PINE RIVERS SHIRE COUNCIL

DESIGN MANUAL

CIVIL INFRASTRUCTURE DESIGN

DESIGN STANDARDS

PINE RIVERS SHIRE COUNCIL

DESIGN STANDARDS

PART 2
DESIGN STANDARDS FOR STORMWATER DRAINAGE WORKS

Section 1 Introduction

Section 2 Strategy Plan

Section 3 Best Management Practices

Section 4 Design Standards

Section 5 Summary Document

PINE RIVERS SHIRE COUNCIL

PART 2 - DESIGN STANDARDS FOR STORMWATER DRAINAGE WORKS

SECTION 3
BEST MANAGEMENT PRACTICES

ABBREVIATIONS

ACT	Australian Capital Territory
approx	approximately
ARI	average recurrence interval
ASCE	American Society of Civil Engineers
AWWA	Australian Water and Wastewater Association
BMP	best management practice
BOD	biological oxygen demand
CDS	continuous deflective separation
CIRIA	Construction Industry Research & Information Association
COD	chemical oxygen demand
CSO	combined sewer overflow
ED	extended detention
EMC	event mean concentration
GPT	gross pollutant trap
ha	hectare
m	metre
mg/l	milligrams per litre
m/s	metres per second
m^3/ha	cubic metres per hectare
NH3	ammonia
NSW	New South Wales
NURP	Nationwide Urban Runoff Program
SS	suspended solids
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TP	total phosphorous
USA	United States of America
USEPA	United States Environmental Protection Agency
µm	microns
Wat. Sci. Tech.	Water Science and Technology

3.1.0 INTRODUCTION

The aim of this section of the Pine Rivers Shire Council Design Manual is to review stormwater quality best management practices (BMPs) used throughout the world, provide draft guidelines for the implementation of BMPs and recommendations for implementation of BMPs in Pine Rivers Shire.

A management system based on BMPs involves the adoption of prescribed management techniques to be applied across different land uses. BMP systems aim to minimise the impact of urbanisation of the stormwater environment. Effective management of the stormwater environment is based on the consideration of all of the following (Sharpin, Morison and Goyen 1995):-

- hydrology
- water quality
- aquatic habitat
- vegetation

This section focuses on water quality issues and is structured as follows:-

Section 3.2.0	Stormwater Management and the Environmental Protection Act.
Section 3.3.0	Nature of urban runoff including urban hydrology, sources of pollutants and their impact on the environment, and the quality of urban and rural runoff.
Section 3.4.0	Stormwater management strategies and best management practices (BMPs).
Section 3.5.0	A review of the concepts of BMP stormwater quality management.
Section 3.6.0	A review of the stormwater quality BMPs used in Australia and overseas and a summary of the uses and limitations of the identified BMPs.
Section 3.7.0	Environmental impacts of stormwater quality BMPs.
Section 3.8.0	Recommendations for use of BMPs in Pine Rivers Shire.

The procedures outlined in this section of the Pine Rivers Shire Council Design Manual are intended to be used as a guide for the development of BMP guidelines in the future. The BMP guidelines contained herein are the results of BMPs used elsewhere in Australia and the world. Specific guidelines for Pine Rivers Shire would require a detailed investigation of Pine Rivers Shire climate, hydrological cycle, topography, soils and geology and land use characteristics. Additionally, given the advancement of technology, any BMP guidelines subsequently developed will need to be updated regularly.

3.2.0 STORMWATER DRAINAGE AND THE ENVIRONMENTAL PROTECTION ACT

The Environmental Protection Act 1994 (EPA) has several important implications for stormwater management. Some of these are well defined, but others are less certain and a "due-diligence" approach is necessary.

Stormwater drainage is not defined as an Environmentally Relevant Activity (ERA) and therefore does not require an environmental authority to operate. However, stormwater may cause environmental harm because of the pollutants it conveys to surface and ground waters.

From practical knowledge of the Act and discussions held with the Department of Environment and Heritage and other local authorities, obligations of the Pine Rivers Shire Council include:-

- ERAs operated by the Pine Rivers Shire Council which generally will require an approved stormwater management plan as a condition of licence to control discharges from the site. It is also likely that the Pine Rivers Shire Council has some liability regarding the ERAs operated by contractors and lessees of the Pine Rivers Shire Council land. The extent of the liability is not clear at present.

- Operation and maintenance of the stormwater system. In this case, the Pine Rivers Shire Council is obliged to minimise environmental harm which could result from activities such as trash rack clearing and sediment removal from GPTs and pipes.

- Other Pine Rivers Shire Council activities i.e. not ERAs, which may cause stormwater pollution. Examples are road and drainage construction. For non-ERAs, the Pine Rivers Shire Council obligation is to exercise due diligence in minimising the risk of environmental harm.

- Activities carried out by other parties which could impact adversely on stormwater and, in turn, on surface or ground waters. This is the most tenuous legally but should not be ignored. Examples are subdivision approvals and EPA licences issued by the Pine Rivers Shire Council.

If the Pine Rivers Shire Council stormwater system caused environmental harm as a result of third party pollution a Pine Rivers Shire Council obligation may arise if it could have taken steps to reduce the impacts. A recent decision in England found that an illegal discharge into a council sewer and which subsequently caused a fish kill was an offence by both the polluter and the Council.

In summary, the clearest obligation occurs in relation to stormwater management associated with ERAs such as fuel storages, vehicle workshops, landfills and sewage treatment plants. The extent of other obligations has yet to be defined in the Act or through the courts. However, the principles of due diligence apply.

Organisational Arrangements

The EPA obliges every Council employee with a general environmental duty to prevent environmental harm. To that extent, the Act is pervasive and no single department can accept the responsibility for the others.

Most Councils (including the Pine Rivers Shire Council) have centralised administration of the Act in an environmental health or environmental protection group. This group is usually responsible for licensing ERAs for which a council is the Administering Authority and for advising systems for managing those activities of a council which may cause environmental harm. In some cases, the group also has a monitoring or audit function.

This arrangement reflects a separation of the operation from audit. It has some parallels in the provider/purchaser (operations/management) split required post-Hilmer.

In relation to stormwater, an appropriate response would be a functional separation of operations from management. The operation function would be responsible for:-

- developing and implementing procedures to minimise risk
- reporting on incidents and environmental monitoring
- implementing corrective action through an agreed process

The management function would be responsible for:-

- ensuring that planning and design activities and management systems are in place to minimise risk
- co-ordinating an integrated approach stormwater policy, planning and practice
- monitoring and disseminating new legislation and other requirements to operational areas
- co-ordinating and evaluating water monitoring information

3.3.0 THE NATURE OF STORMWATER RUNOFF

3.3.1 URBAN HYDROLOGY

Urbanisation has a significant impact on the hydrological cycle, including changes in the yield, peak flow rate and groundwater regime. The impacts will depend on the extent of urbanisation, soil conditions, topography, climate and the amount of garden watering.

Urbanisation changes the hydrological cycle through the following changes to catchment characteristics (Joliffe, 1995):-

- introduction of garden watering which will lead to an increase in soil moisture
- introduction of impervious areas which reduce infiltration and lead to an increase in the runoff volume or yield for the catchment and also an increased peak flow rate for rainfall events
- introduction of impervious areas which lead to runoff from the catchment for events which would not have produced any runoff under rural conditions
- on a regional basis, the extraction of potable water from streams can also impact on the hydrological cycle as can discharge from a sewage treatment plant back into the watercourse

The impacts of urbanisation on surface flows have been identified by Packman (1981) and Hollis (1975) and reported for Australian conditions by Carroll (1994):-

- Undeveloped catchments with a low runoff coefficient and a slow response time are more greatly affected by urbanisation than those with higher runoff coefficients and more rapid response time.
- The effect of urbanisation is dependent upon the magnitude of rainfall events. The effect is greater for small storms than for storms having a larger rainfall volume.
- The response of urbanised catchments is influenced by any decrease in soil moisture conditions. This results from the high proportion of impervious area within urban catchments.
- A more rapid response to rainfall can be caused by shorter duration rainfall events because the catchment time of concentration will be reduced with urbanisation.
- The effect of urbanisation depends on the location of the urban development within the catchment.

Runoff volume from urban catchments is dominated by the directly connected impervious area and to a lesser extent, the temporal rainfall distribution (Sharpin and Morison, 1995). For an urban catchment, the percentage of rainfall appearing as runoff is approximately equal to the directly connected impervious fraction of the catchment. There is more variation of runoff volume generation for rural catchments between events of similar magnitude.

In summary, urbanisation of catchments leads to decreased infiltration (caused by the increase of impervious area) and decreased catchment storage. This leads to an increase in both the magnitude of floods and the volume of runoff, resulting from a given rainfall event. The time of concentration (peak of flood flow) decreases as the impervious area increases. Flood velocities also increase. Additionally, groundwater flows are reduced. Catchment deforestation results in reduced evapotranspiration and infiltration, leading to reduced stream flow persistence and increased peak flows.

3.3.2 POLLUTANTS AND THEIR IMPACT

There are a wide range of potential pollutant sources from urban catchments. These sources can be external to the water body or can be derived within the water body (internal sources) (Sharpin, 1995). The actual extent and magnitude of the external sources of pollutants will depend on factors including rainfall patterns and catchment hydrology, soil type and geochemistry, catchment geology, catchment and floodplain vegetation, air pollution and land use practices. Internal pollutant sources will be related to the geomorphology of the water body, including bed and bank characteristics and the stream flow regime, the extent and nature primary productivity and riparian vegetation.

The instantaneous concentration of a pollutant in a water body can be a function of either external or internal sources or both. Additionally, the instantaneous concentrations may be affected by in-stream processes.

The sources of pollutants in urban runoff include:-

- atmospheric deposition
- erosion (including that from subdivision and building activities)
- litter and debris
- traffic emissions and vehicular wear
- animal droppings
- leaching of pollutants from septic systems and landfills
- pesticides and fertilisers
- application, storage and wash-off of car oil, detergents and other household and commercial solvents and chemicals
- solids accumulation and growth in stormwater systems
- cross-connections of sewers and industrial wastes from sanitary sewers and other sources into storm water systems
- weathering of buildings

The pollutants in stormwater can be categorised according to their water quality impacts as follows:-

- suspended solids
- nutrients
- biological oxygen demand (BOD) and chemical oxygen demand (COD) materials
- micro-organisms
- toxic organics
- trace metals
- oils and surfactants
- litter

The nature and impacts of each of these pollutant categories is outlined below.

Suspended Solids

Increased suspended solid concentrations lead to reduced light penetration, affecting the growth of aquatic flora and fauna. Suspended solids also reduce the aesthetics of affected water bodies and the perceived amenity of the water for recreation. When the sediment settles it may smother benthic organisms and alter or destroy fluvial habitats. Since metals, phosphorous and various organics are adsorbed and transported with sediment, deposition may lead to a slow release of toxicants and nutrients leading to possible prolonged effects on water quality.

Nutrients

The two nutrients of prime concern are phosphorous and nitrogen. Nutrients promote eutrophication - the increase in the biological productivity of water bodies, including accelerated growth of microphytes, phytoplankton and algae. This increase in organic matter leads to reduced light penetration and re-aeration, and upon decomposition, causes odours and reduced oxygen levels in affected water bodies. Under eutrophic conditions there can exist diurnal variations in oxygen and pH. Biomass growth can increase to the extent where water bodies become choked and unsuitable for uses such as boating, swimming and water supply.

Eutrophication tends to occur in a water body when nutrient inflow is consistently greater than the outflow, with the water body acting as a nutrient sink. Hence, the flow of nutrients in a watercourse is not necessarily an indication of its susceptibility to eutrophication.

In fresh waters, biological productivity is usually limited by phosphorous availability, and in estuaries, either nitrogen of phosphorous can be limiting (Hecky and Kilham, 1988). In the lower reaches of an estuary there is a tendency for nitrogen to be the limiting nutrient with phosphorous the limiting nutrient in the upper reaches.

Nutrient levels impact upon water quality over periods of time greater than a single storm event. Full nutrient water quality impact, namely, eutrophication, could take between one month and ten years to develop.

Oxygen-demanding Materials

Sources of oxygen-demanding materials are bio-degradable organic debris, such as food and garden wastes and the organic matter contained in sewage. The addition of some organics to a water body will result in an increase in oxygen demand.

Organic matter acts as an energy food source to bacteria. In consuming organic matter, bacteria require oxygen leading to reduced oxygen levels. If the organic concentration is high enough or the oxygen demand cannot be met by the supply, then the resulting oxygen sag could create an anaerobic environment. These conditions may be toxic to some organisms, including fish. In an anaerobic environment, pollutants, e.g. nutrients and heavy metals, absorbed to sediment may be released into the water column causing further deterioration of water quality. Anaerobic environments are also characterised by the release of odours. Dissolved oxygen levels in urban waterways may take weeks to recover after a storm event. When the organic matter has been consumed the oxygen status will return to normal and the ecosystem will be restored (Manahan, 1991).

Micro-organisms

Micro-organisms include bacteria and viruses found in soil, decaying vegetation and putrescible material. Coliforms also originate from sewer overflows, septic tank seepage and animal wastes. Micro-organisms have the potential to accumulate in benthic organisms and shellfish.

Micro-organisms can have a significant impact on human health and can lead to outbreaks of waterborne disease such as cholera, typhoid, infectious hepatitis and gastroenteritis. Bacteria can also lead to increases in biological oxygen demand (BOD).

Generally, micro-organism levels are higher in summer than in winter.

Toxic Organics

Toxic organics originate from garden pesticides, industrial chemicals and landfill leachate. Toxic organic chemicals carried by urban runoff are generally not present in concentrations high enough to have acute toxic effects in receiving waters but they may cause long term ecological damage and may pose a risk to human health.

Heavy Metals

Heavy metals include copper, zinc, lead and chromium derived from motor vehicles, pavement degradation, pipe and roof corrosion. Most heavy metals can be present in a variety of chemical species. The different metals, species, loading characteristics and exposure times can result in different effects on the aquatic ecosystem. Heavy metals can exert short term acute exposure or bioaccumulation. In receiving waters, heavy metals can accumulate in sediments and may become available for uptake by benthic organisms or other aquatic species. Heavy metals are the pollutants in urban stormwater with the greatest potential for chronic impacts on aquatic life (USEPA, 1983).

Oils and Surfactants

Hydrocarbons, including petroleum derivatives, are flushed from road surfaces and from paved areas of service stations and factories. Surfactants are generally derived from detergents, most commonly from car washing.

Some hydrocarbons are toxic to aquatic life and if they reach the bottom sediment, they may persist for long periods of time and result in an adverse impact on benthic organisms. Hydrocarbons can accumulate in fish and shellfish. Surfactants can be very damaging to biological membranes. They can cause foaming and toxicity in waterways, although this problem has decreased since the introduction of biodegradable detergents. Floating oils and grease adversely impact upon aesthetics.

Litter

Litter includes paper, plastics, glass, metal and other packaging materials. The impacts of litter are primarily aesthetic although litter can pose risks to human health and aquatic ecosystems.

3.3.3 URBAN AND RURAL RUNOFF QUALITY

There has been little research into the quality of runoff in Pine Rivers Shire and Queensland.

Sharpin (1995) compared the quality of urban and non-urban runoff in south-eastern Australia using event mean concentrations (EMCs) of pollutants. The EMC is calculated as the event pollutant load divided by the runoff volume. He found that:-

- a significant degree of variability exists between EMCs from catchments with similar land uses
- there is generally no trend for urban catchments to have consistently higher nutrient concentrations than those from rural catchments - this is expected to be due to the influence of land management practices on rural pollutant characteristics
- generally, phosphorous from both urban and rural catchments is predominantly in particulate form
- the dominant form of nitrogen for both urban and rural catchments is generally total Kjeldahl nitrogen (ammonia and organic nitrogen)
- uncontrolled construction of urban development in a catchment can have a significant impact on pollutant concentrations
- it appears that the pollutant concentrations from forested catchments are appreciably lower than those from rural catchments

Sharpin (1994) summarised stormwater quality data for catchments in south-eastern Australia. There is little comprehensive stormwater quality data for Queensland. This summary is given below in Table 3.3.1.

Table 3.3.1

**AVEAGE STORMWATER EVENT MEAN CONCENTRATIONS (mg/l)
FOR SOUTH-EASTERN AUSTRALIA (SHARPIN, 1994)**

Land Use	Suspended Solids	Total Phosphorous	Total Nitrogen
Urban	50 - 540	0.08 - 0.65	1.4 - 9.8
Rural	85 - 270	0.22 - 1.3	2.4 - 5.1
Forest	30 - 140	0.04	NA

3.4.0 STORMWATER QUALITY MANAGEMENT

Stormwater quality management strategies are intended to enhance the water quality of runoff with the objective of protecting the water quality and ecological integrity of receiving waters. Effective management of the stormwater environment is based on consideration of the following (Sharpin, Morison and Goyen, 1995):-

- hydrology
- water quality
- aquatic habitat
- vegetation

In the last fifteen years, systems of stormwater quality best management practices (BMPs) have been implemented in North America, Europe and Australia to protect the water quality of water bodies receiving urban runoff. A management system based on BMPs involves the adoption of prescribed management techniques to be applied across land uses. BMP systems aim to limit or reduce export of critical constituents to levels consistent with the sustainable loading of downstream waters (Willing and Partners, 1995).

Willing and Partners (1995) outlined advantages of the BMP approach:-

- it is simple to administer
- it minimises uncertainty in relation to investment
- it is effective, economic and equitable attainment of goal

In selecting appropriate BMPs for a specific site there are a number of factors that need to be considered:-

- type of receiving water
- environmental value of receiving water
- ecosystem protection
- sustainable flows
- sustainable discharges and loads
- existing and proposed land uses within the catchment
- export reduction targets
- the range of possible management techniques
- viability of techniques in relation to terrain, soils, climatic and land use constraints
- pre-treatment requirements necessary for each technique to protect its hydraulic, chemical and ecological characteristics
- environmental impacts of BMP

Different types of receiving waters have different types of physical, chemical and biological characteristics. These characteristics will determine the type and extent of impacts of urbanisation. The major types of inland waters can be broadly classified as follows (Morison and Williams, 1995):-

- estuaries - comprise a variety of coastal waters. Transitional environments from the land to the sea and between sea water and fresh water. Estuaries have variable salinities, bi-directional flows of water and a biota of largely marine derivation.

- running waters (lotic environments) - rivers and streams which maintain a uni-directional flow. Lotic waters are characterised by linear morphology, shallow depths, relatively unstable bottom and shoreline areas and significant land/water interactions.

- standing waters (lentic environments) - lakes, reservoirs, ponds, lagoons, wetlands and other water bodies in which there is no obvious movement of water. Lentic environments have non-linear morphology, variety in depth, of stable bottoms and shorelines, and often a decreased interaction with the surrounding land.

The environmental values of receiving waters include (Morison and Williams, 1995):-

- ecological
- economic
- recreational
- aesthetic and cultural
- scientific and educational

The most effective method of stormwater quality management involves an integrated system of stormwater quality best management practice. This includes source controls, waterway corridors and treatment measures. To ensure the integrity of all waterways within a catchment, stormwater quality BMPs should be implemented as close to the pollutant source as possible. That is, a number of BMPs should be implemented in the upstream reaches of a catchment as opposed to one large treatment measure in the lower reaches of a catchment. Stormwater treatment measures should consist of a system or BMPs or a "treatment train" e.g. grassed swales draining to wet basins to wetlands.

Where possible, stormwater quality BMP systems should be considered on a catchment/subcatchment basis and designed to suit the environmental characteristics of that catchment.

3.4.1 NON-URBAN RUNOFF QUALITY MANAGEMENT

Because much of non-urban development can have a significant impact on downstream lake, river and creek systems, increasing emphasis has been placed on runoff management from non-urban areas. Many of these management activities are being considered by if not incorporated by land care groups.

The following is a list of source controls/management practices which may assist enhancing the water quality emanating from non-urban catchments. They should not be seen as prescriptive and may require modification depending on local topography and soil characteristics.

Predominant Land Use

- **Dairy farming**
  - use the QDO 1993 Manual for the Management and Re-use of Dairy Effluent
  - avoid application of fertilisers within 30 m of creeks and gullies
  - revegetate creeks in a coordinated way through catchment land care groups

- **Stock Management**
  - stock should be kept away from major watercourse (30 m) including the water supply reservoirs (100 m) i.e. they should be watered through troughs
  - the agistment of goats, horses and donkeys should be discouraged
  - stocking rates should be kept to 1 beast per 3 ha of land
  - stocking rates should be halved in forested areas

- **Cropping**
  - crop land (pineapples) should be at least 100 m from water supply reservoirs and 30 m from any creek or gully
  - a 30 m vegetation corridor should be preserved along all creek corridors
  - cropping should occur along contours
  - lands steeper than 1:6 should not be cropped
  - all farm dams should be built to at least receive the first flush runoff from the upstream catchment

- **Rural Living**
  - retain all significant strands of vegetation
  - tree density should be maintained at not less than 40% nearby forest
  - effluent disposal areas should be at least 200 m^2 (absorption trench) and 500 m^2 (land application area)
  - all effluent disposal areas should be no closer than 50 m to a watercourse

- **Rural Residential**
  - as for Rural Living *plus*
  - maximise lot size to allow for retention of vegetation
  - access roads limited to areas with slopes less than 20%
  - all grey water should be directed through the septic tank or other on-site treatment
  - erosion and sediment plans should be lodged with any development application
  - a reticulated water system should not be introduced to rural residential areas without appropriate measures being introduced to manage the effects of effluent into nearby discharging streams

- **Park Residential**
  - high quality on site treatment of black and grey water is essential for park residential due to lack of treatment space e.g. use of anaerobic sand filters
  - in general park residential development is best placed in areas which are capable of being sewered

3.5.0 STORMWATER QUALITY BEST MANAGEMENT PRACTICES

Many source controls rely upon changing community behaviour in the catchment or keeping potential pollutants close to their point of generation. Structural controls are methods which to a degree imply an acceptance of non-point source pollution of waterways and a commitment to reducing its impact (Aitken, 1993).

