The impact of stormwater source-control strategies on the (low) flow regime of urban catchments

L'impact des stratégies de contrôle à la source sur le débit d'étiage des bassins versants urbains

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RÉSUMÉ

Les stratégies de gestion des eaux pluviales urbaines impliquent de plus en plus des objectifs liés au régime d'écoulement, en parallèle de ceux liés à la réduction de la pollution. Toutefois, la capacité des techniques de contrôle à la source à restaurer un régime d'écoulement naturel est encore incertaine, en particulier pour le débit d'étiage. Cette étude a pour but de modéliser de telles stratégies, incluant des alternatives visant explicitement à restaurer le débit d'étiage, et de les évaluer à l'aune du volume total de ruissellement et de trois indicateurs de bas débit. Les stratégies utilisant des citernes d'eau semblent être plus efficaces que celles utilisant des ouvrages de biorétention pour la réduction du volume ruisselé. Parallèlement, les stratégies visant explicitement à reproduire un débit d'étiage naturel, au moyen d'un exutoire à faible débit, montrent des résultats mitigés. Nous démontrons aussi que les indicateurs hydrologiques diffèrent en termes de leur sensibilité à la proportion du bassin versant traité, ce qui souligne l'importance de leur sélection dans l'évaluation des stratégies de contrôle à la source. Ces résultats mettent en évidence la complexité de restaurer un régime de débit d'étiage à son niveau de pré-développement, au moins pour les cours d'eau pérennes. Toutefois, une combinaison de techniques de rétention (citernes d'eau) et de bioretention (avec infiltration ou drain qui limite le débit sortant) semble capable de restaurer un régime d'écoulement quasi–naturel, tout en améliorant la qualité de l'eau via les processus de rétention et filtration.

ABSTRACT

Stormwater management strategies increasingly recognise the need to emulate the pre-development flow regime, in addition to reducing pollutant concentrations and loads. However, it is unclear whether current design approaches for stormwater source-control techniques are effective in restoring the whole flow regime, and in particular low flows, towards their pre-development levels. We therefore modelled and compared a range of source-control stormwater management strategies, including some specifically tailored towards enhancing baseflow processes. The strategies were assessed based on the total streamflow volume and three low flow metrics. Strategies based on harvesting tanks showed much greater volume reduction than those based on raingardens. Strategies based on a low flow rate release, aimed at mimicking natural baseflow, failed to completely restore the baseflow regime. We also found that the sensitivity of the low flow metrics to the proportion of catchment treated varied amongst metrics, illustrating the importance of metrics selection in the assessment of stormwater strategies. In practice, our results suggest that realistic scenarios using low flow release from source-control techniques may not be able to fully restore the low flow regime, at least for perennial streams. However, a combination of feasibly-sized tanks and raingardens is likely to restore the baseflow regime to a great extent, while also benefitting water quality through the retention and filtration processes.

KEYWORDS

Baseflow, Natural flow regime, Scenario modelling, Source-control

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1 INTRODUCTION

The effects of urbanisation on the hydrology of receiving waters are well documented, being recognised, along with water quality, as a primary driver of ecological condition (Walsh et al., 2005). The streamflow volume and the magnitude and frequency of high flows are typically increased by the creation of impervious areas. The effects of urbanisation on low flows are more catchment-specific, depending on the physiography of the catchment and the strategies and practices employed during urban development (e.g. characteristics of sewage network, spatial distribution of impervious areas; Price, 2011). To prevent the degradation of urban stream health resulting from these hydrological changes, the paradigms driving stormwater management are evolving to consider the whole flow regime of receiving waters (Burns et al., 2012b). Specifically, stormwater management strategies increasingly aim at restoring the flow regime characteristics back to their predevelopment level (Hunt et al., 2012): flow management objectives based on this “natural flow regime” (Poff et al., 1997) are thought to provide the best opportunity to return healthy stream function, when combined with suitable water quality and channel form.

Source-control techniques, including retention and infiltration systems such as tanks and raingardens (i.e. biofilters, also called bioretention systems), may be used to meet the natural flow regime objectives (Hunt et al., 2012). Their basic principles emulate the hydrological processes of natural catchments, namely retention of the precipitation in soils, losses by evapotranspiration and slow release via interflow or groundwater flow. However, the amount of stormwater retention and harvesting needed to approach the water balance of a natural catchment is very large. Both tanks and raingardens, installed at the allotment- or precinct-scale, are likely to show limitations in the restoration of the water balance.

