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Quantity is the road to quality

Emma Monk, Environmental Officer, Department of Environment and Bill Till*, Stream and Stormwater Management Program Manager, Department of Environment

* Paper presenter

Author Profiles

Emma Monk
Environmental Officer, Stream and Stormwater Management, Department of Environment

Emma Monk is an Environmental Officer with the Department of Environment in Western Australia. Emma has been working in the field of environmental management for ten years. This work has included: developing stormwater management guidelines, water quality protection guidelines, drinking water source protection plans, and wetland management assessments and policies/processes at Water and Rivers Commission / Department of Environment; assessment of wastewater reuse schemes and wastewater treatment systems at Department of Health; and contaminated site assessments at Golder Associates.

Bill Till
Program Manager, Stream and Stormwater Management, Department of Environment

In his current position of Program Manager Stream and Stormwater Management, Bill has a significant role in the Department's River Restoration and Stormwater Management programs. Bill is responsible for policy development and provision of technical advice, as a 'centre of expertise' in river and stormwater management in the Department. He joined the old Public Works Department in 1970 and has been involved in water management, both fresh and marine, for over 30 years. He worked in the Irrigation and Drainage and Harbours and Rivers Branches and moved to the Department of Marine and Harbours on the closure of the PWD in 1985. In 1990 Bill transferred to the Waterways Commission and subsequently was appointed to the position of Director, Waterways Protection and Enhancement. He moved into the Water and Rivers Commission on its creation in 1996 and then on to the Department of Environment.

Name of author:	Ms Emma Monk
Position:	Environmental Officer, Stream & Stormwater Management
Organisation:	Department of Environment (WA)
Qualifications:	B Sc. (Environmental Science), with First Class Honours
Address:	PO Box K822, Perth WA 6842
E-mail:	emma.monk@environment.wa.gov.au
Telephone:	(08) 6364 6627
Facsimile:	(08) 6364 6516

Other author:	Mr Bill Till
Position:	Program Manager, Stream & Stormwater Management
Organisation:	Department of Environment (WA)
Qualifications:	MIE Aust; CPEng
Address:	PO Box K822, Perth WA 6842
E-mail:	bill.till@environment.wa.gov.au
Telephone:	(08) 6364 6626
Facsimile:	(08) 6364 6516

Abstract

This paper will explore how stormwater quantity management significantly impacts on the quality of receiving water bodies and urban areas and will highlight the approaches to stormwater management that can address these impacts.

The objective of conventional stormwater management systems is to rapidly drain runoff from large storms, but in the process, small to moderate storms are also collected and discharged into receiving water bodies (such as waterways, wetlands and marine areas). Conventional stormwater systems involve the collection and piping or draining to receiving water bodies, or the collection and concentration of stormwater in large retention/detention areas. This results in either direct transportation of pollutants (such as nutrients and hydrocarbons) to receiving water bodies via pipes and drains every time there is enough rainfall to produce runoff from impervious surfaces, or the concentration of pollutants when collected and discharged into large stormwater infiltration systems. The conventional approach also results in less local groundwater recharge, which reduces base flow water inputs in waterways and wetlands, particularly during drier parts of the year. Conventional systems also significantly increase the

peak flows in flood events and the flow rates in receiving water bodies from small to moderate events. The impacts on water quality and hydrology due to conventional stormwater systems result in reduced biodiversity and increased algal blooms in receiving water bodies. The quality of urban areas is also reduced due to large areas of land (often fenced-off from public access) allocated to individual stormwater devices, as well as reduced public amenity of water bodies due to algal blooms and fish kills.

The water sensitive approach to stormwater management aims to maintain the pre-development hydrologic regime – that is, maintain the pre-development stormwater quantity characteristics. This involves distributed retention/detention (e.g. at or near source infiltration) of small-moderate events throughout the catchment. This approach increases disconnection between impervious areas and receiving water bodies. Stormwater should not be discharged directly into receiving water bodies and only major events should reach receiving water bodies via overland flow paths. Stormwater management should be integrated in the urban landscape, with catchment/neighbourhood scale systems incorporated in public open space and linear multiple use corridors. By having stormwater systems distributed throughout a catchment and integrated in the urban landscape, there will not be the social and economic issues associated with allocating (and often fencing off) large areas of land for traditional devices such as open drains and large sumps. These approaches result in improved biodiversity and health of receiving water bodies and improved amenity and quality of urban areas.

