INTEGRATED STORMWATER AND GROUNDWATER MANAGEMENT IN PERTH, WESTERN AUSTRALIA

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ABSTRACT

Perth, Western Australia, is situated on a sandy coastal plain overlying a shallow superficial aquifer and semi-confined aquifers. Groundwater is a major water source for the city's population and industries. This has provided unique challenges and opportunities for the management of stormwater to maximise recharge, whilst protecting the quality of the water stored in the underlying aquifers.

The Department of Water developed the *Stormwater management manual for Western Australia* as a comprehensive guideline to assist land developers, industry, state agencies and local governments in the planning, design and ongoing management of stormwater management systems. It provides guidelines for 'non-structural' practices that prevent pollution entering the stormwater stream. The manual also provides guidance on 'structural' practices to manage the quantity and quality of stormwater runoff and to maximise aquifer recharge. A range of engineering designs and their associated maintenance requirements are presented.

The manual strongly advocates 'at-source' management of rainfall, before it becomes runoff. This appears simple in theory, but is complicated by high groundwater levels that can seasonally fluctuate by over a metre and inundate large areas. The closeness of the aquifer to the surface also heightens the need for comprehensive pollution prevention and treatment mechanisms.

This paper will outline how policies, guidelines and design criteria have been developed to ensure Perth has sustainable and integrated urban water management outcomes and is moving towards becoming a 'water sensitive city'.

Introduction

Perth is a city of 1.65 million people living principally in single residential allotments spread out over more than 100 kilometres of a sandy coastal plain. The city is built over three underlying aquifers, two confined and one unconfined superficial aquifer. The unconfined aquifer is close to the surface and expresses itself at the surface as wetlands over significant areas. By 2031 future population forecasts predict that the Perth region will house a population of more than 2.2 million people. This is an addition of 556,000 people on today's population. To accommodate this level of growth, a further 328,000 dwellings will be needed, with potential for significant affects on the water resources and hydrology of the region.

The water supply for the city is sourced from both surface water dams (~100 GL/yr) and groundwater bores (~460 GL/yr), and more recently from a desalinisation plant (~45 GL/yr). A second desalinisation plant is now under construction with an initial capacity of 45GL/yr due to commence supply in 2012, with provision for a future upgrade to a capacity 90GL/yr. The major source of water for both private and public supply remains groundwater. The management of the underlying groundwater aquifers is therefore crucial in facilitating the forecast growth of the city. Unlike major cities in Australia and around the world, most stormwater in Perth recharges the superficial groundwater aquifer. The Department of Water published the *Stormwater management manual for Western Australia* (DoW 2004–2007). One approach promoted in the manual is maximum aquifer recharge with stormwater that is not a threat to the overall quality of the groundwater stored in the aquifer.

Significant environmental and urban amenity benefits can be achieved by retaining flows from frequent, low intensity rainfall events. This approach aims to maintain the pre-development hydrologic regime – that is, maintain the pre-development stormwater quantity characteristics. This paper will discuss how designing stormwater management systems for small events significantly helps manage the quality of aquifers, surface water bodies and urban areas.

What are the impacts of traditional drainage design?

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. Impervious surfaces are built, such as roads, roofs and pavements, resulting in increased runoff during storm events due to the decrease in pervious area available for infiltration. At the same time, impervious 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. 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.

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). 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). If runoff is collected and managed downstream, the local and downstream hydrologies are altered.

Traditionally drained catchments can also result in more water being discharged to receiving water bodies. Walsh et al. (2004) and Department of Water (2004–2007) discussed 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.
- There may be a change in urban waterways from ephemeral to perennial systems, which will have consequences on their ecology and channel form.
- Increased runoff can increase the volume and velocity of water flowing into and through natural waterways, causing erosion of stream bed and banks.
- Increased erosive forces may change the waterway channel form. The channel can become deeper or wider. 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, loss of fisheries habitats and in some cases may cause problems with waterway navigation.

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 local 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.

What is the new drainage design criterion for urban development?