To address these challenges, the design of source-control techniques could be modified to increase their retention capacity and their ability to restore natural flow paths. Tanks can be used for passive irrigation, releasing harvested water at a low flow rate onto the nearby garden via a perforated pipe (Burns et al., 2012a). This design has the advantages of releasing to catchment soils a flow rate consistent with the catchment baseflow rate, while increasing the available storage in the tank for retention of subsequent rain events. Similarly, raingardens can be designed with a low flow underdrain (Palhegyi, 2010) that diverts the treated water to the piped network at a low flow rate, consistent with the catchment’s pre-developed hydrology.

However, the extent to which these design enhancements can help meet a range of flow regime targets is relatively unknown. In retrofit projects, it is also unlikely that the whole area of the catchment is treated, raising the question of the minimum area to be retrofitted to achieve significant results on streamflow. In this study, we thus aim to explore two primary questions: (i) To what extent can the pre-development low-flow regime be maintained through the use of commonly available source-control stormwater control techniques? (ii) What are the effects of the partial treatment of an urban catchment, and do these vary between different flow metrics? Our analyses, based on a typical urban development for the Melbourne area, compare the performance of various stormwater management strategies based on the total streamflow and three low flow metrics.

2 METHODS

2.1 Overview

We first calibrated a double reservoir linear model to a reference (natural) catchment. Next, we simulated the urbanisation of the catchment and assessed the resulting disturbance to low-flow hydrology. We then applied five stormwater source-control strategies to assess the extent to which the pre-developed low-flow regime could be retained. For the best scenario, we finally investigated the effect of a partial retrofit of the catchment as measured by our four flow metrics.

2.2 Study catchment

The McMahons Creek catchment, located 90 km east of Melbourne (S 37.8206, E 145.9376) and with an area of 40 km^2, served as our reference condition. The geology of the catchment is Devonian granites and sandstones, separated by a band of Devonian metamorphics (Feikema et al., 2006). Soils are red and brown earths, and the catchment is almost exclusively covered by Eucalyptus regnans forest. Our calibration was undertaken for the period from 01/01/2003 to 31/12/2006, during which time the average annual rainfall was 1003 mm. Hourly rainfall data were obtained from the Upper Yarra Reservoir (operated by Melbourne Water), some 10 km from the catchment centroid. Missing rainfall data made up 57 hours (or 0.16%) of the total record and were infilled using the nearby O'Shannassy Reservoir gauge, located 8.1 km west of the Upper Yarra Reservoir gauge. Hourly flow data (from Melbourne Water gauge 229106) were intact, with only 31 hours of missing flow data for the 4 year record (i.e. less than 0.1%). We infilled the two gaps with linear interpolation (for the 4-hour gap) or application of the calibrated model predictions (for the 27-hour gap). Given the very small amount of missing data, the objective function of the calibrated model did not vary measurably between the raw and infilled time series. Finally, we obtained areal potential evapotranspiration from the ESOCLIM climate database, for the Warburton/O'Shannassy's site (station 86090).

2.3 Development and calibration of the reference model

The reference catchment showed significant inter-annual changes in soil moisture storage, resulting in high baseflow during winter months (Figure 1). Despite this buffering effect of soils, the streamflow responded quickly to rainfall, likely due to the precipitation on the channel and nearby riparian zone, with rapid interflow processes. We therefore used a model with two retention stores, representing the quick and slow contributions from the two distinct parts of the catchment (Figure 2). All modelling was undertaken using MUSIC 5.1 (eWater, 2012), with the model's classical linear reservoir structure being adapted for our simple model conceptualisation.

The basic catchment node in MUSIC uses three principal stores: a quickflow store (or "impervious area", with initial loss representing depression storage), a slow flow store (or "pervious area", with parameters describing infiltration and storage capacity), and a groundwater store (with initial depth and daily rates of recharge and baseflow release). However, MUSIC does not have the capability to represent rainfall interception by vegetation, which is particularly important with the dense Eucalypt forest of the reference catchment (Melbourne and Metropolitan Board of Works, 1977). Based on Duncan (1980), we applied a 20% continuing loss to precipitation, in addition to 1-mm initial loss representing depression storage in the riparian zone. In the urban state (see subsequent sections), we assumed that the continuing loss would be reduced by 50%, through the reduction in canopy cover in the main part of the catchment.