Quantity is the road to quality

This paper will discuss how managing stormwater quantity significantly helps manage the quality of water bodies and urban areas. There are other aspects to stormwater management, such as using structural and non-structural measures for the primary purpose of stormwater quality management, that are not addressed in this paper. See the *Stormwater Management Manual for Western Australia* for more information.

Traditional / conventional approach

The traditional / conventional approach to urban development and stormwater management is to:

- Clear almost all native vegetation.
- Cut (hill tops) and fill (depressions, usually wetlands).
- Construct large areas of impervious surfaces.
- Install pipes and constructed / hydraulically efficient channels that drain water away from an area as quickly as possible, by directly discharging stormwater into receiving water bodies.
- Install large-scale systems/devices (such as large sumps or constructed wetlands) downstream of the source of runoff.

These processes significantly change the hydrology of a catchment and the amount and characteristics of stormwater to be managed.

In temperate climate zones, when rain falls on undeveloped land, most of the water will soak into the topsoil and slowly find its way to the nearest receiving water body. A small portion of rainfall in undeveloped catchments, around 10-15%, will become direct surface runoff and most of this will be generated by only a few intense rainfall events a year. Runoff moves slowly through the catchment because the ground surface is rough due to the presence of vegetation. This means that the effect of rainfall is spread out over hours or days. Short, heavy storms have little impact on flow rates in surface water bodies because the major movement of water to receiving water bodies is through groundwater.

In traditionally drained urban areas, there is a reduction in natural water catchment storage when floodplains and natural wetlands are in-filled for development. Most native vegetation is also cleared, so there is less evapotranspiration. At the same time, paved surfaces are smoother than natural surfaces, so water can travel faster across the surface and reach the receiving water body more quickly. Peak flow rates can increase by a factor of up to ten. In these conditions, receiving water bodies have to hold larger and often sudden or rapidly peaking runoff flows. As described in Walsh *et al*. (2004), when urban impervious surfaces are constructed, runoff becomes more frequent. This occurs because even small rainfall events produce runoff from impervious surfaces. Less area is available for infiltration into the soil and construction often involves the removal of permeable topsoil from the catchment. Conventional stormwater drainage reduces infiltration further again by ensuring that all water draining off impervious surfaces is transported directly to the water body via an efficient network of drains and pipes (see Figures 1 and 2 for examples of Perth's drainage system).

Figure 1. Trapezoidal drain, Bayswater, WA. (Photograph: Department of Environment 2002.)

Figure 2. Pipes entering Lake Monger, Wembley, WA. (Photograph: Department of Environment 2005.)

Stormwater systems in WA were originally developed in response to flood prevention, to control groundwater levels and to enable development to occur. Consequently, the traditional emphasis of stormwater management was one of efficiently collecting and conveying runoff and groundwater from urban areas into nearby lower areas such as wetlands, streams, rivers, estuaries and marine areas. Little or no consideration was given to the 'downstream' consequences of a conveyance-dominated approach.

Walsh *et al*. (2004) discuss the following changes to stream systems as a result of conventionally drained urban areas. Stream flow is much more variable ('flashier'), and in larger storms, the peak flow is significantly increased and the decline back to base flow is much quicker. Increased runoff can increase the volume and rate of water flowing into and through natural waterways, causing erosion of stream banks and vegetation. There may be a change in urban waterways from ephemeral to perennial systems, which will have consequences on their ecology and channel form. Increased erosive forces caused by increased water quantity and velocities may change the waterway channel form. This can result in deeper or wider channels and erosion of banks and the channel bed. The channel may also move laterally to accommodate the flows. Undermining of the banks by the changed hydrology can cause a loss of riparian vegetation that holds the banks and exacerbate the problems. The erosion of bank material also leads to sedimentation of downstream waterways and estuaries that can cause ecological loss and in some cases may cause problems with waterway navigation.