This section outlines the main concepts behind implementation of best management practices for enhancement of stormwater quality.

3.5.1 SOURCE CONTROLS

The philosophy behind source control is to minimise the amount of pollution entering a watercourse from the contributing catchment. This is motivated by recognition that structural stormwater treatment measures cannot generally reduce pollutant loads to pre-development levels. Additionally, source controls are often cheaper and have a lower environmental impact.

Willing and Partners (1995) categorised source controls under two headings:-

- reduction in runoff rates (leading to reduced erosion)
- reduction in pollutant volume available to be transported into the stormwater system

Typical runoff reduction techniques include lawn coring, recharge basins, seepage pits, porous pavements, on-site detention and overland flow modification. Some of these controls are discussed as hydraulic controls in more detail in Section 3.5.2 and Section 3.6.0 of the Design Standards for Stormwater Drainage.

Pollutant quantities can be reduced by the following:-

- elimination of sewer overflows
- drain labelling
- improved street and gutter sweeping
- appropriate use of fertilisers and pesticides
- improved litter bin servicing
- appropriate management of oil and other household chemicals
- cleaning of gully pits and/or installation of trap gully pits
- control of littering and rubbish dumping
- appropriate disposal of grass cuttings and other matter attained during garden maintenance
- provision of trade waste services
- public education and clean-up campaigns
- land capability assessment prior to development
- increased use of public transport
- minimised impervious area
- proper disposal of pet droppings
- negotiations with manufacturers to reduce a chemical content of stormwater pollutants in products e.g. brake pads, paint

If pollutant quantities can be reduced at the source, there will be a decrease in the need for structural BMPs and there will be increased performance of structural BMPs.

When a site is developing during the construction stage, disturbance of ground cover can lead to increased erosion which will adversely impact upon water quality. To decrease these impacts, stringent sediment and erosion control requirements should be in place and enforced.

3.5.2 STRUCTURAL CONTROLS

As mentioned previously, structural controls are methods which to a degree imply an acceptance of non-point source pollution of waterways and a commitment to reducing its impact (Aitken, 1993). The philosophy behind most structural controls is that stormwater runoff is polluted and hence must be treated for removal of pollutants. However, recently there has been acknowledgment that environmentally sensitive stormwater conveyance systems can remove pollutants from stormwater to some degree and can also enhance water quality by reducing erosion. Hence both stormwater treatment and conveyance methods are dealt with as structural controls.

BMPs can be divided as follows:-

- sediment and litter traps - designed to remove coarse particulates and trash from stormwater. Often used as a pre-treatment before the runoff drains to a more complex treatment e.g. wet basin or wetland.

- retention systems - designed to capture and store specified volume of runoff. Primary pollutant removal mechanism during storage is sedimentation.

- vegetative systems - complex biological systems, incorporating biological treatment into the pollutant removal process

- infiltration systems - runoff is drained over highly permeable soil and infiltrated to groundwater. Similar to sand filters for wastewater treatment

BMP stormwater treatment measures can be constructed on-line or off-line. An on-line BMP receives all flows through the drainage system while off-line BMPs receive only a specified maximum volume during a storm event, say, the volume of runoff contained in a one year ARI storm, or the volume of flow containing the first flush. Flows in excess of this volume bypass the BMP.

3.5.3 MULTIPLE/COMBINED SYSTEMS

The most efficient methods of enhancing stormwater quality involve implementing a system of a number of different best management practices. Combined systems are advantageous in that they can overcome the limitations of individual BMPs in order to optimise pollutant removal.

As mentioned in Section 3.5.0 of the Design Standards for Stormwater Drainage, swales and vegetated channels need to be used in conjunction with other BMPs to adequately enhance stormwater quality. Gross pollutant traps (GPTs) are often placed at the upstream end of a wet basin or wetland to remove large quantities of coarse sediment.

Schueler (1992) listed three potential combinations of pond systems:-

- extended detention basin and wet basin
- extended detention basin and wetland
- wet basin followed by a wetland

All of these systems utilise sedimentation as the first pollutant removal mechanism to remove particulates, followed by biological treatment to remove soluble pollutants.

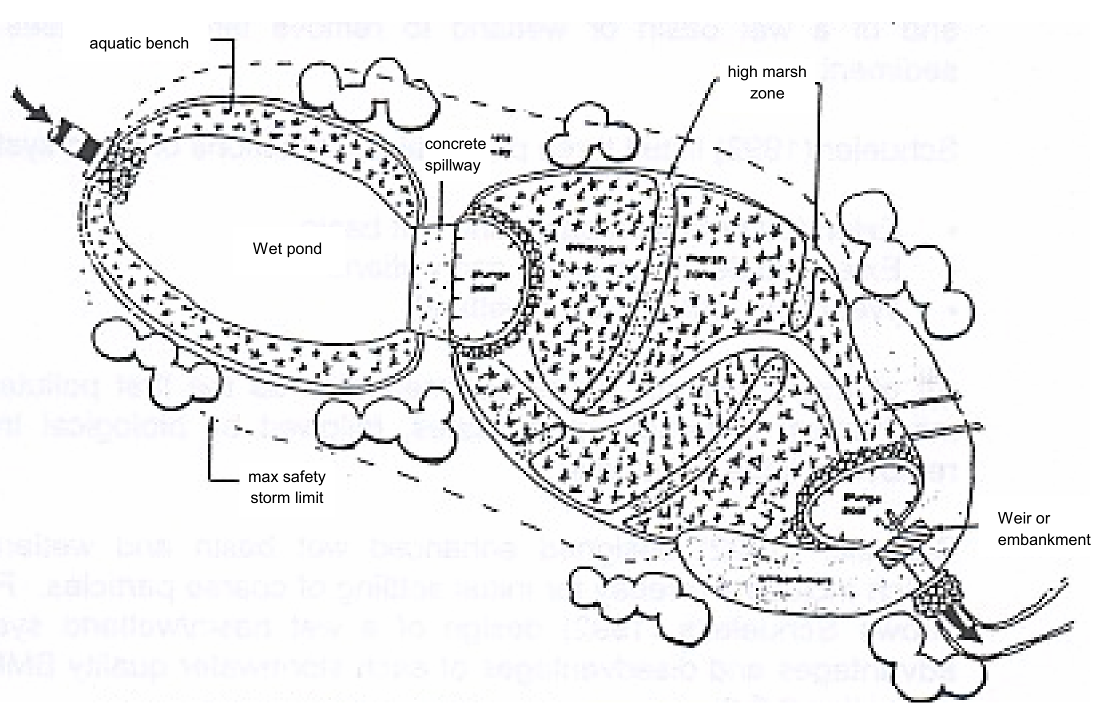
Schueler (1992) designed enhanced wet basin and wetland systems which include a fore-bay for initial settling of coarse particles. Figure 3.5.1 shows Schueler's (1992) design of a wet basin/wetland system. The advantages and disadvantages of each stormwater quality BMP are listed in Section 3.6.0 of the Design Standards for Stormwater Drainage.

Canberra has a sophisticated system of stormwater treatment measures. Urban streams flow through GPTs and pollution control ponds into large artificial lakes. The series of stormwater treatment measures trap litter, suspended solids and nutrients and allow considerable detention time. Additionally, Canberra has used land capability assessment prior to development and in certain locations, grassed swales instead of concrete gutters.

The best stormwater quality management requires careful planning of the path of stormwater runoff from one end of the catchment to the other. For example, stormwater could be carried to a drainage line via a filter strip and the waterway corridor itself could consist of a grassed swale or a vegetated channel. Draining the runoff into a wet basin for removal of particulates followed by a wetland to enhance removal of soluble pollutants would provide the major source for stormwater quality treatment. From the wetland, water could be drained through a natural creek, thus minimising downstream erosion.

It is preferable to treat stormwater runoff as far upstream in the channel as possible. That is, a small treatment device in each tributary is preferable to one large treatment device at the downstream end of the creek. Treating the runoff as far upstream as possible preserves the environmental values of more stream reach.

To achieve an efficient stormwater treatment system of BMPs, careful planning and design of the entire catchment system is required.



WET BASIN / WETLAND SYSTEM (AFTER SCHUELER, 1992)

Figure 3.5.1

3.6.0 SUMMARY OF USES AND LIMITATIONS OF BMPS

Selection of BMPs for water quality enhancement will depend upon site characteristics, i.e. topography, rainfall patterns, soil types, present and future land use and the environmental value of the receiving water.

To assist in the selection of an appropriate BMP this section provides a description of best management practices, giving a summary of the applications/functions, design considerations, variations/alternatives, advantages and disadvantages, maintenance and performance information for each structural BMP identified.

The information contained in this section was obtained from a review of the stormwater quality BMPs used elsewhere in Australia and overseas. These results can be used to guide development of BMP guidelines specifically for the Pine Rivers Shire region.

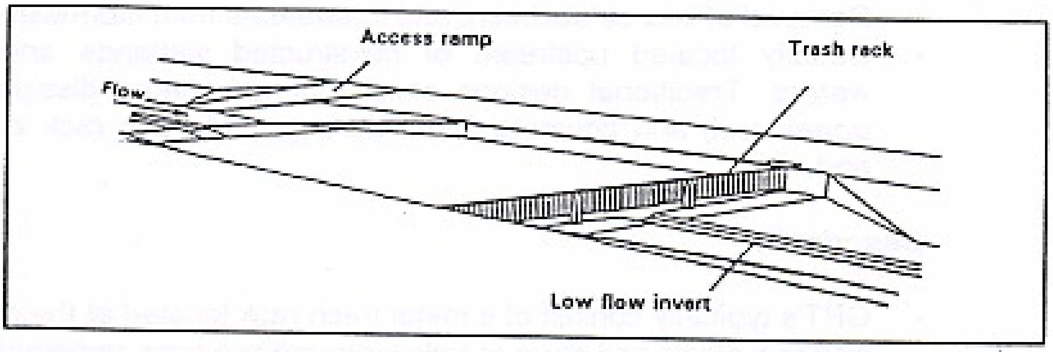
3.6.1 SEDIMENT AND LITTER TRAPS

A. Gross Pollutant Traps (GPTs)

- **Application/Function**
  - Removal of coarse sediment and litter/debris from stormwater runoff.
  - Usually located upstream of constructed wetlands and receiving waters. Traditional designs consist of an energy dissipater at the upper end, and concrete sediment trap and trash rack at the lower end.

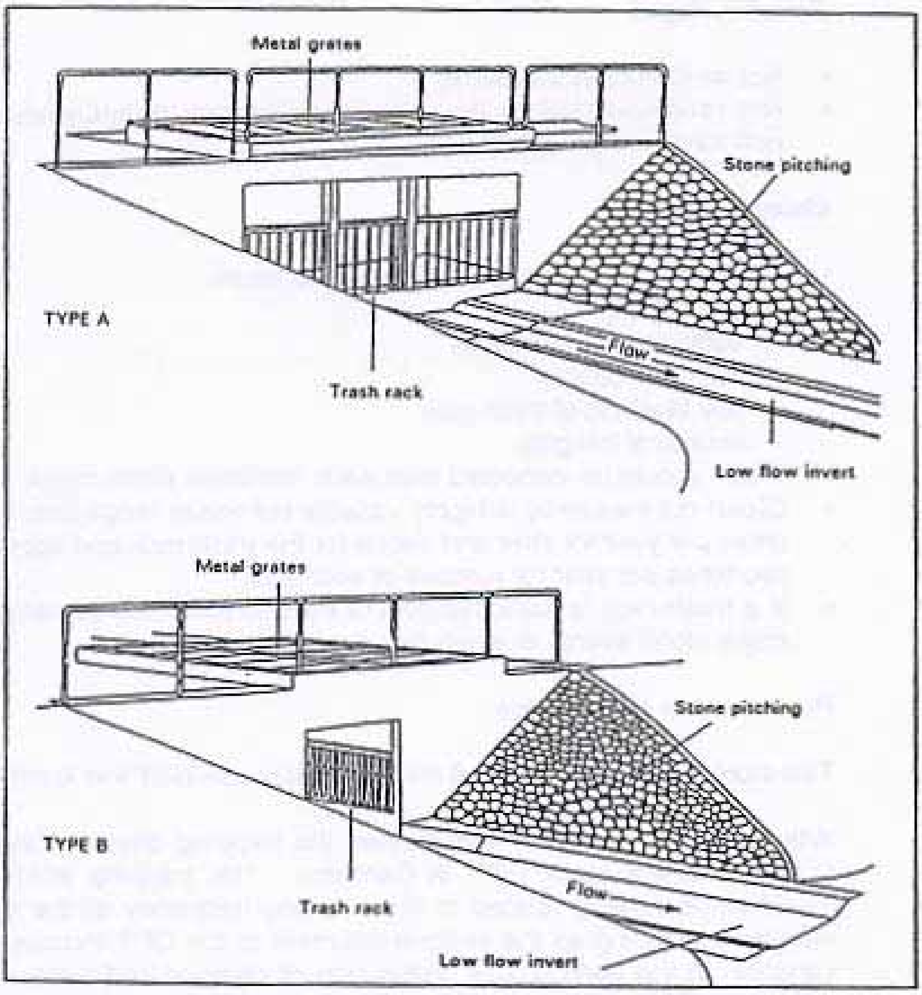
- **Description**
  - GPTs typically consist of a metal trash rack located at the downstream end of a single cell open or below ground concrete sediment trap.
  - GPTs can be classified as major or minor:-
    - often located at the upstream end of a receiving water body, or in a position to provide protection to a wet basin or wetland
    - major - located on major flood ways and waterways to intercept medium to high flows (see Figure 3.6.1)
    - minor - enclosed GPTs can be located at heads of major flood ways and/or where stormwater discharges into flood ways or water bodies (see Figure 3.6.2)

- **Design Considerations**
  - Catchment area greater than 5 ha.
  - Feasible serving catchments up to 100 ha.
  - Capture of 70% of grain sizes greater than or equal to 0.04 mm (ACT Government, 1992).
  - Need to ensure peak flow velocities are less than 0.3 m/s in the one year ARI storm event.
  - Need to take into account any backwater effect from a blocked trash rack.
  - Provide capacity for at least six months deposition of sediment.
  - The structure should have sufficient capacity and stability to discharge the inlet flow with the trash rack blocked.



SCHEMATIC OF A MINOR GROSS POLLUTANT TRAP
(SOURCE: PHILLIPS, 1992 QUOTED IN ACT GOVERNMENT, 1994)

Figure 3.6.1



SCHEMATIC OF MAJOR GROSS POLLUTANT TRAP
(SOURCE: PHILLIPS, 1992 QUOTED IN ACT GOVERNMENT, 1994)

Figure 3.6.2

- **Variations/Alternatives**
  - Above or below ground.
  - With or without trash rack.

- **Advantages**
  - Removal of coarse sediment and associated pollutants.
  - Removal of litter and debris.
  - Below ground GPTs are not obtrusive to landscape.

- **Disadvantages**
  - Not aesthetically appealing.
  - Not recommended for the removal of fine gravel particulates, soluble pollutants or hydrocarbons.

- **Maintenance**
  - Removal of accumulated sediment and debris.
  - Inspections for:-
    - sediment accumulation
    - litter and debris
    - any blocking of trash rack
    - structural integrity
  - Traps should be inspected after each moderate storm event.
  - Clean out frequently is highly variable but would range from five to ten times per year for litter and debris for the trash rack and approximately two times per year for removal of sediment.
  - If a trash rack is used, removal of trapped litter may be required after major storm events or every few weeks.

- **Performance Information**

  Two studies have investigated the performance of GPTs in Australia.

  Whytecross et al (1989) investigated the trapping characteristics of the Sullivans Creek major GPT in Canberra. The trapping efficiency was found to be heavily related to the cleaning frequency of the GPT, with efficiency reducing as the sediment content of the GPT increased. Little variation in the particle size distribution of retained sediment was noted within the GPT, with over 70% of the sediment being silt fraction. The trapping of total phosphorous (TP) and total Kjeldahl nitrogen (TKN) was relatively poor, comprising only 0.1 and 0.6% respectively of the total sediment load within the trap. The sediments were, however, anaerobic, with a high potential to release adsorbed orthophosphate. The carbon content of the retained sediments was 12%, although the heavy metal content was found to be insignificant. Water quality (primarily TP and ammonia) within the GPT was relatively poor, primarily due to the microbial decomposition of organic matter.

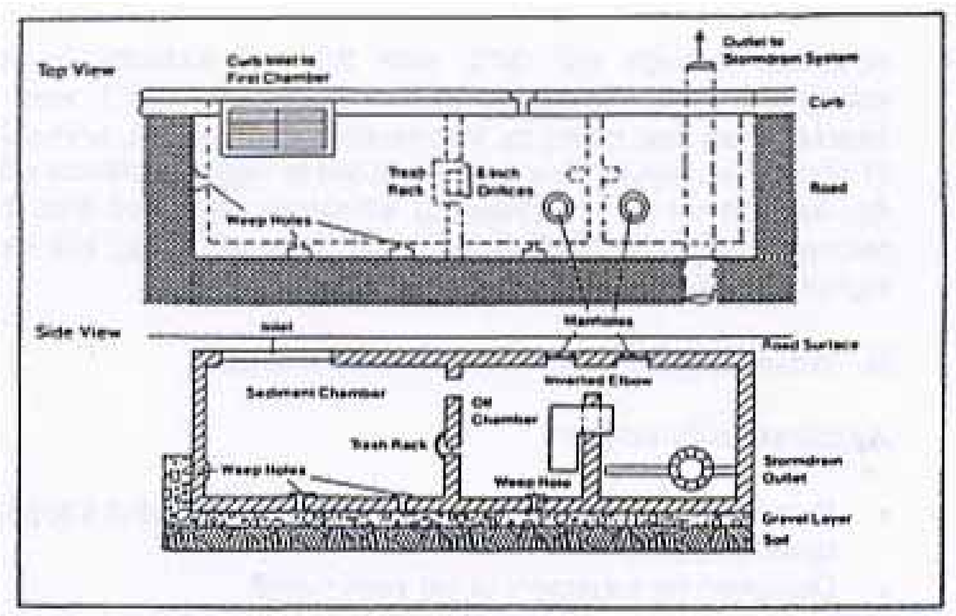
  The study of a minor GPT in Armidale was reported by Southcott (1995). Limited monitoring during dry weather conditions upstream and downstream of the GPT indicated that a small reduction in nitrate, orthophosphate and biological oxygen demand (BOD) concentrations occurred through the GPT, with SS and turbidity levels increasing marginally. The sediment trapped within the GPT was considerably coarser than that noted by Whytecross et al (1989), primarily comprising of gravel and sand. This was attributed to high turbulence within the GPT. An experiment on the trapping efficiency indicated that the efficiency decreased with increasing flow and for finer soils, but increased with higher sediment loads.

B. Water Quality Inlets - Oil/Grit Separators

- **Application/Function**
  - Removal of coarse sediment, litter and debris, and trapping of oils and hydrocarbons.
  - Designed for treatment of car park runoff.

- **Description**
  - A two or three cell underground concrete structure, a modified version of a gravity settling tank, located within the pipe drainage system (see Figure 3.6.3).
  - The first cell contains a permanent pool of water 1-1.15 m deep. This cell is used for gravity settling of grit and sediments.
  - The second cell also holds a permanent pool of water. An inverted pipe elbow leads to the third chamber which regulates water levels in the structure. The opening of the inverted pipe is below water level - this prevents clogging and traps oil in the second cell. Oil remains in the second cell until gradually adsorbed by sediment particles and settle out.
  - The third cell forms the opening to a storm outlet pipe.

- **Design Considerations**
  - Catchment area typically less than 0.4 ha (Whelans, 1993).
  - The volume of the permanent pool should be maximised. At least 27 m^3/ha impervious catchment is suggested as an initial sizing rule (Schueler, 1987).
  - Pool depth 1-1.15 m.
  - Need dry storage above permanent pool to cater for design storm.
  - An inverted pipe with a 90 degree elbow should connect the second and third chambers of the inlet.
  - Should be designed to pass the two year design storm without hydraulic interference.



SCHEMATIC OF AN OIL/GRIT SEPARATOR (SOURCE: SCHUELER, 1987)

Figure 3.6.3

- **Variations/Alternatives**
  - A trash rack between the first and second cells to trap litter and debris and prevent the orifice joining the first and second cells blocking.
  - Instead of a permanent pool, runoff drains through a series of weep holes situated on the flood in each chamber, then through a layer of stone aggregate, eventually infiltrating into the subsoil. The first and second cells fill up only temporarily during storms and then should drain completely. Pollutant removal is enhanced through infiltration. If the structure became clogged it would act in a manner similar to the conventional inlet.
  - Vertical baffle plates on floor may help alleviate any problems with resuspending of sediment.
  - Can be used as a pre-treatment before other stormwater treatment device.
  - An alternative design for silt arrestors which can collect oil, silt or both is detailed in Australian Standard AS3500-1990.