The model was calibrated using the following statistics, calculated at an hourly time step: mean and median annual flow; 10th, 50th and 90th percentile flows; standard deviation of flows; and Nash-Sutcliffe efficiency (NSE) for flow and $\log_{10}$-transformed flow. These statistics were selected to assess the overall performance of the model with regards to magnitude and timing of flow, but also its specific performance for low flows (Pushpalatha et al., 2012), which are the principal focus of this study. With a large number of parameters in the model, it is very likely that multiple calibration solutions exist. Calibration was therefore undertaken manually, using hierarchical iteration of parameters, starting with those that were considered the most physically significant. The model calibration resulted in Nash-Sutcliffe efficiency of 0.49, and 0.58 on $\log_{10}$-transformed data (evaluation on $\log_{10}$-transformed data giving a better indication of the *low flow* performance of the model), with the parameters reported in Figure 2.

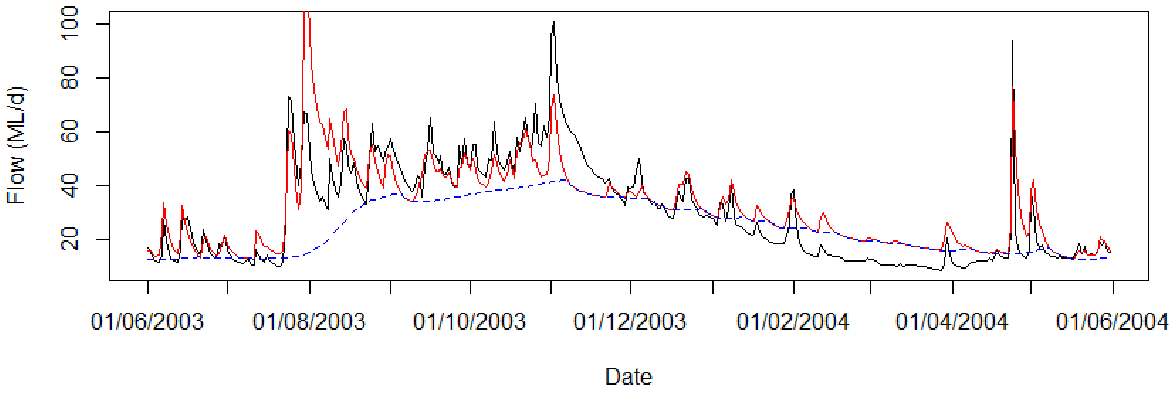

Figure 1. Observed (black line) and modelled (red line) hydrographs for the reference catchment over the first 1.5 years. Dashed blue line shows the baseflow computed from a recursive filter with parameters from Nathan and McMahon (1990)

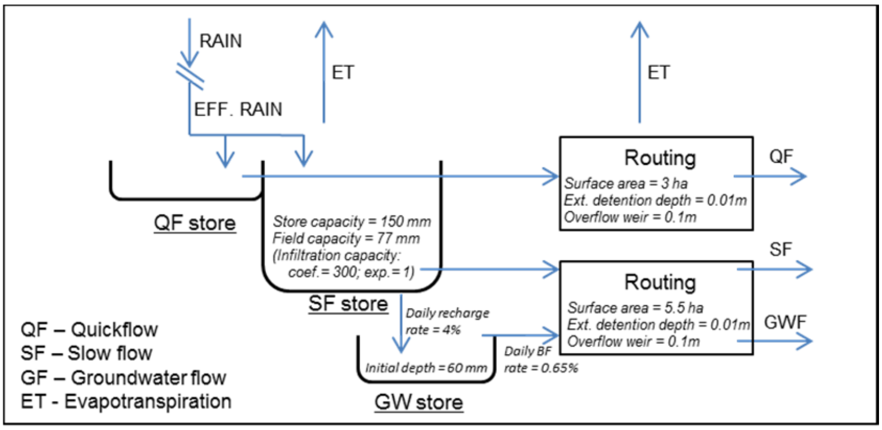

Figure 2. MUSIC the model structures for the reference model. QF store represents 9% of the area of the SF store. Initial storage is 25% of SF storage capacity. ET from the routing module is 50% of PET.

2.4 Modelling of urbanisation scenarios

2.4.1 Baseline urban development

We simulated the urbanisation of the catchment, assuming a medium density residential development typical of Melbourne (Table 1). The urban development was applied across the entire catchment, with the exception of 5% set aside for public open space, consistent with typical planning provisions in the region. This area was assumed to sit within the riparian areas specified in the model. Based on the total stream length (31.2 km), it represented a buffer of approximately 30 m on each side of the stream.