In some cases, the efficiency of conveyance systems results in less water being received by some waterways and wetlands in a catchment. Flows may be diverted away from the original receiving waters, or the efficiency of the drainage system means that the water is removed too quickly from the environment (i.e. the peak flows are higher, but occur over a shorter period). Artificial drainage channels are often designed to contain and convey large flood events (e.g. 10-year ARI events), resulting in isolation of the floodplain from the waterway and rare floodplain inundation. Many fish species and other aquatic fauna rely on annual flooding of the floodplain for breeding purposes and as a food source. Many waterways and wetlands receive water from groundwater as well as overland flow. Removal of water from a catchment through traditional piped systems can result in reduced recharge of the groundwater. As a result, the groundwater contribution and base flow in the water bodies is reduced. This may have an effect on the geomorphological processes, such as the ability of the water body to retain its form (such as pools and riffles) and size, as well as ecological impacts such as dying vegetation and reduced species diversity. (Adapted from Department of Environment 2004 and Department of Environment and Swan River Trust 2005a.)

Polluted runoff has been identified as the most significant contributor to the deterioration of water quality in natural and artificial waterways in many parts of WA (Welker 1995). Taylor *et al*. (2004) suggested that frequent pulses of high nutrient water with moderate increases in flow were the primary drivers behind increases in the biomass of algae on the bottom of streams in urban catchments. If impervious surfaces are conventionally drained, then the contaminants are delivered efficiently to receiving water bodies via pipes and drains every time there is enough rainfall to produce runoff from an impervious surface (Walsh *et al*. 2004.) Research conducted by the Cooperative Research Centres for Freshwater Ecology and Catchment Hydrology (Australia) has shown that waterway biodiversity is significantly impacted by the amount of impervious surfaces directly connected (i.e. through pipes and drains) to waterways and the subsequent poor quality stormwater runoff (Walsh 2004).

Walsh *et al*. (2004) discusses the impact of effective imperviousness on stream ecology. Effective imperviousness is defined as the combined effect of the proportion of constructed impervious surfaces in the catchment, and the 'connectivity' of these impervious surfaces to receiving water bodies. A summary of the effect of increased effective imperviousness on water body ecology and processes are highlighted in Table 1.

Table 1. The effect of increased effective imperviousness on water body ecology and processes.

Increased imperviousness leads to:	Flooding	Habitat loss	Erosion	Channel widening	Stream bed alteration	Biodiversity decline
Increased volume	√	√	√	√	√	√
Increased peak flow	√	√	√	√	√	√
Increased water temperature		√				√
Decreased base flow		√				√
Sediment loading changes	√	√	√	√	√	√
Increased contaminant loads						√

Traditional systems also increase potential public health hazards, due to the commonly steep sides of trapeziodal drains, detention basins and sumps requiring fencing or other protective measures. The appearance and exclusion fencing of these types of systems also reduces the aesthetics and public amenity of valuable urban land.

Water sensitive approach

Main approaches:

- **Mimic natural processes.**
- **Managing stormwater quantity helps manage the quality of water bodies and urban environments.**

The removal of catchment vegetation cover contributes to increased runoff, due to reduced transpiration rates and less removal of water from the soil by plants (see Figures 3 and 4). Therefore, retaining native vegetation is an important feature in stormwater management. In a vegetated catchment in temperate zones of Australia, runoff only occurs during infrequent large storms that are either large enough to saturate the topsoil of the catchment, or intense enough to exceed the infiltration capacity of the soil (Walsh *et al*. 2004). Rainfall is mostly evapotranspirated or infiltrated into the soil in natural catchments (Walsh *et al*. 2004). Therefore, the water sensitive approach should mimic these processes as much as possible.