- **Advantages**
  - Unobtrusive since totally below ground.
  - Compatible with drainage network.
  - Easy access.
  - Pre-treatment before entering other stormwater treatment measures.

- **Disadvantages**
  - Limited stormwater and pollutant removal capabilities. Not recommended for removal of fine particulates or soluble pollutants.
  - Frequent clean outs required.
  - Possible difficulties disposing of sediment if sediment is contaminated for example, by hydrocarbons.
  - Possibility of groundwater contamination with infiltration system.
  - Not suitable for large areas.
  - Possibility of build up of gases and flammability.
  - Turbulence of stormwater entering cells can resuspend particulates or entrain floating oil in outgoing stream.
  - Ineffective for erosion or flood control.
  - Potential for mosquito breeding.

- **Maintenance**
  - Must be cleaned out at least twice a year by vacuum pumping or siphoning of the permanent pool, and manual removal of sediments.
  - Accumulated sediment deposits should be disposed of in an approved landfill area. Some additional treatment of waste may be required.
  - To facilitate maintenance, there should be access to each cell by an appropriate access hole.

- **Performance Information**
  - Since runoff is only briefly retained in the inlets, only moderate removal of coarse sediment, oil/grease and debris can be expected (Schueler, 1987). The inlets mostly trap coarse-grained sediments and some hydrocarbons.

C. Litter/Trash Traps

- **Application/Function**
  - Removal of coarse sediment and litter by a device which is integrated into the drainage system.

- **Description**
  - A trash rack and pit incorporated in the drainage system at the kerb inlet, the downstream base of the drainage system or at the end of large headwalls.

- **Design Considerations**
  - Should not compromise efficiency of drainage system.
  - Catchment area not exceeding 5 ha.

- **Variations/Alternatives**
  - A litter basket at the bottom of a large drop pit, a trash rack is provided at the downstream base of the sediment trap to minimise overflows of litter. The litter baskets are designed to be removed by a conventional council truck fitted with a crane. This has been used in North Sydney (Brownlee, 1995).
  - A trash rack and sediment trap can be installed at kerb inlets to treat incoming runoff. Litter baskets placed below grated inlets can be easily removed for cleaning.
  - Trash racks have been installed at the end of large head walls. The trash rack base is located at a level lower than the invert of the drainage pipe, with the top of the rack being constructed at a point approximately half way up the pipe.
  - Provide figures/diagrams indicating acceptable solution for both trash rack/sediment basin and litter baskets.

- **Advantages**
  - Unobtrusive.
  - Easily maintained.
  - Integrated part of drainage network.
  - Easily incorporated into existing drainage network.

- **Disadvantages**
  - Since not highly visible, maintenance may be neglected.
  - No removal of fine particulate or soluble pollutants.
  - If blocked, has potential to cause failure of drainage system.

- **Maintenance**
  - Removal of accumulated sediment.
  - Removal of accumulated litter and debris.
  - Litter traps will need to be cleaned out about three to four times a year, but this will depend on the size of the trap. Traps should be checked and if necessary cleaned out after large storm events.

- **Performance Information**
  - GPTs provided with trash racks at the downstream end are the most commonly used litter traps in Australia. Litter traps are not widely used in the USA or Europe at this stage.

D. Pollute Continuous Deflective Separation (CDS)

- **Application/Function**
  - Removal of litter and coarse sediments.

- **Description**
  - See Figure 3.6.4.
  - An on-line unit consisting of a stainless steel perforated and deformed separation plate placed in a hydraulically balanced separation chamber. Stormwater and pollutants are deflected away from the mainstream flow into the chamber where water is able to pass freely through the separation plate. Solid contaminants are deflected away from the plate, the deflective force along the face of the plate preventing blocking. A mild vortex action in the chamber also assists the concentration of solids away from the separation plate. Solid pollutants are retained in a centrally located solids catchment chamber.

- **Design Considerations**
  - A bypass system operates if the unit becomes overloaded.
  - The screen surface area is 40-45 times the pipe inlet area.
  - Pollute designs CDS systems on a catchment specific basis, based on site specific water quality objectives and desired design storms. For a large catchment, a number of CDS units may be used throughout the catchment. CDS is a “primary” stormwater treatment measure and as such is best used in the uppermost reaches of the catchment as is feasible and practical.

- **Advantages**
  - Unobtrusive.
  - Self-cleansing, non-blocking.
  - Low maintenance due to absence of moving parts.
  - Ease of sediment and litter removal.

- **Disadvantages**
  - Unproven as a BMP.
  - Does not remove fine fraction of pollutants.
  - No mitigation of stormwater volume.

- **Maintenance**
  - Inspections for:-
    - structural integrity of device
    - any blocking
    - sediment and litter accumulation
    - downstream erosion
  - Sediment and litter removal.

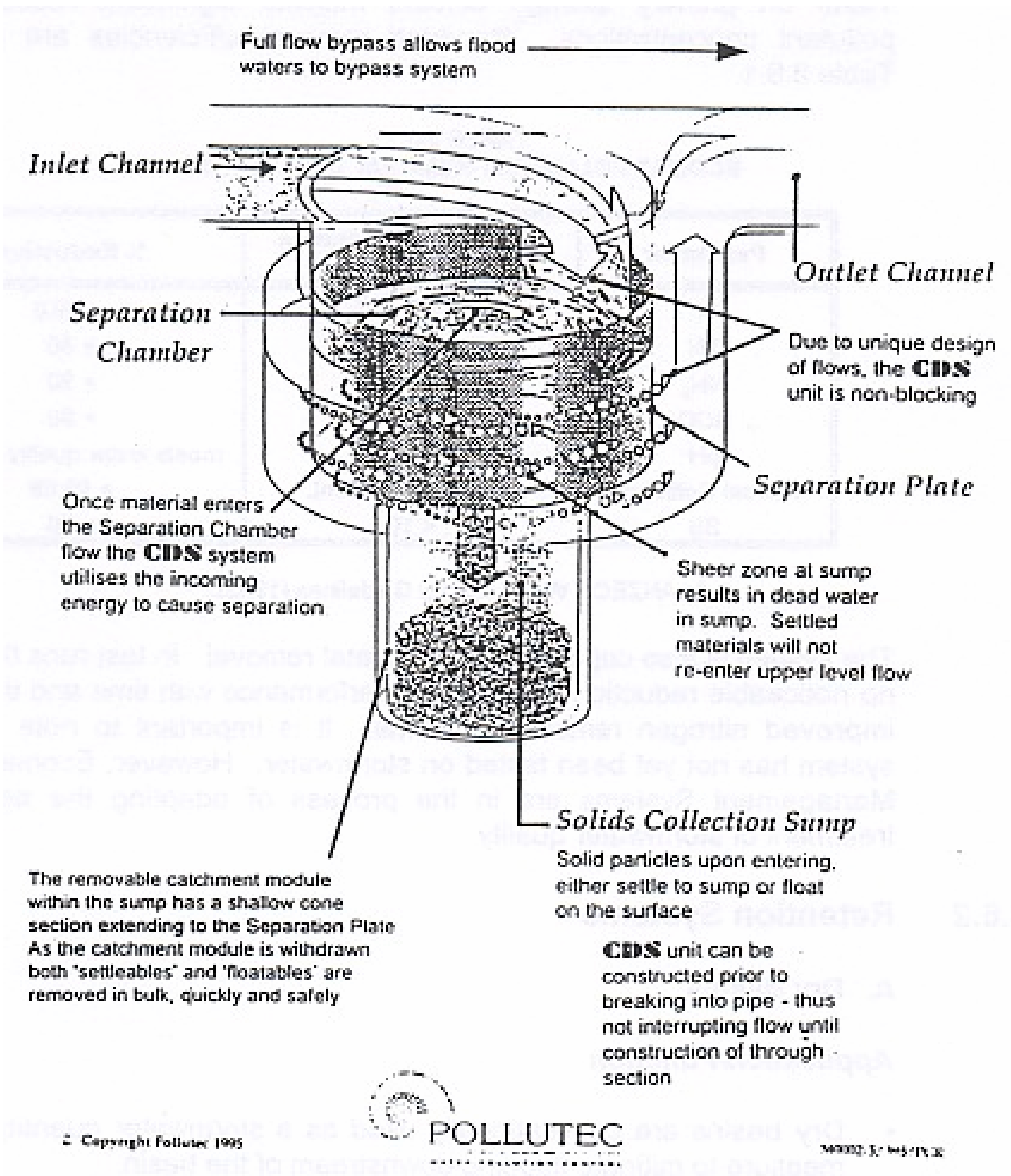
- **Performance Information**

  The pollute CDS device has only been tested as a scale model in laboratory conditions. These tests showed that the CDS unit captures 95-100% of all litter, and sediment down to 1 mm.

CDS units have been installed (Darren Blakely, pers. comm.) at the following locations:-
- Mornington Peninsula (2)
- Hoxton Park
- Mosman
- Melbourne
- Sutherland

All of these units have been designed for treatment of conventional urban stormwater runoff except for the Melbourne unit which was designed for an industrial application. This unit was designed to capture particulates down to 100µm.

Monitoring of installed Pollute CDS units will be undertaken to measure the efficiency of the units in the field. Conventional urban stormwater Pollute CDS units are designed to capture particulates down to 1 mm diameter. However, inspections of installed field units are showing removal of silt size particulates as well (Darren Blakely, pers. comm.).



FEATURES OF THE POLLUTE CDS UNIT
(SOURCE: POLLUTE CORRESPONDENCE, 1995)

Figure 3.6.4

E. Ecomax Waste Management Systems

Ecomax Waste Management Systems have developed an “amended soil” filtration media which could be used in the treatment of stormwater runoff. Tests on primary sewage effluent indicate significant reductions in pollutant concentrations. Reported removal efficiencies are given in Table 3.6.5.

Table 3.6.5

ECOMAX POLLUTANT REMOVAL EFFICIENCIES

Parameter	Outflow Concentration (mg/L)	% Reduction
TP	0.01 - 0.05	> 99.6
TN	<10	> 80
NH_3	< 5	> 90
BOD	< 10	> 90
pH	7.5 - 8.5	meets water quality criteria*
Faecal Coliforms	< 500 CFU/100 mL	> 99.99
SS	< 10	> 90

* ANZECC Water Quality Guidelines (1992)

The system is also capable of heavy metal removal. In test runs there was no noticeable reduction in treatment performance with time and there was improved nitrogen removal with time. It is important to note that this system has not yet been tested on stormwater. However, Ecomax Waste Management Systems are in the process of adapting the design for treatment of stormwater quality.

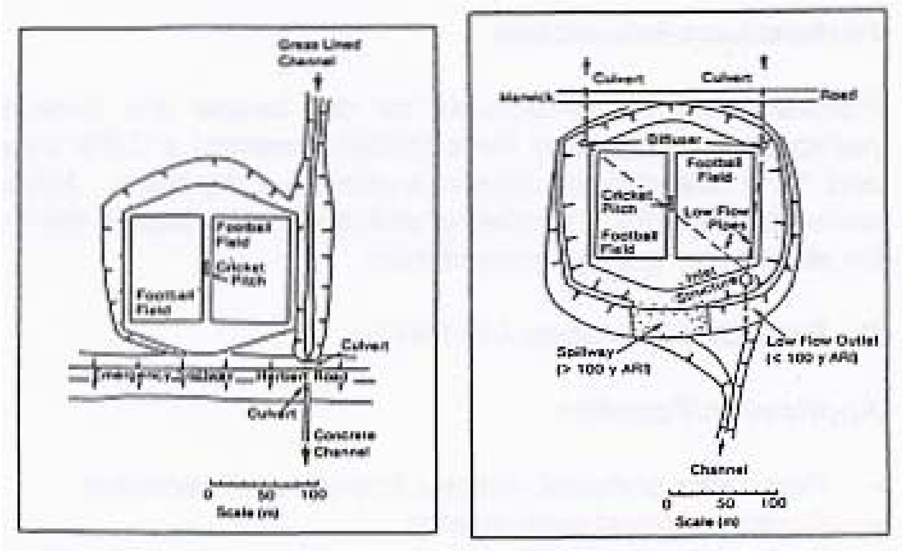
3.6.2 RETENTION SYSTEMS

A. Dry Basins

- **Application/Function**
  - Dry basins are conventionally used as a stormwater quantity control measure to mitigate flooding downstream of the basin.
  - Some degree of pollutant removal through sedimentation.
  - Reduction in downstream erosion.

- **Description**
  - Dry basins are typically designed to provide temporary storage for increased surface runoff. Stored water is subsequently released at a controlled rate. The outlet is typically located on the bottom of the basin which is designed to restrict the outflow. Dry basins are designed to empty completely between storms and are therefore dry except during storm events.
  - Figure 3.6.6 shows two layouts for dry basins which have incorporated sporting fields.

- **Design Considerations**
  - More practical and cost effective for catchments over 8 ha.
  - Sideslopes should be about 1:4 (h:v) to allow mowing.
  - Should be located at or near the lowest point of the site.



SCHEMATIC OF TWO DIFFERENT DRY BASIN LAYOUTS (PILGRIM, 1987)

Figure 3.6.6

- **Variations/Alternatives**
  - May be vegetated to increase aesthetic appeal.
  - Extended detention dry basins (Section 3.6.2(B) of the Design Standards for Stormwater Drainage).
  - Wet basins (Section 3.6.3(C) of the Design Standards for Stormwater Drainage).

- **Advantages**
  - Effective peak discharge control and stream bank erosion control.
  - Can be used for recreational purposes e.g. sporting fields if designed and maintained appropriately.

- **Disadvantages**
  - Low pollutant removal efficiency.
  - Not aesthetically appealing, no habitat value.
  - Safety hazard due to intermittent nature of flooding - may need fencing.
  - Large surface area required if a flat site.
  - Not as effective as other stormwater quality BMPs.

- **Maintenance**
  - Needs to be emptied of debris and rubbish after storm events.
  - Inspections for:-
    - integrity of spillway
    - clogging of water
    - sediment accumulation

- **Performance Information**
  - Pollutant removal efficiencies for dry basins are quite low, even for particulates. Pope and Hess (1988) observed a 2.5% suspended solids and 18% total phosphorous reduction in a dry basin. Negative removals were observed for a number of pollutants. Dry basins are not widely used for stormwater quality enhancement.

B. Extended Detention Dry Basins

- **Application/Function**
  - Particulate pollutant removal through sedimentation.
  - Controls downstream erosion.
  - Reduce frequency of occurrence of floods downstream.

- **Description**
  - Similar to dry basins but with a greater pollution reduction due to longer hydraulic residence time.
  - Retention times generally range from 6-24 hours (sometimes up to 48 hours).
  - A conventional extended detention basin is dry following the passage of a storm event.

- **Design Considerations**
  - More practical and cost effective when serving catchments over 8 ha.
  - The outlet device must be kept clean.
  - The extended detention storage volume will be designed to capture and control flood flows for a specified average recurrence interval.
  - Must be designed for a site specific detention time dependent upon rainfall characteristics and soil type. Rainfall characteristics and soil type will determine the runoff volume generated and rainfall characteristics will determine storm average recurrence intervals.
  - Sideslopes should be no steeper than 3:1 (h:v) and no flatter than 20:1 (h:v).
  - Stabilisation with riprap of the low flow channel through the upper stage of the pond is required.
  - The stream channel immediately below the pond outlet should be lined with riprap and graded to a slope of approximately 0.5% to prevent scouring during large storm events.

- **Variations/Alternatives**
  - Extended Detention Wet Basins (Section 3.6.4(B) of the Design Standards for Stormwater Drainage).
  - Buffer zone to enhance aesthetics.

- **Advantages**
  - Reduces the frequency of occurrence of erosive floods downstream.
  - Can improve local wildlife habitat if the basin is vegetated.
  - Protection of downstream habitat.
  - Can be applied in most new development situations.
  - Can be used as recreation area.

- **Disadvantages**
  - Highly variable pollutant removal capabilities - low soluble pollutant removal capabilities.
  - Not aesthetically attractive, can include presence of odour, debris and weeds.
  - Will not function correctly if outlet device becomes blocked or if the base becomes clogged.
  - Significant land consumption.
  - Safety hazard if banks are steep - may require fencing.
  - Not as effective as other stormwater quality BMPs.
  - Risk of resuspending previously deposited materials.

- **Maintenance**
  - An access track is required for maintenance.
  - Moderate to high maintenance requirements.
  - Mowing and if necessary microphyte harvesting.
  - Regular inspections for:-
    - structural stability of basin
    - clogging of outlet and accumulation of sediment around riser
    - upstream and downstream erosion
    - subsidence
    - cracking or tree growth on embankment
    - modifications to pond and/or catchment that may alter basin performance
    - sediment build up in basin
  - The findings of the inspections will determine appropriate maintenance measures.
  - Clogging of basin floor (evident through any long term ponding).

- **Performance Information**

  The primary pollutant removal mechanism in these basins is sedimentation which is dependent on detention time and the proportion of annual runoff that is effectively detained within the basin (Schueler, 1987). Extended detention basins are relatively efficient at removing particulates. Schueler et al (1992) quoted suspended solid removal efficiencies of 14-87% with an average of 70%. The removal rates for nutrients were generally lower, 13-66% for TP and 10-35% for TN. The removal efficiency for soluble nutrients is relatively low and has in some cases been reported as negative.

  Galli (1992) in a study of extended detention basins in Maryland reported that while few extended detention dry basins have totally failed, many do not operate as designed. Some extended detention dry basins become clogged and are transformed to de facto wet ponds, and a majority do not achieve target detention times.

C. Wet Basins

- **Application/Function**
  - Permanent pool of water to allow time for settling of pollutants and biological uptake of pollutants by fringing microphytes.
  - Some degree of flood mitigation.
  - Reduction of downstream erosion.

- **Description**
  - See Figure 3.6.7
  - A small dam holding a permanent pool of water.
  - In theory, the incoming storm runoff displaces "old water" and is stored until the next storm.
  - Pollutant mechanism is primarily sedimentation. However, depending on design, there may be some degree of biological uptake and filtration by vegetation.

- **Design Considerations**
  - A catchment area greater than 4 ha.
  - Cannot be placed on steep unstable slopes.
  - Basin size is dependent upon rainfall characteristics and soil type at site.
  - Short-circuiting can be largely prevented by maximising the distance between basin inlet and outlet. A minimum length to width ratio of 3:1 is recommended. Additionally, energy dissipaters and entrance berms at the inlet will help reduce short-circuiting.
  - Shallow ponds have higher removal efficiencies than deeper ones. However, extremely shallow ponds may be prone to resuspending problems. Basin depth should be about 1-2 m.
  - Sideslopes no greater than 3:1 (h:v).
  - The stream channel immediately below the basin outlet should be lined with riprap to prevent scouring and have a slope close to 0.5%.
  - Invert levels for all inlet pipes should be set to discharge at or below the surface of the permanent pool.

- **Variations/Alternatives**
  - Installation of a forebay to trap incoming sediments close to the inlet.
  - Fringing microphytes to enhance pollutant removal and wildlife habitat and reduce shoreline erosion.
  - Buffer strip to enhance habitat value and aesthetic appeal.
  - Variation in basin depth to enhance habitat value.
  - Thermal discharges may be alleviated by designing risers to withdraw water from the bottom of the basin.
  - Aerators or fountains can be installed to maintain dissolved oxygen levels.
  - A riprap cascade can be incorporated into the basin outfall for enhanced aeration.
  - Inclusion of extended detention to reduce peak flood flows.
  - Extended detention wet basins (Section 3.6.2(D) of the Design Standards for Stormwater Drainage).
  - Enhancement of water quality within wet basin by dosing with gypsum or alum.

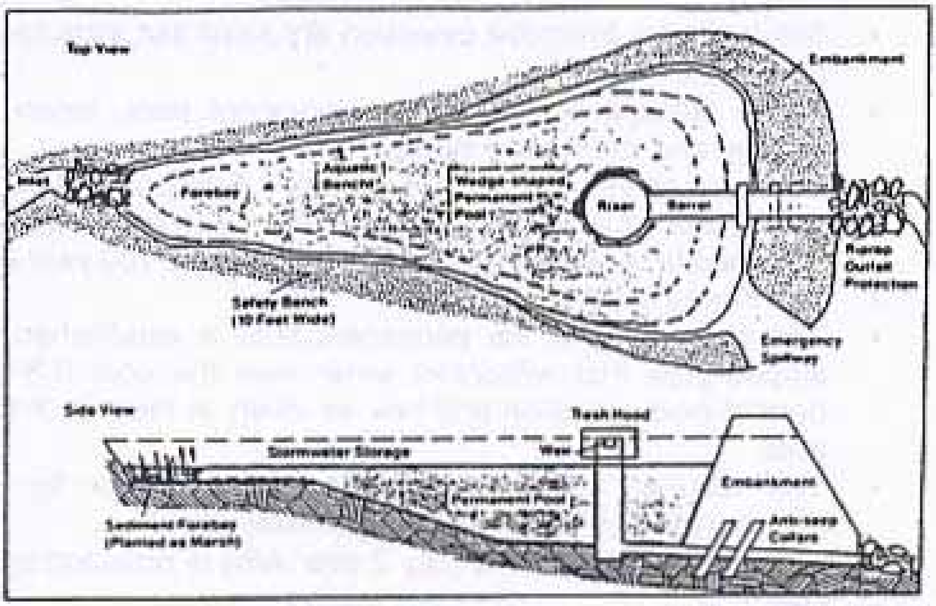
- **Advantages**
  - High to moderate pollutant removal capability for both particulate and soluble pollutants.
  - Some level of flood mitigation.
  - If properly sized and maintained, wet ponds can achieve a high removal rate of sediment, biological oxygen demand, organic nutrients and heavy metals.
  - Biological processes remove soluble nutrients.
  - Creation of local wildlife habitat, higher property values, recreation and landscape amenities.

