Can water sensitive urban design systems help to preserve natural channel-forming flow regimes in an urbanised catchment?

Chathurika Subhashini Wella-Hewage, Guna Alankarage Hewa and David Pezzaniti

ABSTRACT

Increased stormwater runoff and pollutant loads due to catchment urbanisation bring inevitable impacts on the physical and ecological conditions of environmentally sensitive urban streams. Water sensitive urban design (WSUD) has been recognised as a possible means to minimise these negative impacts. This paper reports on a study that investigated the ability of infiltration-based WSUD systems to replicate the predevelopment channel-forming flow (CFF) regime in urban catchments. Catchment models were developed for the ‘pre-urban’, ‘urban’ and ‘managed’ conditions of a case study catchment and the hydrological effect on CFF regime was investigated using a number of flow indices. The results clearly show that changes to flow regime are apparent under urban catchment conditions and are even more severe under highly urbanised conditions. The use of WSUD systems was found to result in the replication of predevelopment flow regimes, particularly at low levels of urbanisation. Under highly urbanised conditions (of managed catchments) overcontrol of the CFF indices was observed as indicated by flow statistics below their pre-urban values. The overall results suggest that WSUD systems are highly effective in replicating the predevelopment CFF regime in urban streams and could be used as a means to protect environmentally sensitive urban streams.

Key words | catchment modelling, channel-forming flow, source control, Storm Water Management Model (SWMM), urbanisation, water sensitive urban design (WSUD)

INTRODUCTION

Urbanisation is a universal and rapidly growing form of land-use change that results in reduced catchment retention and infiltration. Consequently, urbanisation alters the flow regime in a variety of ways including: (i) increasing the magnitude and frequency of floods (Henshaw & Booth 2000; Hardison et al. 2009); (ii) increasing the duration of geomorphologically significant flows (McCuen & Moglen 1988; MacRae 1997); and (iii) altering baseflow and associated low flow statistics (Bosch et al. 2003; Elliott et al. 2010). The impact of urbanisation is not limited to disrupted flow regimes, but extends to diminished quality of stream runoff and receiving waters (Hatt et al. 2004; Walsh et al. 2005). There is increasing evidence and understanding that the drainage network is a key contributor responsible for geomorphic and ecological change in streams, rather than the catchment imperviousness itself (Burns et al. 2012; Vietz et al. 2014). The flow regime fundamentally influences the geomorphology of streams (Hawley & Bledsoe 2013) and aquatic ecosystem health and function (Walsh et al. 2012). Consequently any activity that leads to change in the components of flow regime would lead to change in stream morphology and associated ecosystems (Konrad & Booth 2005).

In order to alleviate hydrologic and water quality issues associated with conventional urban drainage systems, recent research suggests focusing on the concept of source control, i.e. hold the rain where it falls (Argue 2009; Burns et al. 2012). Retaining stormwater at the source and promoting evapotranspiration help to restore components of the hydrologic cycle and aims to attain a more natural flow regime. Regenerating the natural flow regime (Poff et al. 1997) in urban streams would be a difficult target to achieve. Fletcher et al. (2014) suggest that mimicking critical components of the natural flow regime relevant for geomorphology and ecosystems of urban streams would be a more practical approach.
Stormwater source control techniques are called water sensitive urban design (WSUD) in Australia, low impact development (LID) in the USA, sustainable drainage system (SuDS) in the UK and low impact urban design and development (LIUDD) in New Zealand. Some WSUD systems, including rooftop rain gardens, green-roofs and various kinds of rain barrels, control stormwater primarily through processes associated with storage and evapotranspiration. The other type of systems, including bioretention systems, permeable pavements, leaky-wells and wetlands, control stormwater through infiltration, storage and evapotranspiration. The latter category is called ‘infiltration-based WSUD systems’ and is increasingly used for stormwater management in Australia. WSUD systems with storage allow collection and reuse of stormwater for non-potable uses (Hatt et al. 2007) and this has been identified as an effective means of reducing stormwater draining into urban waterways (Fletcher et al. 2008).