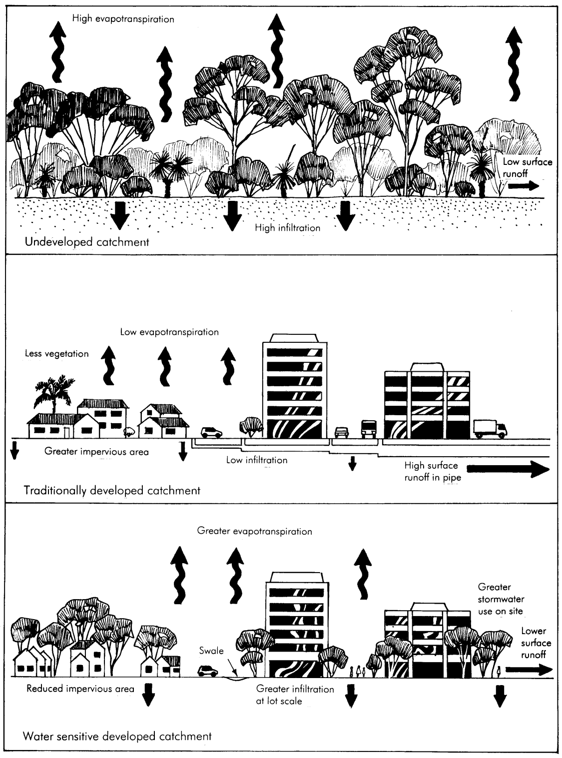

Figure 3. Effect of development on the catchment hydrology for low intensity rainfall events (Department of Environment 2004).

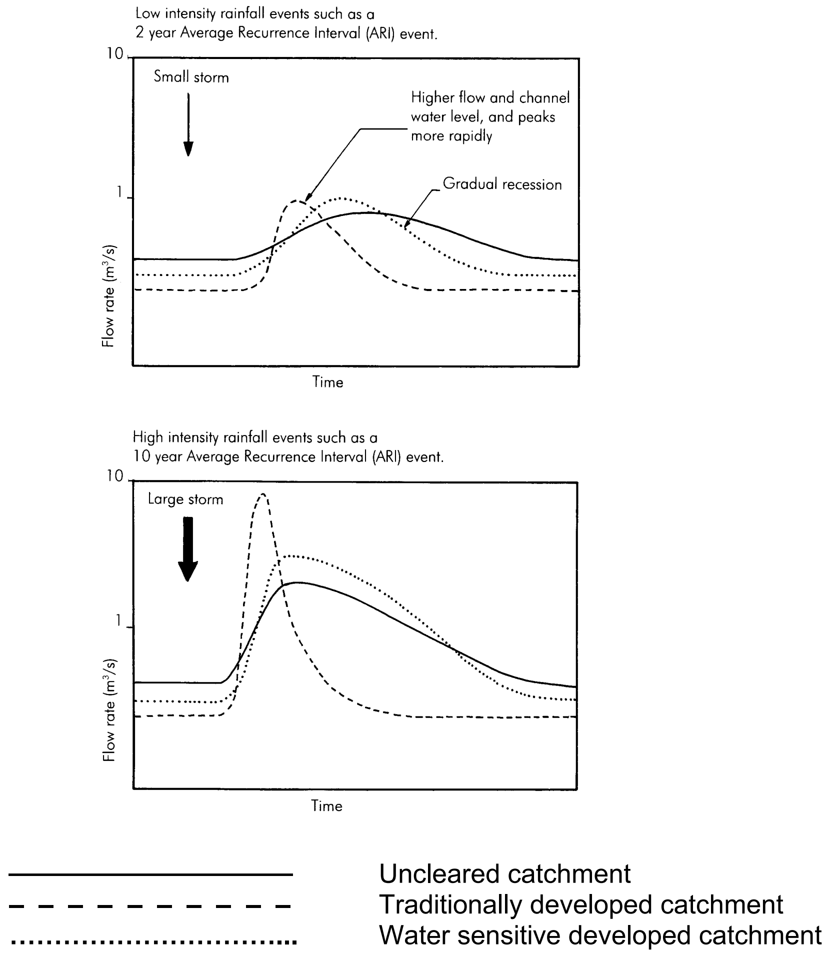

Figure 4. Differences in stream flow hydrographs between traditional land development and water sensitive development (Department of Environment 2004).