- **Disadvantages**
  - Possible upstream and downstream habitat degradation.
  - Potential safety hazards.
  - Occasional nuisance problems e.g. odour, algae and debris.
  - Possibility of mosquito breeding.
  - Barrier to fish migration.

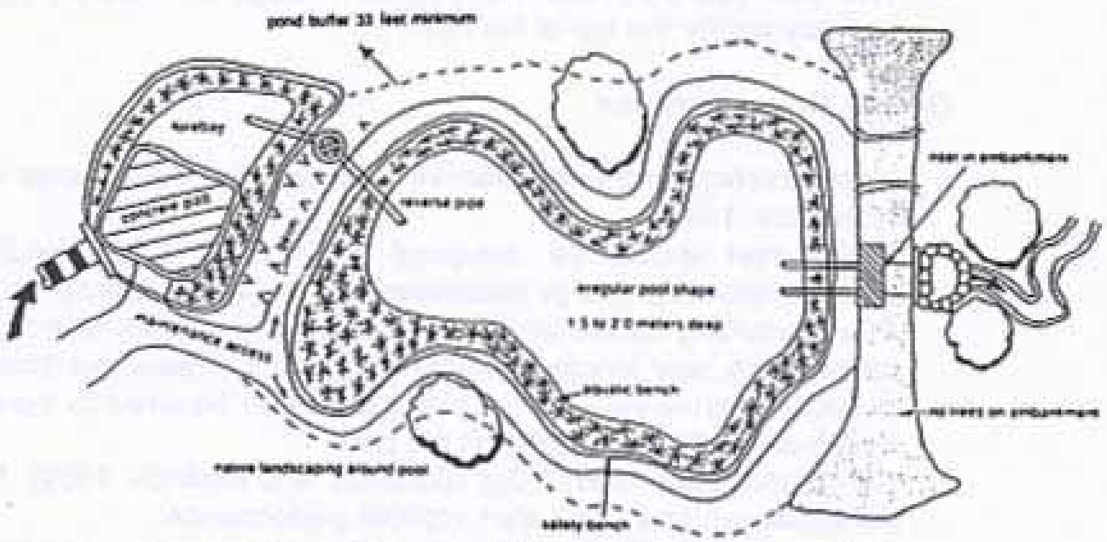
- **Maintenance**
  - Moderate to high maintenance requirement.
  - Mowing and, if necessary, harvesting of microphytes.
  - Regular inspections for:-
    - structural stability of basin
    - outlet performance
    - upstream and downstream erosion
    - weed infestation
    - subsidence
    - cracking or tree growth on embankment
    - condition of emergency spillway
    - alterations to basin and/or catchment that may alter pond performance
    - sediment build-up in basin
  - The findings of the inspections will determine appropriate maintenance measures
  - Sediment can be removed from pond by either dredging the basin (which causes some resuspending of settled particles) or by draining the basin and excavating the sediment.

- **Performance Information**

  Wet basins achieve pollutant reduction by a combination of sedimentation, algal settling, biological uptake and bacterial decomposition (Yousef et al, 1990). Schueler (1992) reported SS removals of 50-90% and TP removals of 30-90%. Soluble nutrients can also be removed at an average rate of 40-80%. Heavy metals, bacteria and organic matter can also be retained in these basins. Wet basins are the most commonly used stormwater treatment measure in Australia to date, with relatively wide use in Canberra and Sydney.



SCHEMATIC OF
(A) A CONVENTIONAL WET BASIN
(SOURCE: SCHUELER, 1987)



SCHEMATIC OF
(B) AN ENHANCED WET BASIN
(SOURCE: SCHUELER ET AL, 1992)

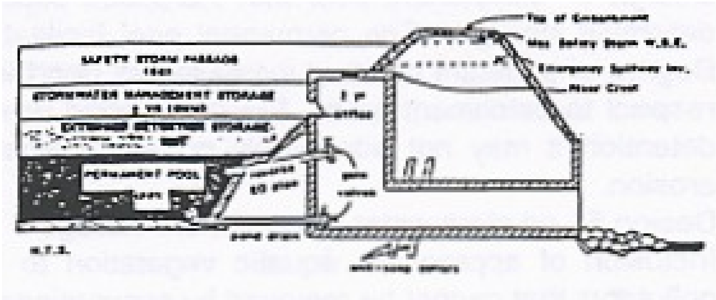
Figure 3.6.7

D. Extended Detention Wet Basins

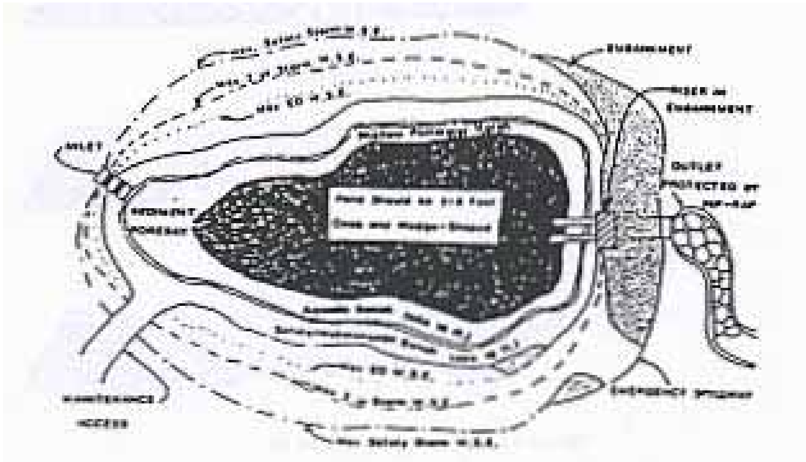
- **Application/Function**
  - Particulate and some degree of soluble pollutant removal.
  - Control of downstream erosion.
  - Reduction of frequency of occurrence of floods downstream.

- **Description**
  - Similar to an extended detention dry basin but includes a permanent pool at the outlet.
  - Three storage elements - a permanent pool, extended detention storage and stormwater storage.
  - The permanent pool and the extended detention volume are sized for stormwater quality treatment. The stormwater storage volume is designed to retard the design flood event (say 100 year ARI flood).
  - See Figure 3.6.8
  - The water level in the permanent pool is established by a reverse sloped pipe that withdraws water from the pool 0.3 - 1 m below the normal pool elevation and has an invert at the top of the permanent pool.
  - The required extended detention release rate for the pond is determined by the reverse pipe diameter.
  - Control of larger storms (say two year ARI) is provided by a weir in the riser.
  - The 100 year ARI storm is passed through an earthen emergency spillway and/or the top of the riser.

- **Design Considerations**
  - More practical and cost effective when serving catchments over 8 ha (Whelans, 1993).
  - Basin inlet should be designed to minimise short-circuiting and resuspending e.g. energy dissipaters and entrance berms.
  - Short-circuiting can be avoided by making the pool as long and narrow as possible, say length to width ratio of 3:1 (measured from inlet to outlet). Alternatively, berms and baffles can be used to increase the length of the flow path through the pool.
  - Permanent pool depth 1-2 m (Schueler and Helfrich, 1989), however, perimeter wetland areas also improve performance.
  - A shallow basin with maximum surface area performs better than a deep basin with the same volume.
  - Set base of pond at least 1 m above bedrock or water table.
  - Extended detention storage should be designed to drain in one to two days.



Cross-section of the Extended Detention Pond System

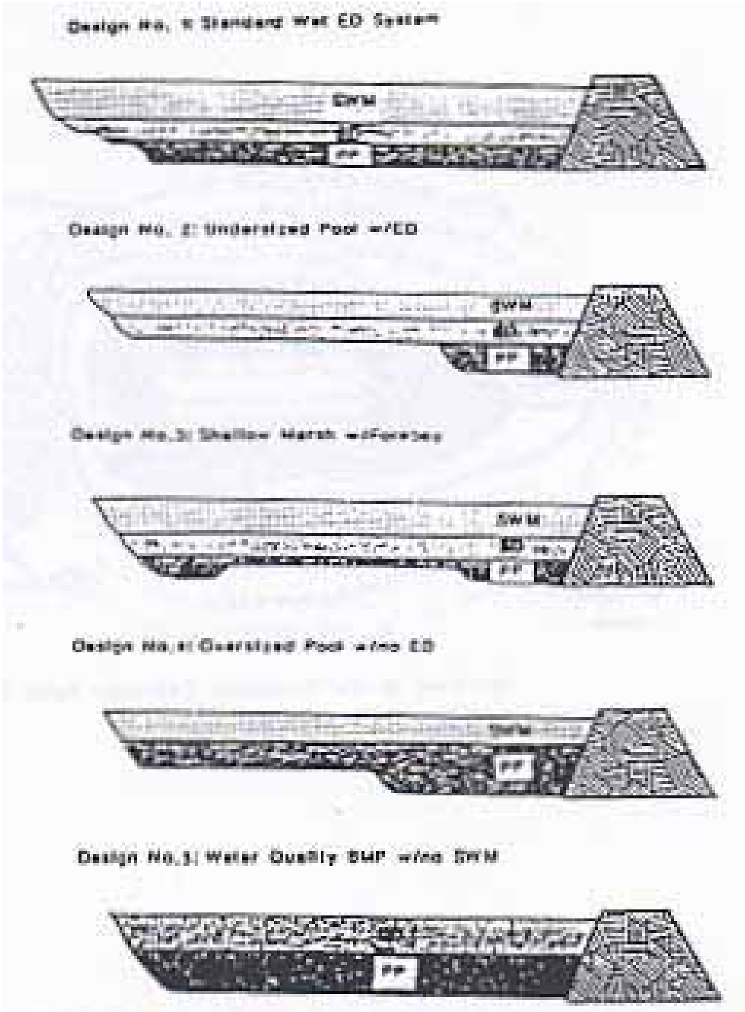


Plan View of the Extended Detention Pond System

SCHEMATIC OF TYPICAL EXTENDED DETENTION WET BASIN
(AFTER SCHUELER AND HELFRICH, 1989)

Figure 3.6.8

- **Variations/Alternatives**
  - See Figure 3.6.9
  - An enhancement of the wet basin.
  - Design 2 - permanent pool sharply reduced in size so that it acts only as a storage area for deposited sediments and a means of keeping the drainage pipe clear. This design relies on extended detention for removal of particulate pollutants.
  - Design 3 - permanent pool replaced by a wetland area.
  - Design 4 - permanent pool with increased capacity but no extended detention storage. The permanent pool facilitates pollutant removal. Degree of pollutant removal increases as pond volume increases with respect to catchment area. Since the pond does not have extended detention it may not adequately protect downstream channels from erosion.
  - Design 5 - no stormwater management storage.
  - Inclusion of appropriate aquatic vegetation to help remove soluble pollutants that cannot be removed by conventional settling.



ALTERNATIVE EXTENDED DETENTION WET BASIN DESIGNS
(SOURCE: SCHUELER AND HELFRICH, 1989)

Figure 3.6.9

- **Advantages**
  - Some removal of soluble pollutants as well as removal of particulate pollutants.
  - Multipurpose i.e. stormwater quality and quantity management.
  - Aesthetic and recreational value.
  - Habitat value.
  - Protection of downstream habitat.
  - Reduces the frequency of erosive floods downstream.

- **Disadvantages**
  - Potential for nuisance problems e.g. odour, debris, weeds, mosquitoes.
  - Potential for blockage of outlet structure.
  - Significant land consumption (however less land consumption than if water quantity and quality were treated separately).
  - Safety hazard if side slopes are too steep - may require fencing.

- **Maintenance**
  - An access track is required for maintenance.
  - Moderate to high maintenance requirements.
  - Mowing and, if necessary, microphyte harvesting.
  - Regular inspections for:-
    - structural integrity of basin
    - clogging of outlet and accumulation of sediment around riser
    - upstream and downstream erosion
    - subsidence
    - cracking or tree growth on embankment
    - modifications to pond and/or catchment that may alter performance
    - sediment build-up in basin
  - Findings of inspections will determine appropriate maintenance measures.
  - Sediment can be removed from pond by draining the pond and excavating the sediment.

- **Performance Information**

  In the extended detention storage the prime pollutant removal mechanism is sedimentation. In the permanent pool, in addition to sedimentation, pollutants can be removed by biological uptake through basin vegetation. Hence, extended detention wet basins are able to remove soluble pollutants as well as particulate pollutants. Pollutant removal efficiencies are expected to be similar to, if not higher than, the wet basin removal efficiencies.

3.6.3 VEGETATIVE SYSTEMS

A. Buffer Zones

- **Application/Function**
  - A buffer zone between receiving water and the polluting urban area.
  - Provides some chance for sedimentation of coarse particulates, filtration and some degree of biological uptake.
  - Chance for some degree of infiltration.
  - In many cases buffer zones can provide storage for flood and pollution control.

- **Description**
  - In an urban context, buffer zones are usually parks along a stream, lake or adjacent to the drainage system.
  - The riparian zone provides a buffer zone between land use and watercourses. Riparian vegetation constitutes a natural filter against non-point source pollution.

- **Design Considerations**
  - Effectiveness is dependent upon zone width. A minimum width of approximately 20 m is recommended.
  - Buffer zones lose efficiency if drainage outlet bypasses the grassed and vegetated areas and discharges directly to receiving water. To counter this problem, level spreaders at outlet points may be required. Catchment areas for level spreaders are limited to around 0.5 ha.
  - Use of native vegetation is preferential.
  - Pollutant removal efficiency increases with vegetative ground cover.

- **Variations/Alternatives**
  - Buffer zones can be incorporated into the floodplain area.

- **Advantages**
  - Removal of coarse sediment and some degree of biological uptake of soluble pollutants.
  - Reduces peak flows.
  - Reduces runoff volume.
  - Aesthetically appealing.
  - Potential to provide important habitat corridor.
  - Recreational purposes.
  - Enhances stream bank stabilisation, reduces channel erosion.
  - Effective in maintaining water temperature.

- **Disadvantages**
  - Large land area required.
  - Ineffective for peak flow control during large events.

- **Maintenance**
  - The degree of maintenance required will be dependent upon the desired aesthetics of the buffer zone.
  - Inspections should be carried out for:-
    - weeds
    - erosion
    - any stagnant pools which may be conducive to mosquito breeding
    - condition of vegetation
    - structural integrity and effectiveness of level spreaders
    - any channels developing through buffer zone
  - Maintenance required will be determined by outcome of inspections.

- **Performance Information**

  Riparian buffer zones have not been widely studied in Australia to evaluate pollutant and sediment removal. However, there are a number of monitoring programs currently underway.

  Riparian buffer zone effectiveness is significantly dependent upon zone width. A minimum width of vegetation is necessary for the sustainability of ecosystems and processes.

  Buffer zones lose efficiency if the storm drainage outlet bypasses the grassed and vegetated areas and discharges directly to the receiving water or into a channel with concentrated flows.

  Woodard (1989) studied buffer zone pollutant removal efficiency of a strip of mixed growth, uneven age stand, predominantly hardwood, moderate ground cover of shrubs and ferns in Maine, USA. Similar measurements were made by Potts and Bai (1989) in Florida. It was found that the critical distance of a grass strip, used for the control of suspended solids and phosphates from residential developments was 22.5 m. Additionally it was found that the efficiency of the buffer zones is highly dependent on a sufficient groundcover of vegetation.

B. Filter Strips

- **Application/Function**
  - Pollutant removal by sedimentation of coarse particles, filtration by vegetation, infiltration and biological uptake.
  - Some degree of groundwater recharge.

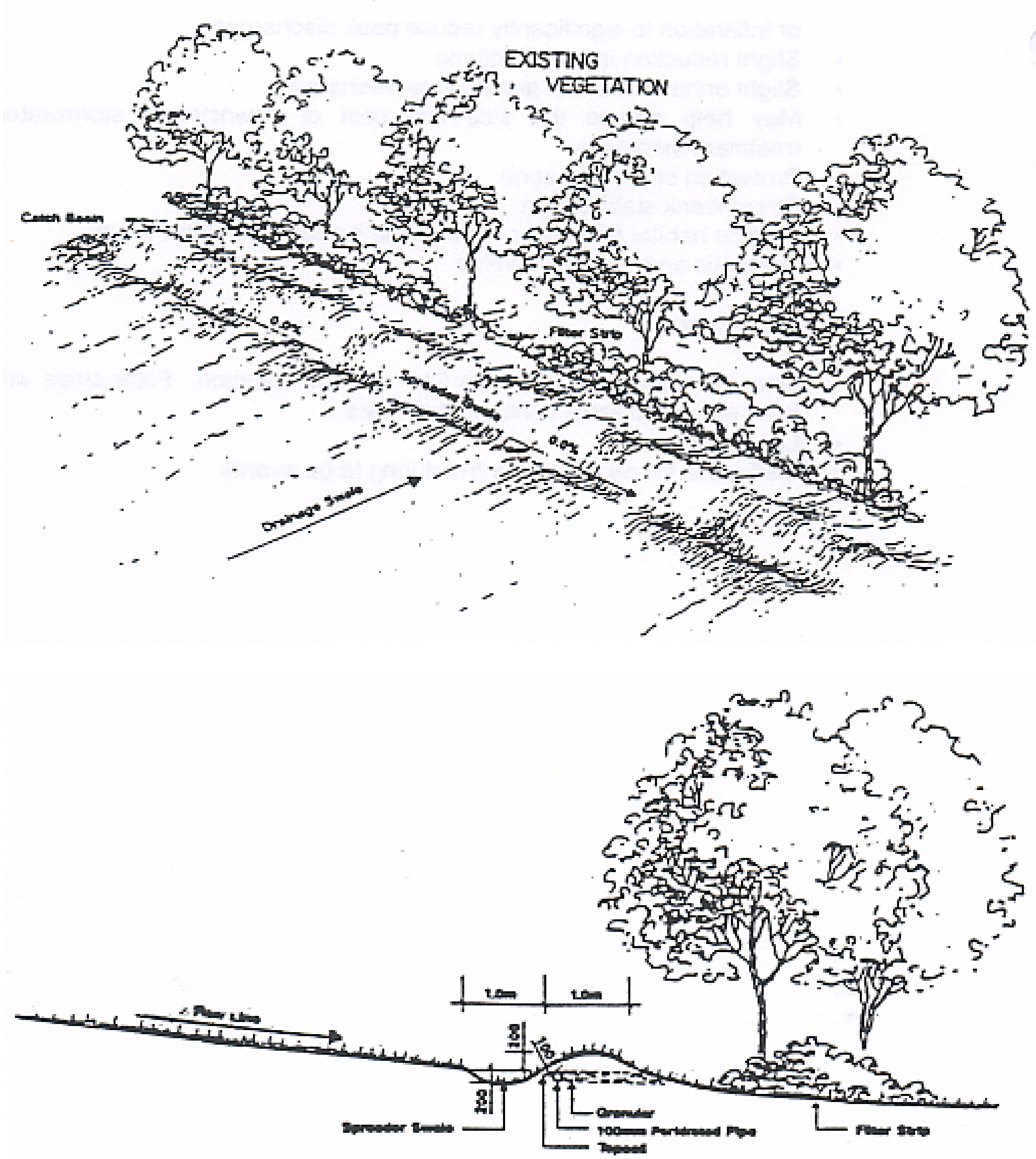
- **Description**
  - Filter strips are designed to accept overland sheet flow. Runoff from an adjacent impervious area must be evenly distributed across the filter strips.
  - Filter strips have a vegetative ground cover. The type and amount of vegetation varies from site to site.
  - Eventually drains to receiving water e.g. creek.
  - See Figure 3.6.10

- **Design Considerations**
  - To prevent concentrated flows forming, each filter strip should serve a contributing area of less than 2 ha (Whelans, 1993).
  - Each filter strip should serve a contributing area of 10 ha or less (Schueler, 1987).
  - Existing vegetation should be incorporated into design where possible.
  - Must be densely vegetated with a mix of moisture resistant native plant species that effectively bind the soil.
  - A slope of 5% or less graded uniformly and evenly.
  - Filter strips should have a width of approximately 20 m.
  - Top edge of filter strip should follow across the same elevation contour. If a section of the top edge of the strip dips below the contour, a channel may form.

- **Variations/Alternatives**
  - Varying levels of vegetation e.g. vegetated filter strip vs. grassed filter strip - vegetated strips work better than grassed strips.
  - A shallow stone trench can be used as a level spreader at the top of the strip.
  - Grassed filter strips can be used to protect infiltration trenches.

- **Advantages**
  - Removal of coarse sediment.
  - Reduction in flow velocities (filter strips do not provide enough storage or infiltration to significantly reduce peak discharges).
  - Slight reduction in runoff volume.
  - Slight enhancement of groundwater recharge.
  - May help reduce the size and cost of downstream stormwater treatment measures.
  - Protection of riparian zone.
  - Stream bank stabilisation.
  - Wildlife habitat (the wider the strip the higher the habitat value).
  - Aesthetic and recreation value.