Table 1. Details of urbanisation layout (adapted from Walsh et al., 2008)

Individual allotments	**Value**	**Other source or rationale**
Property area (m^2)	567	Typical medium density for region
Frontage width x depth (m x m)	21 x 34	As above
Roof\Paved area (m^2)	200\67	As above
Garden area available (and used) for irrigation (m^2)	300 (150)	As above
No. of occupants per property	2.67	(Wilkenfield & Associates, 2006)
4000 ha catchment	**Value**	**Other source or rationale**
Total imperviousness (%)	50	Calculated
No. of allotments:		Calculated (13 allotments/ha net)
- on access roads	44,000	
- on main distributor roads	8000	
Public open space (% of catchment)	5	Typical medium density for region:
Road reserve (& pavement) width (m):		http://planningschemes.dpcd.vic.gov.au/VPPs/default.html
- access roads	15 (7.5)	
- distributor roads	21.5 (12.5)	
Public impervious areas (roads, footpaths) (ha)	604	Calculated

2.4.2 Alternative scenarios based on source-control techniques

We tested five basic stormwater source-control strategies (Figure 3). Our aim was to compare scenarios based on retention for rainwater and stormwater harvesting (T1 and T2) to scenarios based on raingardens (R1 and R2), and to a combination of both (TR). For scenarios based on tanks, we considered two alternatives at the allotment scale, based on indoor use of harvested water for toilet, laundry and hot water (details of the assumptions are provided in Appendix). T1 additionally assumed outdoor use for irrigation, while T2 was designed with a focus on low-flow restoration, adding a passive irrigation tank that released harvested water at a low flow rate in the garden. The low flow rate was designed based on the mean flow in the natural catchment. For public open space, in both scenarios, we assumed that a stormwater pond was used for harvesting and subsequent irrigation.

The two scenarios based on raingardens compared the performance of two designs (Figure 3): in R1, raingardens were unlined to allow infiltration, despite the fact that restrictive soils found in the catchment were likely to limit the exfiltration. Raingardens were 800 mm deep (with an additional 200 mm ponding depth), and hydraulic conductivity of surrounding soils set at 36 mm/h for the top 300 mm and 0.36 mm/h below this, based on data from Hamel et al. (2011). The other raingarden strategy, R2, used entirely lined raingardens, focusing on baseflow restoration via a low flow underdrain that released treated water at low flow rate via the stormwater network. Similar to the T2 scenario, the low flow rate was set to the mean baseflow from the natural catchment. A final scenario (TR) was designed to combine the effect of stormwater harvesting and low flow release via passive irrigation and use of unlined raingardens.

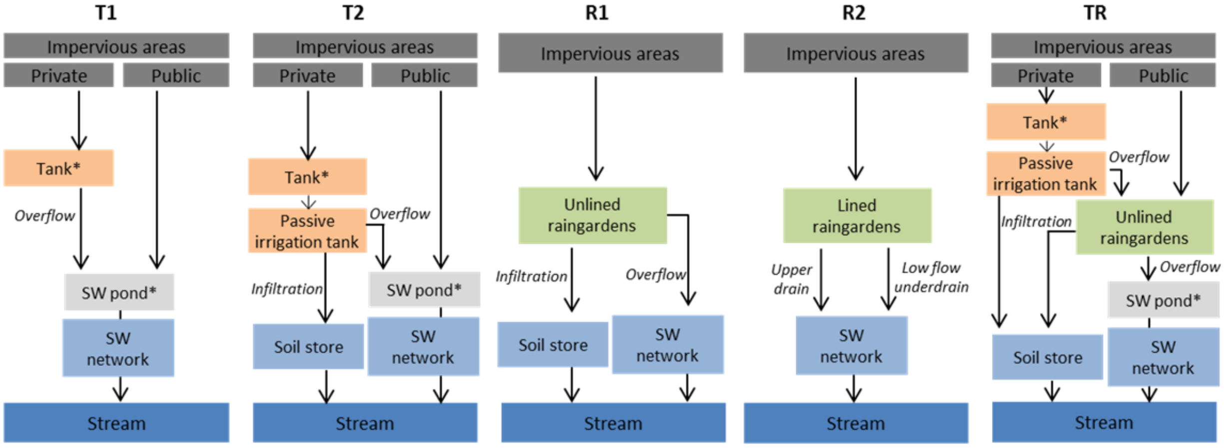

Figure 3. Details of stormwater (SW) source-control strategies applied to the urban catchment. *Tank water is used for garden irrigation and indoor use, while the stormwater pond is used for irrigation of public open space. See Section 2.4.2 and Appendix for details.

2.4.3 Effect of partial treatment of the urban catchment

Finally, to investigate the effect of a retrofit of the urban catchment, we tested the effect of a partial treatment of the urban catchment based on the TR scenario. We modelled the case where 25, 50, or 75% of the catchment was treated, with the remaining undergoing urban development as per the baseline scenario.