Walsh *et al*. (2004) reported that models suggested that when a very small amount of land in a catchment is developed and drained using conventional stormwater management techniques, the receiving stream's baseflow water quality is likely to be typical of degraded streams in metropolitan areas. They concluded that the most hopeful approach for developing urban land while maintaining good stream water quality (at levels close to pre-development levels) is the dispersed, catchment-wide application of water sensitive urban design, so that very little or none of the catchment's impervious surfaces drain directly to streams.

Walsh *et al*. (2004) recommended the following: Retain water from small-to-moderate rain events. This water should be allowed to infiltrate into the soil, or evaporate or be transpired back into the atmosphere. This is most easily achieved at small-scales, close to the impervious surfaces that the water runs off. If water throughout the catchment is collected and transported to a point some distance downstream for retention and treatment, often impractically large areas would be required to allow sufficient infiltration or evaporation.

Infiltration systems include a number of devices, such as soakwells, soakage areas (e.g. basins and retention trenches), leaky gully / side entry pits, swales, pervious paving and bioretention systems, designed to promote stormwater permeation into the soil profile. Using infiltration systems at source has a number of environmental and economic benefits, including reducing peak stormwater flows, reducing downstream flooding, reducing stormwater management capital costs, improved groundwater recharge and improved stormwater quality (Coombes 2002).

Increasing on-site stormwater infiltration recharges the groundwater system. This can re-establish base flows in waterways and help restore groundwater dependent ecosystems, such as some wetlands that are degrading due to declining groundwater levels in response to low rainfall and high groundwater abstraction rates.

Infiltration of stormwater and reuse through garden bores helps manage the local water balance, limiting consequential environmental impacts from urban developments. Maintaining the water cycle balance can prevent problems associated with acid sulphate soils, salinity and waterlogging.

Techniques to improve storage and infiltration of stormwater in the catchment can reduce the velocity of water entering water bodies. Decreasing the 'flashiness' and peak velocities of flows will decrease the potential for erosion of water bodies.

By retaining water from the small-to-moderate events, increased total catchment imperviousness would still cause flows from larger rain events to be greater and more intense than those of the pre-urban state (and probably associated with higher levels of pollutants), but the timing of these events would be in line with the pre-urban stream. The ecological impacts of these larger events may be relatively small because they are closer to the type of disturbance to which plant and animal life that live in flowing water are adapted. (Ladson, Walsh and Fletcher 2004.)

Stormwater should be kept clean and infiltrated as close as possible to the point where it falls as rain, before it becomes contaminated. As significant amounts of organic and inorganic pollutants are bound to sediment, the minimisation and control of sediment runoff, principally by reducing runoff as close to its source as possible, is now a fundamental component of effective stormwater quality management (Wong *et al*. 2000). Correctly designed infiltration systems can remove pollutants from stormwater through the processes of adsorption, filtration and microbial decomposition. So by managing the quantity of runoff at source, the water quality will be better managed.

The impacts of stormwater-derived pollution are inextricably linked to hydrological impacts (Walsh *et al*. 2004). Studies in urban areas have shown that there is no general trend of increased concentrations of contaminants such as nutrients and metals with increasing storm sizes. Figure 5 shows that most hydraulic structures can be expected to treat over 99% of the expected annual runoff volume when designed for a 1 year ARI peak discharge. Unlike flood mitigation measures, stormwater quality treatment devices do not need to be designed for rainfall events of high ARI to achieve high hydrologic effectiveness (i.e. the percentage of mean annual runoff volume subjected to treatment) and therefore a high level of beneficial environmental outcomes.