- **Disadvantages**
  - Channelisation of flow across filter strips is common. Filter strips will fail if erosion creates concentrated flows.
  - Large land use.
  - Ineffective for peak flow control during large events.



TYPICAL FILTER STRIP
(AFTER MARSHALL MACKLIN MONAGHAN, 1994)

Figure 3.610

- **Maintenance**
  - Extra maintenance during first few months to ensure establishment of vegetation.
  - Watering may be required in times of drought.
  - The degree of maintenance required will be dependent upon the desired aesthetics of the filter strip. Maintenance and costs are significantly reduced for "natural" filter strips. Grassed filter strips will need mowing.
  - Inspections at least annually for:-
    - weed inundation
    - channelisation
    - erosion
    - sediment deposition
    - vigour and density of vegetation
    - integrity of level spreading device
  - Maintenance is required to prevent channelisation across the filter strip.
  - Repair of any erosion.
  - Removal of large sediment deposits.
  - Watering reseeding and fertilisation may be required to maintain dense, vigorous growth of vegetation.
  - Maintenance of level spreader.

- **Performance Information**

  Filter strips do not provide enough storage or infiltration to significantly reduce peak discharges to pre-development levels (Wong and McCuen, 1982) but will reduce runoff volume from smaller storms. Filter strips are usually viewed as one component in an integrated stormwater management system (Schueler, 1987). Filter strips can lower runoff velocity, and hence time of concentration, reduce runoff volume and catchment imperviousness and can contribute to groundwater recharge.

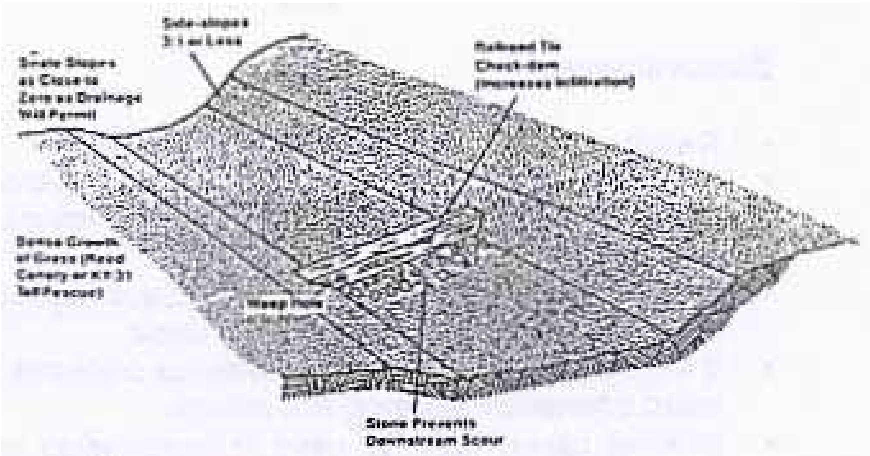
  Pollutants are removed from runoff by filtration, infiltration, reduction of flow velocity or biological uptake by vegetation. Results (Wong and McCuen, 1982, Pitt 1986, Overcash et al 1981, Tollner et al 1982) suggest that filter strips are effective in removing particulate pollutants such as sediment, organic material and trace metals. The ability of filter strips to remove soluble pollutants is variable and depends on the fraction of infiltrated runoff in the strip and adsorption of contaminants on organic matter and soils (Scholze et al, 1993).

C. Grassed Swales

- **Application/Function**
  - Typically applied in residential developments and highway medians as an alternative to kerb and gutter.
  - Reduction of runoff volume and peak rates by reducing runoff velocity and infiltration of stormwater.
  - Removal of coarse sediment and some degree of filtration of other particulate pollutants.
  - Groundwater recharge.

- **Description**
  - Grass-lined channel often running along roadside for drainage purposes.
  - See Figure 3.6.11
  - In most cases, must be used in combination with other stormwater treatment measures to meet downstream water quality requirements.

❖ **Design Considerations**
- More practical and cost effective when serving catchments up to 2 ha (Whelans, 1993).
- Slope of swale channel as close to zero as drainage will permit; not to exceed 5%. Slopes should be constant.
- Sideslopes 3:1 (h:v)or flatter.
- Top width to depth ratio of 6:1 or greater (Whelans, 1993).
- Dense ground cover of water tolerant, erosion resistant grass is required.
- Underlying soils must have a high permeability.
- Site must have a low water table say 1 m below swale.
- Swales have a limited capacity to accept runoff from large design storms and often must lead into storm drain inlets to prevent large, concentrated flows eroding the swales.
- Swales must be well developed before being required to carry runoff.
- Velocities must be kept below 2 m/s.



SCHEMATIC REPRESENTATION OF A GRASSED SWALE WITH A CHECK DAM (AFTER SCHUELER, 1987)

Figure 3.6.11

❖ **Variations/Alternatives**
- Check dams can be installed to promote additional infiltration and reduce velocities to non-erosive levels. The check dam should not be likely to erode.
- Swales may need to be supplemented by pipe for major storm events and steep terrain.
- Infiltration trenches along part or whole swale length.

- **Advantages**
  - Swales reduce runoff velocity, depending on the length and slope of the swale and hence lengthen the concentration time.
  - Some degree of infiltration depending on soils and slope hence reduction in storm runoff volume and enhanced groundwater recharge.
  - Greater opportunity for evapotranspiration.
  - Applicable to many urban situations.
  - Roadside and backyard swales can be managed as a natural area. Over time swales might be colonised by wetland plants and other shrubs that provide wildlife habitat and more aesthetically appealing.
  - Elimination of pipe maintenance.
  - Some removal of nutrients by biological uptake.
  - Not as effective in water quality enhancement as wet basins, extended detention basins and wetlands because there is minimal hydraulic residence time.
  - Easily combined with other BMPs.
  - Wildlife habitat (the wider the strip the higher the habitat value).
  - Aesthetic and recreation value.

- **Disadvantages**
  - Require on-going maintenance of vegetation.
  - Not capable of removing large amounts of soluble pollutants.
  - Not capable of accepting large storm volume because of high erosivity of these flows.
  - Mowing too close to ground or excessive application of fertiliser may detrimentally affect performance of swale.
  - If not maintained adequately, nuisance problems such as mosquitoes, weed infestation, dumping and erosion.
  - In most cases, must be used in combination with other stormwater treatment measures to meet downstream water quality requirements.

- **Maintenance**
  - Need to ensure dense, healthy grass cover, including periodic mowing, occasional spot reseeding and weed control.
  - Watering in times of drought, particularly in the first few months after establishment.
  - Need to keep slope of swale relatively constant to prevent formation of bogs.
  - Removal of any dumped litter.
  - Public education on function and importance of swales and the need for and type of maintenance required.

- **Performance Information**

  Swales can filter out particulate pollutants but are not generally capable of removing high levels of soluble pollutants. Pollutants are removed by the filtering action of the grass, deposition in low velocity areas, by infiltration into the subsoil or biological uptake by vegetation. Kercher et al (1983) and Yousef et al (1985) reported moderate to high removal of particulate pollutants in low gradient, densely vegetated soils in Florida. However, Oakland (1983) found low to moderate removal of particulate pollutants and negligible removal of soluble pollutants in a low gradient swale underlain by relatively impermeable soils in New Hampshire.

  Table 3.6.12 below summarises removal efficiencies of grassed swales.

Table 3.6.12

POLLUTANT REMOVAL EFFICIENCIES OF GRASSED SWALES

Reference	Constituent Removal Efficiency (%)					
	TSS	COD	Pb	Zn	Cu	Cd
Athayde et al (1986)			50	50	50	50
Horner (1988)		25	80	60	60	
Wang et al (1982)	80		80	70	60	
Yousef et al (1985)			91	90	41	29

D. Vegetated Channels

- **Application/Function**
  - An alternative to concrete drainage channels
  - Removal of coarse sediment and some degree of filtration of other particulate pollutants.
  - Some reduction in flow velocities and storm runoff volume (in comparison to concrete channels).
  - Small pools in the channel will enhance biological uptake of pollutants.
  - Rehabilitation or restoration of a stream system to a condition of equilibrium by preserving natural morphological characteristics and stream bank stability.
  - Creation of new channels.

- **Description**
  - Can range from vegetated swales to wetland channels and "natural" channels.
  - Some vegetated channels are specifically designed and constructed while others are formed by gradual vegetation of grassed swales and/or erosion of a low flow path in a grassed swale.
  - Similar to grassed swales but with a more extensive covering of vegetation.
  - The type and extent of vegetation is variable.
  - Could be the natural channel flowing through the site prior to development.
  - Vegetated channels should be part of a system with other BMPs.

- **Design Considerations**
  - Slope of channel as close to zero as drainage will permit; not to exceed 5%.
  - Dense ground cover of water tolerant, erosion resistant vegetation is required.
  - Underlying soils must have a high permeability.
  - Channels often have a limited capacity to accept runoff from large design storms and often must lead into storm drain inlets to prevent large, concentrated flows causing erosion.
  - Urbonas and Stahre (1993) suggest that wetland channels be designed to carry a two year peak runoff event.
  - Channel cross-section can be of almost any type suitable to the site. However, for the two year peak flow rate the depth should be uniform and the bottom width should be at least eight times the two year flow depth (Urbonas and Stahre, 1993). Two year flow depth should be 0.9-1.8 m.

- Velocities should be limited to non-scour levels.
- Other BMPs are required upstream to significantly reduce peak rates of runoff.
- Safety considerations should be taken into account.

- **Variations/Alternatives**
  - The formation of small pools in the channel will enhance biological uptake of pollutants. Such pools may form naturally.
  - Wetland channels:-
    - characterised by the presence of microphytes throughout the channel
    - can provide some level of water quality treatment for urban base flows, releases from upstream retention systems and smaller runoff events (Urbonas and Stahre, 1993)
  - "Natural" channel design:-
    - the goal is to create a channel path for streams which reflects natural morphology and allows streams to maintain themselves physically and ecologically (Gerdes, 1994)
  - "Natural" channels are self-regulating systems which lead to stream stabilisation and hence reduced erosion. The erosion/sedimentation balance leads to:-
    - greater ability of the stream to adjust to future changes
    - improved water quality
    - increased habitat diversity
    - enhanced aquatic production

    To protect the integrity of "natural" channels in urban areas, upstream water quality treatment is required.
  - Restoration of the floodplain and wetland ecosystem vegetation associated with streams can play a major role in enhancing water quality (Salvatori and Jurak, 1994).
  - In certain cases, the establishment of new wetlands can also be implemented to polish water quality. Hydrophytic wetland plants in association with their complex terrestrial and aquatic microbial community enhance acid, heavy metals, inorganic and organic compound removal from polluted streams.
  - The presence of pool and riffle systems will further enhance water quality by aiding re-oxygenation, assisting in sediment and nutrient control and assisting in control of organic material in a water course by providing habitat for bacteria (Hader, 1994).

- **Advantages**
  - Reduction in flow velocities.
  - Reduction in storm runoff volume through some degree of infiltration, especially with formation of pools and evapotranspiration.
  - Reduced stream bank erosion due to stabilising effects of riparian vegetation.
  - Aesthetically appealing.
  - Habitat value.
  - May become self-sustaining “natural” channel.
  - Elimination of pipe maintenance.

- **Disadvantages**
  - Longer period of time to fully establish.
  - Excessive application of fertiliser may detrimentally affect performance of channel.
  - Water in any pools and boggy conditions has the potential to become stagnant for mosquito breeding.
  - High initial costs.

- **Maintenance**
  - Need to ensure dense, healthy grass cover, including occasional spot reseeding and weed control.
  - Watering in times of drought, particularly in the first few months after establishment.
  - Removal of any dumped litter.
  - Inspections for erosion and any subsequent mitigation measures.
  - Stream banks should be inspected following high discharge events.
  - Amount of maintenance will depend on desired vegetation types. If specific vegetation types are desired, more maintenance will be required than for a "natural", almost self-sustaining channel.

- **Performance Information**

  The pollutant removal mechanisms of vegetated channels include flow retardation and subsequent enhanced settlement of suspended sediment and associated pollutants. Vegetation provides some degree of filtering, depending on vegetation density, and also biological uptake of nutrients and possibly heavy metals.

  The effectiveness of pollutant removal in wetland channels has not yet been quantified, but it is likely that they help to enhance the quality of urban runoff before entering receiving waters. Pollutant removal in wetland channels is not expected to be as effective as for a confined wetland because of the reduced detention time in a channel resulting in reduced time for pollutant removal mechanisms.

  The "Ontario Stormwater Management Practices Planning and Design Manual" (Marshall Macklin Monaghan, 1994) promotes the use of natural channel design techniques where possible. Stream restoration techniques have been employed in Washington DC (Metropolitan Washington Council of Governments, 1991) and the Australian Conservation Foundation is rehabilitating a Sydney concrete channel to its "natural" state.

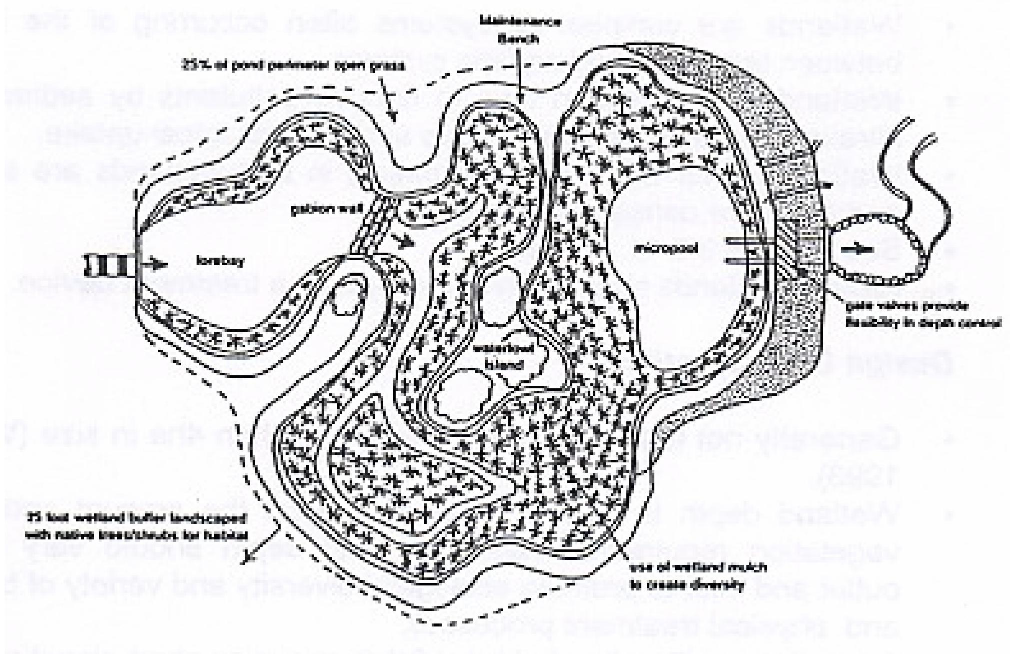
E. Artificial Wetlands

- **Application/Function**
  - Water quality improvement through:-
    - sedimentation of coarse sediments
    - filtering of particulate pollutants
    - biological uptake of soluble pollutants
  - Reductions in flow velocities and storm runoff volume.
  - Habitat and aesthetic value.

- **Description**
  - Artificial (as opposed to natural) wetlands are used for stormwater treatment.
  - Wetlands are lands where the water table is at or near the surface, or where the land is inundated by relatively shallow water or where the land supports aquatic vegetation.
  - The dominant factor in soil development and species composition is saturation.
  - Wetlands are complex ecosystems often occurring at the interface between terrestrial and aquatic systems.
  - Wetlands use retention time to remove pollutants by sedimentation, filtration and biological processes such as biological uptake.
  - Wetlands differ from retention basins in that wetlands are shallower and are more densely vegetated.

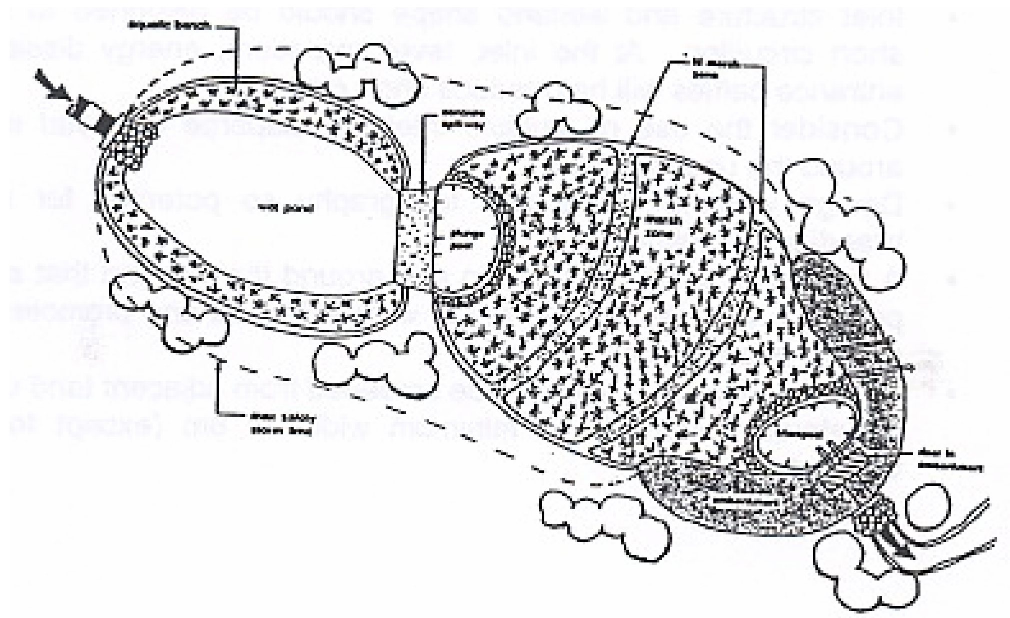
- See Figures 3.6.13 - 3.6.17.
- Natural wetlands should never be used as a treatment device.

- **Design Considerations**
  - Generally not feasible in catchments less than 4 ha in size (Whelans, 1993).
  - Wetland depth is largely dependent upon the amount and type of vegetation required/desired. Wetland depth should vary between outlet and inlet to promote ecological diversity and variety of biological and physical treatment processes.
  - A length to width ratio of at least 3:1 to minimise short-circuiting.
  - Native wetland plants should be used.
  - Water table at or near soil surface.
  - The wetland area must be kept wet during extended periods of no precipitation. A wetland needs sufficient base flow to sustain itself.
  - Inlet structure and wetland shape should be designed to minimise short circuiting. At the inlet, level spreaders, energy dissipaters or entrance baffles will help reduce short circuiting.
  - Consider the use of multiple inlets to disperse the total inlet load around the upstream end.
  - Design wetland shape and topography so potential for mosquito breeding is minimised.
  - A functional ponds cape within and around the wetland that enhances pollutant removal, creates better wildlife habitat and promotes a more natural appearance.
  - Stormwater wetlands should be screened from adjacent land uses by a vegetated buffer with a minimum width of 8 m (except for pocket wetlands).



