Chapter 4

Stormwater

Introduction

4.1 Light rain falling in natural, undisturbed catchments is generally totally infiltrated or absorbed into the ground. In urban areas rainwater is referred to as stormwater and impervious surfaces such as roads, roofs and pathways prevent its absorption. To avert flooding it is piped and channelled to watercourses or constructed stormwater drains which discharge onto beaches and into rivers, streams and the bush:

> The construction of large impervious surfaces through urbanisation has created traditional urban stormwater conveyance systems such as pipes and kerbs and gutters to relay water away from the urban areas as quickly as possible to minimise flooding potential. As a result, there is decreased groundwater recharge and lower base flows resulting in an imbalance in the water cycle.[1]

4.2 Natural pre-development catchments can absorb and infiltrate up to 90 per cent of precipitation falling upon them, whereas dense urban catchments can, in extreme instances, only hold as little as 10 per cent of precipitation.[2]

4.3 The average annual volume of stormwater discharged nationally is about 3,000 gigalitres and the quantity of stormwater shed by an urban area is a function of climate, geology, topography, degree of imperviousness, and stormwater drainage practices. Urban areas usually cover part of one or more catchments, and in the case of Australia's many coastal settlements, the urban area is located at the lowest reaches of these catchments. Stormwater flowing from a catchment therefore originates in both the undeveloped and urbanised areas, making it difficult to separate stormwater from either source.

4.4 In the past, point sources of pollution such as factories were the principal targets for water quality improvement programs but stricter regulation has generally seen progress in that area. Consequently the focus is now shifting to stormwater management as the priority issue in water quality management. Additionally, as Chapter 2 showed, cities are exhausting their current water supplies and so stormwater is increasingly being regarded as a hitherto undervalued resource.

4.5 Future stormwater use is therefore likely to be of significant environmental benefit through minimising the need to augment traditional water supplies,[3] a fact recognised in the COAG Water Reform Agenda.

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1 Hornsby Shire Council, *Submission 6*, p 2.

2 Stormwater Industry Association Inc, *Submission 37*.

4.6 In this context, and in comparison to sewage effluent, stormwater may appear to be much more suitable for urban use because of its perceived higher quality. However, wider use of stormwater can be complicated by the intermittent nature of rainfall and the variable quality of stormwater run-off.

4.7 This chapter examines some of these problems as well the many opportunities for making better use of stormwater, including on-site rainwater tanks, community collection and storage for irrigation, aquifer storage and recovery, and habitat restoration such as for wetlands and streams.

4.8 The chapter concludes with an examination of Water Sensitive Urban Design theory, and how it has been successfully applied in sites around Australia.

Problems with stormwater

4.9 The stormwater drainage system was designed on the assumption that stormwater was benign in nature. However we now realise that stormwater can be extremely polluted. The problem is exacerbated by the traditional drainage infrastructure and hard urban surfaces which were designed with the purpose of conveying the water from built-up areas as quickly as possible. The resulting fast flowing water causes erosion and silt build up, as well as pollution problems.

Stormwater pollution

4.10 During its passage, stormwater collects contaminants and litter from urban surfaces such as roads, roofs, pathways and gardens, and deposits them into rivers, estuaries and coastal waters. These receiving water have some capacity to cope with the changes of flow and pollutant load brought on by urbanisation, but beyond a certain point, the changes cause major environmental damage.

4.11 Despite its high pollutant loads stormwater enters waterways without undergoing any treatment. The contaminants comprise fine particles and dissolved materials (micro-pollutants), as well as litter and vegetation (gross pollutants). Natural sources of stormwater contaminants are derived from the atmosphere, from organics in the soil, and from decaying organic debris. Sources of contamination which can be attributed to human activity include: sediment transmission from construction sites, pesticides and fertilisers, litter, weeds, faecal matter, vehicle emissions, metal particles from corrosion and abrasion, spills of substances like oil and paint on land surfaces, cigarette butts, and air pollution emissions.[4]

4.12 Research by the Cooperative Research Centre for Catchment Hydrology shows that stormwater becomes polluted in two phases – build-up and wash-off.[5]

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3 CSIRO, *Submission 47*, p 51.

4 CSIRO, *Submission 47*, p 42.

5 Cooperative Research Centre for Catchment Hydrology, *Urban Stormwater Pollution*, Industry Report, 97/5, July 1997, pp 8-9.

4.13 The build-up occurs as pollutants accumulate on pavements and other surfaces during dry weather through: the settling of fine particles from the atmosphere; the accumulation of fine particles and gross pollutants from local sources; and the redistribution of surface pollutants by wind and traffic.

4.14 Roads have high pollution loads because of vehicle and road wear, particularly heavy metals from brakes and clutches, and oil (hydrocarbons) from leaking engines.

4.15 The level of pollutant build-up depends on the rate of deposition; the length of the dry period; and any removal by redistribution, decomposition, street sweeping or wash-off. Build-up of pollutants increases with time until it reaches a certain point where it stabilises. This is because the removal rate of surface pollutants increases as the buildup increases, and it eventually equals the input rate.

4.16 Wash-off is where the accumulated pollutants are removed from surfaces by rainfall and run-off. Rainfall not only dislodges and dissolves pollutants from surfaces, but also washes them out from the atmosphere, adding to stormwater pollutant loads. Typically only a small proportion of surface pollutants are washed off in a single rainfall event and most of the pollution in urban catchments is generated during heavier storms.

4.17 In general terms though, the most heavily polluted stormwater is the run-off from the initial rainfall, and the water containing this high initial pollutant load is called the ‘first flush’. Stormwater then becomes cleaner as the rain ‘cleanses’ the catchment.

4.18 After stormwater enters the drainage system, its quality can be further reduced by sewer overflows and the infiltration of poor quality water leaching from landfill or septic tank sites. In periods of high rainfall, sewage overflows into the stormwater system from both leaks in the sewerage system as well as from in-built relief valves that prevent sewage backing-up into buildings when there is an accumulation of pressure in the pipes. Transfers between the two systems can also occur from groundwater infiltration as well as illegal septic or industrial connections on individual properties.

4.19 There is also some concern over the cumulative effects of small unlicensed industries releasing waste into the stormwater system, although the extent of this practice is unknown.[6]

Atmospheric deposition

4.20 Another source of water pollution is the deposition of airborne pollutants onto urban surfaces or directly into waterways. These can come from unburnt fuel of older cars, and from all other particulates in smog.

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6 Mr McCarthy, *Proof Committee Hansard*, Perth, 29 April 2002, p 409.

4.21 The Moreton Bay Study[7] estimates that an average of 69 tonnes of nitrogen and 25 tonnes of phosphorous are delivered via atmospheric deposition to Moreton Bay each year. The study notes that these model estimates for atmospheric deposition of nitrogen appear to be quite low when compared with measured loads from other locations, such as from the Richmond River Catchment in coastal northern New South Wales. Atmospheric inputs of nutrients into waterways will not be affected by programs to reduce nutrients from sewage and stormwater discharges and atmospheric inputs may be increasing due to nitrogen oxides from car and truck emissions.

Accelerated run-off from sealed urban catchments

4.22 The speed with which stormwater flows, as well as its turbidity,[8] scours the water courses it enters and erodes river banks and beds, preventing the growth of vegetation which could provide habitat as well as assist in removing pollutants.

4.23 Some watercourses in cities have been smoothed, straightened and concreted to accelerate stormwater removal from the cities. This effectively destroys riverine ecosystems that, in their natural state, have some capacity to filter pollutants and allow the capture of contaminants in sediment.

Flooding

4.24 Natural systems are designed to flood and when this happens rivers collect nutrients from the land which support aquatic ecosystems. Many ecosystems on the land also depend on periodic inundation for their health. These systems have adapted to both small floods as well as larger but more infrequent flood episodes, and many ecosystem and breeding patterns are linked to these flood cycles.

4.25 As is explained in more detail below, by building on floodplains, cities incur significant risks of inundation and cities often find themselves in a double bind. By creating dense urban areas, they leave no room for the flooding that is the natural way of dealing with stormwater. At the same time, the increased density and corresponding increases in impermeable surfaces, greatly increase loads on stormwater infrastructure, making flooding more likely. In some areas it is even becoming more cost effective for authorities to purchase properties than attempt to use flood mitigation methods to protect them.[9]

Impacts of urban infill

4.26 Greater urban densities worsen the impact of stormwater run-off and increase the quantity of water as buildings, paving and concrete cover pervious areas and the

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7 *Moreton Bay Study, A Scientific Basis for the Healthy Waterways Campaign*, William C Dennison and Eva G Abal, South East Queensland Regional Water Quality Management Strategy, pp 50-51. [Tabled document, 4 April 2002]

8 Turbidity is a measure of the concentration of particles. It is also referred to as total suspended sediment.

9 Committee briefing, Brisbane City Council, Brisbane, 5 April, 2002.

water cannot then be slowed in its passage and infiltrate the soil. Instead efficient hydraulics force it into channels, where the volumes rapidly increase:

> Until recently in Australia … the low-density development that we have had has permitted this reasonable control of urban stormwater run-off, through gardens. As cities start to be in-filled, we are increasing the urban run-off. As I keep stressing, we do not really know what is happening in the long term. If we keep doing that, groundwater levels will possibly drop, and that will have an effect on tree growth in our cities.[10]