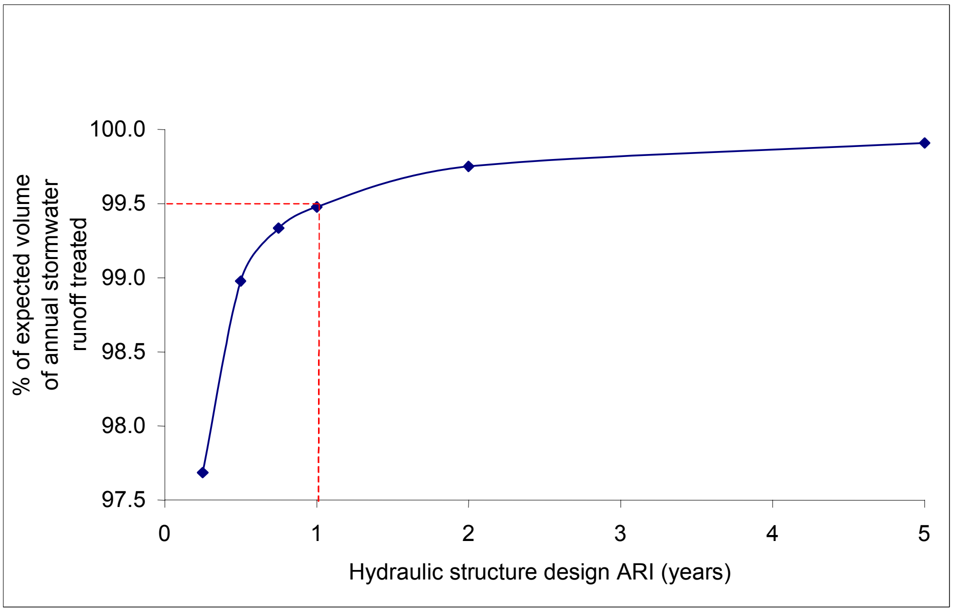

Figure 5. Treatment efficiency of stormwater hydraulic structures for Perth, Western Australia (adapted from Wong *et al*. 1999)

It is important to note that pollution reduction is a primary objective for managing stormwater runoff from more frequent, low intensity rainfall events and 'first flush' storm events. For stormwater flows from high intensity rainfall events, the primary objective remains to reduce flooding of buildings, infrastructure and other assets. 'First flush' describes situations when pollutants (e.g. sediments) that have accumulated on impervious surfaces are transported at the beginning of a rainfall event. This results in high pollution concentrations at the start of the runoff hydrograph, reducing to lower levels before the flood peak occurs (Argue 2004).

Improving water quality also improves the opportunity for water related recreation, such as canoeing and fishing, and decreases the occurrence of algal blooms that present a health risk. Areas like the lower Canning River catchment upstream of the Kent Street Weir in Perth occasionally experience harmful blue green algal blooms shortly after late summer/early autumn rainfall events. These blooms often occur after long, dry periods when large loads of material and associated nutrients have accumulated on impervious surfaces and this material is then conveyed by 'first flush' rainfall events into the Canning River.

Impervious areas such as roads, carparks and footpaths create high runoff rates during a storm event. Where appropriate, pervious paving can be installed in place of impervious surfaces such as bitumen or concrete. The pervious paving not only allows for infiltration but can improve the water quality. Pervious pavement has been shown to be very effective at retaining dissolved metals (Dierkes *et al*. 2002).

Infiltration of stormwater throughout the catchment in small scale infiltration systems (e.g. soakwells and swales) is also a better use of urban land because large areas of land are not excised from public/urban use to incorporate large scale (often fenced off) drains and sumps (see Figures 6 and 7). Linkages through the landscape can be formed through water, such as swales, waterways and riparian vegetation corridors, connecting communities through public open space, particularly if walkways are integrated with the stormwater management systems. Playing fields can also act as temporary stormwater detention areas and parks can incorporate swales and living streams. Incorporating catchment-scale stormwater systems in public open space, rather than installing them in fenced-off drainage/basin reserves, can make developments more desirable and marketable and increase property values. Property values adjacent to retrofitted drainage features, such as living streams and landscaped stormwater features (such as swales), have been shown to increase due to the increased amenity of the area. Chapter 6: Retrofitting of the *Stormwater Management Manual for Western Australia* discusses restoration works at Bannister Creek that improved the recreational and aesthetic value of the area. It was estimated that average property values adjacent to the restored creek increased 17% more than properties adjacent to unrestored sections of Bannister Creek (pers. comm., J. Robert 2004)[1].

