

Can allotment-scale rainwater harvesting manage urban flood risk and protect stream health?

La récupération des eaux pluviales à la parcelle : peut-elle protéger contre les inondations et la dégradation des milieux aquatiques?

Matthew J. Burns¹; Tim D. Fletcher¹; Belinda E. Hatt¹; Anthony R. Ladson² and Christopher J. Walsh³

¹Institute for Sustainable Water Resources, Dept. of Civil Engineering, Building 60, Monash University., Victoria 3800, Australia (corresponding author: Matthew.Burns@eng.monash.edu.au). ²Sinclair Knight Merz, 590 Orrong Rd., Armadale, Victoria 3134, Australia. ³Dept. of Resource Management and Geography, The University of Melbourne, 221 Bouverie St., Parkville, Victoria 3010, Australia.

RÉSUMÉ

La gestion traditionnelle des eaux pluviales, axée principalement sur la diminution du risque d'inondation, a eu pour conséquence la dégradation des milieux aquatiques. L'état des cours d'eau urbains est ainsi dégradé par une accumulation de sources de stress, notamment la perturbation provoquée fréquemment par les ruissellements sur les surfaces imperméables. Nous étudions donc ici les effets de la récupération des eaux pluviales à l'échelle de la parcelle sur le risque d'inondation et la protection des milieux aquatiques. Pour ce faire, nous avons utilisé une analyse de probabilité jointe pour estimer le risque d'inondation dans un bassin versant théorique avec différents degrés d'imperméabilisation et de récupération des eaux pluviales. Cette étude a révélé que la récupération des eaux pluviales à l'échelle de la parcelle peut réduire modérément le risque d'inondation. Pour réduire davantage ce risque, il faut utiliser une gestion plus intégrée, combinant la récupération de l'eau à toutes les échelles (de la parcelle, du quartier et en aval) avec d'autres techniques d'assainissement des eaux pluviales comme l'infiltration.

ABSTRACT

The traditional management of stormwater with a singular focus on flood protection has resulted in the degradation of receiving waters. The health of urban streams is degraded by a suite of stressors, notably, the frequent disturbance due to stormwater runoff. We investigate the catchment scale implications of allotment scale rainwater harvesting, in terms of potential simultaneous benefits for stream protection and flood risk. We used an event joint probability approach to estimate flood risk for hypothetical catchments with varying degrees of urbanization and rainwater harvesting. We found that allotment-scale rainwater harvesting can provide moderate (but potentially significant) reductions to flood risk. To further reduce flood risk, attention should be given to decreasing the volume of rainfall which becomes runoff, by combining allotment-scale rainwater harvesting with a range of other stormwater techniques, such as infiltration and complementary application of larger-scale stormwater harvesting.

KEYWORDS

Catchment hydrology; decentralized stormwater management; flood estimation; rainwater tank.

1 INTRODUCTION

It is well known that urbanization has a number of impacts on catchment hydrology, in particular an increase in the frequency and magnitude of streamflow (Leopold 1968). This increase in flood risk has traditionally been managed through the efficient routing of stormwater runoff to urban streams. While this approach to stormwater management has proved successful from a flood risk perspective, its success has largely been to the detriment of urban streams, in particular aquatic ecosystems¹ (Walsh et al. 2005a).

A number of reviews concerning the impacts of urbanization on urban streams (Paul and Meyer 2001; Walsh et al. 2005b) suggest that the frequent routing of stormwater runoff to urban streams is the primary stressor to aquatic ecosystems. Apart from physically disturbing aquatic ecosystems, stormwater runoff contains a suite of pollutants (Hatt et al. 2004; Duncan 2005) which can degrade the water quality of urban streams.

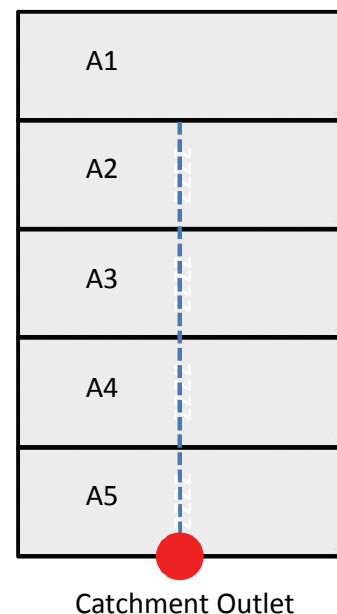
Without exploring in extensive detail the impacts of urbanization on urban streams, it is apparent that effort to restore the health of urban streams should focus on the primary mechanism of disturbance - the frequent routing of stormwater runoff to urban streams. While stormwater management has advanced considerably over the past few decades, particularly in regard to improving the water quality of receiving waters, there is scope for further advancement considering recent insights into the mechanisms of stormwater runoff which degrade urban streams.

A number of studies (Fletcher et al. 2008; Walsh et al. 2009b) have suggested that decentralized stormwater management - which amongst other objectives, attempts to mimic the natural (pre-developed) frequency of storm event flow - is a considerable advance compared to current stormwater management. It has been shown that the use of simple technologies (e.g. rainwater tanks, biofiltration and infiltration) at the allotment-scale (i.e. at the scale of a single dwelling) can successfully mimic the natural frequency of surface runoff leaving a site, although space constraints can be significant. Furthermore, it has been suggested that such technologies could assist in the management of a possible increase in flood risk due to climate change (Ashley et al. 2005)

In recognising that the most important objective of stormwater management is flood protection, could allotment-scale stormwater management simultaneously assist in the protection of urban stream health by mimicking the natural frequency of stormwater runoff as well as help to manage flood risk? This is a preliminary study which attempts to develop context for future research into the impacts of small-scale stormwater management on overall catchment hydrology.

