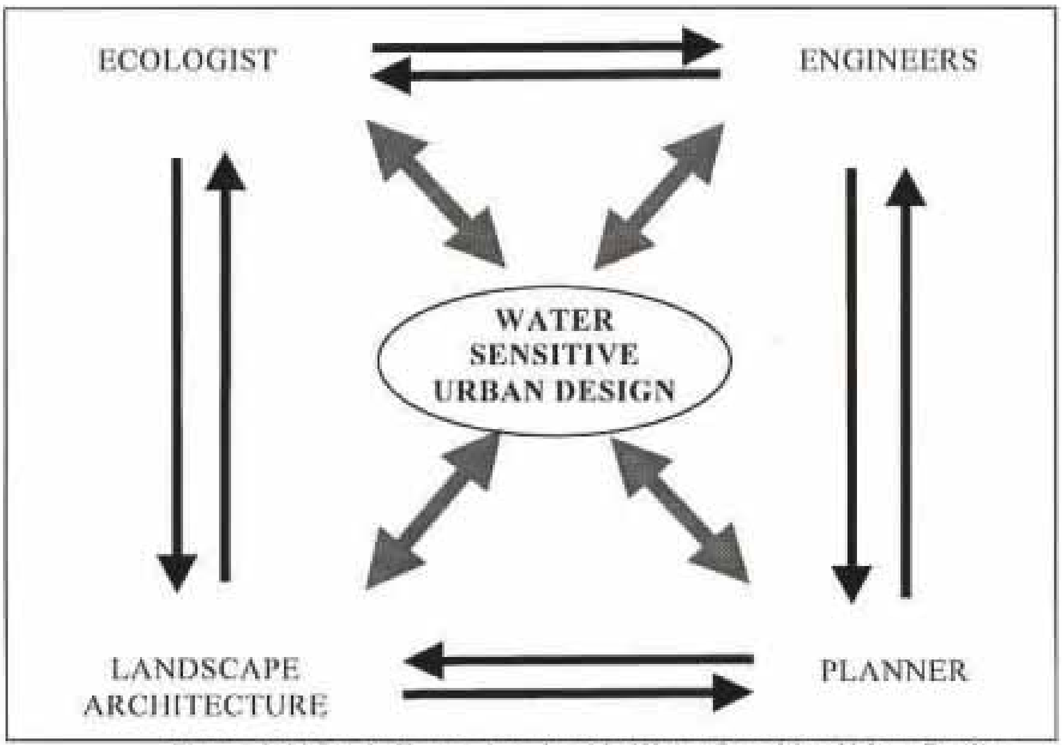

Figure 2.11 Study Teams Involved in Water Sensitive Urban Design

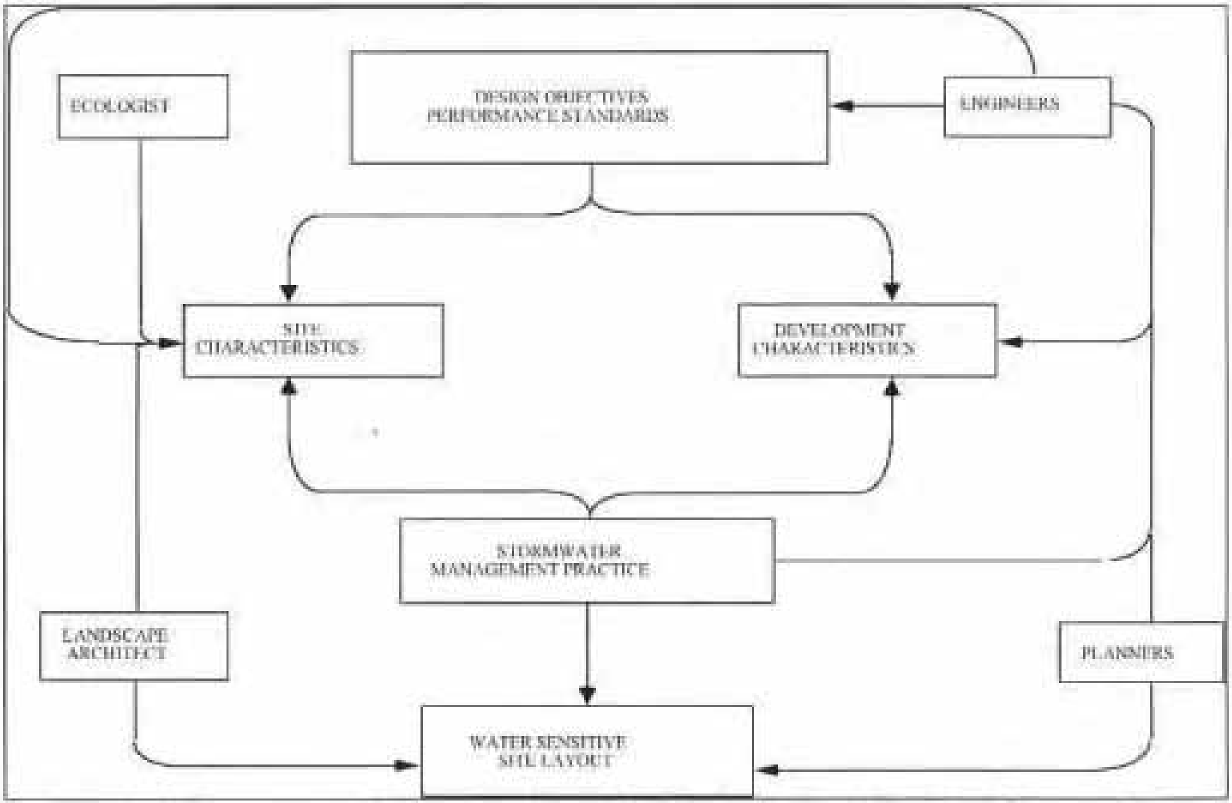

Figure 2.12 **Steps to Developing the Site Layout for Integrated Stormwater Management**

2.5 OVERVIEW OF STORMWATER QUANTITY AND QUALITY MANAGEMENT MEASURES

2.5.1 Stormwater Quantity Management Measures

Detention Basins (Chapter 8)

On-site detention basins are used in urbanised catchments to facilitate urban consolidation in a climate of aging and under-capacity stormwater infrastructure. These devices are most common in NSW as devices which may be constructed in lieu of a drainage levy payment (Ribbons *et al*, 1995) associated with inner city re-development. Common problems associated with this type of runoff control device are siltation of the basins and poor construction which have raised questions on the long-term sustainability of such devices as effective runoff control measures.

Retarding basins have been extensively used in conjunction with urban development to attenuate urban runoff peaks for flood protection of downstream areas. They generally fall into the category of in-transit control measures and the attenuation of stormwater runoff can often lead to the environmental benefits of facilitating erosion protection along natural creeks downstream of urban developments. There are opportunities for retrofitting retarding basins to provide water quality enhancement functions as described by Breen *et al* (1992).

Retarding basins have generally been designed with the single objective of flow attenuation, often based on meeting a prescribed peak discharge for the 100 year Average Recurrence Interval (ARI) event. It is possible for these systems to be sized such that discharges corresponding to frequent events can be attenuated to pre-development levels. Wong *et al* (1998) showed that existing retarding basins could be retrofitted, by incorporation of additional outlet structures, to control peak discharges over a wide range of flow frequency. This will be discussed in more detail in Chapter 5.