Although various stormwater management guidelines have been developed at the national, state and local government level, there is no nationally accepted set of objectives for stormwater management in Australia. The objectives of stormwater controls in these guidelines vary from low flow conservation to flood protection with a primary focus on water quality targets. Some examples for implementation of WSUD systems to achieve water quality objectives can be found in the City of Onkaparinga, City of Salisbury and some of the local councils in the Greater Adelaide region in South Australia (Myers et al. 2013). Argue & Barton (2007) reported 13 cases of residential projects that applied WSUD systems with the aim to achieve stormwater quantity and quality targets in South Australia, New South Wales, Queensland, and Western Australia.

Among the stormwater objectives, the channel forming flow (CFF) regime has been considered as crucial for the protection of aquatic ecosystems and the morphology of urban channels. CFF is expressed using different measures including effective discharge, bankfull flow, and recurrence interval flow. The bankfull discharge is the flow that fills in the main channel while the effective discharge is the discharge that transports most sediments over time. The bankfull flow has historically been considered as the geomorphically effective flow considering it performs a larger portion of total geomorphological work done on the landscape (Wolman & Miller 1960). In most studies, bankfull flow is commonly related to the recurrence interval flow of 1–2 years. For instance, summarising the flood frequency studies conducted in the last decades, Schneider et al. (2011) found that 80% of the studies reported a 1–2 year recurrence interval for bankfull flow. Studies have shown that effective discharge, bankfull flow and recurrence interval flow are approximately equal in stable channels (Wolman & Miller 1960; Andrews 1980) and consequently bankfull and recurrence interval flows are widely applied in channel design projects as an approximation to effective discharge (Doyle et al. 2007). Due to data limitations to exclusively estimate effective flow, recurrence interval flow was used as CFF in this study. However, reliance on a single discharge measure such as recurrence interval flow for channel design has been confronted in recent studies (e.g. Doyle et al. 2007). Several studies have shown that geomorphologically significant sub-bankfull flows are capable of channel erosion owing to their greater frequency (Pallegyi 2010a; Vietz et al. 2014) and hence there is a need to incorporate sub-bankfull flows in channel erosion studies.

For evaluating channel erosion, the erosion potential index (EPI), which incorporates a range of geomorphologically significant flows, has been used in several studies (MacRae 1993, 1997; Bledsoe 2002; Pallegyi 2010a). In this approach, sediment transport capacity of flows is calculated based on shear stress on a stream channel, and a critical shear stress that initiates movement of sediment particles is estimated. Based on this concept, Pallegyi (2010a) presented a modelling approach to evaluate the feasibility of LID controls to manage stream erosion associated with increased imperviousness in urban catchments. LIDs were designed using the flow duration control approach, and erosion potential and work curves were used as stream erosion indices. Evaluating stream erosion using EPI is an effective approach; however, quantification of these indices requires detailed information on the stream reaches being assessed, including bed and bank materials, material sizes, channel slope, cross-section geometry and vegetation. This information is often unavailable for most of the channels; hence surrogate approaches for evaluating stream erosion are needed. The stream erosion index (SEI) is a simple flow-based alternative to sediment transport capacity calculations (McAuley et al. 2010). The SEI incorporates duration of erosive flows; however, frequency of erosive flows is also a critical factor for channel erosion. Consequently a more comprehensive approach for evaluating erosion potential, in the absence of information for calculating EPI based on sediment transport capacity, would be to incorporate CFF magnitude, frequency and duration indices. In the current study, CFF regime indices were used to evaluate the impact of urbanisation and performance of infiltration-based WSUD systems in preserving predevelopment channel geomorphology of urban channels. It should be noted.
that evaluation was performed based on one measure of CFF regime, i.e. the 1–2 year recurrence interval flow.