2 METHODOLOGY

To undertake this study, we adopted a hypothetical catchment (Figure 1) and divided it into five sub-areas (A1 to A5), each of equal area (1 km²), based on runoff routing model recommendations given by Boyd (1985). We then developed a range of different modelling scenarios which reflect pre-developed conditions (Scenario 1), developed conditions with no treatment (Scenarios 2 and 6) and developed conditions which feature allotment-scale rainwater harvesting (Scenarios 3, 4, 5, 7, 8 and 9, Table 1). In regard to the rainwater harvesting scenarios, it should be noted that we only considered the roof area of allotments and assumed that runoff from any remaining impervious areas (e.g. driveways, pavement etc) went untreated. The modelling scenarios were developed based on typical, Australian urban catchments (Mitchell et al. 2005). The rainwater tank sizes adopted are moderately large and may not be possible for retrofit installation in catchments with very high density land use. Our analysis considers only the temperate Melbourne climate and results would vary for different climates such as those with extended dry periods and intense wet seasons.



Catchment Outlet
Figure 1 – Conceptual diagram of the hypothetical catchment, showing the five sub-areas.

¹ This paper deals exclusively with separate storm and sanitary sewerage systems.

Table 1 – Rainwater harvesting scenarios.

Scenario	Catchment Characteristics [^]	Rainwater Harvesting Configuration [^]	Demand		Leaking Tank	Cost (AU\$) [^]
			In-house	Outdoor		
1	100% pervious catchment (pristine); natural channel	No rainwater harvesting	NA	NA	NA	NA
2	42% impervious catchment; medium density (15 allotments/Ha); channelized unlined channel	No rainwater harvesting	NA	NA	NA	NA
3		100% of roof area (230 m ²) connected to 5KL rainwater tank to service indoor (occupancy of 2.67 persons) and outdoor (garden area 187 m ²) usage	Toilet flushing	Garden watering	NA	\$2,145
4			Clothes washing, hot water usage and toilet flushing	Garden watering	NA	\$2,695
5			Clothes washing, hot water usage and toilet flushing	Garden watering	Yes	\$2,695
6	70% impervious catchment; high density (40 allotments/Ha); piped channel	No rainwater harvesting	NA	NA	NA	NA
7		High density – 100% of roof area (110 m ²) ² connected to 3KL rainwater tank to service indoor (occupancy of 2.67 persons) and outdoor (garden area 35 m ²) usage	Toilet flushing	Garden watering	NA	\$1,895
8			Clothes washing, hot water usage and toilet flushing	Garden watering	NA	\$2,445
9			Clothes washing, hot water usage and toilet flushing	Garden watering	Yes	\$2,695

[^]Catchment characteristics and rainwater harvesting configurations were largely developed from Mitchell et al (2005) and Wilkenfeld (2006). The regularity of rainwater harvesting was increased for some scenarios on the premise that supplying more constant demands is more likely to reduce flood risk since the probability of storage available in rainwater tanks would be greater. We included the option of a “Leaking Tank” as a surrogate means of providing a baseflow to the stream. The cost of each system was estimated from Walsh et al (2009a) and includes installation. The cost per kL including installation and pump operation amounts to around \$3.30/kL. We assumed that no additional cost would be required for a “leaking tank”.

To estimate the frequency and magnitude of large to rare floods at the catchment outlet for each modelling scenario, an event joint probability approach was adopted (Figure 2). This approach recognises that the same depth of rainfall could result in an array of different flood peaks depending on the catchment initial loss and storm temporal pattern. It is appropriate for estimating floods with annual exceedance probabilities (AEPs) less than 1 in 10 years (Nathan et al. 2006) and is well developed (Kuczera et al. 2006). Furthermore, flood estimates from this approach are more defensible than those estimated using design event approaches (Weinmann et al. 2002). The adoption of the most rigorous flood estimation approach (i.e. total joint probability using continuous simulation) was beyond the scope of this preliminary study and will be the subject of future endeavours.

In Australia, a number of different flood event models are used for flood estimation (e.g. RAFTS, WBNM, URBS and RORB, (Carroll 1995). Of these models, only the current version of RORB (Laurenson et al. 2006) features event joint probability capability, based on a Monte-Carlo simulation framework (Nathan et al. 2003) and thus was utilised for this study. For the sake of brevity, only the salient parameters of the RORB model will be discussed. The RORB model assumes that a catchment's response to rainfall is non-linear, indicated by parameter m being less than one (i.e. m represents the degree of non-linearity in catchment response³). Catchment attenuation is represented by the parameter K_c ; a small catchment has less flood attenuation than a larger catchment and this is represented in RORB using a relatively small K_c value. The storm initial loss is represented by the

²Mitchell et al (2005) report a roof area of 105 m², however we adopted 110 m² because the modelling software used (MUSIC) allows the user to enter a catchment area (hectares) with an accuracy of three decimal places.

³ An m value of unity would indicate that a catchment's response to rainfall is linear.

parameter IL_{PERV} . For a catchment with some imperviousness, the storm initial loss is calculated as follows:

$$IL_i = (1 - F_i) IL_{PERV} \tag{Equation 1}$$

Where IL_i is the storm initial loss for sub-catchment i (mm), F_i is the impervious fraction of sub-catchment i , and IL_{PERV} is the storm initial loss for the pervious component of sub-catchment i (mm).