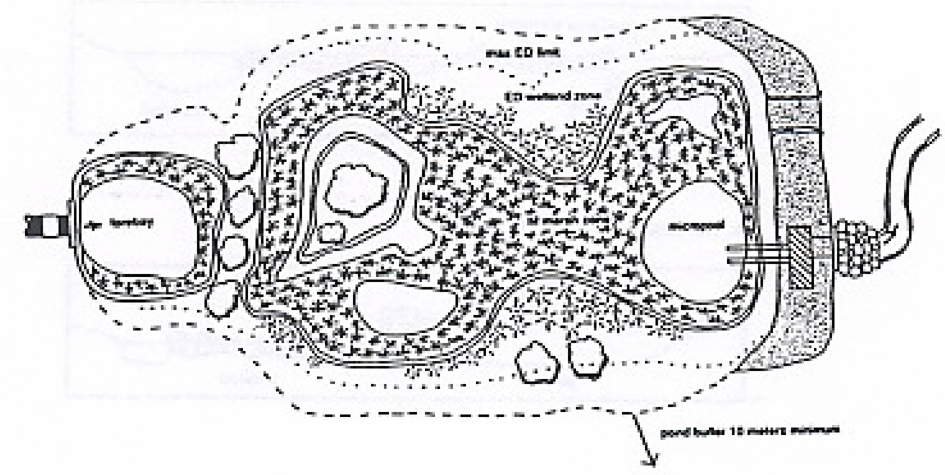
SHALLOW MARSH SYSTEM WETLAND (AFTER SCHUELER, 1992)

Figure 3.6.13



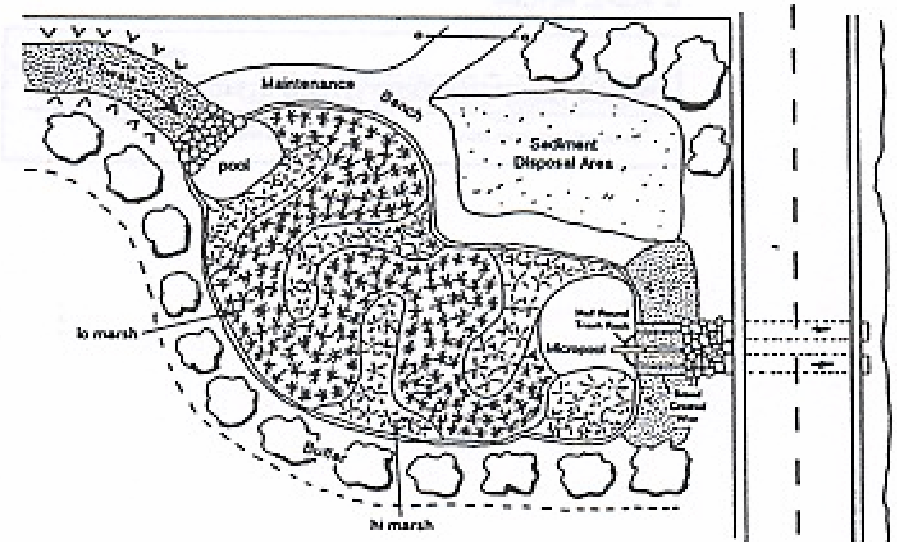
POND / WETLAND SYSTEM (SOURCE: SCHUELER, 1992)

Figure 3.6.14



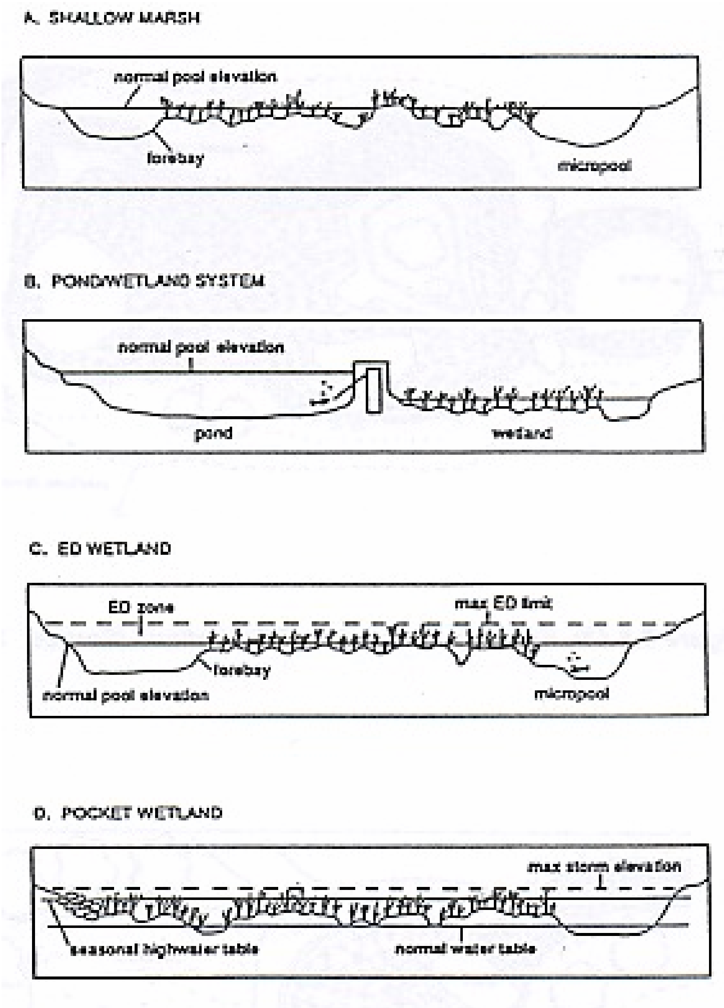
EXTENDED DETENTION (ED) WETLAND (SOURCE: SCHUELER, 1992)

Figure 3.6.15



POCKET WETLAND SYSTEM (SOURCE: SCHUELER, 1992)

Figure 3.6.16



PROFILES OF THE FOUR WETLAND SYSTEMS
(SOURCE: SCHUELER, 1992)

Figure 3.6.17

- **Variations/Alternatives**
  - Deep pond area in the middle of the wetland for sedimentation processes. This reduces wetland surface area.
  - Extending the flow path by putting bends in the wetland, i.e. making a zigzag wetland.
  - Pre-treatment of runoff before entering the wetland to reduce water velocity and trap coarse sediment e.g. a GPT, or forebay at upstream end of wetland.
  - Enhanced settling and uptake of pollutants by using appropriate wetland topography.
  - Provision of a small pool at the wetland outlet to minimise outlet blockage.
  - Schueler (1992) suggested four alternative wetland designs:-

    - Design 1 - Shallow Marsh System - a large surface area and requires a reliable source of base flow or groundwater supply to maintain the desired water elevations to support emergent microphytes. Consequently a large space is required and a catchment area often in excess of 10 ha to support the permanent pool. See Figure 3.6.13.

- Design 2 - Pond/Wetland System - utilises two separate cells for stormwater treatment. The first cell is a wet pond and the second is a shallow marsh. The wet pond is designed to trap sediments, reduce incoming velocity and remove pollutants. This system requires less space because the bulk of the treatment is provided by the deeper pool rather than the shallow marsh. A catchment area of 10 ha or more is required. See Figure 3.6.14.

- Design 3 - Extended Detention Wetland - extra runoff storage is created above the shallow marsh by temporary detention of runoff. The extended detention enables the wetland to consume less space. A catchment area of at least 4 ha is required. See Figure 3.6.15.

- Design 4 - Pocket Wetlands - adapted to serve smaller sites 0.5-4 ha in size. Because of the small drainage area, pocket wetlands usually do not have a reliable source of base flow, and therefore exhibit widely fluctuating water levels. During dry periods the pocket wetlands may not have a pool of water at all, but saturated soils instead. See Figure 3.6.16.

The profiles of Designs 1-4 are compared in Figure 3.6.17.

- Design 5 - Fringe Wetlands - formed by shallow aquatic benches installed along the perimeter of the permanent pool of a wet pond. Fringe wetlands are a very useful design feature in ponds as they promote a more natural appearance, conceal trash and changes in water levels, reduce safety hazards and provide some aquatic habitat. However, they provide only a minor increment of additional pollutant removal.

- **Advantages**
  - Removal of soluble and particulate pollutants.
  - Removal of soluble pollutants through biological uptake.
  - Nutrient removal.
  - Reduction of flow velocities.
  - Reduction of downstream channel erosion.
  - Reduction in peak storm flows through detention.
  - Reduction in storm runoff volume through some degree of infiltration and evapotranspiration.
  - Groundwater recharge.
  - Assists with stabilisation of base flows.
  - Can be designed to capture first flush.

- **Disadvantages**
  - Large land use required.
  - Sedimentation of permanent pool.
  - May promote mosquito breeding - a higher risk of mosquito breeding than for wet basins.
  - Possible thermal effects due to solar heating.
  - Possible eutrophication - negative impact on water quality.
  - If groundwater levels drop, influent flows maybe too small to maintain a permanent pool during summer, aesthetic values may deteriorate and odours may be generated.

- **Maintenance**
  - Access track for maintenance is required.
  - High level of maintenance following establishment to ensure viability of vegetation community. Need to ensure diversity of plant life.
  - May require watering during periods of drought.
  - Inspections for:-
    - weed infestation
    - sediment accumulation
    - integrity of inlet and outlet structures
    - downstream erosion
    - channelisation and short circuiting
    - mosquito breeding
    - viability of vegetation
    - litter and debris
    - eutrophication
  - Maintenance will be dependent upon results of inspections.
  - Microphyte harvesting to prevent accumulation of dead and decaying plant biomass and to promote an actively growing well-balanced plant community.
  - Weed removal.

- **Performance Information**

Pollutant removal mechanisms in wetlands include gravity and algal settling, wetland plant uptake, absorption, bacterial decomposition and filtration. Strecker et al (1990) summarised Nationwide Urban Runoff Program (NURP) and other data on efficiencies of existing wetlands for control of urban runoff pollution in the USA. Average pollutant removal efficiencies were 85% for lead, 56% for zinc and 40% for copper. Schueler (1992) reports SS retention rates of 50-98%, TP rates of 20-97% and TN rates of 20-30%. Metal retention rates exceeding 50% and nitrate retention rates of 30-90% have been reported.

Bell (1994) used the data of Schueler (1987) to predict pollutant removal efficiencies for wetlands in south-east Queensland. The predicted pollutant removal efficiencies are given in Table 3.6.18.

Table 3.6.18

PREDICTED POLLUTANT REMOVAL EFFICIENCIES FOR WETLANDS IN SOUTH-EAST QUEENSLAND (BELL, 1994)

Basin Volume $m^{3/}ha$	Basin Volume / Runoff Volume	Surface Area % of Catchment Area	TSS Removal (%)	Sediment Removal (%)	P Removal (%)	N Removal (%)
100	0.6	1	87	60	45	35
250	1.5	2.5	92	80	65	50
420	2.5	4.2	98	85	78	65

It should be remembered in considering the above data that Schueler's information was obtained from North American conditions.
Bell (1994) has designed a model artificial wetland for stormwater treatment in south east Queensland.

F. Urban Lakes

- **Application/Function**
  - Water quality improvement through:-
    - sedimentation of coarse sediments
    - filtering of particulate pollutants
    - biological uptake of soluble pollutants
  - Reductions in flow velocities and storm runoff volume.
  - Habitat and aesthetic value.

- **Description**
  - Lakes can vary in shape and depth.
  - Can support a diversity of aquatic flora and fauna.

- **Design Considerations**
  - To maintain aesthetic and recreation value and water quality and habitat value, stormwater should be pre-treated (for removal of coarse sediment and litter) before entering an urban lake. This will also enhance the efficiency of the lake in water quality treatment.
  - The depth of an urban lake will be dependent on ecosystem requirements.
  - Native plants should be used.
  - Depth should vary throughout lake to provide habitat diversity.
  - Design lake shape and topography such that potential for mosquito breeding is minimised.
  - Lakes should be screened from adjacent land uses by a vegetated buffer zone.
  - Water table close to surface.
  - To reduce stratification aerators, water jets or large fans may be required on the bed of a lake.

- **Variations/Alternatives**
  - Similar to a large wet basin.

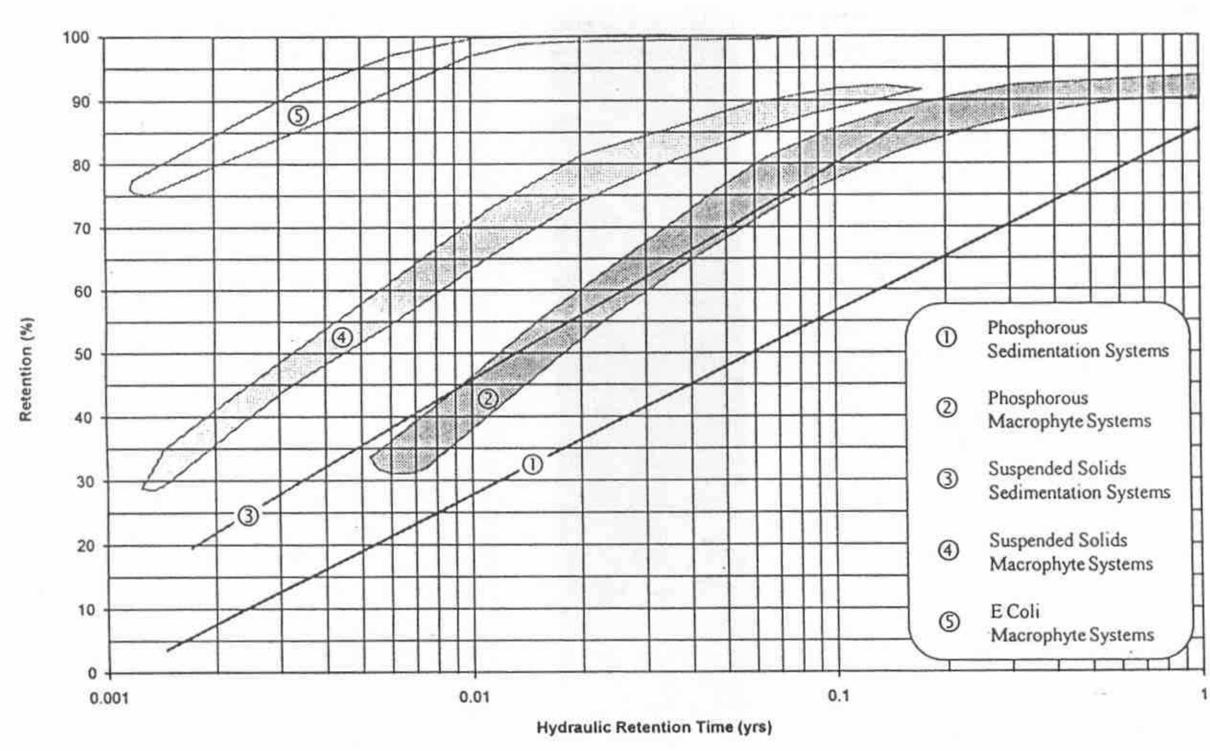
- **Advantages**
  - Removal of both particulate and soluble pollutants.
  - High aesthetic and recreation value.
  - High habitat value for aquatic and terrestrial flora and fauna.

- **Disadvantages**
  - High land consumption.
  - Possibility for nuisance problems e.g. odour, algal and debris.
  - Possibility of mosquito breeding.

- **Maintenance**
  - Regular inspections for:-
    - algal blooms
    - trash accumulation
    - sediment build-up
    - alterations to catchment which may alter lake performance
    - ecosystem viability
    - weed infestations
    - upstream and downstream erosion
  - The findings of these inspections will determine appropriate maintenance measures.

- The vegetated buffer zone and fringing vegetation will need to be maintained.
- Sediment removal by dredging or by draining the lake and excavating sediment.

❖ **Performance Information**
- Urban lakes have been used successfully as an integral component of the stormwater treatment system in Canberra.
- Curves have been derived for the pollutant removal of Lake Burley Griffin in Canberra. These curves are shown in Figure 3.6.19.



HYDRAULIC RETENTION TIMES FOR POLLUTION ABATEMENT IN AN URBAN LAKE (SOURCE: ACT GOVERNMENT, 1994)

Figure 3.6.19

3.6.4 INFILTRATION DEVICES

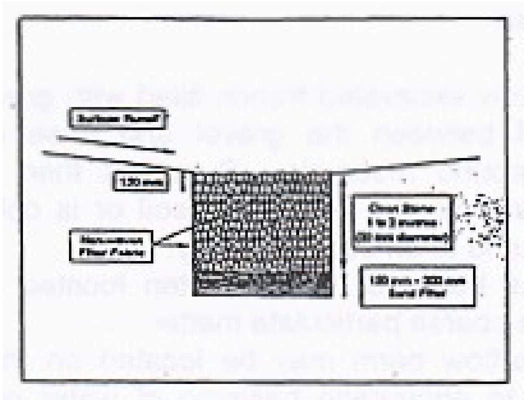
A. Infiltration Trenches

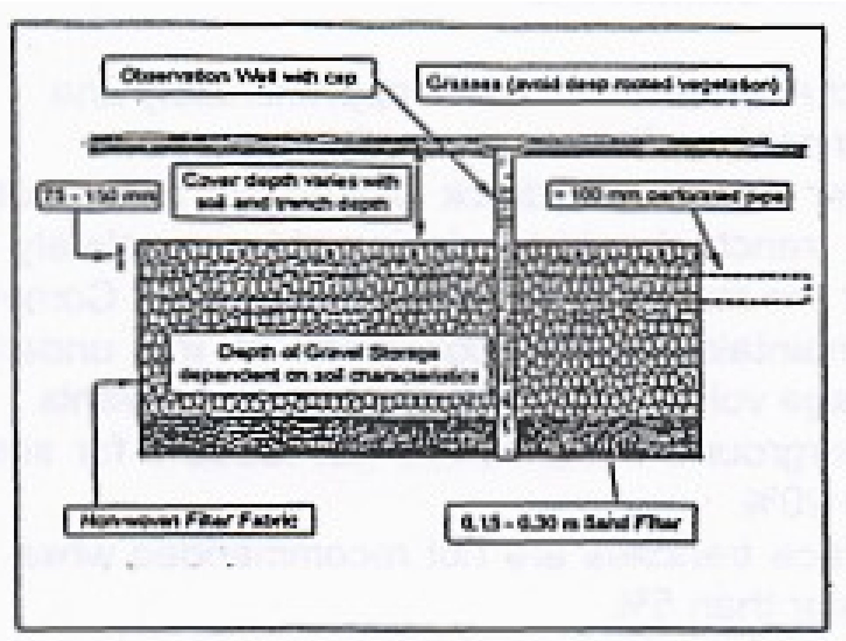
❖ **Application/Function**
- Removal of soluble and particulate pollutants.
- Reduction of flow velocities and runoff volume by infiltrating stormwater.
- Groundwater recharge.

❖ **Description**
- A shallow excavated trench filled with gravel, often with a sand layer located between the gravel and base of the trench to form an underground reservoir. Runoff is then either infiltrated from the reservoir into the underlying soil or is collected by perforated pipes and routed to an outflow facility.

- A grass buffer or filter is often located upstream of the trench to remove coarse particulate matter.
- An overflow berm may be located on the downstream side of the trench to encourage basining of water over the trench to increase infiltration.
- See Figure 3.6.20

- **Functional Limitations**
  - Catchment area less than approximately 2 ha.
  - Permeable soils are required.
  - Water table and bedrock located well below bottom of trench.
  - The trench should be designed to completely drain within three days after the maximum design rainfall event. Complete drainage is needed to maintain aerobic conditions in the underlying soil and provide storage volume for the following storm events.
  - Underground trenches are not feasible for sites with a slope greater than 20%.
  - Surface trenches are not recommended when contributing slopes are greater than 5%.
  - Slope of the bottom of the trench should be close to zero to evenly distribute infiltration.
  - At least a 1 m clearance will be needed between the bottom of the stone reservoir and the bedrock level.
  - About 1 m of clearance will be needed from the bottom of the stone reservoir to the seasonally high water table.
  - Pre-treatment is required for removal of coarse particles to prevent clogging.
  - Before the site is developed, the area planned for the trench should be roped off to prevent heavy equipment compacting underlying soils.
  - During the construction phase sediment and runoff should be kept away from the trench area.
  - Construction of the trench should not begin until the catchment has stabilised.
  - The bottom and sides of the stone reservoir should be lined with filter fabric or clean sand to prevent upward piping of underlying soils.
  - Clean, washed aggregate should be used.





SURFACE AND SUBSURFACE INFILTRATION TRENCHES
(SOURCE: MARSHALL MACKLIN MONAGHAN, 1994)

Figure 3.6.20

- **Variations/Alternatives**
  - Pollutant removal is enhanced by increasing the surface area of the trench bottom. Additionally, broader trench bottoms reduce the risk of clogging.
  - Trenches can be located either on the surface or below ground. Surface trenches accept sheet flow directly from adjacent areas, while underground trenches can accept more concentrated flow (from pipes and storm drains). Surface trenches require grass buffer strips to capture sediment. Underground trenches require the installation of special inlets to prevent coarse sediment and oil/grease from clogging the stone reservoir.
  - Soakaways are often underground structures, similar to a large manhole with no base (CIRIA, 1992). Runoff enters the soakaway via a piped drain and infiltrates through the base and walls.

- **Advantages**
  - High to moderate pollutant removal capability if properly maintained.
  - Protect downstream aquatic habitats by maintaining the pre-development water balance at the site, minimising stream bank erosion and filtering out pollutants.
  - Preserve the natural groundwater recharge capabilities of the site.
  - Low flow stabilisation.
  - Easy to fit into the margins, perimeters and other unused areas of a development site.
  - Can be designed as an unobtrusive feature of the landscape.
  - Provide pollutant removal on small sites or infill developments.
  - Attenuate peak discharges for the design storm.
  - Helps prevent stream bank erosion.

- **Disadvantages**
  - Severely restricted by soils, water table, slope and contributing drainage area conditions.
  - Approximately 50% of infiltration trenches partially or totally fail in the first five years after construction (Galli, 1992).
  - Easily clogged - pre-treatment is required.
  - Need to keep coarse sediment away from structure (particularly difficult during construction).
  - Possible risk of groundwater contamination.
  - Best used in conjunction with other BMPs.
  - Pollutant removal efficiencies quite low compared to other BMPs because of high failure rate.
  - Difficult to monitor effectiveness.
  - Cannot treat large amounts of stormwater runoff.

- **Maintenance**
  - Observation wells should be installed to monitor the performance of the trench.
  - Regular inspections for:-
    - effectiveness of sediment and erosion controls
    - vegetated buffer strips
    - any surface ponding to indicate clogging
  - Grassed filter strips will need to be mowed depending on choice of grass.
  - Adjacent trees may need to be trimmed if branches extend over a surface trench so that leaves do not clog the trench.
  - Trees that start to grow in the vicinity of a trench should be removed to avoid damage by roots to the trench.
  - If surface trenches become clogged, clogging is likely to occur near the top of the trench between the upper layer of stone and the protective layer of the filter fabric. Replacement of the top stone layer and filter fabric will relieve clogging.
  - Clogging of underground trenches is likely to occur at the bottom of the trench. To relieve clogging in this cast the entire trench may need to be replaced.
  - Maintenance costs will be largely dependent upon the susceptibility of the trench to clogging.

- **Performance Information**

  Infiltration trenches remove pollutants by processes including absorption, filtration and microbial decomposition (Wanielista et al, 1991). This occurs primarily in the soil material beneath the trench and also in the grass filter strips located above the trench. Although performance data on infiltration trenches is rare, trenches are believed to have high capability to remove particulate pollutants and a moderate capability to remove most soluble pollutants. Schueler (1992) quotes SS removal rates in excess of 90%, with TP and TN removal rates of approximately 60%. However removal rates are expected for dissolved nutrients and other soluble matter.