4.27 The prospect of flooding, particularly from smaller, more frequent storms, as a consequence of urban consolidation is elevated:

> Our stormwater drainage system has been in place for many years. In fact, our city has developed on its infill housing which is adding to the population. It is true to say that our stormwater drainage system would probably not be able to cope with the return of a one in 10-year flood. Melbourne Water has put an overlay on 4,500 properties in the city. For the one in 100-year return storm, many properties would be flooded and there would be flooding at normal ground level over the area. Our stormwater drainage systems, designed up to 100 years ago, were designed for perhaps a one in five-year return flood or a one in 10 at best. That has caused a lot of concern within the city over the issue.[11]

4.28 Increases in run-off provide additional stress to aging infrastructure that was not designed to cope with the greater flows:

> With Port Phillip being so close to the bay, when we get a high tide and only a moderate downpour of rain, we can get the stormwater drains filling up to the point that there is just no more capacity, and we get localised flooding that can last for several hours, and that must not be exacerbated as a result of further development.[12]

4.29 Professors Troy and White note that the major stormwater drainage problems now occur in areas undergoing redevelopment to higher densities and site coverage that increases the run-off, frequently resulting in flows above those for which the original developments were designed.[13]

4.30 The effect of the increase in run-off from redevelopment projects is magnified because the area available for soakage and water retention is reduced. The resulting nearly 'instantaneous' run-off frequently leads to peak localised flooding as the runoff exceeds the design capacity of the drainage systems. The costs of amplification of the stormwater drainage system are high and are rarely born by developers.

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10 Prof Taylor, *Proof Committee Hansard*, Canberra, 22 March 2002, p 36.

11 Cr Beadle, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 305.

12 Mr Holdsworth, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 354.

13 Centre for Resource and Environmental Studies, *Submission 50*, p 3.

Impact of stormwater on receiving waters

4.31 Stormwater has become the single most important source of pollution of the water bodies around or on which cities are developed.[14] The accelerated runoff from sealed urban catchments increases erosion, contributes to flooding and increases transport of litter, nutrients, toxicants and other pollutants to receiving waters. The associated impacts on the waterways include:

- increases in peak discharge and frequency affecting scouring;
- increases in nutrient loads with associated risk of eutrophication and impacting on primary production as a result of nuisance algae;
- increases in toxicants (heavy metals, pesticides, ammonia) accumulating in estuarine and near shore sediments and impacting on aquatic biota;
- increases in sediment and suspended solids;
- oxygen demanding substances impacting on dissolved oxygen (aquatic animals) and sediment redox processes (water quality);
- bacteria impacting on recreation and water supply suitability;
- rubbish and debris impacting on visual quality of waterways; and
- reduction in biodiversity within the waterways and increased risk of algal blooms and other ecological perturbations.[15]

4.32 Research by the CRC for Freshwater Ecology has led to a better understanding of key in-stream processes in urban waterbodies. The high levels of suspended solids, nutrients and toxicants in stormwater are rapidly adsorbed[16] onto the surfaces of suspended particles during high flows, and which then settle as sediments during low flow periods.

4.33 Bacteria and other biota play an important part in stream processes. Organic carbon (essentially from decaying vegetable matter) triggers the release of nutrients from sediment through microbial processes, and these nutrients then stimulate algal growth. These understandings highlight the importance of managing organic carbon inputs as a significant driver of algal blooms. This has implications for catchment management strategies, licence setting and wastewater treatment.[17]

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14 Centre for Resource and Environmental Studies, ANU, *Submission 50*, p 2.

15 CRC for Freshwater Ecology, *Submission 52*, p 2; *and* Melbourne Water, *Submission 46*, p 9.

16 Adsorption is the bonding of metals and nutrients onto the surfaces of suspended particles, by way of physical, chemical and biological processes, and their removal by a process of sedimentation of the suspended particles.

17 CRC for Freshwater Ecology, *Submission 52*, p 2.

Lack of clarity in roles, responsibilities and reporting requirements of public agencies

4.34 Unfortunately, any attempts to deal with these problems of pollution in stormwater are frustrated by the lack of clarity in the management arrangements in relation to stormwater. To begin with, stormwater flows through a number of jurisdictions between where it falls and its arrival into receiving waterways. Thus, agencies with the responsibility for maintaining water quality in a river, may have no control over the quality of the stormwater that flows into that river. Similarly, responsibility for stormwater infrastructure is shared between developers, local authorities, roads and traffic authorities, trunk drainage utilities and many others.

4.35 This fragmentation is discussed in greater detail in Chapter 6, but at this point, it can be concluded that the result is often a mismatch between the regulatory authority with responsibility for an outcome, and those with the authority to do something about it.

Best practice stormwater management

4.36 Increasingly, efforts are being made to address the negative effects of urban stormwater on receiving waters and there have been significant advances in technologies for improving the quality of urban stormwater to either support its ultimate reuse or to protect and sustain the environmental values and health of urban aquatic ecosystems.[18]

4.37 Contemporary urban stormwater management objectives now encompass issues beyond the traditional stormwater drainage objective of efficient conveyance of stormwater to the receiving waters for local flood protection, and they include such management objects as:

- stormwater quality improvement;
- stormwater as a resource (for meeting both human and environmental demands);
- protection or rehabilitation of ecosystem health of urban aquatic systems; and
- incorporation into urban landscapes for promotion of aesthetic and passive recreation attributes.[19]

4.38 Essentially the technical solutions to the problems are available and best practice aims to reduce the impacts of stormwater on receiving waters by reducing the volume and intensity of stormwater flows, slowing the speed of the water, retaining water on site, trapping pollutants at appropriate points and cleansing the water.

4.39 Better urban design that minimises impervious areas and allows for infiltration throughout the catchment can achieve this. Grassed waterways and creek

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18 CRC for Catchment Hydrology, *Submission 25*, p 3.

19 CRC for Catchment Hydrology, *Submission 25*, p 2.

restoration can replace concrete drains and slow run-off, help filter contaminants and at the same time provide the community with amenities such as bikeways and footpaths. Erosion and sediment control measures, particularly at building and construction sites, can prevent sediment being washed into waterways. Artificial wetlands can be constructed at appropriate points in the urban catchment to capture run-off, slow down water flows, allow sediment to settle out, and nutrients to be absorbed by plants.

4.40 However, there are different management techniques for different climatic regions and for different sites within regions. Solutions will depend on the nature of the soils, impervious areas, terrain and climate. For example, the Committee found that North Queensland in particular faces the challenge of managing tropical catchments with heavy, intensive rainfall and a long dry season.

4.41 To accommodate these regional differences, the Stormwater Industry Association has been developing a new manual, *Water sensitive urban design: basic procedures for stormwater source control—a manual of Australian practice* which is a design manual for stormwater management for every climatic region in Australia.[20] It provides engineering design methodologies for water sensitive urban design systems and gives engineers a systems approach with formula calculations that gives substance to integrating water sensitive urban design principles into conventional engineering practice.

4.42 However, there are insufficient funds available to complete the graphic drawings necessary to illustrate the various design and management techniques or to print the edition. The Committee considers that it is important that this manual be widely available to assist in stormwater management solutions.

First flush targeting

4.43 The existence of a first flush of pollutants provides an opportunity for controlling stormwater pollution from a broad range of land uses. First flush collection systems can be employed to capture and isolate this most polluted runoff, with subsequent runoff being diverted directly to the stormwater system.[21] For example, the Townsville City Council makes no attempt to retain and treat the entire flow from large rain events, for this would be an impossible task. Instead, it limits its efforts to treating the first flush.

4.44 However, a toxic first flush does not occur in all cases. Intensive monitoring of stormwater runoff from some (usually larger) catchments has shown no evidence of

20 Mr Wood, *Proof Committee Hansard*, Sydney, 18 April 2002, p 159.

21 *Stormwater First Flush Pollution*, NSW Environment Protection Agency site, at: http://www.epa.nsw.gov.au/mao/stormwater.htm

a ‘first flush’ and this can have a major influence on the design of stormwater pollution controls.[22] Some of the reasons for the absence of a first flush may be:[23]

- the drainage characteristics of the catchment may prevent it. In larger catchments, the time taken for pollutants from different parts of the catchment to reach a given outlet may be some time after a storm starts, resulting in a less detectable first flush. This time lag is rarely an issue for smaller, individual catchments;
- the pollutants may not be very mobile. For example, bare soils or vegetated surfaces are generally not ‘cleansed’ as easily or effectively as sealed surfaces; and
- pollutant sources that are effectively continuous may exist within the catchment. First flush is generally seen only where the supply of pollutants is limited. Sediment washing off from soil erosion, for example, will not give a first flush because the supply of soil particles is (for all practical purposes) unlimited.

4.45 Other pollution discharges that are not directly related to stormwater runoff may mask any first flush associated with the runoff. For example, in urban catchments during large storms, there can be continuous discharges from sewer overflows.