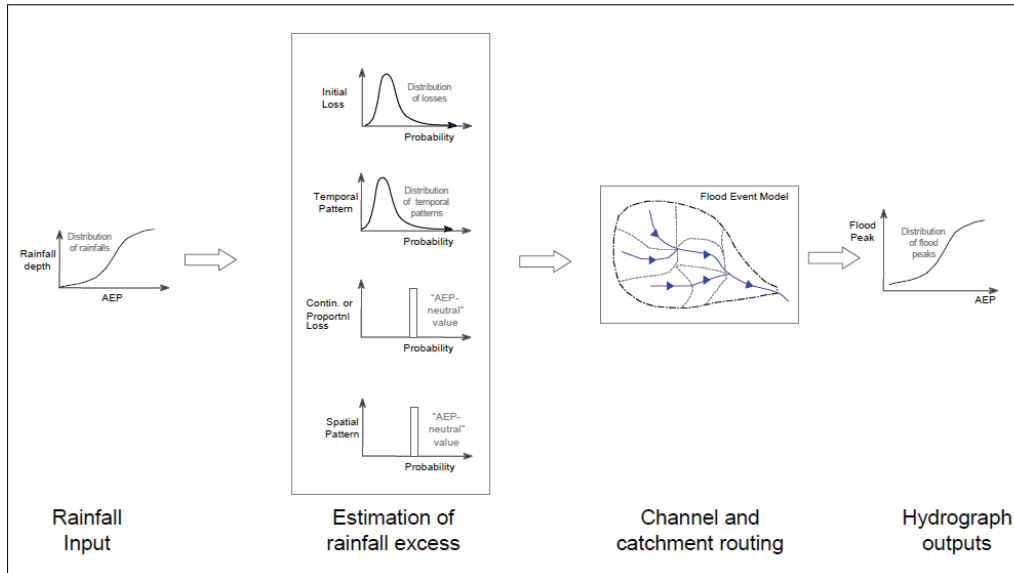


Figure 2 – Event joint probability approach as implemented in RORB Version 6 (Laurenson et al. 2006).

The storm continuing loss can be modelled in RORB two different ways. Firstly, the storm continuing loss can be specified directly (i.e. loss/hour). Secondly, the storm continuing loss can be specified through specification of a runoff coefficient for the catchment (parameter C ; Equation 2). For example, specifying a runoff coefficient of 0.5 implies that throughout the duration of a storm, 50% of the storm rainfall would be lost to evapotranspiration and infiltration.

$$C_i = (F_i \times C_{IMP}) + (1 - F_i) C_{PERV} \tag{Equation 2}$$

Where C_i is the runoff coefficient for sub-catchment i , C_{IMP} is the runoff coefficient for impervious surfaces of sub-catchment i (preset to a value of 0.90), and C_{PERV} is the runoff coefficient for pervious surfaces of sub-catchment i .

For each modelling scenario, we ran RORB using model inputs and parameters as shown in Tables 2 and 3. We selected a range of storm durations (30 minutes to 24 hours) ensuring not to select long duration storms since they are likely to contain embedded bursts (i.e. periods of intense rainfall). The hypothetical catchment was modified to reflect the appropriate catchment characteristics of each modelling scenario. For example, to establish Scenario 2 we changed the fraction imperviousness of each sub-area to 0.42 and channel type to channelized, unlined. We extracted peak flows from the model output for a range of AEPs for each modelling scenario.

Table 2 – Inputs for event joint probability approach.

Input	Description
Rainfall Depth	For each storm duration (e.g. 30 minutes to 24 hours, excluding 45 minutes), rainfall depth distributions (1 year ARI to 500 year ARI) were derived based on intensity frequency duration curves for Melbourne (Institution of Engineers Australia 1987) using a tool within RORB Version 6.
Storm Initial Loss	Refer to Section 2.1 below.
Temporal Pattern	A range of temporal patterns representative of large storms (durations: 0.5, 1, 1.5, 2, 3, 4.5, 6, 9, 12, 18 and 24 hours) were adopted. They were extracted from pluviograph data (6 minute time-step) from the Melbourne Regional Office gauge using a tool within RORB Version 6. The period of record was 30 th of April 1873 to the 31 st of December 2001 and 34% of data was missing (Laurenson et al. 2006).
Spatial Pattern	A uniform spatial pattern was adopted since our modelled catchment is small.

Table 3 – Model parameters for RORB Version 6 flood event model.

Parameter	Value
K_C	A value of 2.50 was adopted based on an empirical regional study of routing parameter values (Pearse et al. 2002).
m	A value of 0.80 was adopted as recommended when no gauged streamflow data is available (Laurenson et al. 2006).
C_{PERV}	A value of 0.30 was adopted. This value is consistent with those derived by Jayasuriya (1988).
IL_{perv}	A value of $[15 + (F * 0.8)]$ was adopted. We incorporated an extra term $(F * 0.80)$ to allow for the fact that some initial loss occurs on impervious surfaces (Zaman and Ball 1994).

2.1 Storm Initial Loss

For the modelling scenarios that do not feature rainwater harvesting (e.g. 1, 2 and 6), an empirical probability distribution of storm initial losses derived from an analysis involving catchments in South-Eastern Australia was adopted (Hill et al. 1997). Importantly, new storm initial loss distributions were derived for modelling scenarios featuring rainwater harvesting. This step recognises that 1) rainwater tanks can retain rainfall during a storm event, thus increasing storm initial loss, and 2) the volume of rainfall that is retained varies with storage volume availability. The MUSIC software (eWater 2009) was used to derive probability distributions of rainwater tank storage availability and runoff frequency for the relevant modelling scenario (i.e. based on the modelled end-uses patterns of the rainwater being harvested).