Conventional infiltration trenches have proven to have relatively short life spans. Approximately half partially or totally fail within the first five years of construction (Galli, 1992). However, longevity could be improved through more rigorous site-specific geotechnical evaluation, regular inspection and maintenance and enhanced pre-treatment control.

B. Infiltration Basins

- **Application/Function**
  - Infiltration basins can be used to remove both soluble and fine pollutants.

- **Description**
  Similar to dry ponds.
  - An impoundment is formed by excavation or by constructing an embankment.
  - Runoff caught in the impoundment is allowed to slowly infiltrate through the permeable soils of the basin floor.
  - Basins are typically sized to store and infiltrate the entire runoff volume associated with the design storm.
  - The basin floor is graded as flat as possible and a dense turf of grass is established to promote infiltration and bind deposited sediments.
  - An emergency spillway is used to pass runoff volume in excess of the design storm controlled.
  - See Figure 3.6.21

- **Design Considerations**
  - Applicable for sites with catchment 12-120 ha (wet basins are preferable for catchments greater than 120 ha).
  - Permeable soils are required.
  - Low water tables are required.
  - Water table and bedrock must be located well below soil surface (approx 1 m).
  - Not feasible if the slope of the contributing watershed is greater than 20%.
  - The rate and quantity of water infiltrated is enhanced by increasing the surface area of the basin floor.
  - Basins should be located away from drinking wells.
  - Inlet channels should be stabilised to prevent incoming velocities reaching erosive levels. The inlet channels should be designed to spread runoff more evenly over basin surface i.e. some type of level spreader.
  - Basin floor should have slope close to zero. Side slopes should be no greater than 3:1 (h:v) to allow for proper vegetative stabilisation.
  - A dense turf of water tolerant grass should be established on the floor and side slopes of infiltration basins immediately after construction.
  - Complete drainage of the basin is required in about three days after a storm event to maintain aerobic conditions in the soil profile.

- **Variations/Alternatives**
  - Full Infiltration Basin - the basin is sized to accommodate the entire runoff volume associated with the design storm. A riprap apron is needed near the inlet to reduce incoming runoff velocities to promote more uniform infiltration. See Figure 3.6.18.

- The longevity of an infiltration basin can be enhanced if small ponds are constructed near basin inlets to allow some sedimentation of coarse sediment.
- Combined Infiltration/Detention Basin - runoff entering the top of the basin to allow settling time for removal of coarse sediment. Flow from the settling basin is spread over the basin floor for infiltration. Depth of water in the basin is controlled by a vertical riser.

- **Advantages**
  - High to moderate pollutant removal capability.
  - Preserve the natural pre-development water balance of the site.
  - Are applicable to small and large scale developments.
  - During construction phase, can be used as sedimentation basins.
  - Reasonably cost-effective.
  - Reduce peak flows.
  - Reduce storm runoff volume.
  - Reduce downstream channel erosion.
  - Enhances groundwater recharge.
  - Protect downstream aquatic life. I
  - In some cases the basin can be utilised for recreation e.g. sport fields and playgrounds.
  - Can have some habitat value.

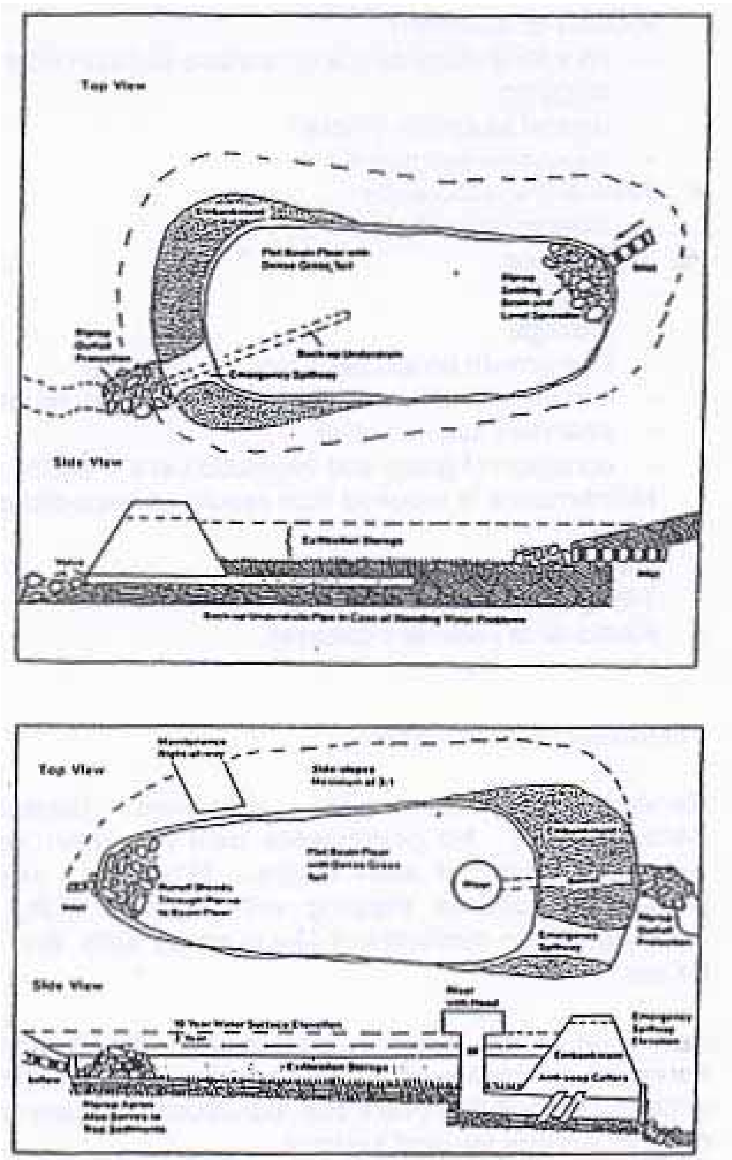
- **Disadvantages**
  - Application is restricted by soil type, slope, water table and contributing catchment area.
  - High level of land consumption.
  - Not very good at treating concentrated flows and high sediment loads.
  - Easily failed through clogging and/or compaction.
  - Potential ground water contamination.
  - Potential for mosquito breeding if water ponds for long periods of time.

- **Maintenance**
  - Regular maintenance is a necessity for ongoing performance.
  - Inspection for the following after every major storm during the first few months of operation:-
    - how long water ponds on surface of basin after a storm event
    - clogging
    - upland sediment erosion
    - excessive compaction
  - Annual inspections for:-
    - differential settlement
    - cracking
    - erosion
    - leakage
    - tree growth on embankment
    - condition of channels and inlet and outlet structures
    - sediment accumulation
    - condition of grass and vegetation in the basin
  - Maintenance is required from results of inspections.
  - Mowing.
  - Debris and litter removal.
  - Tilling to enhance infiltration.
  - Removal of sediment deposits.

- **Performance Information**

  Removal mechanisms are adsorption, filtration and microbial decomposition. No performance data has been located regarding the removal capacity of such basins. However, it can be assumed that particulate pollutant trapping will be quite high, dissolved pollutant trapping will be moderate or low in sandy soils, and nitrate retention will be low.

  Infiltration basins generally have a short life span. Only 38% of basins surveyed by Lindsay et al (1991) (quoted in Galli, 1992) were capable of infiltrating runoff five years after construction. Many failed basins become de facto artificial wetland systems.



SCHEMATIC OF INFILTRATION BASIN AND EXTENDED DETENTION INFILTRATION BASIN (SOURCE: SCHUELER, 1987)

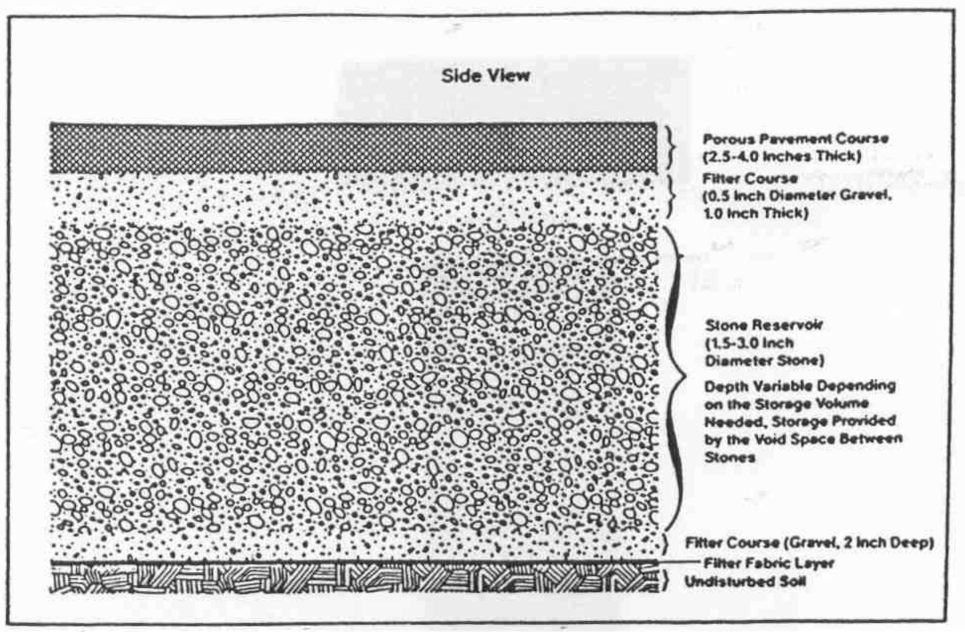
Figure 3.6.21

C. Porous Pavements

- **Application/Function**
  - For removal of both soluble and fine particulate pollutants in urban runoff for low volume parking areas, for rooftop runoff of adjacent paved areas.

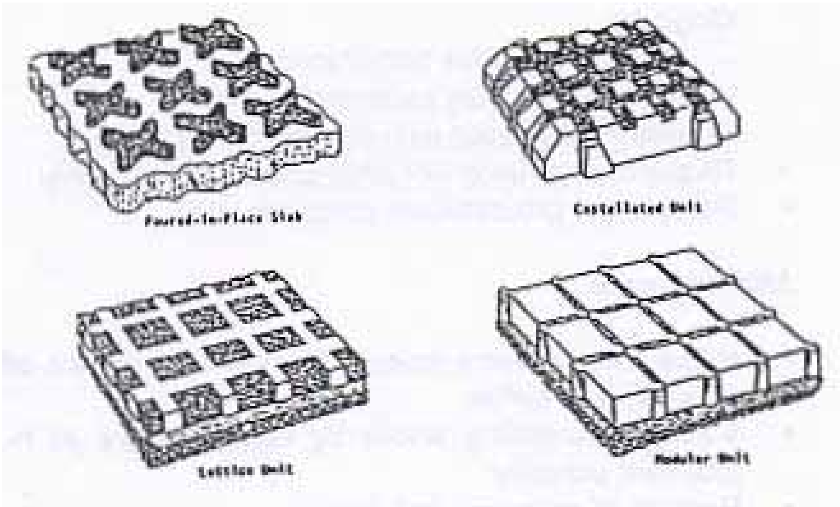
- **Description**
  - A deep pavement incorporating an open graded asphalt/concrete wearing course above a gravel layer bedded on a sand filter layer. Runoff percolates through the asphalt/concrete layer into the gravel storage reservoir. This infiltrates at a relatively slow rate through the base of the pavement into the groundwater (see Figure 3.6.22).
  - Pollutant removal is achieved through filtration, adsorption and microbial decomposition/transformation of pollutants during infiltration.

- **Design Considerations**
  - More practical and cost effective when serving catchments 0.1-4.0 ha.
  - Permeable soils are required and pavement must be at least 1 m above bedrock (Whelans, 1993).
  - A low water table is required - pavement must be at least 1 m above the water table.
  - Only feasible for low volume parking areas and lightly used roads.
  - Slope should not exceed 5% and performance best when as flat as possible.
  - Should drain within three days, allowing soils to dry out and preserving capacity for the next storm.
  - Sediment must be kept away from site before, during and after construction.
  - The more soil surface area available for infiltration the better the pollutant removal performance.
  - Not recommended for areas with high wind erosion.



SCHEMATIC REPRESENTATION OF TYPICAL POROUS PAVEMENT SECTION (SOURCE: SCHUELER, 1987)
Figure 3.6.22

- **Variations/Alterations**
  - Areas within a large parking lot that are expected to receive moderate or heavy traffic intensity, or that will accommodate heavy trucks, can be conventionally paved and then sloped to drain over to an adjacent porous pavement area.
  - There are various performed modular pavers in brick and concrete which, if laid on a permeable base, will allow water to infiltrate, either through joints or perforations. These pavers are more practical and cost effective when serving catchments up to 2 ha. Recommended for parking lots, on street parking aprons and light traffic access roads, bike paths and driveways. Not recommended for walkways. See Figure 3.6.23.



MODULAR PAVING
(FLORIDA DEVELOPMENT MANUAL QUOTED IN WHELANS, 1993)

Figure 3.6.23

- **Advantages**
  - High to moderate pollutant removal rate.
  - Preservation of pre-development water balance at site.
  - When properly constructed pavement has similar load bearing strength, longevity and maintenance requirements similar to conventional pavement.
  - Reduced land consumption in comparison to other BMPs.
  - Reduction or elimination of the need for kerb and gutters and downstream conveyance systems.
  - Safer driving surface.
  - Protection of downstream aquatic life.
  - Minimisation of stream bank erosion.
  - Peak discharge control.
  - Groundwater recharge.
  - Storm runoff volume control.
  - Stream bank erosion control.

- **Disadvantages**
  - Only feasible for low volume parking areas and lightly used roads.
  - Not recommended where erosion, heavy or high volume traffic is expected to supply large quantities of sediment.
  - If clogged is difficult and costly to rehabilitate.

- Galli (1992) found that 75% of porous pavement systems fail within the first five years after construction. Failure is due to partial or total clogging:-
  - immediately after construction
  - when clogged by sediment and oil
  - when resurfaced with non-porous pavement
- Requires high level of construction workmanship.
- Potential of groundwater contamination.

❖ **Maintenance**
- Inspections several times in the first few months after construction and annually thereafter.
- Vacuum sweeping and/or by high-pressure jet hosing is required to maintain porosity.
- Repairs of potholes and cracks.
- Replacement of clogged areas.

❖ **Performance Information**

Pollutant removal mechanisms are similar to those for infiltration trenches; porous pavements have high particulate pollutant capabilities and moderate soluble pollutant removal capabilities (Schueler, 1987). However, porous pavements have a high failure rate and as such their use is not recommended. Galli (1992) found that 75% of porous pavements failed within the first five years of construction.

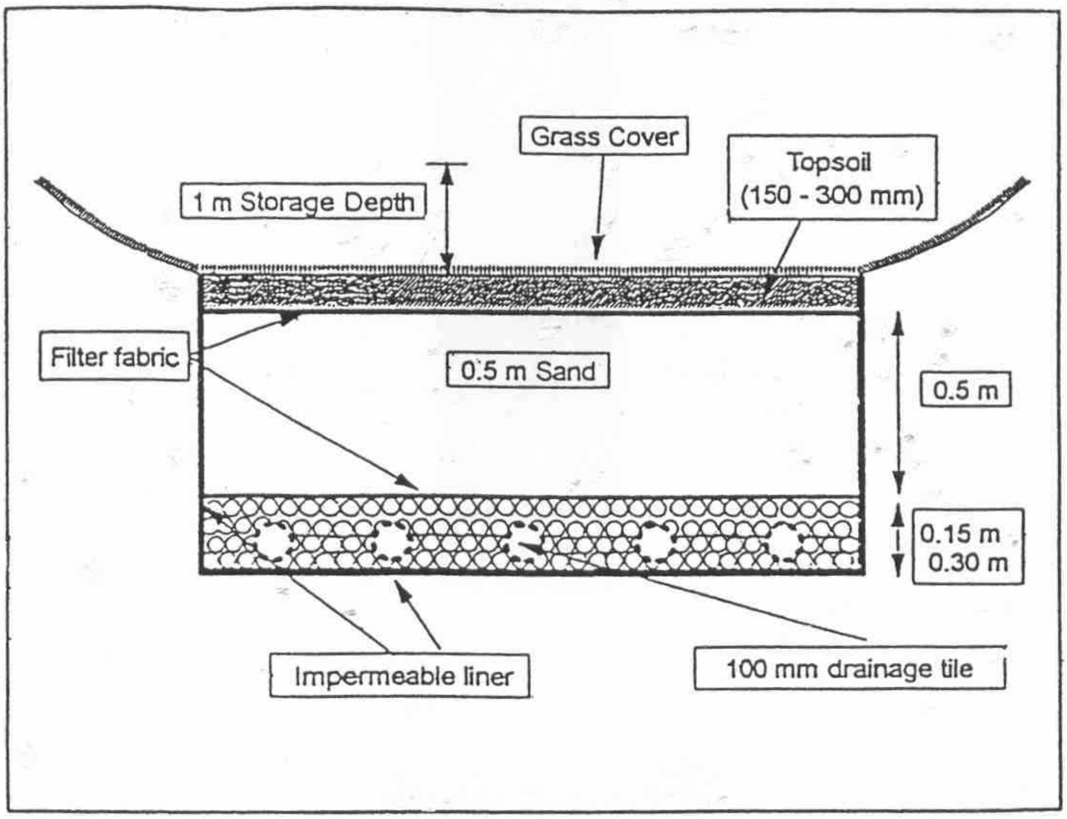
D. Sand Filters/Peat Sand Filters

❖ **Application/Function**
- Removal of pollutants.

❖ **Description**
- Runoff is diverted into a self-contained bed of sand. The runoff is strained through the sand, collected in underground pipes and discharged.
- See Figure 3.6.24.

❖ **Design Considerations**
- Catchment area not exceeding 20 ha.
- Head of 0.6 m-1.2 m required.
- Pre-treatment is preferred for removal of coarse sediment.

❖ **Variations/Alternatives**
- Enhanced sand filters utilise layers of peat, limestone and/or topsoil, and may also have a vegetative cover. The adsorptive media is expected to improve removal rates.
- Can be used either above or below ground.
- Sand-trench systems have been developed to treat parking lot runoff.
- Filters can be used as a final treatment measure say, draining water from a water quality control pond or lake through a sand filter before discharge into receiving water.



SCHEMATIC REPRESENTATION OF SAN FILTER SECTION
(AFTER MARSHALL MACKLIN MONAGHAN, 1994)

Figure 3.6.24

- **Advantages**
  - High pollutant removal abilities.
  - Can be applied to most development sites.
  - Good for groundwater protection.

- **Disadvantages**
  - Clog easily if not regularly maintained.
  - Surface filters can be aesthetically unpleasing.
  - Do not provide detention.

- **Maintenance**
  - Sand filters require frequent maintenance for:-
    - raking
    - surface sediment removal
    - removal of litter and debris
    - mowing

- **Performance Information**

  Removal of pollutants by this technique is primarily due to filtration. Filters have been used on a limited basis in the USA. Schueler (1992) quoted removal rates of 85% SS, 35-50% TP and 40-70% TN from a single study. Negative removal was reported for nitrate which may be due to the nitrification process. Galli (1991) projects higher pollutant removal rates in peat-sand filters due to the high absorption capacity of the peat material.

3.7.0 ENVIRONMENTAL IMPACTS OF STORMWATER TREATMENT MEASURES

The purpose of stormwater quality best management practices is to reduce pollutant loadings from catchments entering receiving waters. However, these BMPs have the potential to directly and indirectly impact upon the environment.

No known Australian study has investigated the environmental impacts of stormwater treatment measures in Australia. However, Sharpin and Morison (1995) have summarised the potential impacts of wet basins and wetlands. The potential environmental impacts of infiltration systems are also summarised below.

When considering the environmental impacts of BMPs it should be remembered that the impacts will be greatest on natural streams than on formal flood ways (where environmental values are minimal).

Additionally, although BMPs have regional benefits for water quality and the environment, BMPs do have the potential for localised adverse environmental impacts. A balance is needed between the environmental benefits and costs of each BMP.

3.7.1 POTENTIAL IMPACTS OF WETLANDS/WET BASINS

A. Habitat Change

Alteration of habitat is the most obvious potential impact of construction of stormwater quality best management practices. There is likely to be some removal of riparian vegetation and physical attributes such as pools and riffle zones. An indirect impact on the riparian vegetation is caused by the localised elevation in groundwater levels and change to soil moisture. This may create conditions unfavourable to some vegetation. However, BMPs also have the potential to provide new habitat for a range of species.

B. Aquatic Fauna Migration Barrier

BMPs which include a barrier across a watercourse will provide a barrier to the movement of aquatic fauna.

Impoundments, which are generally located in lowland streams, may divide fish populations and prevent the migration necessary for life cycle processes. Fish populations in upland streams on which BMPs are located, are less developed that in the lower reaches due to the unreliability of flow. The resulting conditions may favour introduced species. Impacts on fish populations can be minimised by appropriately designed fish ladders.

Barriers may reduce the ability of amphibians to access new food sources and alternative habitats.

Macro invertebrates will experience a reduction in ability to respond to physico-chemical stresses and to recolonise stressed downstream areas. BMPs are expected to alter species dominance and association. Upstream of a BMP insects are expected to be dominant as they can recolonise through flight. Downstream, more pollution tolerant taxa are likely to be present if low flow water quality leaving the BMP is worse than upstream water quality.