Treatment trains

4.46 One of the best ways to address the problems of urban water management is to use treatment trains, or the sequencing of best management practices:

> … commonly, best management practices work better when they are used in concert with other complementary practices rather than in isolation. Commonly, the practices are applied sequentially to address the sources, transmission and removal of pollutants to maximise their effectiveness.[24]

4.47 This series of treatment processes can be designed to collectively meet prescribed water quality objectives. Stormwater may be managed using a combination of source control, mid-pipe and end of pipe measures, depending on the circumstances and the management requirements for the catchment. To design an effective, economical and robust stormwater system requires planning and engineering expertise. In order for it to be effective, an urban stormwater management plan must address the following issues:

- stormwater quantity – flood and drainage management, stormwater reuse;

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22 *Stormwater First Flush Pollution*, NSW Environment Protection Agency site, at: http://www.epa.nsw.gov.au/mao/stormwater.htm

23 *Stormwater First Flush Pollution*, NSW Environment Protection Agency site, at: http://www.epa.nsw.gov.au/mao/stormwater.htm; *and* Cooperative Research Centre for Catchment Hydrology, *Urban Stormwater Pollution*, Industry Report, 97/5, July 1997, p 9.

24 Mr Bott, *Proof Committee Hansard*, Canberra, 22 March 2002, p 6.

- stormwater quality – litter, nutrients, chemicals and sediment; and
- aquatic ecosystem health – aquatic habitats, riparian vegetation, stream stability and environmental flows.[25]

Stormwater improvement devices

4.48 There are many options for improving the quality and quantity of stormwater and they range from engineered systems to landscaping methods that control the way water flows. The options chosen will depend on the limitations of the area being treated. For example options that are available to treat established urban areas will be limited by the open space available, and solutions to dense urban areas will differ from those for suburban or rural residential areas.

Pollutant traps

4.49 In many cases, improvements in stormwater management have been prompted by aesthetic imperatives, and communities have urged their local councils to address unsightly consequences of stormwater drains – such as scouring, and deposition of leaf and other litter on beaches and in waterways. Gross pollutant traps are designed to prevent the visual pollution of litter from entering waterways.

4.50 Gross pollutants are large (more than five millimetres) pieces of debris that get flushed through urban catchments and stormwater systems.[26] Gross pollutant traps come in various designs that provide a physical barrier to the pollutants while allowing water to flow through. The appropriate type of trap will depend on whereabouts in the catchment it is to be installed, and what are the targeted pollutants.

4.51 Typically, gross pollutant loads in Australia's urban areas lie between 20 and 40 kilograms per hectare per year of dry mass.[27] The largest proportion of gross pollution load (about three-quarters of all stormwater gross pollutants) is vegetative matter such as leaves, twigs and garden refuse, however this is not a major source of nutrients compared with other sources.

4.52 Most of the human-derived material is paper and plastics and these enter the drainage network as street litter mainly from commercial areas. There are also large quantities of food, drink and cigarette refuse, which suggests that fast food consumers and smokers are a significant source of litter in urban streams.[28]

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25 Great Barrier Reef Marine Park Authority, *Submission 60*.

26 Cooperative Research Centre for Catchment Hydrology, *Stormwater Gross Pollutants*, Industry Report, 97/11, December 1997, p 1.

27 Cooperative Research Centre for Catchment Hydrology, *Urban Stormwater Pollution*, Industry Report, 97/5, July 1997, p 10.

28 Cooperative Research Centre for Catchment Hydrology, *Stormwater Gross Pollutants*, Industry Report, 97/11, December 1997, pp 3-4.

4.53 Some of the most common types of pollutant traps include:[29]

- side entry pit traps (SEPTs). These are baskets fitted below the entrance to drains from road gutters and they retain any material larger than the size of the basket mesh. By fitting them at many locations throughout the urban catchment, they can trap up to 80 per cent of litter. They need to be emptied every four to six weeks;
- litter control devices (LCDs). These are large baskets that are placed below the entry point of an inlet pipe to collect litter from the pipe. As debris builds up in the devices, it allows smaller material to be caught as pore sizes in the baskets are reduced. Their efficiency ranges from 30 to 80 per cent depending on the frequency with which they are cleaned out;
- trash racks. These consist of vertical or horizontal steel bars placed 40-100 mm apart, fitted across stormwater channels that are up to 10 metres wide. As water passes through the trash rack, large material is caught and as it builds up, finer material is collected. They require manual, usually monthly, cleaning;
- continuous deflective separation (CDS) units. These are installed in stormwater channels and work by diverting the incoming flow of stormwater and pollutants into a pollutant separation and containment chamber. Solids are kept in continuous motion which prevent them from blocking the screen. Water passes through the screen and flows downstream. All gross pollutants are retained except for flows that overflow the by-pass weir during large floods. Floating objects are kept in continuous motion on the water surface while heavier pollutants settle into a containment sump from which they can be removed;
- gross pollutant traps (GPTs). These are large concrete-lined wet basins upstream of weirs that slow down the water flow to encourage coarse sediments to settle to the bottom. Gross pollutants are retained by trash racks usually made from vertical steel bars at the downstream end of the basin; and
- floating debris traps (FDTs). Also called litter booms, these traps are made by stringing partly submerged floating booms across waterways. They collect floating objects as they collide with them. Some use floating polyethylene boom arms with fitted skirts to deflect floating debris through a flap gate into a storage compartment. These traps are best suited for gathering highly buoyant materials in slow-moving waters, as they will miss most of the gross pollutant load which sinks.

4.54 In general pollutant traps can be effective in preventing visual pollution from entering waterways but their installation may instil a false sense of environmental security as less visible, but equally damaging, sources of pollution such as nutrients,

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29 Cooperative Research Centre for Catchment Hydrology, *Stormwater Gross Pollutants*, Industry Report, 97/11, December 1997, pp 8-10.

sediment and chemical elements will continue to flow to the environment. It is this area that needs to be tackled:[30]

> The fine sediments are generally not captured because of the filtering mechanism and the fine sediments, unfortunately, are the ones which lead to the turbidity in the rivers and the bay, causing the seagrasses to die.[31]

4.55 However, the Committee received evidence that CDS units were collecting more than just gross pollutants. Some preliminary work in which Dr Peter Fisher is involved suggests that the litter in such units becomes contaminated with heavy metals, herbicides and pesticides by up to three times more than the liquid in which it is immersed. This suggests that the litter is acting as a filter within the trap by adsorbing contaminants from the catchment,[32] which also implies that in catchments that do not have traps, these substances are freely entering waterways.

4.56 There is also a suspicion that wet vault pollutant traps of this type, which are not cleaned out regularly enough, re-contaminate the water that flows through them during and after downpours,[33] thereby becoming sources of pollution themselves.

4.57 Mr Diprose raised concerns that the claims made by various manufacturers of pollutant traps are not independently evaluated. He recommends that there should be some kind of accreditation for them:

> My suggestion would be that anything that is going to be installed on a stormwater outfall to prevent the discharge of pollution into the marine environment should go through the same form of evaluation process. Unfortunately, all that needs to happen is that the supplier says, 'We are nearly as good as a CDS unit, but we are much cheaper.' … If we spend money on anything which is designed to protect the environment, we should have some assurance—as we do with washing machines, televisions and cars—that that thing does what it says it does. At the moment, there is no regulatory structure anywhere in Australia that requires that to be so.[34]

4.58 Without wishing to see more impediments such as increased costs and bureaucracy placed in the way of the installation of stormwater improvement devices, the Committee supports the idea that manufacturers' claims as to their products' efficacy is independently verified. These issues are dealt with in Chapter 6.

Artificial wetlands

4.59 The term 'artificial wetland' is loosely used to describe a self-sustaining filtration and water treatment system designed to maximise removal of pollutants from

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30 Cr Johnstone, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 351.

31 Dr Abal, *Proof Committee Hansard*, Brisbane, 4 April 2002, p 92.

32 Dr Fisher, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 368.

33 Dr Fisher, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 369.

34 Mr Diprose, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 377.

water. It consists of various combinations of reed beds, open water, sedimentation ponds and gross pollutant traps.

4.60 Wetlands have shallow water that is less than 2 metres deep, although their water levels often fluctuate in wetting and drying cycles ranging from regular to very erratic. Ponds are more permanent, deep, and open water bodies with narrow, steep edges that may be fringed with emergent macrophytes (plants such as rushes, reeds and sedges. These macrophytes often have algae growing on their surface, known as epiphytes). They may also contain submerged aquatic plants. [35]

4.61 Wetland systems exhibit seasonal variability but have the potential to remove suspended solids, nutrients and toxicants. They can remove pathogenic bacteria by sedimentation, predation, and natural die-off. Open water sections in wetlands allow ultraviolet radiation to kill pathogens and significant die-off rates have also been demonstrated for viruses.

4.62 A typical stormwater management system includes:[36]

- gross pollutant trap (GPT)—to trap artificial and natural litter and coarse particles such as gravel and sand;
- pollution control pond/constructed wetland inlet zone—to trap sand-to silt-sized particles and improve water quality. This component of the system can have additional benefits such as aesthetic value and slowing down flows;
- an area of plants such as rushes, reeds and sedges (macrophyte zone)—to improve water quality through the trapping of fine particles and soluble pollutants. Secondary benefits include wildlife habitat and slowing down flows;
- lake/island—to provide passive recreation, landscape enhancement and wildlife habitat. Depending of their construction, lakes can significantly slow down water flows, and they can also provide water quality benefits. However if the lake attracts large populations of wildlife, water quality can be degraded by the addition of such things as bird droppings and other organic matter; and
- flood retarding basin—to protect downstream areas from flooding and to control stream hydrology.

4.63 Periodic harvesting of material from constructed wetlands may be necessary to remove nutrients and pollutants from the system.