2.4.4 Selection and calculation of metrics

The performance of each scenario was assessed with four metrics: the total flow volume (annual daily flow, or ADF), and three metrics representing the magnitude, duration, and frequency of low flows (Hamel et al., in review).These were the 95th percentile (Q95), its ratio over ADF (Q95/ADF), and the frequency of low flow spells (FL1), where a spell is defined as a period during which the flow remains under a threshold, defined here as the 75th percentile. This selection of metrics results from our focus on the low flow regime, with our source-control scenarios targeting the enhancement of infiltration in the urban area. Each metric was calculated on an annual basis and the mean and standard deviation were reported.

3 RESULTS

3.1 Reference catchment and baseline urban scenario

Implementation of urbanisation to the reference catchment resulted in the typical hydrological changes visible on the flow duration curve, both for high flows and low flows (Figure 4). It is apparent that high flows are altered proportionally more than are baseflows. On average, the total flow (ADF), Q95 and the frequency of low flow spells (FL1) increased by a factor of two and Q95/ADF showed the strongest effect, being decreased by a factor of five (Figure 5). Inter-annual variability was high in the natural catchment for each metric over the four years of the study, but the response of each of the metrics to urbanisation went well beyond this natural variability (Figure 5). Our model replicated the observed variability relatively well based on metric values and the flow duration curve, although our modelled Q95 was more variable than the observed (and thus the Q95/ADF) less variable than observed. These differences highlight some limitations in our model, which cannot fully replicate the strong inter-annual variability of streamflow.

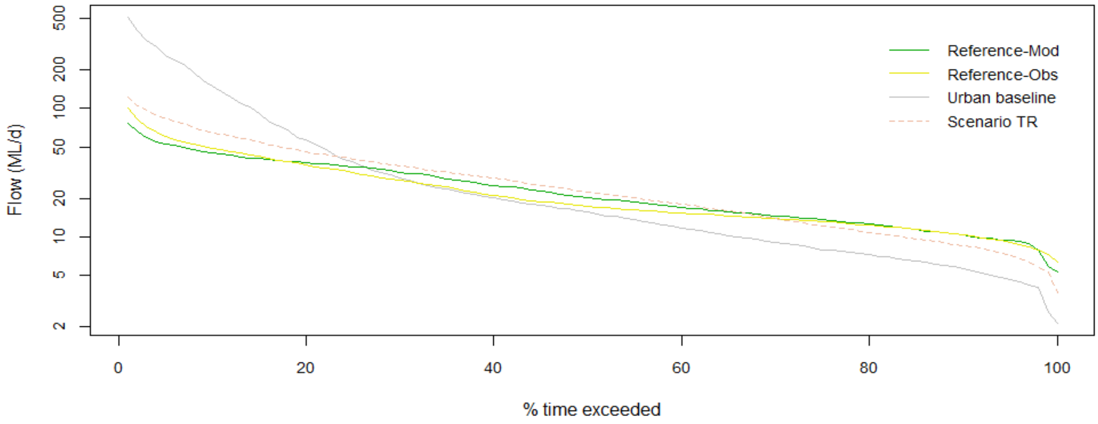

Figure 4. Flow duration curves for the reference (model and observed), urban baseline and source-control TR scenario (see section 3.2.3 for details of TR scenario).

3.2 Performance of source-control technique strategies

3.2.1 Tank-based strategies

As expected, tank-based scenarios performed well for the ADF metric, due to the high level of indoor and outdoor use of stormwater (Figure 5). These strategies also restored the number of low flow spells (FL1) to its reference value. However, both tank strategies failed to restore low flow magnitude and duration as measured by Q95 and Q95/ADF. The two tank strategies (T1 and T2) produced similar values, despite the hypothesised restoration of low flows due to the passive irrigation in scenario T2. Increasing the capacity of the passive tanks to 3 kL (from their default 1.5 kL) did not change the results significantly, suggesting that the size of the storage was not the factor limiting the increase of low flows (results not shown).