C. Trapping of Sediment and Organic Matter

BMPs are better at trapping coarse sediment than the fine fraction. They are generally designed to reduce the long term load of both sediments and nutrients from a catchment to predevelopment levels. Stormwater treatment measures tend to be more efficient at trapping sediments than nutrients. Therefore, BMPs may be designed to reduce sediment load to below predevelopment levels in order to achieve the desired reduction in nutrient loads. The coarse particulates retained within a BMP are composed of both inorganic and organic matter (including leaf litter).

The trapping of coarse sediment in a wet basin or wetland can result in a change in the morphology of the downstream watercourse. During flood events floodwater has a capacity to convey sediment. Downstream of the stormwater treatment measure, these floodwaters may have an excess conveyance capacity that may be satisfied by the erosion of particles from the bed or banks of the watercourse. This could reduce the diversity of habitats for aquatic fauna, deplete riffle zones and impact riparian vegetation.

The inability of stormwater treatment measures to effectively trap a large proportion of fine particulate matter can result in deposition of a fine layer of sediment on the substrate. This can reduce the available attachment sites for macro invertebrates, clog the gills of filter feeding invertebrates and result in degradation of habitat quality for other fauna.

BMPs trapping organic matter will reduce the downstream supply which many species use as an energy source. Provided that indigenous riparian vegetation is maintained downstream of the BMP, any impacts should only be localised.

D. Low Flow Water Quality

The construction of a relatively large body of still water on a previously running stream can result in increased water temperature and reduced dissolved oxygen relative to the inflow. In urban areas, stormwater runoff temperatures can already be significantly higher than those from a “natural” stream.

The length of stream downstream of the BMP for which the effects of the altered temperature and dissolved oxygen conditions will be felt will be dependent upon the nature of the substrate and the riparian vegetation. If the stream has riparian vegetation for shading and riffle zones for aeration, the impact may be discernible for a short distance.

Many BMPs are designed to reduce the pollutant load from storm events by trapping a proportion of the inflow pollutant load. However, during low flow situations, outflow nutrient concentrations may exceed inflow concentrations. Under certain conditions e.g. anaerobic conditions, phosphorous adsorbed to sediment may be released back into the water column. The decay of organic matter may also result in some nutrient release. Also, inflows may displace partially treated runoff from previous storm events.

Poor low flow water quality can be expected to result in a range of impacts similar to those generally associated with point sources of pollution due to the more constant outflow concentrations. Impacts can include elevated algal growth, depression of dissolved oxygen levels and reduction of aquatic fauna species richness and diversity. The nature of the impacts will be dependent on concentrations.

E. Altered Stream flow Regime

Stormwater treatment measures have the potential to alter post-urbanisation stream flow regime, particularly during low flow conditions due to the loss of water by evaporation and infiltration. The extent of these losses will depend upon the local climate and soil types.

Alteration of stream flow regime can have a wide range of impacts including disruption to the life cycle of aquatic fauna and exacerbation of natural movement barriers. More regular flow conditions favour introduced species of aquatic fauna and riparian vegetation.

F. Soil and Groundwater Contamination

The sediment that accumulates in the base of BMPs may contain heavy metals and other toxicants. Therefore, there is potential for pollutants to be leached through the soil layer and into the groundwater.

This may not, however, have a significant impact. Harper (1988) investigated groundwater conditions beneath a wet basin in Florida. He found that pollutant concentrations that were higher than surface water concentrations were generally limited to a 1 m layer beneath the basin.

3.7.2 POTENTIAL MITIGATION MEASURES

Sharpin and Morison (1995) suggest measures to mitigate environmental impacts.

A. Site Investigation

A detailed investigation of the terrestrial and aquatic ecosystems at the site, to assess whether the BMP will have any direct impact on endangered species or valuable habitats, should be undertaken.

B. BMP Location

The location of a BMP should be considered at the planning stage. The impacts associated with a BMP in the upper reaches of a watercourse is likely to impact less upon aquatic ecosystems than a BMP located in the lower reaches. BMPs located in the upper reaches have the potential to provide maximum protection to the aquatic ecosystems, rather than allowing degradation occurring in the untreated watercourse upstream of BMPs.

C. BMP Design

The low and high flow outlets from BMP structures can be designed using stepped outlets or spillways to maximise aeration. Unshaded concrete or rip-rap on the inlet and outlet works can be minimised. Aligning ponds in a north-south direction will minimise exposure to sunlight. Outflows could be drawn from below the surface to withdraw cooler water. The expected temperature and dissolved oxygen profile would need to be investigated to determine whether this would achieve a significant temperature reduction and if this would result in the release of lower dissolved oxygen concentration waters. Structures should be designed to minimise stratification and the occurrence of anaerobic conditions. Outlet structures should incorporate energy dissipation devices.

Measures can be integrated into stormwater treatment measures to reduce the effects of stratification. These include aerators (air jets, water jets or large fans) to mix the water. All of these are installed on the floor of the water body.

D. Riparian Vegetation

Riparian vegetation should be maintained both within and downstream of the BMP. Native plant species should be used. Vegetation will provide shade, hence reducing water temperature. Vegetation also provides important habitat value and is a source of organic matter.

E. Downstream Creek Characteristics

The channel downstream of the BMP should include a series of pools and riffle zones. Pools would encourage the decay of organic matter from the riparian vegetation and the riffle zones would assist in the aeration of the watercourse.

3.8.0 RECOMMENDATIONS

An integrated approach is required to effectively manage stormwater. Effective management of the stormwater environment should include consideration of:-

- ❖ hydrology
- ❖ water quality
- ❖ aquatic habitat
- ❖ vegetation

This document has dealt primarily with water quality. However, a framework of integrated catchment management and water sensitive urban design, which also includes integrated consideration of hydrology, aquatic habitat, vegetation and water quality, should be developed to manage stormwater in a sustainable way. Effective stormwater management systems should include pollution source controls, community education and stormwater re-use and harvesting as well as the BMPs outlined in this document. It is recommended that potential stormwater re-use and harvesting methods be investigated further.

The most effective method of stormwater quality management includes an integrated system of stormwater quality best management practice. This includes source controls, waterway corridors and treatment measures. To ensure the integrity of all waterways within a catchment, stormwater quality BMPs should be implemented as close to the pollutant source as possible. That is, a number of BMPs should be implemented in the upper reaches of a catchment as opposed to one large treatment measure in the lower reaches of a catchment. Stormwater treatment measures should consist of a system or BMPs or a "treatment train" e.g. grassed swales draining to wet basins to wetlands.

In planning BMP systems a number of factors need to be taken into account.

To develop an effective BMP system the environmental values of the receiving waters to which the stormwater drains need to be assessed. Assessment of these values should be used to determine management priorities. These environmental values include:-

- ❖ ecological
- ❖ economic
- ❖ recreational
- ❖ aesthetic and cultural
- ❖ scientific and educational

Additionally, the type of receiving water will also impact upon management requirements i.e. is the receiving water an estuary, a running water body or a standing water body?

Selection of BMPs will also be dependent on the following:-

- ❖ total limits
- ❖ soils
- ❖ topography
- ❖ depth to water table
- ❖ existing and future land use
- ❖ depth to bedrock

Hence BMP systems will be site specific.

Where possible, stormwater quality BMP systems should be considered on a catchment/sub catchment basis and designed to suit the environmental characteristics of that catchment.

From this document the BMPs recommended for the development of stormwater management systems are:-

- Vegetative systems, buffers - environmentally sensitive, high environmental value if properly maintained. Water quality is enhanced by complex biological processes as well as sedimentation.

- Wet basins - less land consuming than wetlands. High particulate removal efficiency with some degree of biological uptake of soluble pollutants as well. Can have high environmental value if properly maintained.

- Extended detention wet basins - the advantages of wet basins with enhanced sedimentation due to the extended detention volume and can be designed for management of large flood events as well.

- Gross pollutant traps - if used, should be installed upstream of wet basins or wetlands to enhance their performance and environmental value.

- Pollute CDS units - as yet unproven in the field. High removal efficiency for litter and coarse sediment under laboratory conditions.

- Infiltration devices are not recommended for use in Pine Rivers Shire because of the low permeability of clayey soils.

This document has not dealt with sizing of BMPs for stormwater quality. A number of methods have been developed for sizing stormwater quality BMPs. To adequately design BMPs in Pine Rivers Shire a more detailed study will need to be carried out. This study should take into account the rainfall patterns in Pine Rivers Shire and variations in pollutant loadings. The volume of runoff to be treated to achieve water quality and environmental goals and variation in rainfall and hence pollutant loadings throughout the year will need to be assessed in detail. Additionally, BMP sizing methods used elsewhere and their applicability to Pine Rivers Shire conditions should also be reviewed.

When planning stormwater quality BMP systems the potential environmental impacts of each BMP component and potential mitigation measures as discussed in Section 3.7.0 of the Design Standards for Stormwater Drainage need to be taken into consideration.

Management plans should be developed for all BMP systems to ensure the ongoing effectiveness of the system.

In addition to the recommendations made above, a list of suitable wetland plants for use in the Pine Rivers Shire region should be developed with preference given to native plants.

Adherence to sediment and erosion control guidelines during all types of development should be strongly promoted by the Pine Rivers Shire Council.

Finally, the protection of vegetated floodplains should be promoted and any modelling of floodplains should be undertaken using fully vegetated conditions.

3.9.0 REFERENCES

- ACT Government (1994) Urban Stormwater, Edition 1, Standard Engineering Practices, Department of Urban Services, Australian Government Publishing Service, Canberra

- Aitken C (1993); Benchmarking and Best Practice for Urban Waterway Management; sponsored by the Urban Water Research Association of Australia and Melbourne Parks and Waterways; UWRAA Project No WR-31(93/130)

- Athayde D N, Meyers C F and Tobin P (1986); EPAs Perspective of Urban Non-Point Sources, Urban Runoff Quality - Impact and Quality Enhancement Technology; proceedings of an Engineering Foundation Conference, ASCE, 217-225

- Bell PR (1994) The Use of Artificial Wetlands for Improvement in Water Quality of Stormwater Runoff from Urban Development in South East Queensland. Criteria for Design. Thesis component for MSc, Griffith University

- Brookes A (1987); Restoring the Sinuosity of Artificially Straightened Stream Channels; Environmental Geology of Water Sciences; Vol 10, No 1, pp 33-41

- Brookes A (1988); Channelised Rivers: Perspectives for Environmental Management; John Wiley and Sons Ltd, Surrey

- Brownlee RP (1995) Evaluation of Effectiveness and Efficiency of North Sydney Council Litter Control Device Program, The Second International Symposium on Urban Stormwater Management, 11-13 July, Melbourne, Australia

- Carroll DG (1994) The Effects of Urbanisation on Peak Flow Rates, 2nd Intd Conference on Stormwater Management, IE Aust. Melbourne, 1994

- CIRIA (1992) Scope for Control of Urban Runoff, London, UK

- Ecomax Waste Management Systems (1995); Correspondence

- Galli J (1991); Peat-sand Filters: A Proposed Stormwater Management Practice for Urbanised Areas, Watershed Restoration Source Book; Metropolitan Washington Council of Governments

- Galli J (1992); Analysis of Urban BMP Performance and Longevity in Prince George's County, Maryland; prepared for Prince George's County, Department of Environmental Resources Watershed Protection Branch; Metropolitan Washington Council of Governments, Washington D C

- Gerdes G (1994); A Geomorphologic Perspective on the Importance of a Watershed Approach to the Design of "Natural" Channel Systems, "Natural" Channel Design: Perspectives and Practice; ed Dan Shrubsole, proceedings, First International Conference on Guidelines for "Natural" Channel Systems, Niagara Falls, Ontario, March 1994.

- Hader W (1994); Managing Urban Streams - Important Natural Ecosystems or Drains; proceedings, Second Annual Conference Soil and Water Management for Urban Development - Creative Stormwater Management; 6-7 September 1994, Sydney.

- Harper HH (1988) Effects of Stormwater Management Systems on Groundwater Quality, report to Florida Department of Environmental Regulation.

- Hecky R E and Kilham P (1988) Nutrient Limitation of Phytoplankton in Freshwater and Marine Environments: A Review of Recent Evidence on the Effects of Enrichment, Limnology and Oceanography, 33 (4 part 2): 796-822.

- Hollis G E (1975); The Affect of Urbanisation on Floods of Different Recurrence Intervals, Water Resources Research, Vol II, No 3.

- Horner R R (1988); Biofiltration Systems for Storm Runoff Water Quality Control; Washington State Department of Ecology, Seattle, Washington.

- Jollife I B (1995); The Hydrological Cycle in Urban Drainage, Environmental Aspects of Urban Drainage; Stormwater Industry Association Seminar Proceedings, ed Sharpin M G.

- Lawrence I (1995); Urban Stormwater Modelling: An Ecological Perspective, Preprints, The Second International Symposium on Urban Stormwater Management; July 1995, Melbourne.

- Manahan S E (1991); Environmental Chemistry; Lewis Publishers.

- Marshall Macklin Monaghan Limited (1992); Stormwater Quality Best Management Practices; prepared for Environmental Sciences and Standards/Water Resources, Ontario Ministry of the Environment, Ontario, Canada.

- Marshall Macklin Monaghan (1994); Stormwater Management Practices and Planning Design Manual, prepared for Ontario Ministry of Environment and Energy, Canada.

- Maryland Department of the Environment (1991); Water Quality Inlets (Oil/Grit Separators); Sediment and Stormwater Administration.

- Morison AJ and Williams WD (1995) Urban Drainage and Aquatic Ecology, proceedings from Environmental Aspects of Urban Drainage, a Stormwater Industries Association Seminar.

- Metropolitan Washington Council of Governments (1991); Watershed Restoration Source Book.

- Morse McVey and Associates (1993); Soil and Water Management for Urban Development Second Edition; NSW Department of Housing.

- Nichols P S and Short S A (1992); Experience in the Application of Stormwater Pollution Control Guidelines in the Illawarra Area, International Symposium on Urban Stormwater Management; Sydney, 4-7 February, 1992.

- North Central Texas Council of Governments (1993); Stormwater Quality Best Management Practices for Residential and Commercial Land Uses.

- Novotny V and Olem H (1994); Water Quality: Prevention, Identification and Management of Diffuse Pollution; Van Nostrand Reinhold, New York.

- Oakland P H (1983); An Evaluation of Stormwater Pollutant Removal through Grassed Swale Treatment, proceedings, International Symposium of Urban Hydrology and Sediment Controls; H J Stirling (ed), Lexington, Kentucky.

- Overcash M R, Bingham S C and Westerman P W (1981); Managing Runoff and Pollution Reduction in Buffer Zones Adjacent to Land Treatment Sites; VASAE 24(3).

- Packman J C (1981); Affect of Catchments Urbanisation on flood flows, ICE Flood Study Report - 5 Years; Thomas Tillford, London.

- Pitt R (1986); Manual of Practice for the Design of Construction Site Erosion and Stormwater Runoff Controls; prepared for NPS and Land Management Section, Wisconsin Department of Natural Resources, Madison, Wisconsin.

- Pollute (1995); Correspondence.

- Potts R R and Bai J L (1989); Establishing Variable Width Buffer Zones Based Upon Site Characteristics and Development Type, Proceedings, Symposium on Water Laws and Management; American Water Resources Association, Bethesda, Maryland.

- Salvatori F and Jurak B (1994); An Ecosystem Based Approach to Stream Protection and Restoration, "Natural" Channel Design: Perspectives and Practice; ed D Shrubsole, Proceedings, First International Conference on Guidelines for "Natural" Channel Systems, Niagara Falls, Ontario, March 1994.

- Schloze R, Novotny V and Schonter R (1993); Efficiency of BMPs for Controlling Priority Pollutants in Runoff; Wat Sci Tech; Vol 28, No 3-5 pp 215-224.

- Schueler T R (1987); Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs; prepared for Washington Metropolitan Water Resources Planning Board, Washington D C.

- Schueler TR (1992) Design of Stormwater Wetland Systems: Guidelines for Creating Diverse and Effective Stormwater Wetlands in the Mid-Atlantic Regions, Metropolitan Washington Council of Governments.

- Schueler T R and Helfrich M (1989); Design of Extended Detention Wet Pond Systems in, Design of Urban Runoff Quality Controls; ed Roesner L A, Urbonas B, Sonnen M B, ASCE, New York.

- Schueler T R, Kumble P A and Heraty M A (1992); A Current Assessment of Urban Best Management Practices: Techniques for Reducing Non-point Source Pollution in the Coastal Zone; Metropolitan Washington Council of Governments.

- Sharpin M G (1995a); Stormwater Quality Characteristics from Urban and Non-urban Catchments in South-eastern Australia; proceedings, AWWA 16th Federal Convention; 1995, Sydney.

- Sharpin M G (1995); Stormwater Quality and Urbanisation, Environmental Aspects of Urban Drainage; Stormwater Industry Association Seminar Proceedings, ed Sharpin M G.

- Sharpin M G and Morison A (1995); Environmental Impacts of Stormwater Treatment Measures. Proceedings, 16th AWWA Conference; Sydney.

- Sharpin ME, Morison AJ and Goyen AG (1995) Managing the Stormwater Environment, Environmental Aspects of Urban Drainage, a Stormwater Industry Association Seminar.

- Sharpin M G and Morison A J (1995); Towards Ecologically Sensitive Drainage Systems, proceedings, Second International Symposium on Urban Stormwater Management; Melbourne, 11-13 July 1995.

- Southcott P H (1995); A Case Study of a Minor Gross Pollutant Trap, proceedings, Second International Conference on Urban Stormwater Management; Melbourne, International E Australian National Conference Publication No 95/3.

- State Pollution Control Commission of NSW (1989); Pollution Control Manual for Urban Stormwater.

- Strecker E W, Pathegyi G E and Driscoll E D (1990); The Use of Wetlands for Control of Urban Runoff Pollution in the USA, Proceedings, 5th International Conference on Urban Storm Drainage; eds Y Iwasa & T Sueishi, University of Osaka, Suita-Osaka, Japan, 1495-1507.

- Tollner E N, Barfield B J and Hayes J C (1982); Sedimentology of Erect Vegetal Filters, Proceedings, Hydraulic Division, ASCE, Vol 108, No 12.

- Urbonas B and Stahre P (1993); Stormwater Best Management Practices and Detention for Water Quality, Drainage and CSO Management; PTR Prentice Hall, Eaglewood Cliffs, New Jersey.

- Urbonas B and Stahre P (1993); Stormwater Best Management Practices and Detention for Water Quality, Drainage and CSO Management; Prentice Hall, New Jersey.

- USEPA (1983); Results of the Nationwide Urban Runoff Program; NTIS Report PB84-185552.

- Wang T, Spyridakis D E, Mar B W and Horner R R (1982); Transport, Deposition and Control of Heavy Metals in Highway Runoff; Washington State Department of Transportation, Seattle, Washington.

- Wanielista M F, Yousef Y A, Harper H H and Cassagnol C L (1982); Detention with Effluent Filtration for Stormwater Management in, Urban Stormwater Quality, Management and Planning; B C Yen (ed), Water Resources Publication, Littleton, Colorado.

- Whelans (1993); Water Sensitive Urban (Residential) Design Guidelines for the Perth Metropolitan Region - Schedule of Best Management Practices; prepared for the Department of Planning and Urban Development, the Water Authority of Western Australia and the Environmental Protection Authority

- Whelans (1993); Water Sensitive Urban (Residential) Design Guidelines for the Perth Metropolitan Region - Discussion Paper; prepared for the Department of Planning and Urban Development, the Water Authority of Western Australia and the Environmental Protection Authority

- Whytecross G J, Johnston T A, Nagy L A and Farrante A A(1989); Physical, Chemical and Biological Processes within a Gross Pollutant Trap and their Management Implications, 13th AWWA Federal Convention; Canberra.

- Willing and Partners (1995); Draft Stormwater Management Strategy for Homebush Bay.

- Wong H F and Wootton R M (1995); An Innovative Gross Pollutant Trap for Stormwater Management, preprints, The Second International Symposium on Urban Stormwater Management; Melbourne, Australia, 11-13 July.

- Wong S L and McCuen R H (1982); The Design of Vegetative Buffer Strips for Runoff and Sediment Control, Stormwater Management in Coastal Areas; Tidewater Administration; Department of Natural Resources, Annapolis, Maryland.

- Woodard S E (1989); The Effectiveness of Buffer Strips to Protect Water Quality; M Sci Thesis; Department of Civil Engineering, University of Maine, Orono, Maine.

- Woodfull J, Finlayson B and McMahon T (1992); The Role of Buffer Strips in the Management of Waterway Pollution from Diffuse Urban and Rural Sources; Land and Water Resources Research Development Corporation, Melbourne, Occasional Paper No. 01/93.

- Yousef Y A, Wanielista M P, Dietz J D, Lin L Y and Brabham M (1990); Efficiency Optimisation of Wet Detention Basins for Urban Stormwater Management; Department of Civil and Environmental Engineering, University of Central Florida.

- Yousef Y A, Wanielista M P, Harper H H, Pearce D B and Tolbert R D (1985); Best Management Practices - Removal of Highway Contaminants in Roadside Swales; FL-ER-30-85, Department of Transportation, State of Florida, Tallahasse, Florida.