4.64 It is important that constructed wetlands are correctly designed, placed and sized, otherwise there is potential for downstream pollution to be worsened.[37] The

35 T Wong, P Breen, N Somes and S Lloyd, *Managing Urban Stormwater Using Constructed Wetlands*, Industry Report 98/7, November 1998, vii.

36 T Wong, P Breen, N Somes and S Lloyd, *Managing Urban Stormwater Using Constructed Wetlands*, Industry Report 98/7, November 1998, pp 1-2.

37 I Lawrence and P Breen, *Design guidelines: Stormwater pollution control ponds and wetlands*, p 4.

Committee notes the concerns of Professor Wong, from the CRC for Catchment Hydrology, in relation to the current drive for councils to spend large amounts of money to construct wetlands, that he considers are often not properly thought out.[38]

4.65 Mr Diprose makes a similar point when he told the Committee that stormwater guidelines do not recommend specific solutions and it is left to councils, who lack the expertise, to be able to judge between the different merits of solutions.

4.66 Professor Wong also raised the issue of the importance of developers and related professionals understanding how wetlands operate:

> If you have $100 million and everybody is building wetlands, how many contractors can really understand the intent of what they see on a drawing of wetlands? I suggest to you that it is not many. I also suggest to you that there are also not many engineering consultants that would fully appreciate the operation of the construction of wetlands. We have a problem where wetlands could well be built out there by contractors who simply believe that building wetlands is digging a hole in the ground, and we have that. It is really about progressively building capacity in all the various sectors in the industry to ensure that we have this flow from technology and science to construction that reflects the intent of technology and science.[39]

4.67 In relation to this point, the Committee was concerned that some developers are filling in or draining natural wetlands in order to instal water features that, despite their being named as such, are not wetlands but instead are ornamental ponds that cannot maximise water treatment.[40]

Stormwater detention basins

4.68 Stormwater detention or retardation basins temporarily store stormwater to reduce the peak discharge rate of the storm runoff. They are commonly used to alleviate flooding of downstream areas. They include such features as lakes, ponds and wetlands, but can also be an excavated area or concrete structure that remains dry until it rains. They can reduce the speed of water flows and encourage sedimentation. The longer the water is detained, the more efficient the pollutant removal.[41]

Permeable surfaces

4.69 Permeable surfaces allow water to infiltrate into the soil and prevent it from running off a site. Depending on the soil type, garden beds and lawns absorb water but hard surfaces do not. However, porous paving is an alternative to conventional

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38 Prof Wong, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 272.

39 Prof Wong, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 273.

40 Committee briefing, Water and Rivers Commission, Perth, 29 April 2002.

41 Cooperative Research Centre for Catchment Hydrology, *Urban Stormwater Pollution*, Industry Report, 97/5, July 1997, p 10.

impermeable pavements with many stormwater management benefits. It allows water to percolate to a sub-base course, from where it infiltrates to the soil.[42]

4.70 Porous paving options include:

- pavements made from special asphalts that allow stormwater to filter through the pavement surface;
- concrete grid pavements that allow stormwater to filter through voids in the concrete;
- plastic modular block pavements that allow stormwater to filter through voids in the plastic matrix.

4.71 Early porous paving, typically asphalt, relied on percolation of stormwater through the pavement and storage in the sub-base prior to infiltration to the soil. These porous asphalt pavements were often subject to failure by clogging with sediments and are generally not as effective as newer methods of paving.

4.72 More recent porous paving designs use concrete grid or plastic modular block pavers which contain void areas that are filled with grass, sand or gravel to cleanse stormwater. The pavers are placed on sand or gravel layers that filter stormwater before infiltration to the soil. These layers are sometimes laid over gravel retention trenches which include overflow pipe systems.

4.73 Porous paving can be used to promote a variety of water management objectives such as:

- reduced (or even zero) peak stormwater discharges from paved areas;
- increased groundwater recharge;
- improved stormwater quality; and
- reduced area of land dedicated solely to stormwater management.

4.74 They can also be used in streets with low traffic volumes, in car parks and for paving within residential and commercial developments.

4.75 Porous pavers may have their drawbacks though. Mr Gersbach, from the Housing Industry Association, felt that porous pavers have higher maintenance requirements than regular paving or concrete, as they would be less effective at suppressing weed growth and the gravel between the joints would be prone to being washed away.[43]

4.76 Governments are increasingly setting targets for minimum levels of permeability. In Melbourne developments are required to retain 20 per cent of permeable surfaces, and Bayside City Council is modifying this general standard in its

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42 Melbourne Water site, at: http://stormwater.melbournewater.com.au/

43 Mr Gersbach, *Proof Committee Hansard*, Sydney, 18 April 2002, p 257.

Planning Scheme to require at least 30 per cent permeable surface.[44] Dr Johnstone explained that this 30 per cent requirement is an interim step towards adopting a more flexible stormwater performance requirement which will allow the 30 per cent to be achieved with a combination of options such as permeable surfaces, rainwater tanks and infiltration devices:

> I mentioned the project we are engaged in with the Association of Bayside Municipalities. The goal for that project is to have a very robust basis for requiring stormwater management, and retaining a percentage of pervious surface land is just one measure. Through that project we are hoping to be able to establish a standard for stormwater performance and certainly the stage 1 report, which came out after our submission was put into this project, sets the first stage for a very strongly based standard for stormwater performance. It also allows flexibility so you could achieve it by having a certain percentage of pervious surface. You could also supplement that with some tank rainwater, so you have storage of rainwater; infiltration devices et cetera. The proposed 30 per cent requirement in the planning scheme is almost an interim step towards this much more objective and more flexibly achieved stormwater performance requirement.[45]

4.77 Professors Troy and White also suggest that by changing gardening practices, stormwater runoff could be reduced:

> Using garden and green kitchen waste to produce compost that is then applied to the soil in domestic gardens not only improves the tilth of the soil it reduces the water needs of gardens and improves the ability of the garden to absorb rainfall thus reducing the runoff or attenuating the peak. Planting gardens with more consideration of their water demands would also reduce the demand for irrigation water thus reducing demand for water from either the reticulated systems of from domestic capture.[46]

Swales

4.78 Swales, either grassed or vegetated, receive rainwater at or near the place it falls. Driveways, paths and roads can be constructed to direct runoff into the swales which then direct the water flows and slow them down allowing time for some water cleansing through filtration and sedimentation. Grassed swales look similar to any grass verge except they have a gentle depression at the centre and gentle incline to give the flow of water direction:

> There is nothing new about grass swales. We see them in a lot of our regional cities. They can look as simple as what you see there. When we started to do our research on those grass swales, we determined that there are some beneficial outcomes in terms of water quality. We started talking to landscape architects about how they could integrate grass swales into

44 Dr Johnstone, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 307.

45 Dr Johnstone, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 307.

46 Centre for Resource and Environmental Studies, *Submission 50*, p 4.

> their designs and we have results that look very much like this. These designs are now adding value to the private ownership of that estate and at the same time serving water quality treatment functions.[47]

4.79 Beneath the surface of the swales can be a system of perforated pipes and gravel filled trenches which maximise infiltration and carry excess water through the system. An advanced example of this is the Lynbrook Estate, which is described in detail below.

Creek naturalisation

4.80 In the past many urban creeks and waterways were concreted and straightened (to create what are referred to as 'trapezoidal drains') which allow rapid removal of stormwater from built-up areas. Various jurisdictions are now considering removing the concrete and returning the drains to a more natural state. Mr Wood from the Stormwater Industry Association told the Committee of the efforts of Fairfield Council in this regard:

> They have actually converted an existing concrete channel to a naturalised creek. In doing this, they have been able to slow down the water flows and improve the water quality as a treatment train process. Obviously, it is very expensive. The community have to understand that, having already paid as their rates enormous sums of money to build these concrete channels and straighten the creeks, they are now being told their money is being used to naturalise it again. I think what has happened has been a paradigm shift.[48]

4.81 The Committee was impressed with the efforts in Canberra of the Sullivan's Creek Catchment Group Inc (SCCG) which is a volunteer, community-based organisation. Its ultimate goal is to restore what are currently, concrete-lined urban sections of Sullivans Creek to a more natural and effective system of wetlands and vegetated channels. The group, in consultation with the catchment community, government agencies, scientific and technical experts and corporate groups, has developed a catchment management plan which has a 20 year horizon.

4.82 The group recognises that concrete channels cannot simply be ripped out because this would increase the hydraulic load downstream, resulting in flooding. It therefore concentrates on carefully designed stages and has identified 14 sites for tributary located wetlands.

4.83 One wetland has currently been completed on open space that is publicly owned land managed by the urban services department. This wetland was retrofitted into a densely populated and developed urban area. The private sector largely funded the project in combination with some Natural Heritage Trust funds and volunteers did the landscaping component. The amenity value of the new wetland translated into

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47 Prof Wong, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 269.

48 Mr Wood, *Proof Committee Hansard*, Sydney, 18 April 2002, p 167.

higher prices for the properties facing the site, allowing the developer to recoup its contribution to the project.[49]

4.84 Another creek naturalisation project brought to the Committee's attention is the Bannister Creek's living stream project in Perth. This creek was originally a series of wetlands, but had been used as a main drain since 1979, conveying stormwater from the urban and industrial catchment into the Canning River.

4.85 The project aims to transform a straight section of the drain into a living stream and enhance its aesthetic values as well. Steep streambanks have been reshaped to a gentler slope and the creek has been allowed to meander. The group has built riffles in the water to aerate flows and create habitat, and sections of the banks have been stabilised and revegetated.