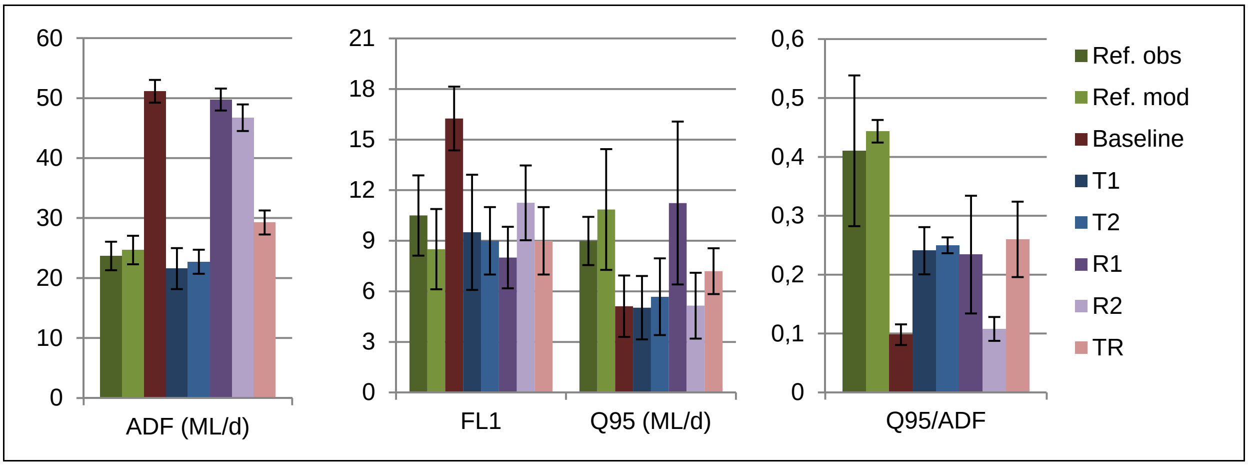

Figure 5. Performance of scenarios compared to the reference (natural) and baseline (urban) models. Each bar represents the mean of 4 years and its standard deviation. Ref. obs. and Ref. mod. are the observed and modelled data for the catchment, respectively.

3.2.2 Raingarden-based strategies

Raingarden-based strategies did not significantly affect the total flow volume. This was expected, given that the only losses in raingardens are due to evapotranspiration from the raingardens, which are constrained by their small area (3%), relative to their contributing impervious catchment. Regarding the magnitude and duration of baseflow, the scenario R1, based on infiltration raingardens, performed much better than R2, which relied on low flow underdrains with controlled release rate aiming to mimic baseflows. This effect may be explained by the storage capacity and subsequently the retention time of the lined raingardens, which are insufficient to impact Q95. A sensitivity study on the release rate (which impacts the retention time) confirmed the very weak response of Q95 to this parameter. However, alternative flow percentiles that represent baseflow magnitude (e.g. Q70) showed greater response to changes in release rate (results not shown). The large value of ADF for R1 also explains the relatively low performance of R1 regarding Q95/ADF, despite Q95 being close to its reference values. Finally, the frequency of low flow spells was restored back to its reference level for both raingarden scenarios.

3.2.3 Combination of tanks and raingardens

The TR strategy combined the advantages of both source-control techniques. Not surprisingly, the stormwater harvesting provided by the tanks resulted in a decrease in ADF by 75% compared to the baseline. ADF remained 19% higher than its reference value, due to the substantial infiltration of water via both passive irrigation and infiltration from raingardens. Like all other strategies, TR restored the frequency of low flow spells to its reference level. Regarding low flow magnitude and duration, TR compared well with R1, the infiltration strategy, although harvesting prior to infiltration reduced the magnitude of the groundwater recharge and subsequent baseflow.

3.3 Effect of partial implementation of strategies

The implementation of the TR strategy on only 25% of the catchment resulted in a reduction of ADF by 38%. The relationship of volume reduction to implementation coverage was non-linear, with the proportional effect of additional treated area being less strong as the total treated area increased. This is because the increased implementation of source-control strategies upstream diminishes the efficiency of downstream measures like the stormwater pond. This effect is particularly visible on the 75% treatment scenario, which resulted in a reduction of ADF greater than for the 100% treatment scenario. The compensatory effect of the stormwater harvesting storage, where the excess runoff from upstream areas is directed, is likely to explain this observation: the storage effectively allows for more water to be lost from the catchment via evapotranspiration.

The effect of a partial implementation of the TR strategy on FL1 showed a threshold, with even a relatively low treatment (25%) resulting in FL1 being close to its reference value. Similarly, the effect on Q95/ADF was non-linear, with the first 25% of treated catchment having a greater effect than the last ones. Again, these relationships are due to the diminished effect of downstream raingardens and stormwater harvesting with increasing application of upstream (at-source) measures. However, the effect of a partial implementation of the TR strategy had a linear effect on Q95.