We need to design our urban stormwater systems to better mimic the hydrology of undeveloped catchments. A fundamental way to achieve this is to consciously design to manage the 1-year average recurrence interval[1] (ARI) event.

Figure 1 illustrates the impacts on catchment hydrology of a traditional drainage design approach compared to a water sensitive approach to development. The water sensitive approach more closely mimics the hydrology of an undeveloped catchment by retaining and using most stormwater on-site and reducing the increased runoff from constructed impervious surfaces, by detention, during small to minor intensity rainfall events.

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[1] Average recurrence interval (ARI) is defined as the average, or expected, value of the periods between exceedances of a given rainfall total accumulated over a given duration.

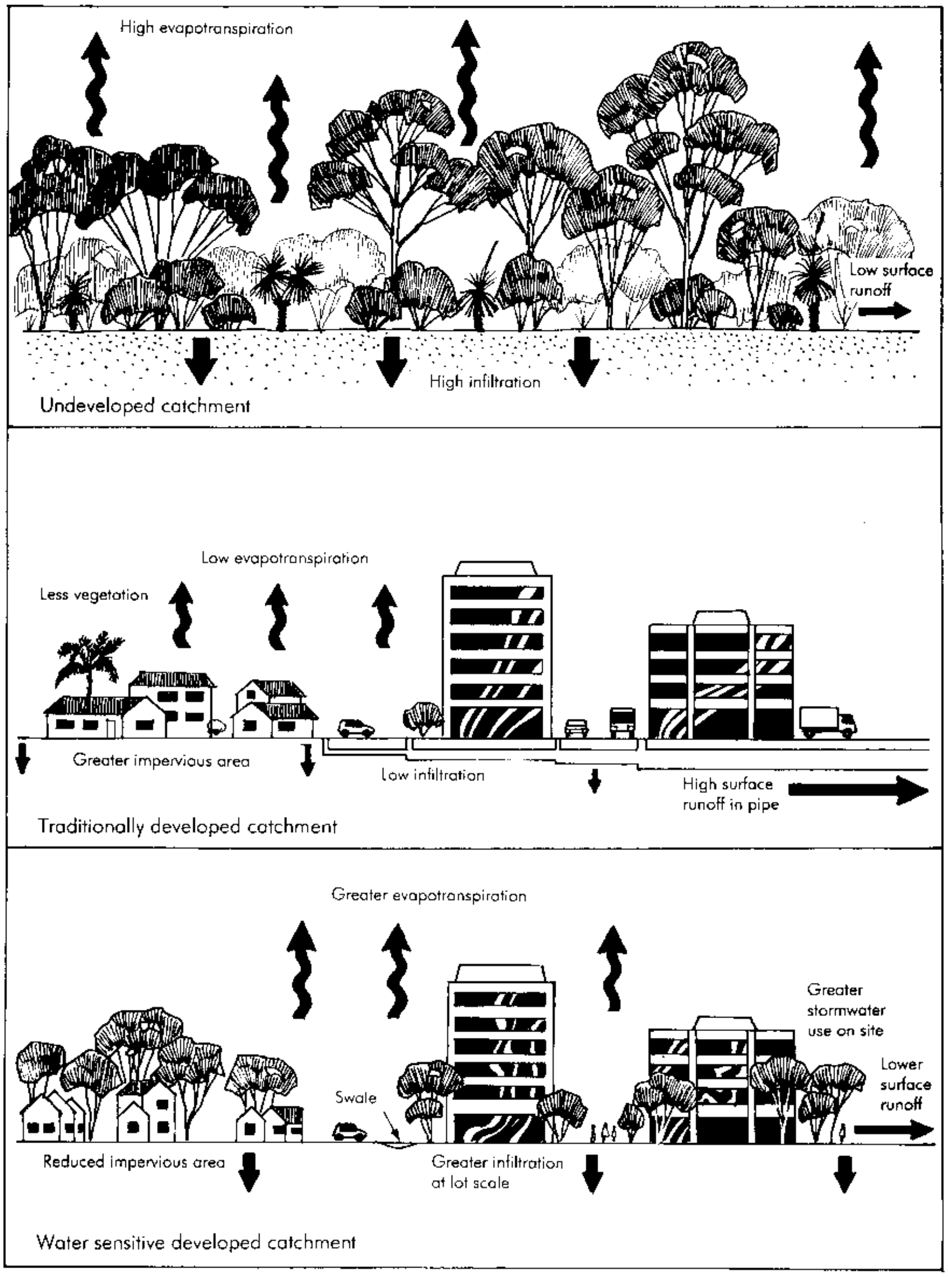

Figure 1. Effect of development on catchment hydrology for low intensity rainfall events. (Department of Water 2004–2007.)

When urban drainage systems are currently designed, most designers address two criteria – flood protection (typically management of 5-year and 100-year ARI events) and water quality (calculated as loads or concentrations). The concept of managing the smaller 1-year (or less) event is implied in design guidelines for stormwater quality controls, but currently is not widely specified as a quantity management criterion. Yet, 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 2 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.

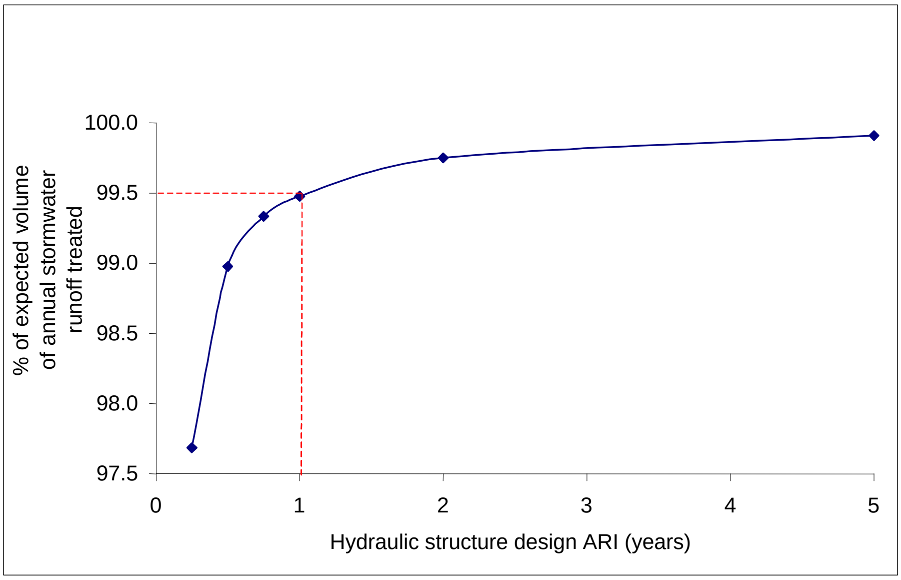