4.86 The success of these works became apparent during a large storm event during 2001 when the living stream was able to withstand increased flows that caused severe damage to a conventional main drain structure upstream.

4.87 It is not just community groups that are looking to return drains to more natural settings. The Committee was told that Sydney Water has introduced a stormwater environmental improvement program that includes de-channelisation of concrete channels into more natural streams; along with the installation of pollutant traps and natural wetlands.[50]

Maintenance

4.88 An important issue that arises in relation to stormwater management devices is the ongoing maintenance and management they require to remain effective. It was made very clear to the Committee that many of these installations are not 'set and forget' but require planned, ongoing funding.

4.89 Pollution control assets, whether active or passive require a management strategy and funds in order to operate as designed. For example: active end of pipe treatments utilise gross pollution traps that must be emptied and the polluted materials safely disposed. Passive constructed wetland treatments require water quality monitoring and macrophyte maintenance plus periodic cleaning out of sedimentation build up. Surrounding park lands require weed and pest control, and management of safety elements where there is community access. Some tertiary treatment systems for example, bio-filtration swales[51] may need complete removal and replacement over time, due to neutralisation and/or clogging.

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49 Mr Wilkinson, *Proof Committee Hansard*, Canberra, 23 May 2002, p 556.

50 Ms Meeske, *Proof Committee Hansard*, Sydney, 18 April 2002, p 178.

51 A bio-filtration swale is a grassed swale with a trench of bioremedial soil mix which is designed to capture particular target pollutants.

4.90 If pollutant traps are not emptied regularly they can increase pollutant loads to waterways as the rubbish breaks down releasing more concentrated toxins than would be the case if they had not been installed. For these reasons some jurisdictions are moving away from installing such traps, saying that pollutants should be intercepted at source.

4.91 A related issue is that although artificial wetlands may be constructed primarily for the purpose of cleaning stormwater, they can also have great amenity value. For proper maintenance, the build up in sediments will eventually require dredging. It may come as a shock to the local community when it observes its attractive recreational facility being dug up. It is important therefore that the community understands the function of these areas and why the work is necessary.

4.92 Professor Wong was supportive of an environmental levy on ratepayers being used to provide ongoing maintenance funding:

> [Councils are] continually pressured with the operating budget and, if there is a tied levy to specifically look at maintaining and ensuring that some of the innovative or sensitive urban design elements are maintained, I think that will provide the certainty.[52]

4.93 In July 2000, the Mosman Municipal Council introduced one such environmental levy. It received almost unanimous community support, and the requisite approval of the State Government, to impose the 5 per cent levy over 12 years onto residents' rates to fund a program called the Community Environmental Contract (CEC). Prior to the introduction of the levy, the Council recruited a group of prominent people from the area to promote the idea and a flyer was sent to residents explaining the concept. People who objected to the levy were involved in more detailed consultation and at the end of the day there were fewer than 10 objections.

4.94 The levy is projected to earn $6.8 million, and is complemented by an additional $2.2 million in grant monies received from such programs as the Coasts and Clean Seas Program under the Natural Heritage Trust. The Council has established a CEC project team and CEC projects concentrate on stormwater management, bushland management, creek rehabilitation and seawall reconstruction.

4.95 CEC Stormwater Projects are targetted at improving the quality of stormwater discharging at Balmoral Beach and Mosman Bay. The Council has adopted a flexible approach, using both structural and non-structural solutions. Works at Balmoral include the installation of four stormwater quality improvement devices (SQIDs), creek rehabilitation, and comprehensive education programs, including drain stencilling, general media awareness campaigns, and awareness campaigns for retail food businesses and their customers. In Mosman Bay, the Council has installed five SQIDs, and undertaken creek rehabilitation works.

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52 Prof Wong, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 272.

4.96 In addition to funding maintenance programs, there is also a role for the community in maintaining elements of water sensitive urban design. For example:

> I think, given that some more progressive stormwater treatments are going to be landscape treatments, the ongoing maintenance and management of them is going to be critical for them to remain effective. That means that people need to understand that the swale—that is their front yard perhaps—has a function and not just an aesthetic value. Carrying that forward will be difficult and will require database management and information management. So as solutions become more dispersed, then there will be a need for capacity in hand so those custodians of that information are able to monitor and ensure that they are effective in the long term.[53]

4.97 A number of witnesses were concerned that water sensitive urban design would be more expensive to build and maintain than conventional drainage[54] but this was by no means a unanimous view. According to Professor Wong:

> The data we have to date suggest that, in terms of capital cost, it is usually not any more than for conventional design. In terms of beneficial returns to property values, we have been able to demonstrate true data that there is clearly an increase in the property value as a result of water sensitive urban design.[55]

4.98 Similarly in relation to maintenance:

> I believe the jury is still out on maintenance costs, because this is all very new. But we have one set of data, which is a water sensitive urban design project that has now run for seven years—albeit at a very small, local, street level—and after the first two years, where the bulk of the maintenance is very intensive, we find that we actually have a maintenance budget that is less than for a conventional design. That is a very positive outcome. The question is whether that can be scaled up to a much larger area. We are doing research to deal with that. The common response by a lot of local governments and, in some cases, private industry is that the maintenance is very high. I think it is more due to lack of information and nervousness about the whole thing compared to the conventional way of doing things, rather than based on fact.[56]

4.99 Furthermore:

> Currently, it is being demonstrated that it is just a different way of doing maintenance, not necessarily a more expensive way of doing it. I think that

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53 Cr Johnstone, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 360.

54 S*ee for example* Mr McCarthy, *Proof Committee Hansard*, Perth, 29 April 2002, pp 405-406.

55 Prof Wong, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 272.

56 Prof Wong, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 272.

> is a clear example of how that relationship we have with Brisbane City Council has led to fairly rapid adoption on the ground, at the policy level.[57]

4.100 In any case, conventional drainage works also require ongoing maintenance for which Councils are required to set aside funds in their budgets.

Other actions

4.101 Dr Humphries from the Water Corporation of Western Australia emphasises the point that treating water at the bottom of the catchments needs to be done in conjunction with other measures to improve water quality upstream and there are often jurisdictional problems associated with implementing these:

> Basically our difficulty is that we cannot control the quality of the water that is given to us. We have been continually put under pressure from the community and from environmental and water resource regulators to spend large amounts of public money putting in things like constructed wetlands at the bottom end of the drainage system, when there needs to be better governance on a catchment scale to ensure, for example, that rubbish collections, street sweeping, fertiliser management and so on all happen in a properly integrated way and that gully traps are cleaned out and better drainage designs are put in place.[58]

4.102 This problem goes to the fragmented jurisdictional arrangements which are discussed in detail in Chapter 6.

Street sweeping

4.103 Modern street sweepers can effectively improve stormwater pollution as they vacuum up the debris for later disposal. Therefore, regular programs of street and footpath sweeping, especially targeting critical areas such as shopping centres and in autumn the streets with deciduous trees, are an integral part of good stormwater management.

Leachate treatment plants

4.104 Old landfill sites can be a significant source of pollution that finds its way to waterways. While modern landfills incorporate liners in their design to contain leachate as waste decomposes, there is a legacy of older sites that do not include this technology.

4.105 Brisbane City Council has developed a method of controlling leachate and the Committee visited its Chandler landfill site where this was demonstrated.[59] The Chandler landfill was operational until December 1991 and accepted predominantly

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57 Prof Wong, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 275.

58 Dr Humphries, *Proof Committee Hansard*, Perth, 29 April 2002, p 425.

59 D Solley, L Don, S Watts, J Doyle and J Keller, *Nitrogen removal from landfill leachate using high rate biological nitrification and sewer denitrification*, paper.

domestic waste. The leachate currently produced is high in ammonia and low in carbonaceous matter and it is estimated that 40 megalitres per year of leachate needs to be removed to minimise its infiltration into the surrounding groundwater and waterways.

4.106 Brisbane Water built a pretreatment plant on the site which would remove the high nitrogen concentrations in the leachate so it could be discharged to the sewer, where it would combine with raw sewage. It then undergoes conventional treatment at the Gibson Island Wastewater Treatment Plant.

4.107 The plant was designed to be compact and unobtrusive because of its proximity to residential development; it is transportable to allow for relocation to other landfill sites; and it operates automatically with low maintenance requirements.

Pipe liners

4.108 During its visit to Townsville on 3 April 2002 the Committee was shown a drain lining project under the railway yards. This involved the trial use of sewerage technology to retrofit an existing stormwater pipeline with a polypropylene liner in an attempt to stop contaminated groundwater from the railway yards seeping into the stormwater network and from there to the creek and ultimately the Great Barrier Reef.

Drain stencilling

4.109 Many local councils have drain stencilling programs to highlight the connection between city streets and rivers, creeks, beaches and bays. For example Townsville City Council is marking “No waste – Flows to creek and reef” on its stormwater drains to emphasise the fact that the contents of the drains will ultimately end up on the Great Barrier Reef.

Stormwater management plans

4.110 New South Wales, Victoria and Queensland, now require local councils and relevant state agencies to develop Stormwater Management Plans that specify strategies for improving the management of stormwater in their jurisdiction.