Recent studies focussed on stormwater management approaches emphasise the necessity for evaluating the catchment-scale hydrologic impact of allotment-scale source control systems (Burns et al. 2012; Petrucci et al. 2013). The ability of WSUD systems to replicate the natural flow regime can vary depending on the approach being used to design the system/device. Typically stormwater management systems are designed for peak flow control and often overly simplified methods are applied to one or more events aiming to capture a percentage of storm runoff. However, these approaches are unlikely to be effective in generating the natural flow regime in urban catchments as they often increase duration above the erosional threshold (MacRae 1997; Roesner et al. 2001; Nehrke & Roesner 2004). Current scientific literature supports the use of a continuous simulation approach for designing stormwater source control measures, as continuous simulation captures the full range of rainfall variability as well as the antecedent moisture conditions that influence the sizing of devices (Palhegyi 2010a).

The aim of the study reported here was to evaluate the performance of infiltration-based WSUD systems, designed using flow duration control, to maintain predevelopment CFF regimes in urban catchments. Consequently two research questions were addressed:

1. How severe is the impact of urbanisation on CFF regime at different urbanisation levels?
2. Can the CFF regime be replicated in urban streams when infiltration-based WSUD systems are employed to manage stormwater?

This paper presents a catchment-scale modelling approach for assessing the performance of infiltration-based WSUD systems for a range of potential urbanisation levels. The results presented here are based on a case study catchment, Scott Creek, located in South Australia.

MATERIALS AND METHODS

Study area

Scott Creek, a subcatchment of the Onkaparinga catchment, is located in the Mount Lofty Ranges in South Australia. This catchment covers an area of 26.6 km² and before 2002 land-use mainly comprised grazing (50%) and natural vegetation (48%). Only 1.5% of the catchment was used for urban and intensive rural activities. The topography of the catchment varies from steep slopes to mildly rolling terrain. The catchment is characterised by a temperate climate with high maximum daily temperatures and evaporation rates in summer. Mean rainfall in the catchment varies from 1,100 mm/yr in the upper reaches to 800 mm/yr in the lower reaches and mean annual evaporation is 1,200 mm/yr. The main soil types found in the catchment are loamy sand (51%), loam (31%) and sandy loam (15%).

Methodology

In order to answer the research questions, it was necessary to model the study catchment to simulate the following three scenarios: (i) pre-urban condition of the catchment (referred to as pre-urban); (ii) urban scenarios with conventional stormwater management (referred to as urban); and (iii) urban scenarios with WSUD systems to control stormwater (referred to as managed). For the pre-urban scenario catchment land uses comprise grazing, natural vegetation and a small percentage of urban and intensive rural activities. Characteristics of the resulting flow regimes were compared to assess the changes that occur when the catchment condition is changed from pre-urban to urban and from urban to managed. The US EPA Storm Water Management Model (SWMM) (Rossman 2010) was used to simulate the different catchment scenarios. SWMM is a widely used hydrologic and hydraulic model with the flexibility to represent WSUD systems (Elliott & Trowsdale 2007).

Pre-urban catchment scenario

In catchment-scale modelling, the ability to represent the spatial variability of hydrological processes is vital and this was accounted for via subcatchment delineation. Each subcatchment was simulated as a homogeneous area where soil, land use, topography and climatic data characteristics were consistent. Each subcatchment was divided into three subareas: pervious; impervious with depression storage; and impervious without depression storage. The impervious area in SWMM modelling is the directly connected impervious area (DCIA), i.e. impervious areas that connect directly into the stormwater conveyance system. Aquifer modelling was used to simulate the subsurface flow processes occurring in the catchment. The stream network is conceptually represented using links (conduits) and nodes in SWMM. All the conduits of the stream network for the study catchment were assumed to be open trapezoidal conduits because no channel profile data were available for the
case study catchment. Flow routing within a conduit link in SWMM is controlled by mass and momentum conservation principles for gradually varied unsteady flow. Flow routing for the channels was accomplished by approximating the channel to a nonlinear reservoir in this study. An hourly time-step, which is smaller than the time of concentration of the catchment (3.57 hr), was used for model simulations. The pre-urban catchment model was calibrated using 10 years of hourly streamflow data (1991–2001) at the outlet, i.e. Scott Bottom gauging station (A5030502). The model calibration process was automated using a local parameter optimisation software called PEST (Parameter ESTimation) (Doherty 2004). A set of optimised parameters was achieved by adjusting the calibration parameters within a physically sensible parameter range until the objective function minimum is reached. The catchment model was validated using 4 years of streamflow data (1981–1985) which were not used for calibration. Nash-Sutcliffe efficiency (NSE) (Nash & Sutcliffe 1970) and water balance were used as the goodness-of-fit measures. The range of NSE can vary from $\infty$ to 1 where 1 designates a perfect fit of model output to the observations. The model performance in terms of water balance can vary from 0 to 1, where 0 represents the best fit and 1 represents the poorest fit. During model calibration and validation, 0.13 and 0.16 were attained, respectively, for water balance, indicating an acceptable difference in water balance. NSE values of 0.63 and 0.52 were attained during the calibration and validation periods, respectively, which showed a good agreement between modelled and observed series. The pre-urban catchment model outcome was used as the base data for comparison with the ‘urban’ and ‘managed’ scenarios.