Figure 2. Treatment efficiency of stormwater hydraulic structures for Perth, Western Australia (adapted from Wong et al. 1999)

In traditional drainage systems, increased flows from impervious surfaces from up to 1-year ARI events usually travel 'unhindered' to the receiving environment because detention designs are focused on achieving the design detention volume only at the flood design event (usually 5 or 10-year ARI events). The design being promoted by the Department of Water is for runoff from impervious surfaces generated by small (up to 1-year ARI) events to be retained or detained at-source, and for minor to major (i.e. greater than 1-year ARI) events to flow overland to the receiving environment after adequate detention and treatment higher in the catchment. Figure 3 illustrates this recommended approach in relation to managing runoff from various design storm events. This design process mimics the hydrology of an undeveloped catchment.

Therefore, the Department of Water has introduced a new stormwater quantity design criterion for assessment of urban developments: *for the critical 1-year average recurrence interval (ARI) event, the post-development discharge volume and peak flow rates shall be maintained relative to pre-development conditions in all parts of the catchment*. Runoff from constructed impervious surfaces generated by up to the 1-year, 1-hour average recurrence interval (ARI) events should be retained or detained as close to source as possible. Generally, detention systems should preserve the pre-development critical 1-year ARI discharge volume and peak flow rate for the catchments, which aids in the protection of ecological values.