The MUSIC model allows for the continuous simulation of stormwater management scenarios at a range of different scales. The climatic data used for each modelling scenario was hourly rainfall data (01/01/1926 to 31/12/1988) (mm/hour) and average areal potential evapotranspiration (mm/month) sourced from the Australian Bureau of Meteorology's Melbourne Regional Office station. While a longer period of rainfall data was available for the gauge of interest (30/04/1873 to current), it was found that the period chosen (01/01/1926 to 31/12/1988) featured the least missing rainfall data over the longest period of time. While the use of a longer period of gauged or synthetic record would have been preferable, we consider that the period chosen was sufficiently long enough to represent climate variability.

A single allotment MUSIC model was established for each relevant modelling scenario which incorporated the rainwater harvesting conditions shown in Table 1, taking into consideration the various combinations of in-house/outdoor water demands and presence or absence of a leaking tank. The in-house water demands included toilet flushing (18.9 L/person/day), clothes washing (35.31 L/person/day and 23.54 L for each additional person) and hot water usage (46.9 L/person/day). The outdoor water demand included garden watering (12,971 L/year per 100 m² of garden area), which varied seasonally.

The estimates of the various in-house and outdoor water demands are Melbourne-centric and were derived from Wilkenfeld (2006). For two scenarios, we coupled the maximum demands with a leaking tank, which we used as a means of increasing baseflow to the stream draining the catchment (5 and 9, Table 1) because urbanization generally decreases baseflow (Rose and Peters, 2001). We estimated leaking tank flow rates as 220 L/day and 100 L/day for medium and high density allotments, respectively. These values represent the daily runoff per roof area which would have occurred under pristine conditions. We used a relationship between annual rainfall and annual evapotranspiration as seen in Zhang (2001) to estimate annual runoff. The annual runoff was disaggregated uniformly to yield daily runoff.

We ran MUSIC for each modelling scenario and extracted the resulting hourly storage availability, based on the temporal patterns of usage and the historic rainfall data. From this we were also able to model the daily outflow. The hourly storage availability data was used to derive new storm initial loss distributions in RORB based on modification of the empirical distributions for non-urban catchments. We carried out this step by scaling the impact of retaining rainfall at the allotment-scale to the catchment-scale based on the relevant density of allotments.

3 RESULTS

3.1 Implications for Flood Risk

As anticipated, urbanization of the hypothetical catchment increased the frequency and magnitude of floods (Figure 3). For catchments featuring both medium- and high-density allotments, rainwater harvesting resulted in a decrease in the frequency and magnitude of floods across all AEPs relative to catchments with no treatment. For example, application of a significant degree of rainwater harvesting (8 and 9) in a catchment with high-density allotments could reduce the magnitude of floods (for the range 1 in 2 AEP to 1 in 100 AEP) by around 20% (Table 4). Similarly, application of stormwater harvesting in a catchment with medium-density allotments could reduce the magnitude of floods by around 10%.

We found that application of a moderate degree of rainwater harvesting (3 and 7) resulted in only a marginal reduction in the magnitude of floods, especially for catchments with medium-density allotments (Figure 3). In general, scenarios which featured more regular rainwater harvesting were more effective at reducing flood risk, compared to those which featured mostly seasonal water demands. However, none of the rainwater harvesting scenarios were able to match the frequency and magnitude of floods for a pristine catchment.