Urban catchment scenarios

The ‘urban’ scenarios represent the catchment development with conventional stormwater management applied to each and every subdivision/allotment. DCIA, subcatchment width and Manning’s channel roughness are the main parameters that were incorporated into SWMM modelling to reflect the change in urbanisation level of each subcatchment. The four selected urbanisation scenarios were represented as 10, 30, 50 and 70% DCIA. A reduced time of concentration due to the reduced overland flow length was incorporated by changing the subcatchment width, which was estimated to be the area-weighted average width of pervious and impervious areas. Impervious percentages were assumed to be evenly distributed over each subcatchment, while reduced overland flow roughness as well as conduit roughness was adopted to reflect the effect of catchment urbanisation on runoff velocity.

Managed catchment scenarios

The ‘managed’ scenario represents the implementation of infiltration-based WSUD systems to manage stormwater from the developed parts of the catchment. It was assumed that 100% of stormwater generated from the DCIA drains into a WSUD device. In each subcatchment WSUD systems were modelled by aggregating the total area of source controls into a single system located at the subcatchment outlet. This aggregated model was used for further simulations and optimisation of the WSUD area required. Stormwater control devices were designed based on flow duration control using continuous simulation. Consequently, in sizing WSUD systems, an attempt was made to match the flow duration curves (FDCs) of the managed scenario to that of the pre-urban scenario.

The research methodology and the results in this paper are based on the use of bioretention systems to represent the infiltration-based WSUD systems. The dimensions of the bioretention systems used for modelling were assigned based on the recommend values given in bioretention design manuals and previous studies (Gold Coast City Council 2007; Palhegyi 2010b). The design of the bioretention system was undertaken based on 350 mm of surface ponding, 600 mm deep amended soil layer and 300 mm of storage for the retention system. The amended soil of the bioretention systems was assumed to have the following properties: 50% porosity; 30% field capacity; 10% wilting point; and 50 mm/hr saturated hydraulic conductivity. The fraction of area occupied by vegetation above the surface was assumed to be 0.5. For the storage layer, porosity of 75% and an initial infiltration rate of 50 mm/hr were assumed. A bioretention system with under-drains can be considered to be a retention system with extended detention, while systems without under-drains are referred to as retention-only systems. Both these systems were employed to manage stormwater in the study. When sizing bioretention systems under various managed scenarios all the features, except the surface area of the system, were kept constant. The surface area of the WSUD system was then altered until a reasonable match between managed FDC and the pre-urban FDC was achieved.