4.111 The main objective of a plan is to provide a strategic basis for a council to improve its environmental management of urban stormwater, both in the short and the long term.[60] Specifically they are intended to:

- generate commitment to and awareness of best practice environmental management of urban stormwater;
- identify priority issues using a risk-based approach;

60 Victorian Environment Protection Agency site, at: http://www.epa.vic.gov.au/Programs/Stormwater/swmp.asp

- develop management strategies to address both the priority risks and priority management issues;
- establish a basis for ongoing cooperation and coordination between different departments of the council and between different agencies; and
- ensure the effective integration of actions and use of investment by all key players.

4.112 The plans should consist of actions and recommendations that feed directly into the council's business and strategic planning. Actions will impact on planning schemes, educational and environmental services, as well as engineering, operations and maintenance programs. They would be expected to incorporate principles of water sensitive urban design including:[61]

- source control, for example removal or prevention of impervious surfaces;
- soak away zones and spoon drains;
- retention of natural creeks, as opposed to transforming them into 'chanellised' drains;
- retention and detention devices to slow the flow of stormwater and allow some settling of particulate matter;
- appropriately designed wetlands; and
- end of pipe controls such as trash racks, screens and separation facilities.

4.113 The Committee is supportive of the development of these plans. It considers that at the very least, the process of formulating them will focus councils' attention on stormwater issues and lead to management improvements.

4.114 By 2005, the Government of South Australia, in conjunction with local government and other stakeholders, will prepare a stormwater management statement to set out a consistent management framework for major stormwater systems.[62]

Equivalent percentage treated areas[63]

4.115 The City of Port Phillip discussed the concept of equivalent percentage treated areas (EPTA) which has been adopted by the Association of Bayside Municipalities of which the City of Port Phillip is a member. A developed site will increase the rate of peak stormwater flows and carry a larger volume of pollutants than an undeveloped site, and the adverse stormwater impacts generally increase as the area of impervious site cover increases.

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61 CSIRO, *Submission 47*, p 47.

62 Government of South Australia, State Water Plan, Volume 1, p 63.

63 Cr Johnstone, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 353; *and* Association of Bayside Municipalities Stormwater Implementation Project Stage 1: Statutory Framework and Standards Environment & Land Management and Ecological Engineering, pp 5-6.

4.116 A developed site can improve its environmental performance through using constructed stormwater measures that retard peak stormwater flows and provide a reduction in pollutant loads carried by that stormwater. Developers are able to incorporate stormwater management measures such as on-site retention, stormwater re-use, and diversion to a landscaped area into their projects to ensure that the drainage profile of the site remains the same post-development, or at some level specified by the local council.

4.117 EPTA provides a mechanism to assess how well the developed site meets standards found in Victorian Environmental Protection Policies and included in *Urban Stormwater Best Practice Environmental Management Guidelines*.[64] If the site can achieve a 100 per cent EPTA, that is, if it treats all developed areas using best practice techniques and accrues an allowance for remaining pervious surfaces, then it is deemed to meet the guidelines.

4.118 Sydney Water has adopted a similar concept in its Rouse Hill estate for which it was nominated as the authority responsible for trunk drainage. Its system aims to ensure that post-development stormwater flows from the area are no more than the pre-development flows and so the actual amount of water that leaves the area will not change. The water is being captured and treated through stormwater management systems including gross pollution and sediment traps, grass channels and artificial wetlands.[65]

Stormwater harvesting

4.119 Despite the fact that stormwater can be highly polluted, its capture and use in some cases can be preferable to using treated effluent as the potential issues in relation to recycling endocrine disruptors and other such contaminants do not apply. There is also the downstream benefit of reducing contaminated runoff to receiving environments.[66]

4.120 However, the CSIRO puts urban stormwater utilisation at less than 3 per cent nationally.[67] Domestic scale rainwater tanks currently make only a small impact on runoff in most capital cities. Larger scale schemes for storing stormwater in aquifers commenced in 1993 in Adelaide. As yet no other aquifer storage and recovery schemes for stormwater have been installed in other Australian states. Costs of water from these schemes, where wetlands are built for flood mitigation and amenity value, are approximately half the cost of mains water. This water is currently used only for irrigation.

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64 *Urban Stormwater Best Practice Environmental Management Guidelines*, 1999, CSIRO Publishing, Melbourne. Compiled by Melbourne Water, Victoria's Environment Protection Authority and Department of Natural Resources and Environment, Municipal Association of Victoria and CSIRO.

65 Mr Gellibrand, *Proof Committee Hansard*, Sydney, 18 April 2002, p 182.

66 CSIRO, *Submission 47*, p 57.

67 CSIRO, *Submission 47*, p 55.

4.121 Dr Nicholas Fleming notes in his submission that while many States are now focussing on improving the quality of stormwater and reducing its ecological impact, the potential for productive use of stormwater is not being pursued as strongly as it should be.[68]

4.122 The City of Salisbury in Adelaide provides an exception to this claim. This Council in particular is noted for its innovative approach to improving urban water management and it has installed wetlands to treat stormwater from its catchments prior to the water flowing into Gulf St Vincent.

4.123 The Committee visited the Council's Parafield Partnerships Urban Storm Water Initiative. This project diverts stormwater from existing drains to a system of constantly flowing, bird-proofed reedbed ponds on Parafield Airport land, where it is filtered, cleansed and supplied directly to users, with the surplus water injected into underground aquifers for extraction during dry periods.

4.124 The benefits of the project are to:

- prevent polluted stormwater flowing to Gulf St Vincent;
- reduce the amount of water pumped from the Murray River for use by industry (one company uses approximately 1 billion litres of Murray River water per year); and
- provide to users a better quality water with lower salinity levels than water supplied from the Murray River.

4.125 Another quite different stormwater harvesting scheme has been introduced by Wide Bay Water which uses stormwater to flush its sewerage system at night, which aims to remove odours from the system that are indicative of corrosion taking place. Mr Waldron told the Committee that most water companies or councils spend a lot of money on odour control, usually through the use of chemicals. By utilising stormwater in this way there is an economic benefit in extending the life of the asset and an anticipated target of reducing operational costs by about $300,000 a year in odour control. The effluent then becomes available for agricultural use through the company's effluent reuse system.[69]

Rainwater tanks

4.126 Many people favour domestic installation of rainwater tanks which provide benefits for improved water management in terms of both curtailing demand for potable supplies and reducing the amount of stormwater runoff. The drawbacks of rainwater tanks are their expense and the measures that are required to ensure human health is not put at risk if the water is used for drinking.

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68 Dr Nicholas Fleming, *Submission 8*, p 7.

69 Mr Waldron, *Proof Committee Hansard*, Sydney, 18 April 2002, pp 200 and 210.

Health risks

4.127 Domestic rainwater tanks used to be standard in all cities established in the nineteenth century, but once reticulated water supplies were developed, the perceived need to secure the finances of the water supply authorities led to the disappearance of backyard water tanks.[70] Professor Troy provides an interesting historical perspective on this point:

> The stormwater drainage systems were designed on the assumption that people collected a lot of rainwater. But a bit over 100 years ago we started to make it illegal for people to have rainwater tanks. There is a general understanding that that was for health reasons. That is in fact wrong. The major reason for it being introduced was that when they started to put reticulated water supply systems into the cities there was a need to make sure they were financially viable. The decision to charge people for water whether they used it or not—that was the first stage—meant that the disincentive for being connected to the water supply system was removed. A little later those tanks were made illegal. For a long period—about 90 years—water collection in tanks became illegal, allegedly for health reasons. That was always a phoney, as I think anyone who gets into the history of these water authorities begins to understand.[71]

4.128 Water companies are responsible for the quality of the water that they supply, but once people start using rainwater tanks, suppliers have little control over the quality of water from those tanks:

> When augmented by devices such as tank water, you introduce a leak into our ability to secure the water supply, because the source is something that we do not have a great deal of control over.[72]

4.129 Drinking rainwater from improperly maintained tanks and surfaces on which the rain falls may increase health risks. For example, bird droppings and other detritus on roofs can contaminate water supplies. However, modern water tanks can include devices to overcome these risks if the water is to be used for drinking:

> Modern water tanks do not have the disadvantages of the older household tanks. Moreover, the simple devices now available to ensure that detritus or dust collected on roofs is washed off before water enters the tank removes the dangers once claimed to be associated with household tank water supplies. The insertion in the line from the tank to house of a modern simple but sophisticated filtration device such as that designed to eliminate cryptosporidium, legionella, giardia, ecoli and all the known harmful bacteria as well as any suspended particles would result in the delivery of

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70 Centre for Resource and Environmental Studies, *Submission 50*, p 4.

