# Determination of Available Storage in Rainwater Tanks Prior to Storm Events

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*Abstract*

*Evaluation of the impact of rainwater tanks on the performance of stormwater management systems is reliant on understanding of the storage volumes available in tanks prior to storm events of a given average recurrence interval (ARI). This study has used continuous simulation, historical rainfall sequences and a unique method utilising virtual storages to determine storage volumes available in rainwater tanks prior to rain events of a given ARI. Available storage volumes in rainwater tanks prior to rain events at each location were observed to (i) increase with tank capacity, household size and the ARI of rain events, and (ii) decrease with increases in connected roof areas at Adelaide, Brisbane, Melbourne and Sydney. The variation in these parameters was observed to be conditioned on local climate and water demand patterns. The optimum use of rainwater tanks as part of a stormwater management strategy will be dependent on careful consideration of the key variables; local climate and water use patterns, the selected end use of rainwater, tank size and roof area.*

## 1. INTRODUCTION

It is now recognised that multiple sources of water from centralised and decentralised locations in combination with a diverse range of water conservation strategies can increase the resilience and reliability of a city's water supply (PMSEIC, 2007). The use of domestic rainwater tanks to supplement mains water supplies in cities is one of the emerging water conservation strategies. The commentary about domestic rainwater tanks has had a limited focus on potential rainwater yield. In contrast, domestic rainwater tanks have the potential to provide both water supply and stormwater management benefits that require a design focus (Coombes & Barry, 2006).

There is a paucity of research into the design of domestic rainwater tanks for stormwater management. Studies by Andoh and Declerk (1999), Coombes (2002), Pezzaniti et al. (2003) and Hardy et al. (2004) have demonstrated the benefits of distributed storages for stormwater management. Indeed Pezzaniti et al. (2003) conclude that rainwater tanks distributed throughout a catchment can produce equivalent reductions in peak stormwater discharges to detention storages situated at the catchment outlet.

The stormwater management benefits of a rainwater tank are a function of the available storage in the tank prior to storm events (Coombes, 2002). Derivation of available storages in rainwater tanks is a complex problem that is primarily dependent on patterns of water usage and climate. This problem is further complicated by the Australian practice of using design storms for analysis of stormwater management strategies that have an uncertain relationship with actual rainfall patterns at any location.

The derivation of available storage in tanks has taken various forms with Pezzanti et al. (2003) assuming that tanks will be empty prior to storm events, Vaes & Berlamont (1999; 2001) investigated the proportion of time that tanks would be empty and developed a modified design storm method to account for the impact of tanks, and Coombes (2002) proposed a method using continuous simulation and virtual storages to derive the probable initial airspace storage in tanks. Coombes et al. (2003) reported that rainwater tanks in the Upper Parramatta River area of Sydney would have 32% to 65% of their volume available for stormwater retention prior to storm events. This study employs the methods proposed by Coombes (2002) to understand the available storages in rainwater tanks used to supply domestic laundry, toilet and outdoor water uses at Adelaide, Brisbane, Melbourne and Sydney.

## 2. METHOD

The PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator) model was employed to continuously simulate the performance of the rainwater tank scenarios in Adelaide, Brisbane, Melbourne and Perth. Rainfall inputs to the model were from pluviograph rainfall data. Rainfall falling on roof areas discharges to a first flush device with a capacity of 20 litres and if the capacity of the roof gutter system is exceeded, rainfall also overflows from the roof gutter system to impervious areas. Rainwater is then routed through the first flush device to a rainwater tank (Figure 1).

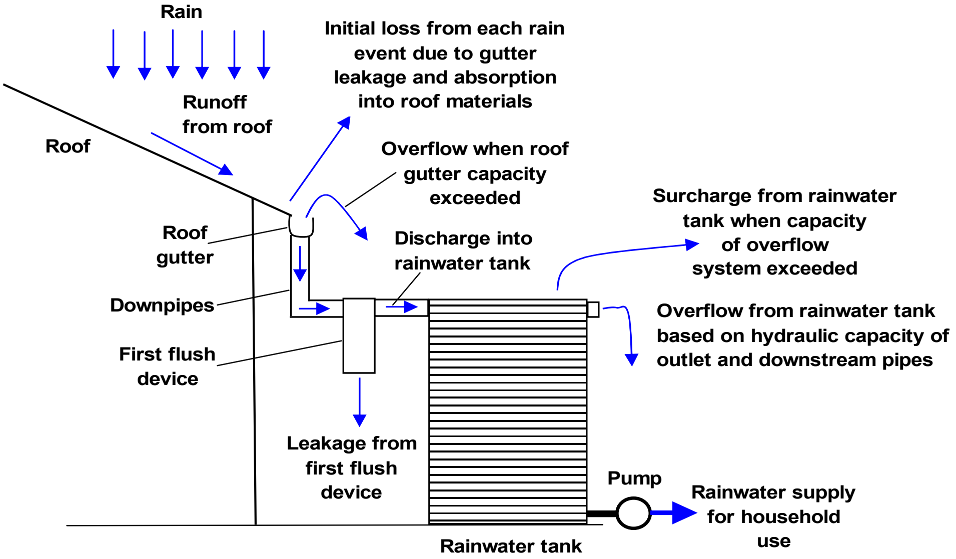

Figure 1: Schematic of the roof runoff to rainwater tank processes in PURRS

Water is drawn from the rainwater tank for household laundry, toilet and outdoor uses in accordance with the distribution of end uses shown in Figure 2 and, if the water level in the rainwater tank is below a set minimum level, the tank is topped up with mains water at a nominated rate (Figure 3). Mains water is used to supply all household uses not sourced from the rainwater tank and to supplement the rainwater tank supply.