Infiltration Systems (Chapter 8)

Infiltration systems are now widely used in Europe and Japan as a means of reducing urban runoff. The infiltration of roof runoff is widely practised in Western Australia and South Australia owing to the sandy soil characteristics of these catchments. Roof areas have been identified as being a potential source of zinc and cadmium contamination of stormwater in Australian communities. Infiltration systems have the effect of removing runoff and associated pollutant from the drainage system and are promoted as a practical means of facilitating urban consolidation in arid and semi-arid regions (Argue, 1994). Such systems require some degree of pre-screening of runoff to remove roof debris. Roof runoff is directed into "leaky" wells or gravel-filled trenches where the stormwater infiltrates into the ground. Studies have found retention efficiencies are often above 80% when these systems are designed accordingly to match soil hydraulic conductivity and rainfall characteristics of the catchment concerned.

The type of area from which runoff is to be directed to infiltration systems appear to be an important design consideration for ensuring the continued effective operation of these schemes. Infiltration systems for treating runoff from more general areas such as streets and car-parks are integrated into landscaping features in urban design in Europe. Local experiences have highlighted the importance of proper design of these systems and the position of these systems in the stormwater treatment train. Poor consideration of catchment pollutant types and characteristics and site conditions is often the main cause for their deteriorating effectiveness over time due to clogging and lack of appropriate maintenance. Pre-screening is a vital component in the treatment train and the use of wetlands is one possible pre-treatment of stormwater runoff before discharging to infiltration systems and swale drains.

2.5.2 Stormwater Quality Management Measures

With densely built up catchments, there is clearly a need for lateral thinking when formulating stormwater pollution control schemes. Stormwater management strategies in such situations would place particular emphasis on incorporating non-structural measures that foster the following activities:

- Community awareness
- Pollution identification
- Source detection and removal
- Modification of inflicting land use practices

These activities are source controls and rely heavily on the support of the community. There is little quantitative information on the success of non-structural measures. For example, the effectiveness of street sweeping varies between 40% to 95% in the removal of pollutants larger than 2 mm (ie. gross solids and associated pollutants) if carried out regularly but are largely ineffective in reducing event concentrations of metals and nutrients in stormwater runoff. Non-structural measures in the form of regulations are often necessary to drive the community and industry towards better catchment management. Regulation of appropriate landuse can often be effective in eliminating source areas or in isolating them to designated regions. The United States has adopted a phased prescriptive program for stormwater control, which requires municipalities and industries to obtain

National Pollutant Discharge Elimination System (NPDES) permits for stormwater discharge standards. This has compelled state and local authorities to implement catchment non-point source pollutant management strategies in all major catchments with population in excess of 100,000 inhabitants (James, 1995).

Structural stormwater quality management techniques involve the utilisation of physical, chemical and biological processes. The respective positions of the various techniques in the treatment train are important considerations in ensuring the sustained effectiveness of the management strategy. As a general rule, the respective positions of the various elements of the treatment train would need to be in accordance to the pollutant size range treated by each of the individual treatment measures. Physical treatment measures such as gross pollutant and coarse sediment removal are important processes which are often required to pre-treat stormwater prior to their conveyance to chemical and biological treatment systems such as wetlands and ponds. Nutrients, heavy metals and organic chemicals utilise sediment as vehicles for transportation in urban runoff. The deposition of sediment can often result in a corresponding reduction of these other pollutants in the waterbody.

Litter Traps and Gross Pollutant Traps (Chapter 6)

Litter and gross pollutants often have the highest visual impact and are the common basis for community perception of a polluted environment. There are a number of devices currently used for trapping of gross solids. Litter traps, trash racks and floating booms are used specifically for trapping litter. These devices simply intercept litter along a water course and at drainage inlets.

Figure 2.13 A floating litter trap placed on the receiving waters near a pipe outfall. (ref. Allison *et al.*, 1997)

Floating boom systems are intended for trapping floating litter and cannot be expected to have high capture efficiencies of gross solids during high flow conditions with removal efficiencies as low as 10%.

Trash racks involve the use of closely spaced vertical rod as a screen to trap gross solids. Their capture effectiveness can be as low as 10% to 15% of gross solids generated from the catchment.