The impact of varying levels of urbanisation and the adopted management strategies on flow regime was evaluated using FDCs (statistics), CFF statistics (magnitude, duration and frequency) and annual average flow volumes
(AFVs). FDCs provide the opportunity to make visual comparisons between the simulated scenarios. In this study, CFF was assumed to correspond with the 1.67 year recurrence interval flow \((Q_{1.67})\). As discussed in the introduction, there is a wide agreement that on average a CFF has an average recurrence interval of 1–2 years. Studies focused on development of flow regime indices often acknowledge a 1.67 year recurrence interval as CFF (Poff 1996) and recent studies increasingly use this in flow regime assessments (Dodds et al. 2004; Konrad & Booth 2005; Chinnayakanahalli et al. 2011; Mohammed et al. 2015). Flood frequency analyses using partial duration series extracted from hourly flow data were conducted for each scenario to demonstrate how the magnitude of CFFs varies. A total of nine modelling scenarios were analysed in this study, i.e. a pre-urban scenario, four urban scenarios and four managed scenarios. Duration of CFF \((D_{1.67})\) was calculated as the average number of hours that \(Q_{1.67}\) was exceeded during a single year. Frequency of CFF \((F_{1.67})\) was defined as the average annual recurrence of flow that exceeded \(Q_{1.67}\), or the number of times \(Q_{1.67}\) was exceeded in a year. The overall system performance was assessed using the annual AFV control achieved by the implemented WSUD systems.

**RESULTS AND DISCUSSION**

**Effect of catchment urbanisation on CFF**

The effect of the four selected urbanisation levels were compared against pre-urban condition using FDCs (Figure 1). It can be observed from the FDC comparisons that high flows and medium flows under urban conditions steadily increase with increased DCIA level (Figure 1(a)–1(d)). The predevelopment CFF \((Q_{1.67})\) for the study catchment was calculated to be 2.8 m³/s. As can be seen from Figure 1, the percentage of time \(Q_{1.67}\) was exceeded under pre-urban condition was approximately 0.67% and this increased notably with increased urbanisation levels. For example, the percentage of time 2.8 m³/s was exceeded was 1.8%, 2.5% and 3.2% for DCIA values of 30%, 50% and 70% respectively.

The ratios of CFF indices at varying urbanisation scenarios, with respect to their pre-urban values, are shown in Figure 2. A value close to 1 indicates that the flow statistic is close to its predevelopment value. A value higher or lower than 1 in any statistic is indicative of an altered flow regime. With the increase of DCIA in the catchment, all three CFF dimensions (magnitude, duration and frequency) increased consistently. Although the FDC of the catchment

![Figure 1](https://iwaponline.com/wst/article-pdf/73/1/78/464525/wst073010078.pdf)
does not show a significant change at 10% DCIA, analysis of flow components confirm that there is a notable impact on the CFF even at low levels of urbanisation. The increased magnitude of the CFF indicates the occurrence of overbank flows. CFFs are responsible for determining and maintaining the shape of the channel through movement and deposition of sediments. Increased CFF duration means the stream is subjected to erosive flows for longer spells. Similarly, increased CFF frequency indicates that the stream is exposed to erosive flows more often. Consequently, increased CFF dimensions resulting from urbanisation of the catchment may result in channel erosion and the impact appears to become more severe with increased DCIA.

According to Figure 2, average AFV increases with increased DCIA. At 50% DCIA the AFV is twice (100% increase) that produced under pre-urban conditions and the flow volume increase is 2.5-fold (150% increase) for the 70% DCIA scenario. Comparable results for increase in flow volume with increased levels of urbanisation have been reported in studies. For example, Jennings & Jarnagin (2002) observed that flow volume increased up to 48% when a 61 km² natural catchment was developed, resulting in 33% impervious area. Bhaduri et al. (2000) reported an 80% increase in runoff volume when catchment imperviousness was increased by 18% in a 70.5 km² catchment. Rather contrasting results, with larger runoff volume changes, have been reported in small catchments. Dietz & Clausen (2008) reported a runoff volume increase of 49,000% when catchment imperviousness was changed from 1 to 32% in a 0.017 km² catchment. As the runoff volume change is a relative measure to the reference value used for flow volume assessment, comparison between studies is difficult. For instance, in the current study, the pre-urban scenario does not represent pristine natural catchment conditions; instead, half of the land uses comprise grazing and intensive rural activities. Consequently pre-urban flow volume used as the reference for comparison in this study would be higher compared to the pristine (natural) condition of the catchment. This may result in reducing the relative AFV increases under urbanised conditions compared to other studies which have used flow volume of pristine conditions of the catchment as reference case for comparison purposes. Relatively low AFV increases followed by catchment urbanisation in the study catchment would also be attributable to the significant baseflow reduction under urban conditions.
which was proportional to level of DCIA. Scott Creek is a groundwater-dominated stream (Banks et al. 2009) and consequently baseflow reduction at higher DCIA levels may restrain the flow volume increase resulting from increased surface runoff. It was observed that although AFV is relatively less altered at higher DCIA levels, Q1.67 is notably changed in the study catchment. Zhou et al. (2013) have shown that impact of urbanisation is more pronounced in peak flow magnitudes than flow volume and concluded that urbanisation would have a slight impact on annual water yield.