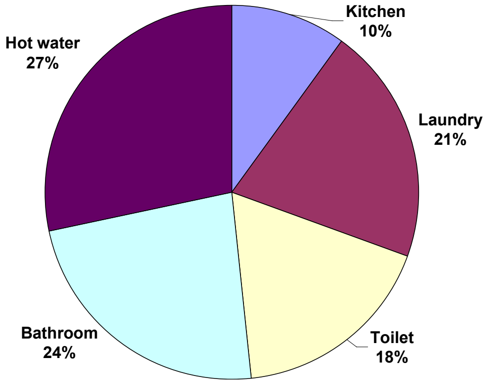

Figure 2: Distribution of household water use categories

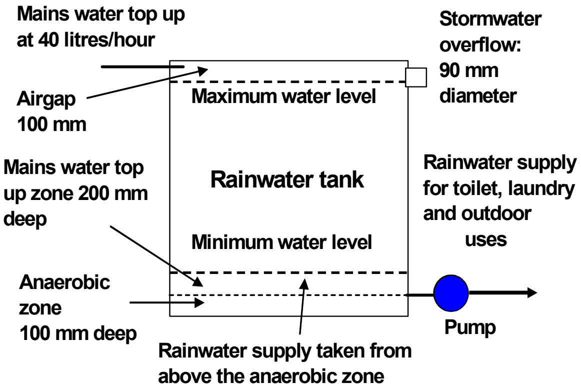

Figure 3: Configuration of rainwater tanks

A full description of the PURRS model can be sourced from Coombes (2006). An important advance in the simulation of roof runoff process as shown in Figure 1 has been included in the PURRS model.

Roof runoff processes used in the model do not include arbitrary initial and continuing losses because these processes may be adequate for stormwater runoff from rural or urban catchments but are not relevant to rainwater harvesting from roofs. Roof systems are relatively impervious and are not subject to significant evapotransporation or infiltration losses. More accurately, these systems are subject to losses that are based on leakage from roof gutter systems and overflows from roof gutter systems when the capacity of gutters and downpipes is exceeded. The arbitrary use of inappropriate initial and continuing losses in analysis of domestic rainwater harvesting creates considerable errors.

Monitoring studies by Coombes (2002) has revealed that initial gutter losses range from 0 to 0.8 mm of roof runoff with the average initial gutter losses being about 0.5 mm. This study has employed an initial gutter loss of 0.5 mm.

## 2.1 Climate

Pluviograph (6 minute) rainfall and daily temperature records were sourced from the Australian Bureau of Meteorology for use in PURRS and water demand models (Table 1).

Table 1: Australian Bureau of Meteorology stations and pluviograph rainfall records

| Location | Station number | Start Date | End Date | Average Rainfall (mm/yr) | Years in record |
|---|---|---|---|---|---|
| Adelaide Regional Office | 23000 | 1/1/1905 | 31/12/1978 | 524 | 74 |
| Brisbane Regional Office | 40214 | 1/2/1911 | 31/12/1993 | 1,093 | 83 |
| Melbourne Regional Office | 86071 | 1/1/1925 | 31/12/2000 | 646 | 76 |
| Sydney Observatory Hill | 66062 | 1/1/1913 | 31/12/1998 | 1,203 | 86 |

## 2.2 Water demand

Household water demand was derived using data from the Australian Bureau of Statistics, State of the Environment Reports and Water Services Association Australia (WSAA). Average annual water demands for households at each location are shown in Table 2.

Table 2: Average water demands derived for households at each location

| Location | Indoor water demand (L/day) versus household size (people) | | | | | | Outdoor demand (L/day) |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | |
| Adelaide | 112 | 230 | 347 | 465 | 583 | 700 | 300 |
| Brisbane | 116 | 215 | 343 | 495 | 610 | 726 | 258 |
| Melbourne | 150 | 288 | 425 | 563 | 700 | 839 | 136 |
| Sydney | 233 | 452 | 670 | 888 | 1,107 | 1,326 | 160 |

The data in Table 2 was used as inputs to the probabilistic behavioural water demand algorithms embedded in the PURRS model. It is important to note that the water demand algorithms in the PURRS model allow for climate generated daily and diurnal variation of water demands that use information from Table 2 as conditioning variables. The PURRS demand algorithms allow for daily and diurnal variation of water use whilst maintaining the expected long term monthly volumes of water use.