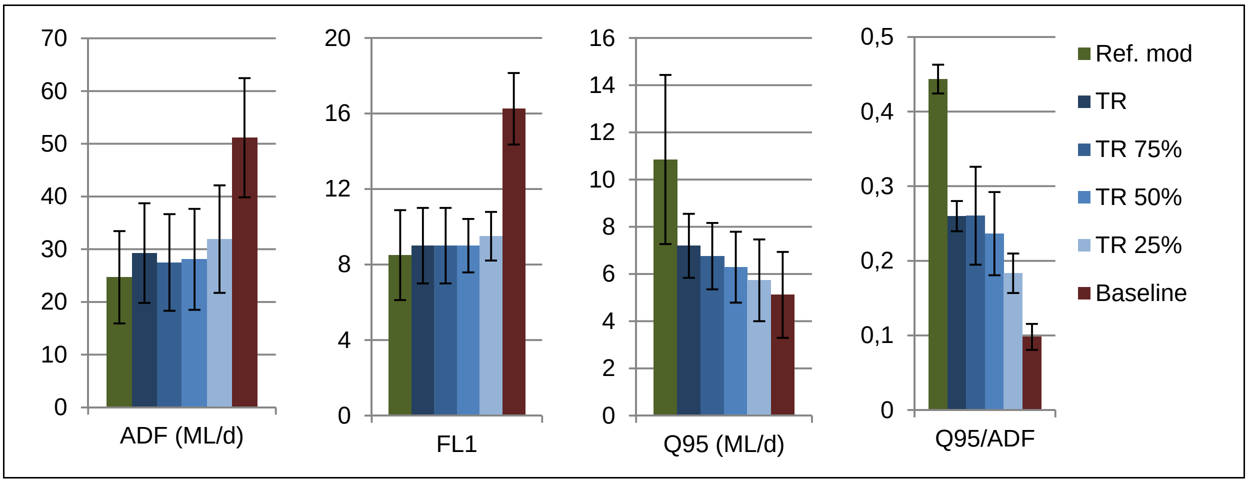

Figure 6. Performance of the TR strategy when implemented on 25, 50, 75, and 100% of the catchment

4 DISCUSSION

4.1 Metric selection

The results from this study highlight the importance of metric selection for stormwater management studies. Our focus was deliberately on the baseflow regime, resulting in three metrics quantifying the low flow part of the hydrograph. We have shown that these metrics potentially ignored some features of the baseflow, with the 95th percentile of flows not being affected by the low flow release by raingardens (while the 70th percentile, or alternative metrics integrating the low flow part of the flow duration curve, showed a stronger response). Similarly, the results from the partial treatment scenarios suggest that a low level of treatment already achieves a significant outcome based on the selected baseflow metrics. This is contrary to the expected effects on high flows, where only treating only 25% of the catchment is unlikely to reduce significantly the effect of urbanisation (whereas a significant decrease in high flows can be achieved with the 100% implementation of the TR scenario, as shown in Figure 4). Overall, this suggests that flow metrics should be selected with careful consideration, based on the specific objectives of the study, and ideally on the components of the flow regime that have been identified as ecologically important. This is obviously often challenging, as it may require specific eco-hydrological and eco-hydraulic studies often unavailable (Hamel et al., in review).

In addition, we note a possible confusion that may arise from the use of the total flow (ADF) metric. In general, the effect of urbanisation on the total streamflow is a large increase due to the much higher runoff peaks and the large loss of evapotranspiration. However, the effect of urbanisation on baseflows is commonly the opposite (notwithstanding anthropogenic inputs), with creation of impervious areas reducing infiltration and subsurface flows. In many situations a restoration of lost baseflows is thus necessary, and it is unlikely that an increased total flow due to increased baseflow only would have a detrimental effect on the receiving waters. Because ADF encompasses both types of flow, care should be taken in the interpretation of its changes.

4.2 Model limitations

While scenario studies provide interesting insight into the optimisation of catchment-scale strategies, our results should be considered in light of the required modelling assumptions. The most important of these pertains to the baseflow generation processes, both for the natural and urban catchments (Price, 2011). Careful observation of the hydrological data allowed development of a model structure which attempts to represent the physical processes, but we have not (in this study) compared this structure to alternatives. Double linear reservoir models have been shown to adequately represent natural catchments (Fenicia et al., 2006), but validation of the urban scenarios remains difficult if not impossible in the absence of “before-after control-impact” type of experimental data. Similarly, secondary effects of urbanisation such as the creation of preferential paths (due to underground pipelines, etc.) or the leakage of water from mains have not been included in our model. Because these effects vary widely between catchments, they would have to be considered individually for each study catchment.

The assumptions for the stormwater management scenarios also deserve attention. We acknowledge that the presence of a downstream stormwater pond used for irrigation had a strong effect on the results for the tank-based scenarios (including the scenarios of partial treatment of the catchment-based on the TR strategy). While this option is not technically complex, it is rarely being applied to such an extent in practice. Second, we have assumed that harvested water on private properties was used for toilet, laundry and hot water. While this is a reasonable assumption in the Australian context, studies have shown that in practice, a non-negligible proportion of households could switch back to main supply over time, if maintenance issues arose.