Litter baskets, which consist of wire mesh baskets inserted at stormwater entry pits can be very effective at individual locations but require a wide coverage of the catchment for them to have an appreciable impact on reducing the total catchment gross pollutant load.

All the above litter trap devices require regular clearing of trapped material to minimise their impacts on upstream hydraulics, especially during high flow periods and to optimise capture of gross solids. In general, trash racks and litter baskets are inexpensive treatment devices to install but require regular maintenance for it to be effective.

Recent development of the Continuous Deflective Separation (CDS) trap has facilitated the efficient trapping of large quantity of gross pollutant and coarse sediment without the associated problems of clogging and blockage of the trap. These devices are designed to be retrofitted to existing stormwater pipes and channels and are gaining much attention in Australian and overseas practices

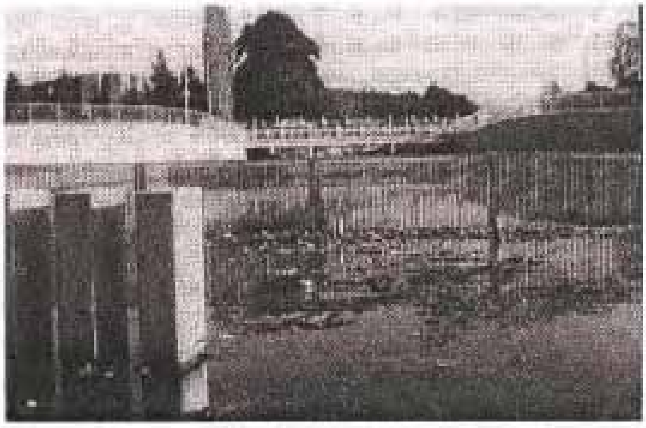

Figure 2.14 **Gross Pollutant Trap in Canberra (ref. Inst. Engrs.,Aust., 1987)**

It is likely that the high degree of effectiveness of the CDS technology will change future practices in the management of litter and gross solids in urban catchments. Inefficiencies in street cleaning can be overcome by utilisationof this highly effective gross pollutant trap.

Specifications for minor and major gross pollutant traps were developed by the ACT Government (1994) for installation at discharge points of underground stormwater pipes to creeks and waterways (ie. minor GPT) and at key locations along major trunk of stormwater waterways (ie. major GPT). These structures are designed to intercept coarse sediment and gross solids and consist of a retention basin with a trash rack at the outlet. Maintenance in terms of regular clean-out of these structure is vitally important to ensure their continued effectiveness. Litter accumulated can potentially be remobilised during subsequent events of higher flow magnitudes.

Swale Drains and Buffer Strips

Swale drains are open grass drains that can be used as an alternative to the conventional kerb and channel while buffer strips provides a medium for stormwater filtration during its passage to the drainage system. These are traditionally found in small country towns and alongside country roads but are becoming increasingly common as a landscaping feature of redeveloped areas in built-up urban catchments.

The main advantage of swale drains and buffer strips is that flow velocities are decreased thus protecting stream banks from erosion. The lower velocities also allow some of the suspended particles to settle out. Grass and other vegetation in the drains act as a filtering device and reported removal efficiencies of suspended solids ranged from 25% to 80% depending on the grading of the suspended solid loads in the stormwater.

Swale drains allow ground infiltration although their long-term effectiveness is not expected to be very high. They are inexpensive to construct compared to the conventional kerb and channel drains but maintenance costs of the drains are expected to be higher owing to requirements for regular cleaning and mowing. The issue of whether they should be mown is a topic of some debate owing to the potential for large export of organic matter from these systems.

A common problem with swale drains occurs in flat terrain. Poor construction can often lead to the ponding of water following a flow event. This can lead to the presence of a number of stagnant pools which may lead to possible mosquito problems. In such circumstamces, the provision of a perforated pipe beneath the swale drain may assist in draining these pools.