## 2.3 Determination of available storage in rainwater tanks

Coombes (2002) proposed a method that utilises continuous simulation and virtual storage volumes to determine a probable initial airspace storage (PIAS), available in a rainwater tank prior to a storm event of a given average recurrence interval (ARI). The virtual storage volume required to mitigate stormwater runoff for a storm event of a given ARI is determined for an allotment with and without a rainwater tank. The difference between the virtual storages with and without the rainwater tank is the likely storage volume available in a rainwater tank prior to a given storm event. The concept is shown in Figures 4 and 5 respectively.

The difference between the virtual storage volumes of the storm event with the same ARI will be the retention storage volume available in the rainwater tank prior to the storm event with a given ARI. The ARI at which a virtual storage spills $ARI_{VS}$ can be estimated by:

$$ARI_{VS} = \frac{Years}{Spills} \tag{1}$$

where Years is the length of the simulation period and Spills is the number of times the retention storage is overwhelmed during the simulation period.

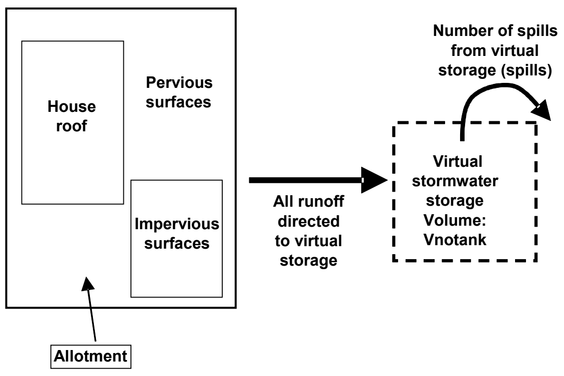

Figure 4: Schematic of initial condition calculation for the allotment without a rainwater tank

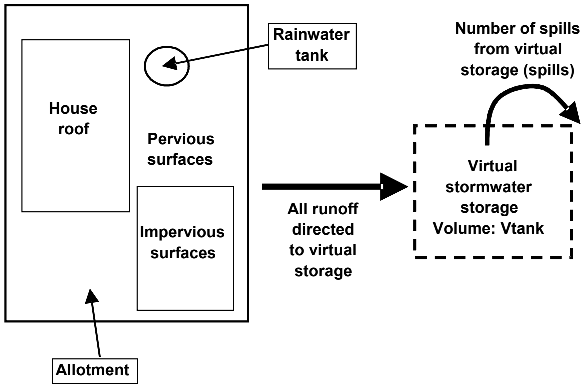

Figure 5: Schematic of initial condition calculation for an allotment with a rainwater tank

The volume of the virtual storage in a rainwater tank prior to a storm event is a function of the retention storage required on the allotment with no rainwater tank $V_{NOTANK}$ and the retention storage required on the allotment with a rainwater tank $V_{TANK}$ for a given $ARI_{vs}$ equal to n years.

$$PIAS_n = \left(V_{NOTANK} - V_{TANK}\right)_n \tag{2}$$

The storage volumes available in a rainwater tank prior to storm events with various ARIs were determined using the PURRS model (Coombes, 2006) and the procedure described above.

## 3. RESULTS

The performance of 1, 2, 3, 4, 5 and 10 kL rainwater tanks connected to 50, 100, 150 and 200 m$^2$ roof areas used to supply household laundry, toilet and outdoor water uses in 1, 2, 3, 4, 5 and 6 person households was continuously simulated for Adelaide, Brisbane, Melbourne and Sydney. Available storage volumes in rainwater tanks connected to different roof areas supplying water demands in 2 person households are presented for each location. The variation in available storage volumes with household size for 3 kL rainwater tanks is also presented.

### 3.1 Adelaide

The variation in available storage volumes in rainwater tanks connected to 50 m$^2$, 100 m$^2$, 150 m$^2$ and 200 m$^2$ roof areas at Adelaide are shown in Figures 6, 7, 8 and 9 respectively.

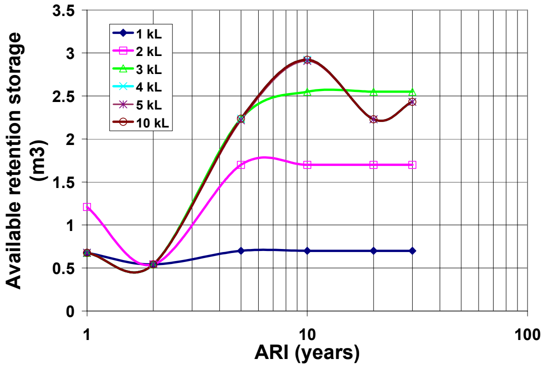

Figure 6: Available retention storage in rainwater tanks connected to a 50 m$^2$ roof area

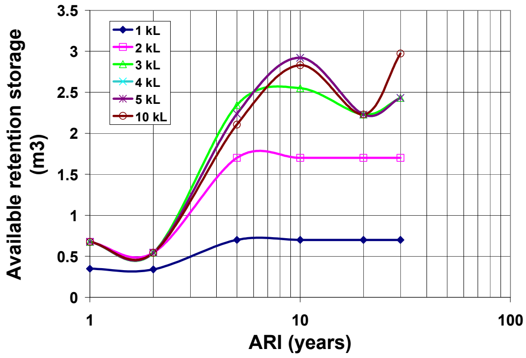

Figure 7: Available retention storage in rainwater tanks connected to a 100 m$^2$ roof area