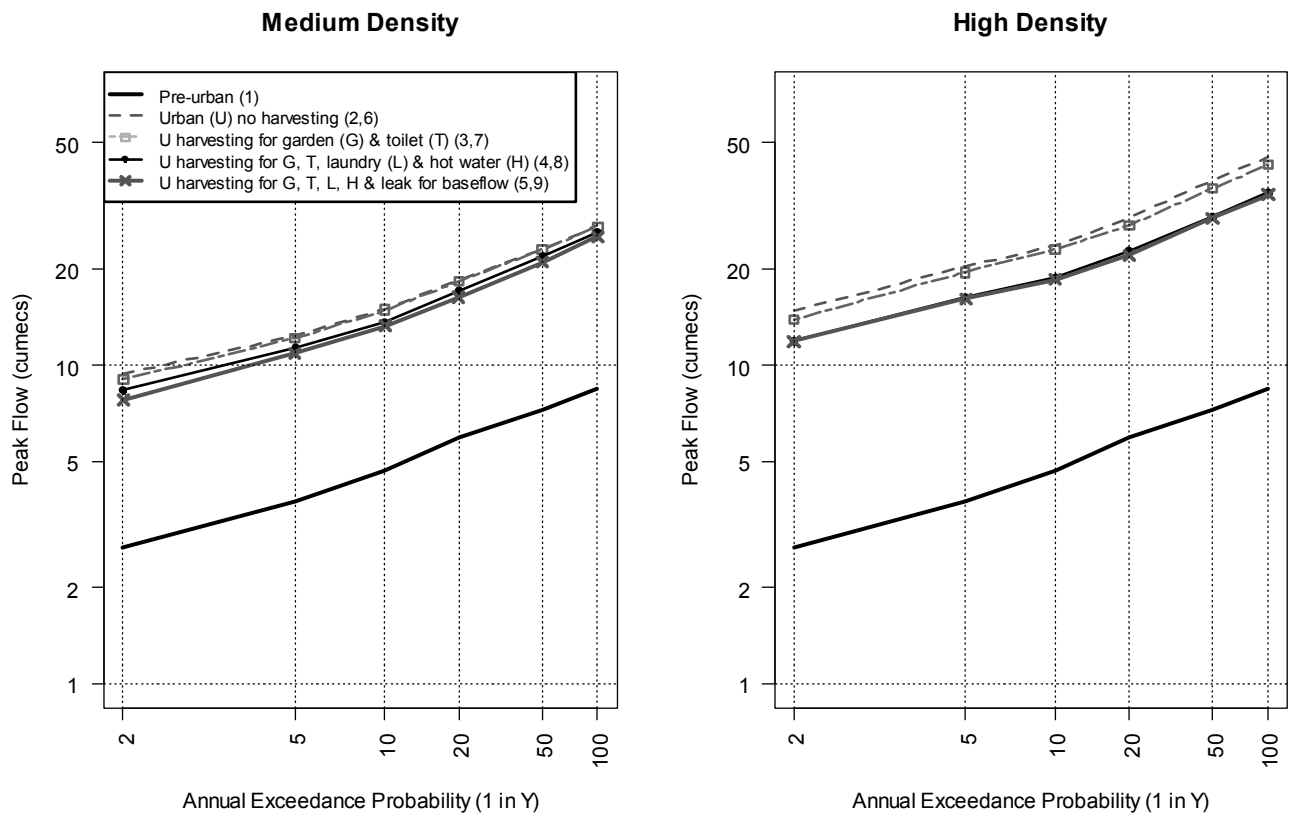


Figure 3 – Flood frequency curves for modelling scenarios (scenario number shown in parentheses).

Table 4 – Percentage reduction of peak flow for rainwater harvesting scenarios relative to their equivalent no-treatment scenario.

AEP (1 in Y)	Medium Density			High Density		
	Garden (G) & toilet (T)	G, T, laundry (L) & hot water (H)	G, T, L, H & leak for baseflow	Garden (G) & toilet (T)	G, T, laundry (L) & hot water (H)	G, T, L, H & leak for baseflow
2	4	11	17	7	20	20
5	2	8	12	4	20	20
10	1	9	12	3	21	22
20	1	7	12	5	21	24
50	0	5	9	6	23	24
100	1	5	8	6	23	24

3.2 Initial Loss and Frequency of Storm Event Flow

Prior to a storm event, the available storage in rainwater tanks varies significantly with catchment characteristics and the degree and type of rainwater harvesting (Figure 4). For example, a medium-density allotment which regularly uses significant amounts of rainwater throughout the year (Scenarios 4 and 5) could retain up to 22 mm of rainfall (i.e. 100% storage availability) approximately 50% of the time. Conversely, when a moderate degree of rainwater harvesting (with less regular use throughout the year) is adopted (Scenario 3), the probability of being able to retain up to 22 mm of rainfall is less than 5%, thus demonstrating the importance of regularly drawing down the rainwater store.

The impact of rainwater harvesting on initial loss was found to be significant for initial losses up to approximately 20 mm (Figure 5). For example, the initial loss distribution for a medium-density urban catchment which featured rainwater harvesting (Scenarios 4 and 5) is comparable to that of a non-urban catchment for the majority of the time. When the degree of rainwater harvesting is significant for a high-density urban catchment (Scenarios 8 and 9), initial losses can even be higher compared to those for a pristine catchment.

Rainwater harvesting resulted in significant reductions in the frequency of runoff for both medium- and high-density allotments (Figure 6). Moreover, as the degree of rainwater harvesting increased, the annual variability of stormwater runoff decreased towards more pristine conditions. For a medium-density allotment, the frequency of runoff can only be brought back to near pristine conditions when significant rainwater harvesting is applied throughout the year (Scenario 5). For a high density allotment, the use of rainwater harvesting to supply the maximum demands (Scenarios 8 and 9) resulted in a frequency and variability of runoff that approached those of pristine conditions. Our results support previous studies (Fletcher et al. 2007), in that reducing the frequency of storm flow to more natural conditions was more achievable when rainwater harvesting was applied to a high-density allotment, because of the relatively larger demand per unit of treated area for the harvested water.