[1] Personal communication with Julie Robert, South East Regional Centre for Urban Landcare, 2004, citing information provided by the Real Estate Institute of WA.

Figure 6. Soakwell amphitheatre, Ascot, WA. (Photograph: Department of Environment 2003.)

Figure 7. Bannister Creek, Lynwood, WA. (Photograph: Department of Environment 2003.)

Effective imperviousness of a development area should be minimised. This is achieved by 'disconnecting' constructed impervious areas from receiving water bodies and by reducing the amount of constructed impervious areas. Minimising effective imperviousness requires the prevention or reduction of run-off from small-to-moderate floods. The most efficient scale at which to achieve this aim is as near the source of runoff as possible (Walsh *et al*. 2004).

The *Decision Process for Stormwater Management in WA* (Department of Environment and Swan River Trust 2005b) was developed to provide a decision framework for the planning and design of stormwater management systems. Implementation of the methodology outlined in the decision process will result in minimising potential changes in the volume of surface water flows and peak flows resulting from urban development. The Decision Process recommends the following approaches:

> Rainfall, for the majority of events occurring each year (generally less than 1 year ARI events), should be retained or detained on-site (i.e. as high in the catchment and as close to the source as possible, subject to adequate site conditions). Runoff from constructed impervious areas (e.g. roofs and paved areas) should be retained or detained through the use of soakwells, pervious paving, vegetated swales or gardens. For detention systems, the peak 1 year Average Recurrence Interval (ARI) discharge from constructed impervious areas should be attenuated to the pre-development discharge rate. Events larger than 1 year ARI can overflow 'off-site'. [That is: Rainfall from most events (generally less than 1 year ARI events) should be infiltrated, evaporated, transpired or stored for later use.]
>
> For larger rainfall events (generally greater than 1 year ARI events), runoff from constructed impervious areas should be retained or detained up to the specified design storm event in landscaped retention or detention areas in public open space or linear multiple use corridors. Any overflow of runoff towards waterways and wetlands should be by overland flow paths across vegetated surfaces. Further detention may be required to ensure that the pre-development hydrologic regime of the receiving water bodies is largely unaltered, particularly in relation to peak flow rates and, where practical, discharge volume. That is, larger rainfall events should still reach receiving water bodies, if that is what occurred pre-development. The peak flow rates and, where practical, the discharge volume of larger events should largely be the same as pre-development. Maintaining the pre-development hydrologic regime helps meet the ecological water requirements of receiving environments.

How to improve stormwater quantity management in existing urban areas – Retrofitting

Retrofitting projects that improve stormwater quality and 'disconnect' impervious surfaces from receiving water bodies can have positive benefits on the health and amenity of water bodies and urban areas.

Retrofitting projects should aim to remove or rationalise the number of pipe and constructed channel outlets to waterways and wetlands. Outlets should be relocated so that runoff flows overland through vegetation towards waterways and wetlands.

Existing stormwater devices can be retrofitted to introduce more on-site infiltration. For example, solid base manholes, gullies and side entry pits can be modified (e.g. by coring out a hole in the base of the pit, as shown in Figure 8) to allow for infiltration, or existing devices can be supplemented with additional soakwells or infiltration cells / leach drains. This allows for on-site infiltration, while still maintaining a stormwater detention function, with larger runoff events accommodated by overflow systems. The base of the unit may need to be covered by a grate to prevent the permeable base material (e.g. blue metal) being sucked up by educting equipment and the unit being destabilised (pers. comm., B.Todd 2005[2]). Figure 9 provides a concept design of a retrofitted gully with a soakwell added to the system.