Assessing the ability of WSUD systems to maintain predevelopment CFF

According to flow duration analysis, managed scenario FDCs closely replicate that of the pre-urban FDC up to 30% DCIA (Figure 1(a) and 1(b)). This observation indicates the ability of the adopted WSUD systems to manage a lightly urbanised catchment. At higher levels of urbanisation (50 and 70% DCIA) the adopted WSUD systems were unable to fully replicate the entire range of the pre-urban FDC. As can be observed from Figure 1(c) and 1(d), the managed scenario FDCs remain below the pre-urban FDCs over the medium flow range, achieving a more conservative CFF regime. Consequently, for scenarios with high levels of urbanisation, WSUD systems reduced the percentage of time Q1.67 flow exceeded that of the pre-urban condition.

The ratios of CFF indices for managed scenarios with respect to their pre-urban catchment values are given in Figure 2. Figure 2 shows that CFF magnitude (Q1.67), duration (QD1.67) and frequency (QF1.67), as well as AFV ratios under managed scenarios are approximately 1 for most of the managed scenarios. These observations suggest that overall flow control can be closely achieved under managed conditions, i.e. predevelopment flow regime can be maintained at almost all the DCIA levels considered in this study. The duration index, QD1.67, shows an overcontrol under managed conditions (except at 10% DCIA) of the catchment and this effect is notable particularly at higher DCIA levels as indicated by flow statistic ratios below 1. For the highest urbanised scenario considered in this study (70% DCIA), an overcontrol of CFF statistics is observed under managed conditions with reduction of CFF magnitude, duration and frequency by 40, 80 and 20% from their pre-urban values. The reason for the overcontrol of CFF indices in managed scenarios can be partly explained by the sizing of infiltration devices to control the entire high flow regime. Reduced CFF statistics may result in reduced channel erosion; they can, however, result in numerous geomorphic and ecological implications such as reduced channel capacity due to vegetation encroachment and increased sedimentation (Magilligan et al. 2005), degradation of aquatic habitats (Bunn & Arthington 2002; Wohl 2012), reduced species diversity and food web structure followed by reduced bankfull flows (Wootton et al. 1996). These issues require further investigation to determine whether or not such negative environmental impacts could result from overcontrol of stormwater flows in urbanised catchments when WSUD systems are implemented. For the 10% DCIA scenario (managed), the AFV ratio falls below 1 indicating reduction of annual AFV compared to predevelopment level. This phenomenon also can be explained by sizing of infiltration devices to control the entire high flow regime. While WSUD systems reduce CFF indices to pre-urban values, the systems increase infiltration and evapotranspiration losses by capturing most of the rain events and reduce overall runoff draining into the stream to below the predevelopment levels.

FDCs shown in Figure 1(a)–1(d) depict that the selected WSUD systems effectively control flows from extreme floods to 20% of Q1.67 close to or below their pre-urban values. Geomorphologically significant flows responsible for channel erosion are generally channel specific and range from a critical discharge that initiates bed movement up to flows having 10 year recurrence interval (Q10) (Brown et al. 2009; Palhegyi 2010a). This critical discharge can be calculated for a stream reach based on the critical shear stress. For management purposes, the critical discharge is generalised and relates to a corresponding peak flow such as 20% of CFF (Brown et al. 2009). Therefore a more conservative approach to preserving urban streams is to maintain the full range of geomorphologically significant flows close to their pre-urban values. When the WSUD systems are designed using FDC matching as shown in our study, we can expect that the entire range of geomorphologically significant flows are maintained at their predevelopment level; hence WSUD systems would help preserve the urban channel form.