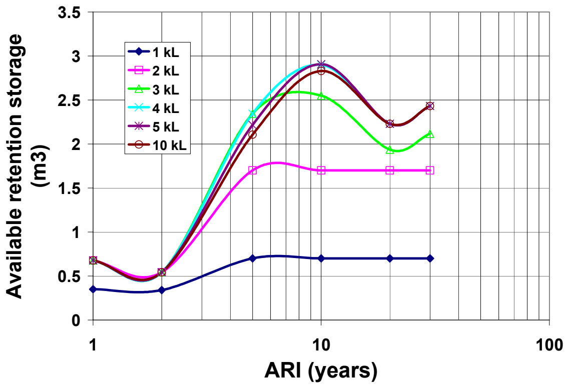

Figure 8: Available retention storage in rainwater tanks connected to a 150 m$^2$ roof area

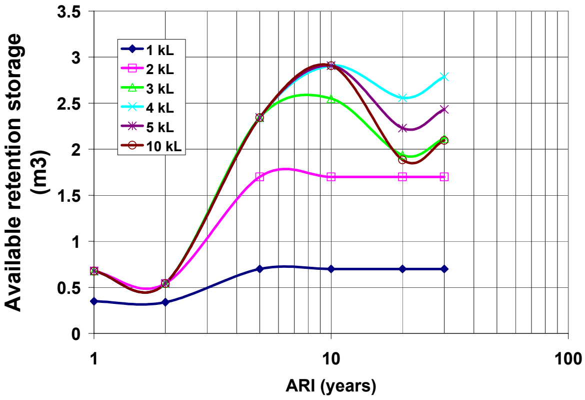

Figure 9: Available retention storage in rainwater tanks connected to a 200 m$^2$ roof area

Figures 6, 7, 8 and 9 show that available storage volumes in rainwater tanks in Adelaide ranges from 0.3 m$^3$ to 3 m$^3$. Available storage volumes were observed to increase with ARI and to decrease with increases in roof area connected to rainwater tanks. The increase in available storage volumes prior to less frequent rain events may be due to these larger storm events occurring during drier periods when water levels in tanks where more likely to be drawn down. The lower summer rainfall in Adelaide corresponds with the potential for higher outdoor water demands during summer (Coombes & Barry, 2006).

The available storage volumes are limited by tank capacity for smaller tanks and by the magnitude of water demands drawn from larger tanks. Figure 9 shows that the draw down of the rainwater tanks in response to water demands appears to be balanced by the carryover storage of rainwater in the larger tanks. The variation in available storage volumes with household size for 3 kL rainwater tanks is shown in Figures 10, 11, 12 and 13.

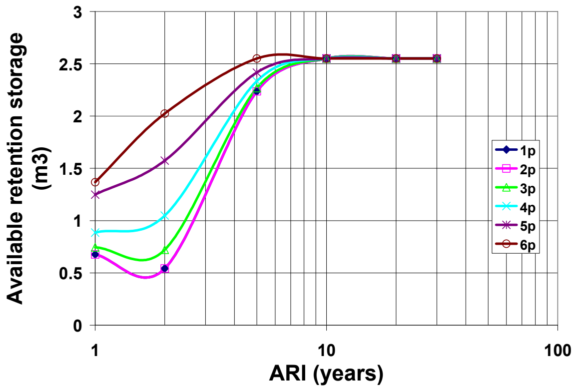

Figure 10: Available retention storage in 3 kL rainwater tanks connected to 50 m$^2$ roof areas

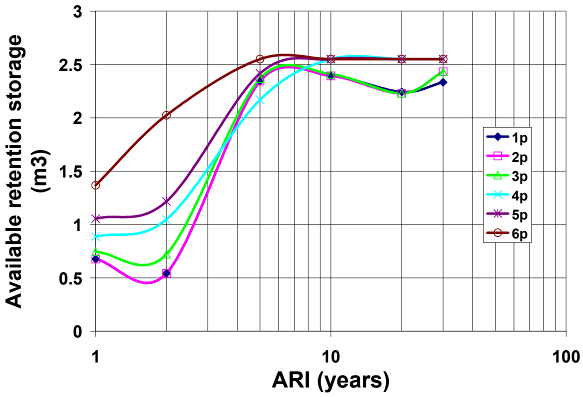

Figure 11: Available retention storage in 3 kL rainwater tanks connected to 100 m$^2$ roof areas