71 Prof Troy, *Proof Committee Hansard*, 22 March 2002, p 26.

72 Mr Gellibrand, *Proof Committee Hansard*, Sydney, 18 April 2002, p 172.

> water of a quality higher than that currently delivered by the reticulated systems.[73]

4.130 The Committee visited Michael Mobbs in his sustainable house in Chippendale in the heart of Sydney where the quality of the rainwater was sufficiently good to comply with the Australian Drinking Water Guidelines. This house uses rainwater for its water supply and through the use of enclosed guttering to prevent bird droppings and leaves entering the tank; a couple of mesh traps and a first flush device to direct the initial rainfall (that contains the most pollutants) to the garden, the resultant water quality is good. Tests carried out by the University of Technology Sydney, demonstrate consistently low turbidity and faecal coliform counts and, importantly, the highest level of lead ever measured recorded in the tank water was 0.03 mg/litre - below the safety threshold of 0.05 mg/litre recommended by the National Health and Medical Research Council. The drinking water compares favourably with that of Australian town water supplies.[74]

4.131 The Nature Conservation Council is of the view that rainwater tanks provide a superior source of drinking water than the reticulated supply:

> When installed in accordance with the Australian standards it in fact is a much safer source of potable water than existing mains water. There are a whole range of chemicals which are added to our existing water supply system whose impacts on human health have not been fully explored. Sydney Water currently has a number of research projects with the CSIRO looking into the rates of bladder and bowel cancer and relating that back to chlorination of our drinking water supply. I would suggest that there are a number of reasons why people may want to provide their own drinking water supply, and water health is a significant reason, as is security of supply.[75]

> … the Australian standard for rainwater tank design is very specifically geared to removing the contaminants that come down in the first flush. From an engineering perspective, it is specifically designed to cope with that problem.[76]

4.132 Adelaide arguably has the need to use a higher level of treatment on its water than any other capital city and, as a likely consequence, has the highest use of rainwater tanks in Australia.[77] In other States people may also have a preference for drinking tank water:

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73 Centre for Resource and Environmental Studies, *Submission 50*, p 4.

74 *Sustainable House,* Michael Mobbs, CHOICE Books, 1998, p 43.

75 *Proof Committee Hansard*, Sydney, 18 April 2002, p 248.

76 *Proof Committee Hansard*, Sydney, 18 April 2002, p 251.

77 Almost half of South Australian households have rainwater tanks, whereas the figure is only 15 per cent for the rest of Australia.

> Quite a lot of people in our councils have a connection to the state water supply but also have their own water tanks and collect water off their roofs, mainly for drinking water. In a lot of the areas in the hills where there is no water supply, catching water off roofs and bores and things is probably the only source of water. So those sorts of things happen in our region both as a requirement and also when people want to use less water and have better control, particularly over the quality of their drinking water.[78]

4.133 Restrictions on installing urban rainwater tanks are not insurmountable and some water authorities are considering their use as part of demand management strategies:

> There are means of controlling the water quality. … As part of the demand management strategy and other initiatives, we are looking at rainwater tanks in such a way that we could see a definite role for them in the urban environment. It is not a matter of if; it is a matter of how. There is a considerable amount of knowledge that already exists to suggest that they can exist quite effectively in the urban environment.[79]

Non-potable use of rainwater

4.134 While there are steps that can be taken to ensure that water from tanks in urban areas is safe for drinking, the issue can easily be sidestepped by only using the collected water for non-potable uses such as toilet flushing, garden watering and in hot water systems:

> The health side of things is a very interesting problem and consequently the [Stormwater Industry Association] has not wanted to get involved with the health applications of water tanks for potable use. What we say is that water tanks and water retention on-site should be used for nonpotable use. Although we have various contentions that water tanks are actually safer than potable water supply systems that is a different exercise. We are not advocating water tanks for water supply retention for potable use; we are advocating that you use the tank water for toilets, irrigation and hot water—hot water systems, of course, sterilise the water—and in that way you meet all the health and regulatory guidelines.[80]

4.135 As with many findings of this inquiry, rainwater tanks will not be suitable in all regions of the country. In Perth, for example, for about 10 months of the year there is little rain and householders would require too large a tank than is feasible to provide sufficient water for their needs.[81]

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78 Mr McCarthy, *Proof Committee Hansard*, Perth, 29 April 2002, p 407.

79 Mr Gellibrand, *Proof Committee Hansard*, Sydney, 18 April 2002, pp 172-173.

80 Mr Wood, *Proof Committee Hansard*, Sydney, 18 April 2002, p 168.

81 Dr Humphries, *Proof Committee Hansard*, Perth, 29 April 2002, pp 420-421.

4.136 Some councils are beginning to require that rainwater tanks be included in new developments but the Housing Industry Association was not in favour this. It calculated that a 5,000 litre tank would add $6,064 to the cost of each house:

> The basic premise of our objection to that is that new home owners, probably those in our society who can least afford an additional cost of this amount, should have to bear the cost of what is really a societal issue. It is not that we do not think that they are a good idea, it is just simply that the cost impost of that extent on new home owners is quite significant.[82]

4.137 Rather than imposing this additional cost on the homeowner, Mr Gersbach suggests that controls on, provision for, and recycling of, stormwater could be incorporated in the actual subdivision design. The cost of those provisions could then be incorporated into the overall land package and sold to the consumer as part of that:

> Some of those solutions may well be that you have a single collection system, which is offline. That might be located either adjacent to a golf course or other community facility which actually requires water usage and that way recycle back into the system, rather than the impost on the home owner.[83]

4.138 However, HIA was more in favour of a rebate being offered to install rainwater tanks.

4.139 While some authorities are not actively encouraging installation of rainwater tanks, there are attempts being made to remove barriers to their installation.[84]

Water sensitive urban design

4.140 The concept of water sensitive urban design (WSUD) was originally developed in Western Australia and it is an holistic approach to the management of water in urban environments. It views the urban water cycle as a whole rather than by its individual sectors such as wastewater, stormwater and water supply, and their interactions with each other and attempts to incorporate water management systems into buildings, urban transport routes and public open spaces. It is based on the principles of water efficiency and reuse. Most importantly, used water is treated as a resource rather than as a waste product.

4.141 The focus is on addressing pollution problems at the source rather than constructing expensive engineered add-ons further downstream, and so it incorporates the options for best practice water management (outlined above) in various combinations to suit the particular constraints and challenges of individual sites.

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82 Mr Gersbach, *Proof Committee Hansard*, Sydney, 18 April 2002, p 253.

83 Mr Gersbach, *Proof Committee Hansard*, Sydney, 18 April 2002, p 254.

84 Mr Woolley, *Committee Hansard*, Brisbane, 4 April 2002, p 607; *and* NSW Department of Land and Water Conservation, *Submission 36A*.

4.142 Water sensitive urban design is also commonly referred to as Integrated Urban Water Management (IUWM) and the Australian Water Association explains the connections between these two concepts as follows:

> The concept of water sensitive urban design (WSUD) has gained currency in recent years and it neatly encapsulates the holistic approach to reducing the environmental footprint of urban infrastructure. The broader notion of integrated urban water management (IUWM) really means much the same thing, but different groups of professionals have tended to appropriate one or other name, according to their cultural orientation. Planners, architects and lateral-thinking developers are probably more aligned to WSUD, while water practitioners as such lean towards IUWM.[85]

4.143 Water sensitive urban design principles are meant to minimise the effects of development on the total water cycle while maximising the multiple use benefits of the stormwater system. To achieve this, water sensitive urban design aims to:

- preserve existing natural features and surface water/groundwater resources;
- integrate public open space with stormwater drainage lines,
- minimise impervious areas and the use of formal drainage systems, and
- encourage infiltration and stormwater reuse.[86]

4.144 According to Professor Mein, to date Australian cities have generally been well served by the arrangements relating to water management: they have had reliable water supplies, they have had good public health and they have had good drainage. However, the time is now ripe for a new approach to be much more effective in terms of water use, and for much more useful environmental outcomes.[87] This is what water sensitive urban design aims to achieve.

4.145 Brisbane City Council, for instance, has changed its City Plan to include water sensitive urban design.[88] The onus is now on developers to demonstrate why they should not use water sensitive urban design rather than the other way round. This change is underpinned by the fact that there are now demonstration projects that show how it can be done and that it will not necessarily impose additional costs.[89]

4.146 Examples of water sensitive urban design demonstrated for the Committee how attractive this type of design can be, and developers too have found that by incorporating water sensitive urban design into their projects, they can command higher prices for amenity value. There are also suggestions that because water

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85 Australian Water Association, *Submission 41*, p 11.

86 Great Barrier Reef Marine Park Authority, *Submission 60*.

87 Prof Mein, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 267.

88 The City Plan is Brisbane City Council's planning scheme which is a document that describes the Council's intentions and outcomes for the city's future development.

89 Prof Wong, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 275.

sensitive urban design incorporates less concrete and hard engineering elements, it is cheaper to construct.[90]

4.147 Some examples of developments incorporating elements of water sensitive urban design that the Committee visited are described below.

Lynbrook Estate, Melbourne

4.148 The Lynbrook Estate claims to be the leading showpiece for water sensitive urban development in Melbourne. The CRC for Catchment Hydrology provided the scientific underpinning for its development.

4.149 The local streets at Lynbrook are the main component of water sensitive urban design. Conventional kerbing and guttering have not been used, and instead stormwater is directed into swales that channel it to wetlands where it is further filtered and purified.

4.150 Driveways at Lynbrook are slightly ‘dished’ in design and aligned to follow the contours of the adjacent swales so that water can flow across them. A small grated pit in each driveway crossover is also included to prevent water ponding. ‘Breaks’ in the kerb and channel on the streets direct stormwater runoff into the swale drains.

4.151 The grass swales slow down runoff, allowing seepage into the ground, and filtering out of pollutants. These swales act as drainage channels in periods of rain, transferring road runoff to an underground system of perforated pipes and gravel filled trenches, to the main boulevard which acts as a bio-retention system with underground gravel filled trench and a 150 mm perforated pipe which allows infiltration and conveyance to the wetlands and Lynbrook Lake. Water from house roofs is piped to the stormwater system and pipes under the swales carry the excess water through the system. Drainage pits at low points in the development also collect surface runoff.