Sediment supply is also a key determinant of channel form. It was assumed that 100% of the stormwater drains into WSUD systems under managed scenarios. When stormwater passes through infiltration devices, they can capture sediments without passing them into streams. Clogging sediments in the infiltration devices reduce the hydrologic and water treatment performance of these systems in the long term (Gonzalez-Merchan et al. 2010). More importantly sediment trapping in infiltration devices may result in significant
reduction of sediment supply into the channel network (Vietz et al. 2014) and may result in channel scouring even if a close to natural CFF regime is established in urban streams through implementation of WSUD systems. Consequently, designing infiltration systems to pass sediments (coarse sediments), while retaining stormwater, is a future challenge (Fletcher et al. 2014).

While the results of this study show infiltration-based WSUD systems to be highly effective for reproducing the pre-urban FDC, caution needs to be exercised when considering the limitations and assumptions associated with modelling. For example, the implementation of infiltration-based WSUD systems requires specific soil properties, i.e. soil with less than 30% clay (Argue 2009). The case study catchment exhibits desirable conditions, having loamy soils across most of the catchment; however this may not be the case for all catchments. Another crucial condition that needs to be considered is the geological strata below the subsoil. Generally, infiltration-based WSUD systems require infiltrative geologic strata at or near the ground surface to accommodate infiltrated water. The case study catchment, Scott Creek, is characterised by fractured rock aquifers across the catchment, which are not suitable for infiltration. Consequently special techniques such as aquifer storage of infiltrated water (as recommended in Argue (2009)) would be required.

CONCLUSIONS

In this paper the potential for using infiltration-based WSUD systems to manage stormwater in urbanised catchments in order to preserve predevelopment CFF regimes was examined. The investigation was performed using continuous simulation modelling with the Scott Creek catchment as the case study. The results of this investigation produced several important conclusions.

1. Significant changes in CFF regime indices (magnitude, duration and frequency) are evident, commencing from a low level of urbanisation (e.g. 10% DCIA) in the study catchment. Furthermore this study confirms that the hydrological impact becomes more severe as urbanisation levels rise.

2. The implementation of infiltration-based WSUD systems to manage stormwater in urbanised catchments can result in CFF regimes that closely replicate predevelopment CFF regimes. This is demonstrated by several statistics (i.e. the FDC, CFF statistics and the AFV) and is particularly relevant at low levels of urbanisation. Under highly urbanised conditions, however, reproducing pre-development flow regimes was challenging and the adopted design approach resulted in the overcontrol of some of the CFF dimensions.

3. The overall results suggest that WSUD systems could be highly effective in preserving predevelopment CFF regimes in the case study catchment.

This study provides findings and an approach that endorse current stormwater control policies which advocate the use of WSUD systems and allow catchment planners/managers to evaluate the effectiveness of WSUD systems in both greenfield and brownfield catchments. The conclusions made in this manuscript were based on the results of an investigation conducted in a South Australian study catchment. It is recommended to test these conclusions for catchments in other climate zones before it can be generalised.

REFERENCES


MacRae, C. R. 1997 Experience from morphological research on Canadian streams: Is control of the two year frequency runoff event the best basis for stream channel protection? In: *Proceedings of the Engineering Foundation Conference: Effects of Watershed Development and Management on Aquatic Ecosystems* (L. A. Roesner, ed.). ASCE, Snowbird, UT, USA, pp. 144–162.


Downloaded from https://waponline.com/wst/article-pdf/73/1/78/464525/wst073010078.pdf by guest


Poff, N. L. 1996 A hydrogeography of unregulated streams in the United States and an examination of scale-dependence in some hydrological descriptors. Freshwater Biology 36 (1), 71–79.