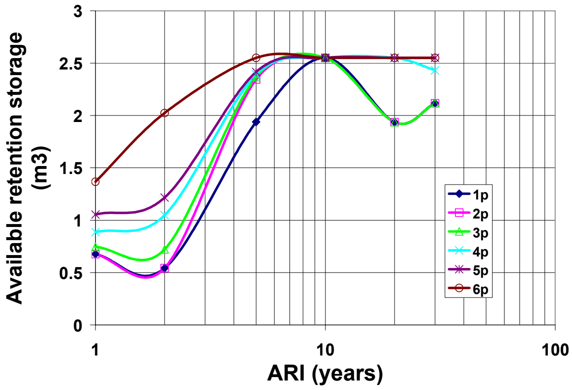

Figure 12: Available retention storage in 3 kL rainwater tanks connected to 150 m$^2$ roof areas

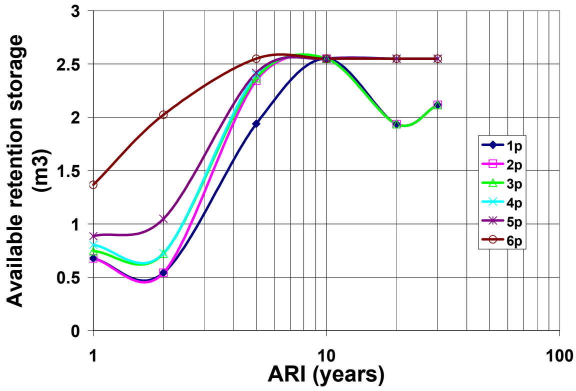

Figure 13: Available retention storage in 3 kL rainwater tanks connected to 200 m$^2$ roof areas

It is revealed in Figures 10, 11, 12 and 13 that available storage volumes in rainwater tanks increase for larger household sizes due to higher water demands. The available storage volumes were observed to decrease for larger roof areas connected to the rainwater tanks caused by increased volumes of roof runoff directed to the tanks. Figure 13 highlights that the lesser water demands drawn from the rainwater tank from the 1, 2 and 3 person households is overwhelmed by the increased runoff from the larger roof area thereby reducing available storage. In contrast, the higher water demands from the 4, 5 and 6 person households were able to balance the increased runoff volumes maintaining storage volumes.

## 3.2 Brisbane

The variation in available storage volumes in rainwater tanks connected to 50 m$^2$, 100 m$^2$, 150 m$^2$ and 200 m$^2$ roof areas at Brisbane are shown in Figures 14, 15, 16 and 17 respectively.

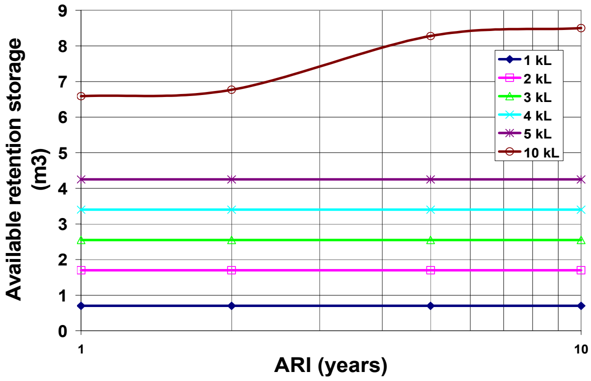

Figure 14: Available retention storage in rainwater tanks connected to a 50 m$^2$ roof area

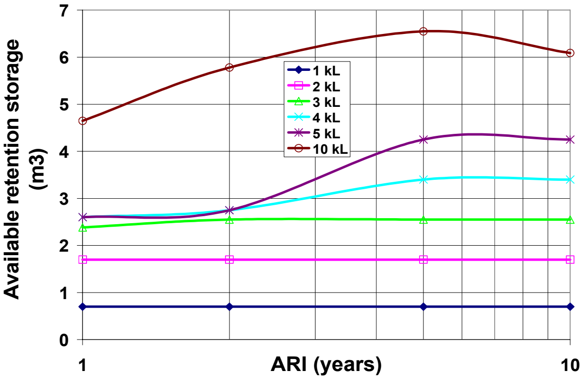

Figure 15: Available retention storage in rainwater tanks connected to a 100 m$^2$ roof area

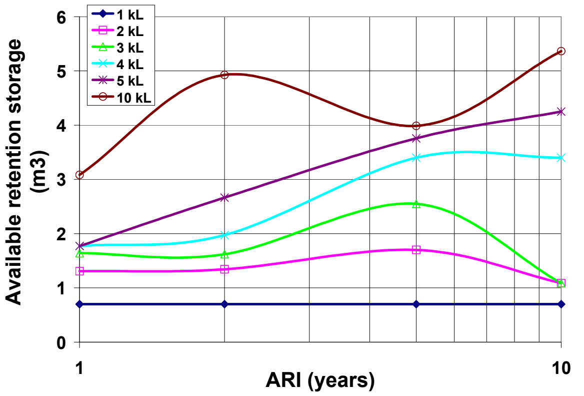

Figure 16: Available retention storage in rainwater tanks connected to a 150 m$^2$ roof area