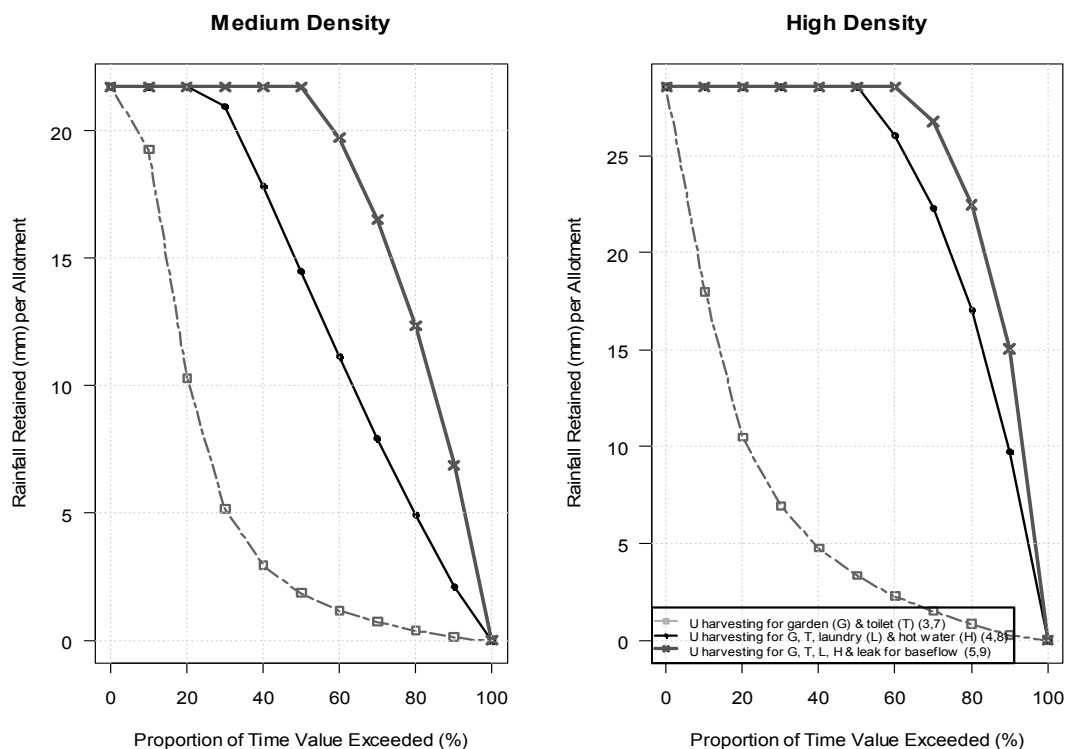


Figure 4 – Distributions of rainfall retained at the allotment scale for each modelling scenario (scenario number shown in parentheses).

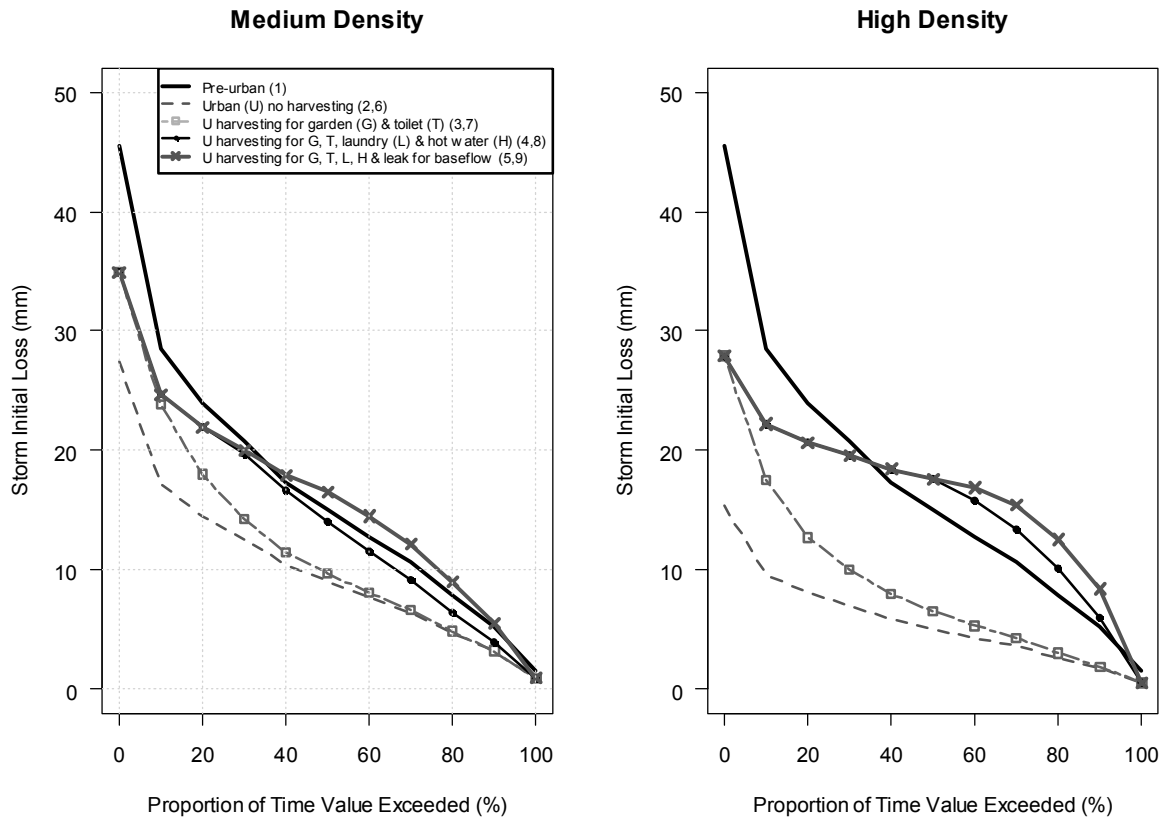


Figure 5 – Distributions of initial loss at the catchment scale for each modelling scenario (scenario number shown in parentheses).