Oil and Grease Removal (Chapter 7)

There are currently a number of oil and grease separators being trialled in the stormwater industry with varying success. Most of these systems utilise a form of chamber or detention tank with an inverted pipe outlet system to convey the clearer stormwater from the floating oil and grease. As reported by NSW-EPA (1996), these systems do not provide a high level of performance generally due to infrequent maintenance and the passage of high flows. The separation of oil and grease in such systems rely on near-quiescent flow conditions and are most appropriate when used in treating runoff from clearly isolated oil and grease source areas. Such systems are not commonly used for stormwater treatment in Australia. Incidental export of oil and grease from urban catchments may be better treated by grass swales and wetlands while source areas of high pollution potential (eg. petrol stations and garages, car wash areas etc) should ideally be isolated and dedicated oil, grease and grit traps installed. Discharges from these traps, including overflows, should ideally be diverted to wastewater treatment facilities.

Wetlands and Ponds (Chapter 9)

The use of wetland and pond systems for stormwater pollution control is an accepted practice in Australia. Stormwater detention systems consisting of emergent vegetation are considered to be an effective means of improving stormwater quality. Vegetation in such runoff control systems is involved in several treatment processes including enhanced sedimentation, fine particle filtration, and nutrient uptake and storage in living and dead plant biomass. Wetland vegetation also performs the function of energy dissipation, flow re-direction and soil stabilisation.

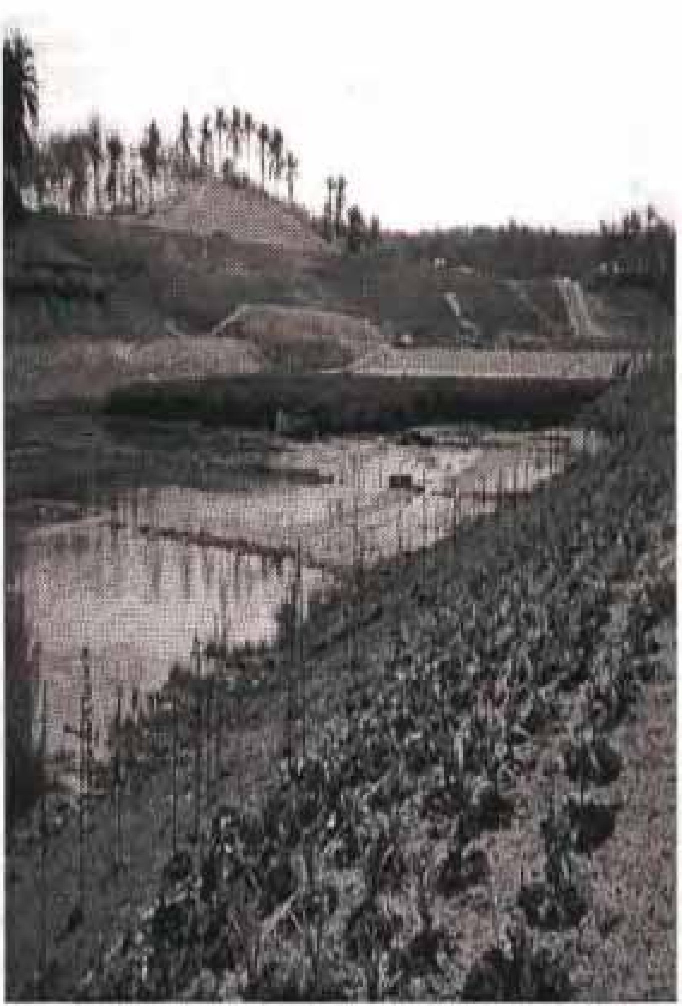

Figure 2.15 Photograph showing Upper North Wetland in Putrajaya

Recent experiences have indicated a trend towards either the incorporation of existing natural wetlands or the development of wetlands and ponds as landscape features to enhance the landscape amenity of associated urban developments. However there appears little thought on how these wetlands can be utilised effectively to serve other beneficial functions. Many of these systems are poorly designed, primarily due to the lack of an integrated approach in the design, operation and management of these systems. As a result, many of these urban wetlands and ponds are becoming a long term liability to the community. Common problems encountered include:-