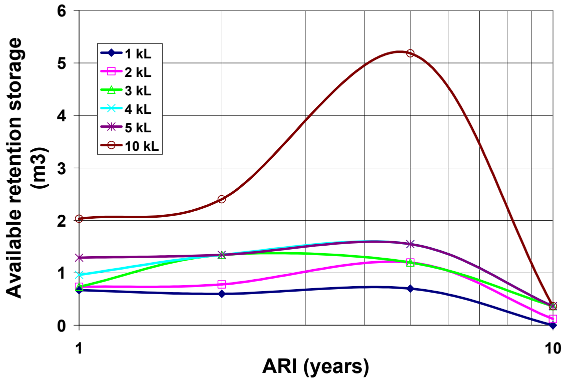

Figure 17: Available retention storage in rainwater tanks connected to a 200 m$^2$ roof area

It is shown in Figures 14, 15, 16 and 17 that the available storage volumes in rainwater tanks in Brisbane ranged from 0 m$^3$ to 8.5 m$^3$. The available storage volumes in rainwater tanks decline with increases in roof areas connected to tanks. Figure 14 shows that the available storage volumes in rainwater tanks connected to 50 m$^2$ roof areas was limited by tank capacity for rainwater tanks with capacities from 1 to 5 kL. Additionally, the available storage volumes in 10 kL rainwater tanks was limited by water demand.

Available storage volumes in rainwater tanks connected to 50 m$^2$, 100 m$^2$ and 150 m$^2$ roof areas were either limited by tank capacity or increased with ARI for larger tanks. In contrast, the available storage volumes in all rainwater tanks connected to 200 m$^2$ roofs were limited by water demands with available storage volumes that diminished with ARI. This same effect was observed for 2 and 3 kL rainwater tanks connected to 150 m$^2$ roofs. This process may be more pronounced for the Brisbane location that experiences seasonal rainfall with greater monthly rainfall depths during the November to April period that is consistent with higher outdoor water demands. The variation in available storage volumes with household size for 3 kL rainwater tanks is shown in Figures 18, 19, 20 and 21.

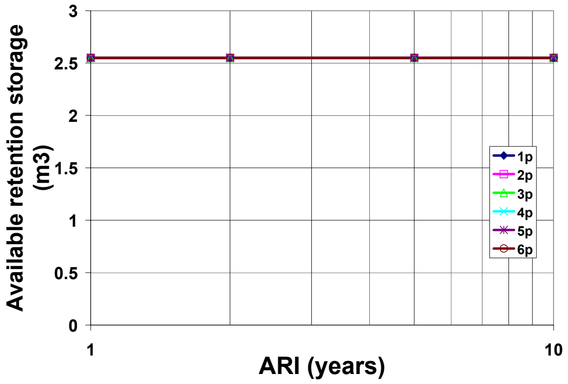

Figure 18: Available retention storage in 3 kL rainwater tanks connected to 50 m$^2$ roof areas

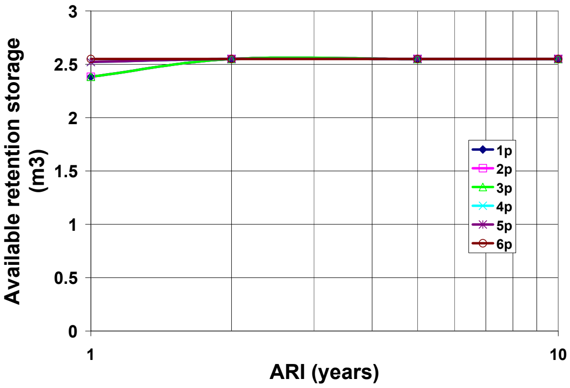

Figure 19: Available retention storage in 3 kL rainwater tanks connected to 100 m$^2$ roof areas

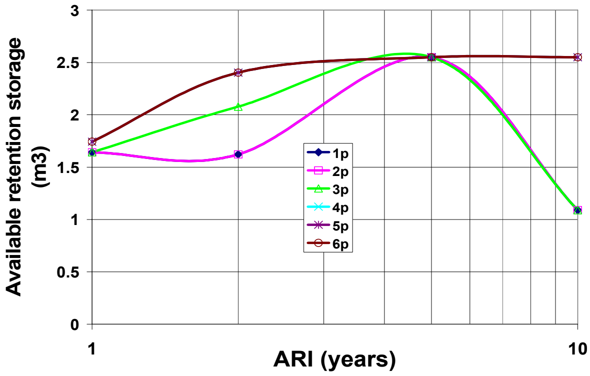

Figure 20: Available retention storage in 3 kL rainwater tanks connected to 150 m$^2$ roof areas

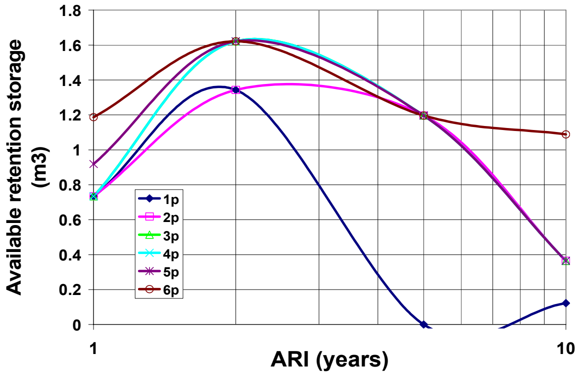

Figure 21: Available retention storage in 3 kL rainwater tanks connected to 200 m$^2$ roof areas