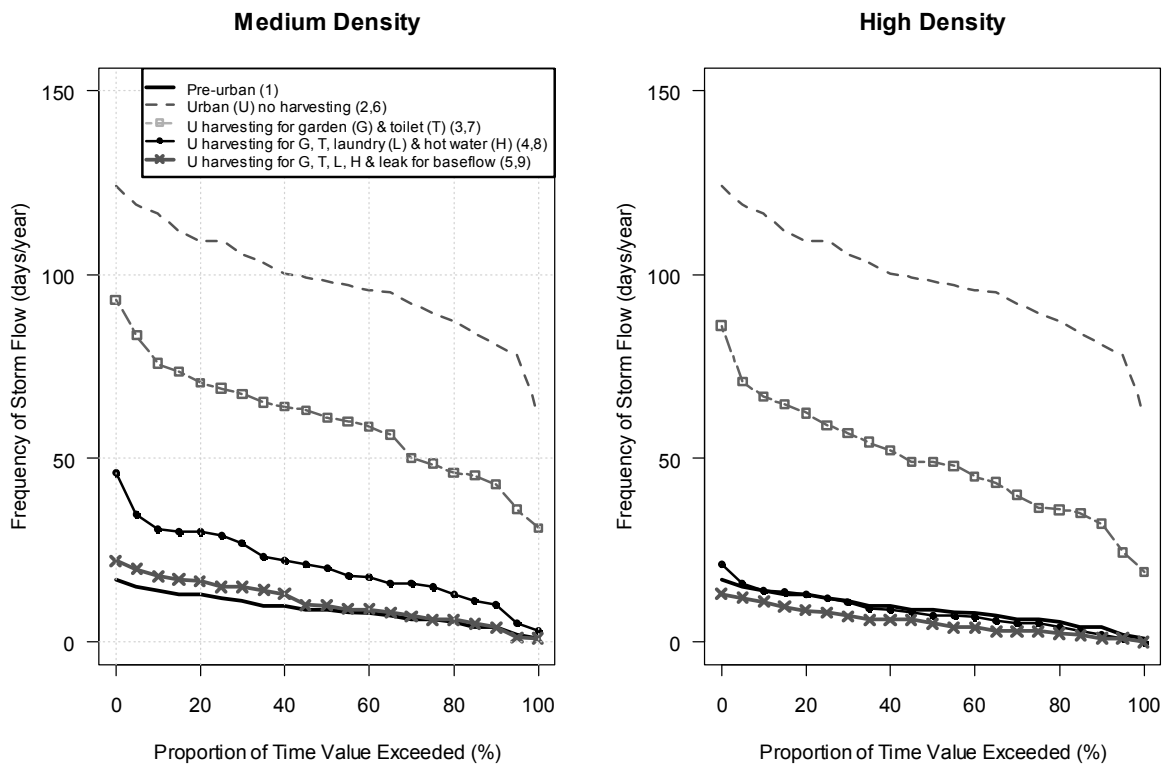


Figure 6 – Flow frequency distributions at the allotment scale for each modelling scenario (scenario number shown in parentheses).

4 DISCUSSION

Restoring post-development flood peaks towards to their pre-development level requires more than just allotment-scale rainwater harvesting. However, there may be some instances where reductions in the magnitudes of floods of only 10 to 20% are required, for example, to avoid expensive upgrades to existing urban drainage infrastructure. In such instances, simple application of allotment-scale rainwater harvesting may suffice. The potential for allotment-scale rainwater harvesting to manage flood risk is limited not by storm initial loss, but rather storm continuing loss (analogous to runoff coefficient). During a storm in a pristine catchment, once the initial loss is exceeded, generally only a relatively small fraction of the remaining rainfall becomes runoff. The other fraction of rainfall infiltrates the soil (continuing loss) and fills natural catchment storage. This phenomenon is similar in an urbanized catchment; however the fraction of rainfall which becomes runoff is much greater because of the prevalence of impervious areas. Thus, while restoring the initial loss distribution of an urbanized catchment to more pristine conditions (through, for example, rainwater harvesting) is important, to further manage flood risk attention should be given to decreasing the volume of rainfall which becomes runoff (i.e. increasing storm continuing loss) through application of technologies which promote infiltration (Hatt et al. 2009).

The application of allotment-scale rainwater harvesting can assist in the protection of urban stream health and manage flood risk, albeit moderately. When a significant and constant volume of rainwater is drawn from rainwater tanks, storage is available to retain most rainfall events (up to 22 mm and 29 mm for medium- and high-density allotments, respectively) throughout a given year, thus reducing the frequency of discharge from allotments. The potential to retain rainfall events is likely to be greater for scenarios in which the treated area is small relative to the storage available, and where there is a regular year-round demand for the harvested rainwater.

The frequency of stormwater runoff and its annual variability can be reduced to those of natural conditions using *typical* allotment-scale rainwater harvesting configurations. This point is important – the widespread adoption of *typical* configurations is feasible. It would seem that application of allotment-scale rainwater harvesting can reduce the occurrence and annual variability of the primary stressor to urban streams (i.e. stormwater runoff) and thus *assist* in the protection of urban stream health. We must acknowledge that this paper only considered treatment at the allotment scale – also in practice, a stormwater harvesting strategy would need to consider harvesting from all scales (including streetscape and sub-catchment) and this will be the subject of future investigation.

We are currently involved in a major research project (Fletcher et al. this volume) which is restoring the health of a degraded urban stream in Melbourne, Australia, (Little Stringybark Creek) through the application of decentralized stormwater management technologies. We anticipate that insights from this project, notably, the field performance of relevant technologies across a range of scales will assist us in developing and reality-testing the ideas posed in this paper.

5 CONCLUSION

Stormwater managers have an imminent challenge to provide flood protection to the community in a climate-uncertain future, whilst protecting and improving the health of urban streams. To meet this challenge, stormwater managers must consider new, integrated management options. The application of allotment-scale rainwater harvesting can moderately reduce flood risk whilst assisting in the protection of urban stream health. It should be one of the suite of tools used to reduce the flooding and ecological impacts of urban stormwater.