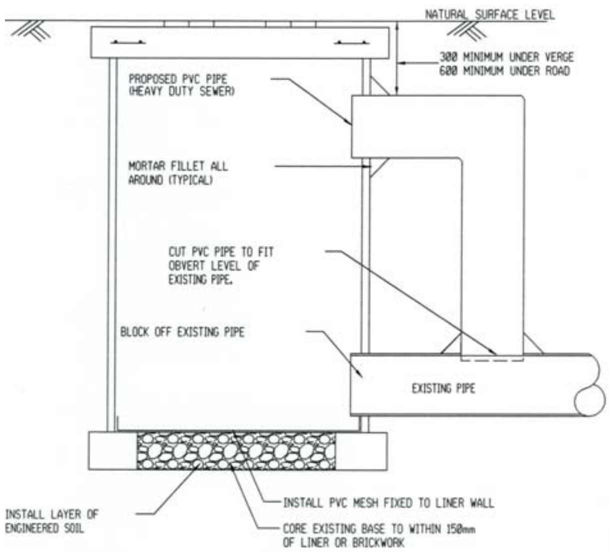

Figure 8. Retrofitting option for solid base pits. (Supplied by B. Todd, Town of Victoria Park.)

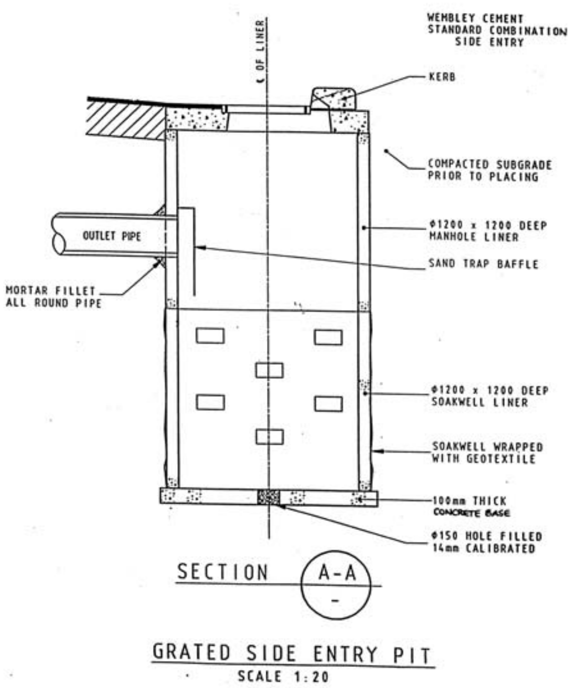

Figure 9. Standard combination gully / soakwell. (Supplied by M. Glover, City of Bayswater.)

2 Personal communication with Bill Todd, Technical Engineering Officer, Town of Victoria Park, 2005.

Impervious surfaces (such as bituminised and paved areas) that convey runoff directly into water bodies (e.g. carparks draining directly to the street's drainage system that then discharges directly into a water body) can be disconnected and stormwater directed instead into permeable systems, such as bioretention areas, swales, garden beds and vegetated open spaces, or the impervious surfaces can be replaced with pervious paving.

Bitumen and other hardstand roads can be retrofitted to improve the quality and quantity of runoff. Rather than collecting and piping stormwater runoff from roads, the road drainage system can be 'disconnected' and on-site infiltration introduced. The road reserve can be utilised to restore or maintain the pre-development runoff characteristics of the site at a street-scale for at least up to a 1 in 1 year ARI event. Retention and detention measures can be implemented in the road reserve, such as swales, soakwells and other controls to promote infiltration and evapotranspiration. Where appropriate, kerbs can be replaced with flush kerbing (e.g. by grinding existing precast barrier kerbs down to the road level), allowing for infiltration of runoff into the road verge, or into roadside or median strip vegetated swales (Figure 10).

Figure 10. Example of flush kerbing and grass swales, Brisbane, Qld. (Photograph: Department of Environment 2002.)

Conclusion

The water sensitive approach to stormwater management aims to maintain the pre-development hydrologic regime – that is, maintain the pre-development stormwater quantity characteristics. This involves distributed retention/detention (e.g. at or near source infiltration) of small-moderate events throughout the catchment. This approach increases disconnection between impervious areas and receiving water bodies. Stormwater should not be discharged directly into receiving water bodies and only major events should reach receiving water bodies via overland flow paths. Stormwater management should be integrated in the urban landscape, with catchment/neighbourhood scale systems incorporated in public open space and linear multiple use corridors. These approaches result in improved biodiversity and health of receiving water bodies and improved amenity and quality of urban areas.

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