Less than and equal to 1-year ARI events:

Retain or detain stormwater runoff from constructed impervious surfaces generated by up to 1-year average recurrence interval (ARI) events on-site (i.e. as high in the catchment and as close to the source as possible). Generally, detention systems should preserve the pre-development critical 1-year ARI discharge volume and peak flow rate for the catchment.

Greater than 1-year and up to 100-year ARI events:

Manage runoff from constructed impervious areas for greater than 1-year ARI events in landscaped retention or detention areas in road reserves, public open space or linear multiple use corridors. Runoff into waterways and wetlands shall be by overland flow paths across vegetated surfaces.

Design for greater than 1-year and less than/equal to 5-year ARI

Minor system conveyance (e.g. via swales and overflow pipes)

Design for greater than 5-year and up to 100-year ARI events.

Major system conveyance (i.e. via overland flow paths)

Figure 3. Approach to maintaining pre-development hydrology

The quantity design criterion has been further simplified at a local scale to require all runoff from constructed impervious surfaces, such as roofs or pavements, during rainfall events up to the 1-year, 1-hour duration ARI event for the locality to be retained or detained at the first outlet point. This effectively leads to distributed retention/detention (e.g. at or near source infiltration) of small events throughout the catchment to manage the quantity and quality of urban stormwater before it reaches receiving water bodies.

How do you design a water sensitive stormwater system?

To achieve the best stormwater management outcomes, both structural and non-structural techniques should be used in particular combinations to suit the local conditions. In most situations, a number of management measures may be implemented in series or concurrently forming a treatment train approach to stormwater management. This arrangement will satisfy the water quantity and quality objectives that might be unachievable if relying on a single technique. If a single, large treatment measure (such as a constructed wetland) is relied on to achieve the desired reduction in pollutant loading from the 1-year event, any failure in the treatment measure may increase pollutant loadings to the receiving environment. If numerous small treatment measures are distributed throughout the catchment, the failure of an individual measure is unlikely to significantly impact on the performance of the overall treatment system protecting the receiving environments.

One of the best methods for maintaining the natural or pre-development hydrologic regime and protecting receiving water bodies is to minimise 'effective imperviousness'. 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. Therefore, reducing effective imperviousness is achieved by 'disconnecting' constructed impervious areas from receiving water bodies as well as by reducing the amount of constructed impervious areas. Minimising effective imperviousness results in the prevention or reduction of runoff from small to minor floods. The most efficient scale at which to achieve this aim is as near the source of runoff as possible (Walsh et al. 2004).

Reduction of effective imperviousness can be achieved by non-structural techniques, such as maximising retention of native vegetation when developing land, and structural techniques, such as installing infiltration systems. Infiltration systems include a number of devices, such as soakwells, soakage areas (e.g. basins and retention trenches), leaky gully / side entry pits, swales (Figure 4), pervious paving (Figure 5), green roofs/walls and bioretention systems (Figure 6), designed to promote stormwater permeation into the soil profile. For example, the Shire of Broome offices have a gutterless roof and aggregate to infiltrate the roof runoff (Figure 7). 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).

Figure 4. Vegetated swale in Gosnells, making use of native species in a parkland setting. (Photograph: Department of Water 2004.)

Figure 5. Pervious paving driveway at an urban development in Baldivis. (Photograph: Department of Water 2008.)

Figure 6. Bioretention system installed to treat carpark runoff in the Busselton Light Industrial Area. (Photograph: Department of Water 2008.)

Figure 7. Pervious surface underneath a gutterless roof, Shire of Broome offices, Broome. (Photograph: Allan Ralph, Shire of Broome 2005.)

Infiltration techniques can be implemented in a range of soil types, and are typically used in soils ranging from sands to clayey sands. Retention of the 1-year, 1-hour ARI event can be achieved at sites with low permeability soils. Infiltration devices can be designed with a slow release drainage outlet that is connected to the downstream stormwater system. Rainfall can also be retained on-site by installing storage devices such as rainwater tanks.