LIST OF REFERENCES

- Ashley, R. M., D. J. Balmforth, A. J. Saul and J. D. Blansky (2005). "Flooding in the future - predicting climate change, risks and responses in urban areas." Water Science and Technology **52**(5): 265-273.
- Boyd, M. J. (1985). "Effect of catchment sub-division on runoff routing models." Institution of Engineers, Australia, Civil Engineering Transactions **CE 27**(4): 403-410.
- Carroll, D. G. (1995). Assessment of the effects of urbanisation on peak flow rates. The Second International Symposium on Urban Stormwater Management. Melbourne, Australia: 201-208.
- Duncan, H. (2005). Urban stormwater pollutant characteristics. Australian Runoff Quality Guidelines. T. H. F. Wong. Sydney, Institution of Engineers Australia.
- eWater (2009). MUSIC - Model for Urban Stormwater Improvement Conceptualisation - User Guide 4. Canberra, Australia, eWater Cooperative Research Centre

- Fletcher, T. D., A. Deletic, V. G. Mitchell and B. E. Hatt (2008). "Reuse of urban runoff in Australia: a review of recent advances and remaining challenges." Journal of Environmental Quality **37**(5): 116-127.
- Fletcher, T. D., V. G. Mitchell, A. Deletic, A. R. Ladson and A. Seven (2007). "Is stormwater harvesting beneficial to urban waterway environmental flows?" Water Science and Technology **55**(4): 265-272.
- Hatt, B. E., T. D. Fletcher and A. Deletic (2009). "Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale." Journal of Hydrology **365**(3-4): 310-321.
- Hatt, B. E., T. D. Fletcher, C. J. Walsh and S. L. Taylor (2004). "The influence of urban density and drainage infrastructure on the concentrations and loads of pollutants in small streams." Environmental Management **34**(1): 112-124.
- Hill, P., R. G. Mein and P. E. Weinmann (1997). Development and testing of new design losses for south-eastern Australia. 24th Hydrology and Water Resources Symposium, Auckland, New Zealand.
- Institution of Engineers Australia (1987). Australian rainfall and runoff. Canberra, IEAust.
- Jayasuriya, M. D. A. (1988). Simulation of runoff from urban watersheds to derive improved runoff coefficients. Department of Civil Engineering. Melbourne, Australia, Monash University.
- Kuczera, G., M. Lambert, T. Heneker, S. Jennings, A. Frost and P. Coombes (2006). "Joint probability and design storms at the crossroads." Australian Journal of Water Resources **10**(1): 63-79.
- Laurenson, E. M., R. G. Mein and R. J. Nathan (2006). RORB Version 6 - runoff routing program - user manual, Department of Civil Engineering, Monash University.
- Leopold, L. B. (1968). Hydrology for urban land planning - a guidebook on the hydrologic effects of urban land use. United States Geological Survey Circular.
- Mitchell, V. G., T. Taylor, T. D. Fletcher and A. Deletic (2005). Stormwater reuse - potable water substitution for Melbourne, Institute for Sustainable Water Resources, Monash University.
- Nathan, R., R. Mein and E. Weinmann (2006). RORB version 5: a tool to move beyond ARR87. Hydrology and Water Resources Symposium (30th : 2006 : Launceston, Tas.). Sandy Bay, Tas., Conference Design.
- Nathan, R. J., P. E. Weinmann and P. Hill (2003). Use of a Monte Carlo simulation to estimate and expected probability of large to extreme floods. 28th International Hydrology and Water Resources Symposium, Wollongong, NSW.
- Paul, M. J. and J. L. Meyer (2001). "Streams in the urban landscape." Annual Review of Ecology and Systematics **32**: 333-365.
- Pearse, M., P. Jordan and Y. Collins (2002). A simple method for estimating RORB model parameters for ungauged rural catchments. 27th Hydrology and Water Resources Symposium, Melbourne, Australia, Institution of Engineers, Australia.
- Walsh, C. J., T. D. Fletcher and R. L. Eddy (2009a). Review of allotment scale flow objective for application at allotment, streetscape and precinct scales, Department of Resource Management and Geography, The University of Melbourne.
- Walsh, C. J., T. D. Fletcher and A. R. Ladson (2005a). "Stream restoration in urban catchments through re-designing stormwater systems: looking to the catchment to save the stream." Journal of the North American Benthological Society **24**(3): 690-705.
- Walsh, C. J., T. D. Fletcher and A. R. Ladson (2009b). "Retention capacity: a metric to link stream ecology and storm-water management." Journal of Hydrologic Engineering **14**(4): 399-406.
- Walsh, C. J., A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman and R. P. Morgan (2005b). "The urban stream syndrome: current knowledge and the search for a cure." Journal of the North American Benthological Society **24**(3): 706-723.
- Weinmann, P., A. Rahman, T. Hoang, E. Laurenson and R. J. Nathan (2002). "Monte carlo simulation of flood frequency curves from rainfall - the way ahead." Australian Journal of Water Resources **6**(1): 71-79.
- Wilkenfeld, G. (2006). Water saving requirements for new residential buildings in Victoria: options for flexible compliance. Sydney, George Wilkenfeld and Associates Pty Ltd.
- Zaman, S. and J. E. Ball (1994). Simulation of small events in an urban Catchment. International Association of Hydrogeologists. Congress (25th : 1994 : Adelaide, S. Aust.). Barton, ACT, Institution of Engineers, Australia.
- Zhang, L., W. R. Dawes and G. R. Walker (2001). "Response of mean annual evapotranspiration to vegetation changes at catchment ccale." Water Resour. Res. **37**.