- accumulation of litter in some sections of the wetland;
- accumulation of oil and scum at "dead zones" in the wetland;
- infestation of weeds or dominance of certain species of vegetation;
- mosquito problems;
- algal blooms;
- section of wetlands subjected to scouring;

A lot of the common problems listed above can be minimised or avoided by good engineering design principles. Poor wetland hydrodynamics and lack of appreciation of the stormwater treatment train are often identified as major contributors to wetland management problems.

Data from overseas and in Australia on the effectiveness of wetland and pond systems in reduction of stormwater pollution show them to be highly varied. This is not unexpected as these systems are highly complex systems with significant interaction between its ecology, soil chemistry, and hydrodynamic characteristics. Current design guidelines for wetland and pond systems as stormwater treatment facilities are still very much in its infancy and based primarily on performance curves from overseas. Attempts at deriving regression equations to predict the performance of these systems and to serve as design guidelines have been of varying degree of success owing to the wide range of conditions in which these systems operate. The processes influencing the effectiveness of ponds and wetlands in removing stormwater pollutant are non-linear and are dependent on a number of factors including the relative difference between the influent pollutant concentration and the background pollutant concentration of these natural systems and the flow hydrodynamics.

Managing Receiving Waters

The management of receiving waters is perhaps the last component of the treatment train and serves to mitigate the impact of stormwater pollution. It is a necessary component in providing short-term protection of receiving waters and their users while upstream management measures are implemented for a long-term sustainable outcome.

Management of receiving waters include:-

- defining appropriate water use
- monitoring and establishing "health" indicators
- in lake treatment
- dredging

2.6 SUMMARY

Stormwater pollution is a catchment-wide issue and thus require a holistic approach in formulating strategies for its management. This holistic approach must incorporate considerations of landuse planning, urban design and landscape architecture if the effectiveness of measures implemented are to be sustainable. As a general policy, the strategic management of stormwater should adopt a risk-based approach assessing the merits of individual measures on the basis of the combined effect of the environment's exposure to the hazard, the risk of pollution and the consequence of pollution. A stormwater management strategy should aim to avoid pollution in the first instance with appropriate source control measures. Stormwater pollution should be minimised if the pollutant source cannot be entirely eliminated through appropriate in-transit control measures. As a last resort, the impact of stormwater pollution should be managed through appropriate receiving water management.

While the adoption of a major/minor drainage approach to designing the components of a drainage network is widespread in Malaysia, there is often insufficient attention given to the performance of the major drainage system. This has led to poorly defined overland flow paths whenever the discharge capacity of the minor drainage is exceeded. It is vital that the major/minor drainage concept be implemented in its entirety with clearly defined overland flow paths and flood storage areas for the major storm event. These include floodways, drainage easements, streets, local playing fields and recreational parks. Performance criteria for these elements of the major drainage system include maximum velocity and depth, extent of inundation, available freeboard to residential dwellings etc.

In relation to treatment techniques, there is a wide variety of methods, all of which have been shown to work effectively when utilised as intended. Individual methods alone cannot be expected to treat the wide range of pollutants generated from an urban catchment and a treatment train approach is necessary. This approach involves the utilisation of a number of treatment methods in series or concurrently which will lead to an optimal overall performance of the treatment system facilitating a sustainable strategy which can overcome site factors that limit the effectiveness of a single measure.

The intermittent nature and temporally-varied distribution of stormwater runoff and associated pollutants requires a statistical approach in evaluating the overall performance of the treatment train. A life-cycle approach to the evaluation of the merits of available treatment methods is also necessary to ensure a sustainable stormwater treatment strategy