In the design of infiltration systems, field investigations must be undertaken to determine the soil type; hydraulic conductivity; presence of soil salinity, rock and other geological limitations; slope of the terrain; stormwater quality; and groundwater level, depth and quality. See Chapter 9: *Structural controls* of the *Stormwater management manual for Western Australia* (Department of Water 2004–2007) for further discussion of the design considerations.

Only runoff from constructed impervious areas should be detained / retained. Once storage is exceeded (which is usually at greater than 1-year ARI events), there will be off-site flow. If we design for the 1-year ARI event, runoff characteristics will be close to pre-development conditions.

The superficial aquifer on the Swan Coastal Plain is unconfined and has a seasonal height variability of over one metre and is close to the ground surface in many areas. Perth's urban drainage system was constructed to control or lower the seasonal maximum level of the aquifer and to 'dispose' of this 'excess' groundwater. With the introduction of water sensitive urban design principles, this seasonal height variability was seen as an opportunity to provide for storage of rainfall and stormwater runoff during winter for use during the long dry summer. Thus, stormwater can be used as a water source to supplement household, commercial/industrial, streetscape and parkland water supply needs, while ensuring the maintenance of groundwater aquifer supply and surface water ecosystems. This recharge to groundwater acts as an opportunity for storage of stormwater that can be drawn over summer and does not present water loss problems through evaporation from storage ponds.

The Department is currently exploring these concepts through extensive investigations in a major urban expansion area south of Perth in the Peel Region. This study is looking at storage of 'excess' winter stormwater both in the superficial and underlying confined aquifers.

Figure 8 shows rainfall at Perth Airport for the period January 2000 to August 2004. If a device is designed to capture events up to the 1-year, 1-hour ARI rainfall event, very few events exceed this value. In this example, the 1-year, 1-hour ARI event is 16.3 mm at Perth Airport. Only 1 to 2 events per year exceeded this value. By designing to capture up to the 1-year, 1-hour ARI event, most of the total annual volume of stormwater would be retained and be available for storage in the superficial aquifer.