4.152 Beyond the wetlands is Lynbrook Lake and a floodway which provide more water quality improvement as well as an aesthetic and recreational amenity for residents. Lake water is used to maintain groundwater levels around a stand of remnant river red gum trees. A gravity fed infiltration system provides subsurface irrigation to those trees and the surrounding landscape.

4.153 Professor Wong drew the Committee’s attention to the fact that any litter at the Lynbrook Estate remains close to where it is deposited and ends up on the grass swales. It does not get carried by stormwater to rivers and lakes which is a benefit to the environment and also saves on cleaning out costs for lakes.[91]

4.154 Several early stages of the Estate were designed with a conventional stormwater system and the CRC for Catchment Hydrology is in the process of carrying out a three year monitoring program to compare the performance of these

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90 Mr Robertson, *Proof Committee Hansard*, Canberra, 23 May 2002, p 557.

91 Prof Wong, *Proof Committee Hansard*, Melbourne, 23 April 2002, pp 269-270.

areas and the WSUD systems. The study will look at the quantity and quality of runoff, as well as costs of construction, ongoing issues of maintenance and community acceptance of WSUD.[92]

4.155 The Urban and Regional Land Corporation (the Estate developer) is now planning for all remaining stages of Lynbrook to incorporate WSUD and is reviewing the design of stormwater systems in all its estates with a view to adopting WSUD as standard practice.

Cairnlea Estate, Melbourne

4.156 Cairnlea is another Urban and Regional Land Corporation housing development that incorporates elements of water sensitive urban design, although not to the same extent as does the Lynbrook Estate. Four major artificial lakes will be constructed at Cairnlea, along with numerous wetlands and sediment ponds to treat the stormwater from the estate. Gross pollutant traps and macrophytes will assist in improving water quality and the lakes will act as storage ponds for irrigating public spaces.

4.157 The two creeks on the site will benefit from improved stormwater flows and Jones Creek will be rehabilitated from a polluted drain to a living creek. The Kororoit Creek corridor will also be protected and improved with weed eradication and replanting of vegetation.

No. 48 Ormond Road, Elwood, Melbourne—Stormwater retention demonstration project

4.158 The Committee visited 48 Ormond Road, Elwood which is a multi-unit demonstration project consisting of seven apartments. It was funded by the Coasts and Clean Seas program. At this development, rainwater is collected from the roof, undergoes ultraviolet treatment, and is used for toilet flushing in the units. It incorporates a monitoring system to gauge the amount of water that overflows into the stormwater drains, the amount used for toilet flushing and the amount supplemented from the reticulated supply during dry periods. This information will guide the implementation of policies in the future.[93]

4.159 One of the drivers for the project is the need to address the localised flooding effects of increased urban infill. As discussed previously, it is possible to retain stormwater flows from a site at their pre-development level, even though the amount of impervious surfaces becomes greater. This development is a demonstration of what can be done and through the monitoring system will provide valuable information for future developments:

92 Melbourne Water site, at: http://www.stormwater.melbournewater.com.au/content/wetlands_4.asp

93 Mr Holdsworth, *Proof Committee Hansard*, Melbourne, 23 April 2002, pp352 and 356.

> the aim of the 48 Ormond Road project was to address one of the real problems that we have in Port Phillip and elsewhere, I am sure, with ageing infrastructure and the fact that, as urban development becomes more intense, the amount of pervious surface reduces—hence the rainfall that is caught and runs off to stormwater drains increases and that stresses the critical and ageing infrastructure. So avoiding a net increase despite an increase in catchment is one of the cornerstones of that policy.[94]

Bridgewater Creek Constructed Wetland Project, Bowie's Flat, Brisbane

4.160 Bowie's Flat wetland in the suburb of Bridgewater was constructed on a site that had previously consisted of a stretch of grass with a large concrete drain. Stormwater flowing into the wetland first passes through a gross pollutant trap to collect litter, vegetation and sediment, followed by a series of shallow ponds to, firstly capture coarse particles of sand and soil, before passing through wetland plants where fine particles and microscopic nutrients are trapped. The wetland is kept to a maximum depth of one metre to ensure plant growth. In heavy rain excess water bypasses the wetland via an overflow channel.

4.161 Despite its functionality, the site is an attractive amenity for local residents, who were extensively consulted during the planning stages. The wetland has transformed a featureless, barren, concrete channel-bisected park into clear pools, reeds, ephemeral marshes with large wetland trees and an ecological haven for aquatic wildlife. With its interpretive signage describing its functions and value, and abundant wildlife, the wetland also becomes a useful educational resource for local schools and other interested groups. A path and boardwalk system provides movement in and around the park and access to nearby community facilities. A deck adjacent to the boardwalk provides a quiet place to sit and observe the wetland.[95]

Windermere housing development, Brisbane

4.162 This housing development incorporates a wetland along the creek in the centre of the development. The wetland is based on a natural design concept with water flowing over gravel and rocks and through reed beds and was installed in lieu of concrete pipes. The Committee was told that the presence of the wetland has added 20 per cent to the value of surrounding houses.

Keith Boden Wetlands, Brisbane

4.163 The Committee visited the Keith Boden Wetlands in Brisbane which were constructed in 1998 on a former drain. They receive stormwater from two major channels, parts of which have been buried to improve the amenity of the immediate area. Prior to the wetlands' installation, flooding in the area was an ongoing problem and was exacerbated by an estimated 76 tonnes of sediment that came from the drain each year. Additionally, levels of nutrient in the stormwater from the area are quite

94 Mr Holdsworth, *Proof Committee Hansard*, Melbourne, 23 April 2002, p 354.

95 N4c site, at: http://www.n4c.org.au/Projects.htm

high because of residential overuse of fertilisers and the installation is designed to absorb these nutrients to prevent them from ultimately entering Morton Bay.

Ascot Waters, Perth[96]

4.164 The Ascot Waters development in Belmont, Perth has the Swan River running through it. The stormwater management system is designed to control stormwater volume and peak discharge rates in a treatment train of best management practices to prevent the river and protected areas from the effects of urban runoff. Pollution in the runoff is reduced through physical containment or flow restrictions designed to allow settling, filtration, percolation, chemical treatment or biological uptake and assimilation of nutrients. Direct runoff into an environmental protection area is avoided.

4.165 Runoff is dealt with in three zones. Zone A, which includes the commercial/marina area and extensive hard surface parking areas, directs runoff into a series of gross pollutant traps and then into wetlands that strip out pollutants before the water enters the Swan River. A horse faecal runoff problem from the nearby Belmont Racecourse has also been addressed by creating a retention pond in the middle of the racetrack.

4.166 Zone B runoff is directed into a shallow, landscaped infiltration basin where it is temporarily held before it seeps into the edge of the saltmarsh area. This basin is designed for rapid infiltration of inflowing stormwater and for additional subsurface conveyance an underdrain is included. This structure removes all sediment and most of the contaminants contained in the runoff.

4.167 Zone C runoff is directed down the central open space corridor within the residential development to an artificial wetland via a perforated pipe. This allows the water to be aerated and stripped of some sediment load. Entry to the wetland is through vegetated swales and detention basins to finally remove solid particles. An overflow into the main water body operates during extreme events.

4.168 The stormwater improvement devices have been attractively landscaped to improve their amenity and incorporate clever multi-use ideas. For example, one of the detention basins has been designed for use as an amphitheatre, while another doubles as a children's playground.

4.169 The stormwater management system deals with both the major and minor storm events by:

- providing a flow path for major events so that flooding of property is prevented;
- limiting the volume and peak flow rates of runoff to predevelopment conditions for minor storm events; and

96 Ascot Waters Stormwater Management Plan, PPK Environment and Infrastructure Pty Ltd, April 2002.

- treating 90 per cent of storm events per year via detention for a minimum of 72 hours or retention of the runoff via infiltration and/or reuse.

Conclusions

4.170 Modern stormwater systems are the inefficient legacy of an out of date mindset that regarded rain water falling on cities as a problem to be dealt with by removing the water as quickly as possible into streams and rivers. These became dumping grounds for the various pollutants that are collected by the stormwater system, derived from vehicles, gardens, rubbish and sewage overflows.

4.171 Techniques are now available that are vastly more efficient and which sustainably reintegrate stormwater flows into urban water cycles, making effective use of this water as a resource. Developments such as the Lynbrook Estate demonstrate the techniques of water sensitive urban design and also show that the associated costs of construction and maintenance are comparable with conventional methods. At the same time, they offer surrounding communities increased levels of utility and aesthetics.

4.172 However, the application of water sensitive urban design principles remains very much the exception rather than the rule, even in new developments, while it is even rarer in existing suburbs.

4.173 Some developers are adopting only the features of WSUD that are attractive to buyers. The Committee was told that it was still common for natural, functioning wetlands to be drained for housing with small ornamental lakes put in their place that provided no filtering or purifying role in stormwater management.

4.174 Nevertheless, much of Australia's stormwater infrastructure will reach the end of its useful life over the coming twenty years and this provides Australia with a rare opportunity to replace this infrastructure with best practice systems. Accordingly, the Commonwealth must take a strong leadership role to ensure that state, and particularly local, governments, have both the resources and the expertise to take this opportunity. How this can be done is the focus on Chapter 6.