Figures 18 and 19 show that available storage volumes in 3 kL rainwater tanks connected to 50 m$^2$ and 100 m$^2$ roofs in Brisbane were limited by tank capacity. This effect was similar for all household sizes and for rain events with ARIs from 1 to 10 years. Figure 20 shows that available storage volumes increase with household size for 150 m$^2$ roofs connected to 3 kL tanks. The available storage volumes in rainwater tanks was observed to decline due to greater roof runoff volumes for 1, 2 and 3 person households with tanks connected to 150 m$^2$ roofs and for all household sizes with tanks connected to 200 m$^2$ roofs

## 3.3 Melbourne

The variation in available storage volumes of rainwater tanks connected to 50 m$^2$, 100 m$^2$, 150 m$^2$ and 200 m$^2$ roof areas at Melbourne are shown in Figures 22, 23, 24 and 25 respectively.

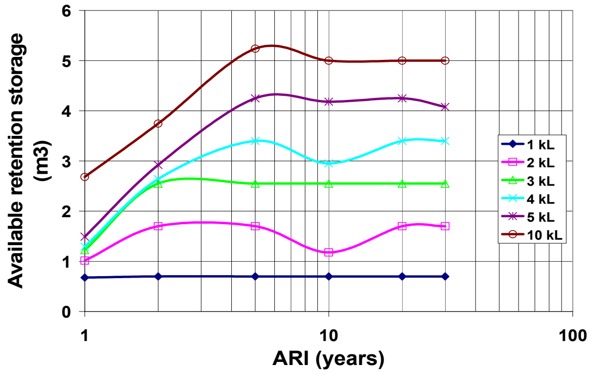

Figure 22: Available retention storage in rainwater tanks connected to a 50 m$^2$ roof area

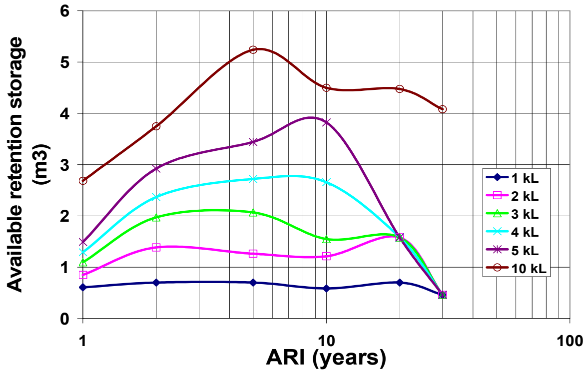

Figure 23: Available retention storage in rainwater tanks connected to a 100 m$^2$ roof area

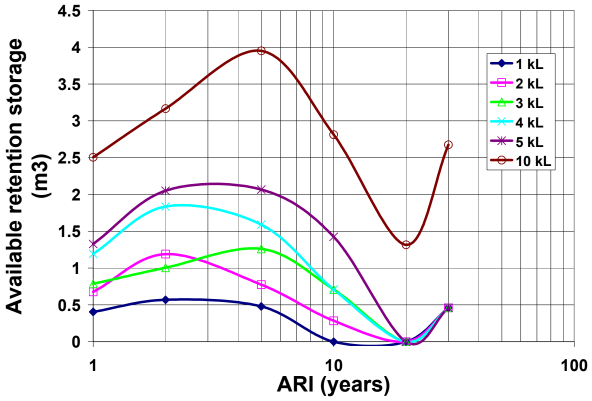

Figure 24: Available retention storage in rainwater tanks connected to a 150 $m^2$ roof area

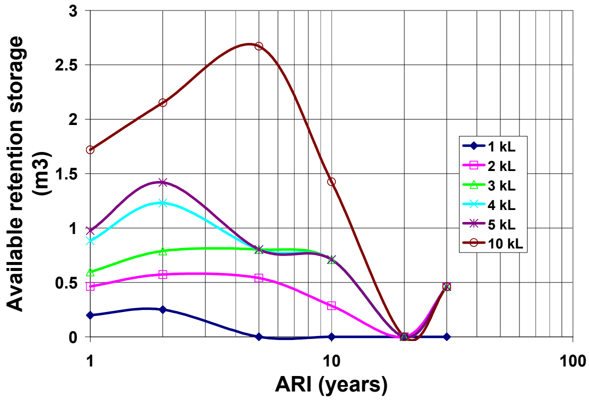

Figure 25: Available retention storage in rainwater tanks connected to a 200 $m^2$ roof area

The available storage volumes in rainwater tanks in Melbourne ranged from 0 $m^3$ to 5.2 $m^3$ (Figures 22, 23, 24 and 25). Figure 22 shows that available storage in rainwater tanks connected to 50 $m^2$ roofs in Melbourne increases with tank capacity and with ARI of rain events. Available storage in tanks is dependent on tank capacity for smaller tanks (1 kL to 3 kL) and on water demands for large tanks.