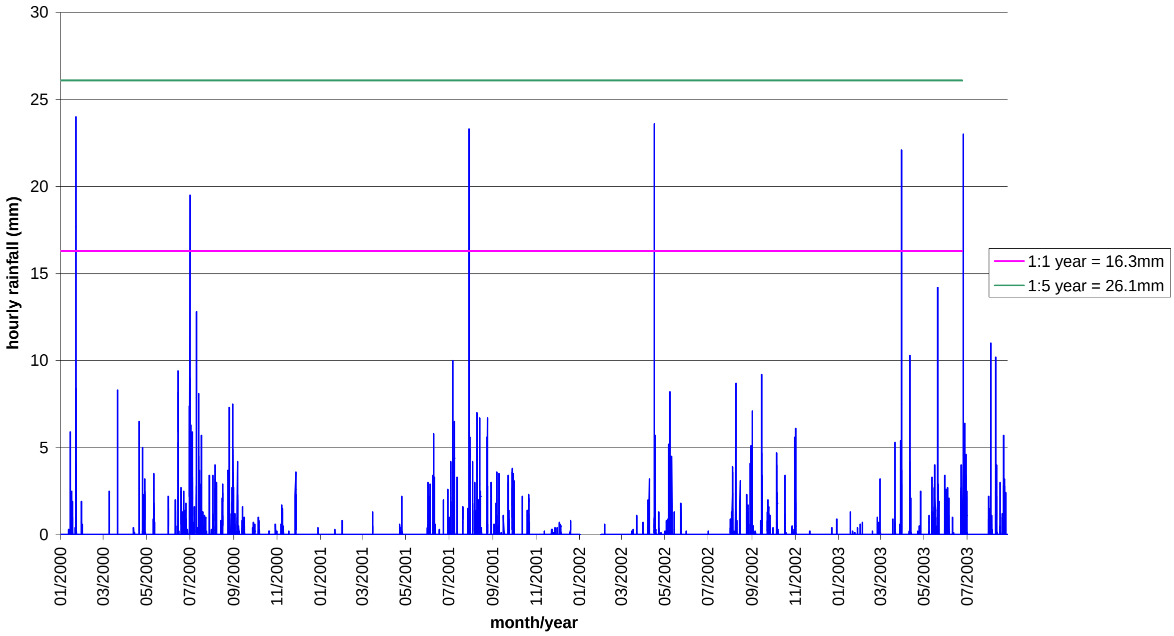

Figure 8. Hourly rainfall for Perth Airport – January 2000 – August 2004

What are the benefits of retaining the 1-year ARI event?

Techniques to improve storage and infiltration of stormwater throughout the catchment can reduce the velocity and volume of water entering water bodies. By retaining or using water from events up to the 1-year ARI, the flashiness and peak velocities of flows, and therefore the potential for erosion of water bodies, will decrease. The increased total catchment imperviousness would still cause flows from larger rain events to be greater than those of the pre-urban state (and probably associated with higher levels of pollutants), but the frequency of these events would be in line with the pre-urban runoff characteristics. The ecological impacts of these larger events may be relatively small because they are closer to the type of disturbance that aquatic plants and animals have adapted to (Ladson, Walsh & Fletcher 2004).

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. Recharging the local aquifer will also provide more resilience during a drying climate.

Infiltration of stormwater and subsequent reuse through 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.

At-source retention (via infiltration/aquifer recharge/rainwater and stormwater use) of small events also helps to reduce the transportation of pollutants to waterways, wetlands and coastal waters. It is important to note that ecosystem health, including aquifer water quality protection, and pollution reduction are the primary objectives for managing stormwater runoff from 1-year (and less) ARI events and first flush storm events. For stormwater flows from minor to major 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).

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, Breen and Lloyd 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. Whereas, collecting and transporting stormwater to a downstream detention or infiltration device will mean that pollutants are collected and concentrated at the downstream device. For example, a large downstream sump or compensation basin would receive concentrated pollutants, which increases the chances of groundwater contamination.

Additionally, if stormwater in a neighbourhood or sub-catchment is collected (rather than infiltrated or used at-source) and piped to a constructed open water body, that water body can experience water quality issues (such as algal blooms) due to the collection and concentration of pollutants (e.g. nutrients).

Infiltration of stormwater throughout the catchment in small scale infiltration systems is also a better use of urban land because large areas of land are not excised from public/urban use to incorporate large scale systems that would be required to treat large volumes of collected water. Some types of infiltration systems can be installed underneath or as part of existing infrastructure (e.g. soakwells underneath road verges and pervious paving footpaths). Other types of infiltration systems can be incorporated within areas used for other purposes (e.g. swales within main road median strips and within parkland).

Conclusion

Flow rate and volume should be managed up to the 1-year, 1-hour ARI event. This approach to stormwater management will achieve catchment hydrologic stability, maximise aquifer recharge and create an ecologically healthy catchment. The criterion can be achieved by installing distributed retention/detention (e.g. at or near source infiltration) of small 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, via traditional direct connected pipe systems. Runoff arriving at receiving water bodies should be by overland flow paths across vegetated surfaces.

The 1-year, 1-hour ARI event retention criterion has been incorporated in new planning guidelines, such as *Better urban water management* (Western Australian Planning Commission 2008). This planning document has been developed to assist the land development industry in Western Australia to demonstrate compliance with the policies and principles of *State planning policy no. 2.9: water resources* (Western Australian Planning Commission 2006). It is recommended that engineering guidelines, such as Engineers Australia's *Australian rainfall and runoff - a guide to flood estimation*, incorporate the principle of the management of 1-year ARI events for better hydrological and ecological outcomes.

In areas where unconfined superficial aquifers on sandy coastal plains occur, such as in the south west of Western Australia, an opportunity exists to combine the concepts of stormwater harvesting and aquifer recharge as a part of the implementation of water sensitive urban design within the new concept of 'cities as water supply catchments'.

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