5 CONCLUSIONS

Because they emulate some natural hydrologic processes at a small scale, source-control techniques have the potential to help restore a near-natural flow regime in urban catchments. Our modelling study provided insight into the advantages and limitations of some typical techniques used in residential catchments: rainwater harvesting tanks and raingardens. Strategies based on a standard design of tanks efficiently decreased the total flow, but did not affect the altered baseflow regime. A design based on baseflow enhancement via low flow release (passive irrigation) did not improve the results significantly, certainly due to the limited storage capacity of source-control techniques. The same limitations were found for strategies based on raingardens designed with a low flow underdrain. Despite this, a combination of tanks and infiltration raingardens seems to be a promising way towards flow regime restoration both in terms of total flow and baseflow regime. Importantly, our study illustrated the role of metric selection in stormwater management studies, showing that low flow metrics responded distinctively to an increase in the retrofitted area of a catchment. In general, this suggests the need to analysing a range of metrics representing the process of interest, especially given the uncertainties related to the ecological significance of particular flow aspects.

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Appendix – Assumptions used for the implementation of the source-control strategies (POS: Public Open Space)

Technique	**Aspect**	**Assumptions**	**Rationale**
Harvesting for indoor use (allotments)	Tank volume	7.5 kL	Based on typical tank volumes in use (Burns, unpublished data)
	Catchment area	Roof area but not paving area	Indoor
	Demand types & amounts	Toilet (50.5 L/day), Hot water (125.2 L/day) & Clothes washing (74.6 L/day)	Based on Wilkenfield & Associates (2006) for 2.67 persons/household
	Assumption for the catchment water balance	*ET*: All harvested water for indoor use is lost to the catchment (conveyed for treatment without pipe loss) *Surface runoff*: overflow is directed to the creek via stormwater pipes *Overflow*: To stormwater system or to raingarden depending on scenario	
Harvesting for active irrigation (allotments & POS)	Tank volume (allotments)	Same tank as for indoor use (only one tank per property); priority for indoor use first	Average household likely to have only one tank and use the water in priority for restricted usage (irrigation)
	Stormwater harvesting pond (POS)	30 kL/ha = 300 kL for 10 ha	Based on storage reliability analysis conducted by Mitchell et al. (2008)
	Catchment area (POS)	All roads + footpaths (public imp) + overflow from private	
	Irrigation demand (amount & timing)	Monthly demand from (Wilkenfield & Associates, 2006). For allotments, only 50% of garden is assumed to be irrigated	
	Assumption for the catchment water balance	*ET*: All water used for active irrigation is assumed to be lost to ET	
Harvesting for passive irrigation (allotments)	Tank properties	Top 20% dedicated to passive irrigation. Assumed to leak at mean flow = 0.274 m^3/sec/ catchment area	
	% of garden to which passive irrigation applied	50%	Assumed to be applied to half of garden, for reasons of practicality and avoiding boundaries, etc.
	Assumption for the catchment water balance	*ET and baseflow*: Assumed to be all infiltration (based on Hamel et al., 2012)	
Raingardens (allotments & POS)	Area (% of impervious catchment)	3% of catchment (roof and paving area for allotments; roads for public open space)	Typical area as required to emerging water quality and flow management targets (Fletcher and Walsh, 2007)
	Ponding depth	0.2 m	Consistent with current guidelines (FAWB, 2009; Melbourne Water, 2005)
	Filter media properties	Sandy loam, hydraulic conductivity = 100 mm/hr, filter depth = 0.8 m	Based on current guidelines (FAWB, 2009; Melbourne Water, 2005)
	Lining & underdain	For R1 and TR: Unlined (no underdrain) For R2: Fully lined (low flow underdrain with release rate set to 0.82 mm/hr and)	Low flow rate calculated baseflow rate for the catchment Upper drain is designed to allow a faster drainage of the upper layers of the raingarden
	Surrounding soil hydraulic conductivity K_s	0-300 mm layer: K_s = 36 mm/hr, Below 300 mm: K_s = 0.36 mm/hr	Adapted from Table 1 of (Hamel et al., 2011)(nearby urban catchment)
	Assumption for the catchment water balance	*ET*: Calculated based on 100% of raingarden area (assuming a crop factor of 1) *Baseflow*: infiltrated water from raingardens recharge the slow flow store *Overflow*: to stormwater system	It is assumed that the infiltrated will contribute to subsurface flow processes in a similar way to the natural catchment