Figures 22, 23, 24 and 25 show that available storage in rainwater tanks declines with increases in roof area connected to tanks. The available storage volumes in tanks were seen to decline for rain events with greater ARIs after reaching a maximum storage for rain events of a particular ARI. The ARI of rain events at which this maxima occurs declines with increases in roof area and for smaller tank sizes. The variation in available storage volumes with household size for 3 kL rainwater tanks is shown in Figures 26, 27, 28 and 29.

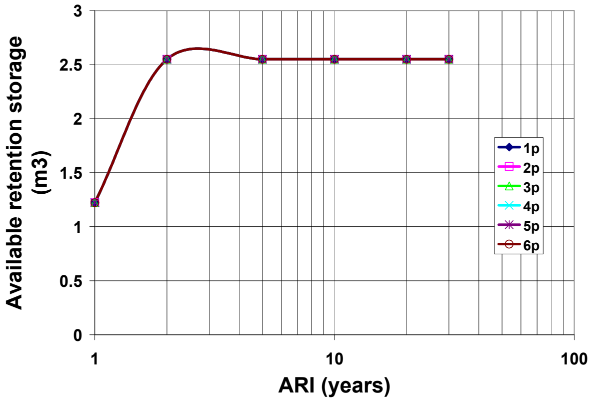

Figure 26: Available retention storage in 3 kL rainwater tanks connected to 50 $m^2$ roof areas

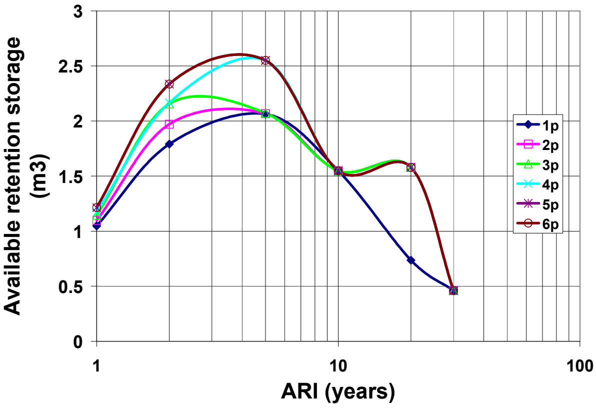

Figure 27: Available retention storage in 3 kL rainwater tanks connected to 100 $m^2$ roof areas

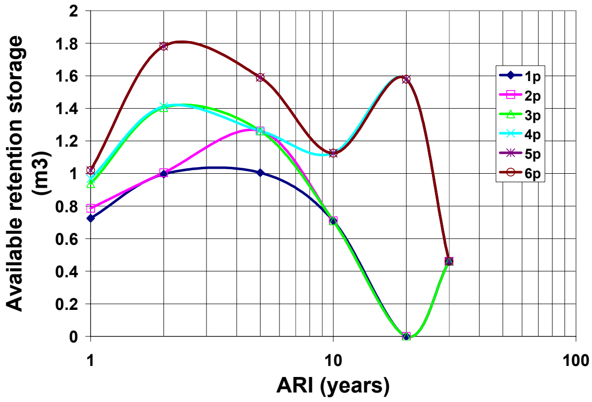

Figure 28: Available retention storage in 3 kL rainwater tanks connected to 150 $m^2$ roof areas

Figure 29: Available retention storage in 3 kL rainwater tanks connected to 200 $m^2$ roof areas

The available storage in rainwater tanks connected to 50 $m^2$ and 200 $m^2$ roof areas in Melbourne were independent of household size (Figures 26 and 29). In the case with tanks connected to 50 $m^2$ roof areas the available storage was limited by the frequency of rain events less than 2 year ARI and by tank capacity. In contrast, available storage in rainwater tanks connected to 200 $m^2$ roof areas was limited by inflows to tanks from the larger roof area that overwhelms water demands. The fairly even distribution of rainfall throughout the year in Melbourne appears to be a driver for this result. Figures 27 and 28 show that available storage in tanks was dependent on household size for tanks connected to roof areas of 100 $m^2$ and 150 $m^2$.

## 3.4 Sydney

The variation in available storage volumes in rainwater tanks connected to 50 $m^2$, 100 $m^2$, 150 $m^2$ and 200 $m^2$ roof areas at Sydney are shown in Figures 30, 31, 32 and 33 respectively.

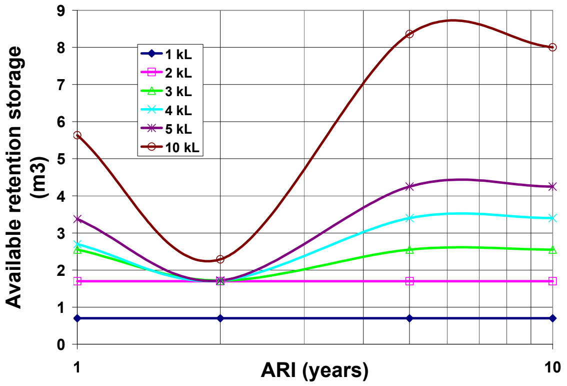

Figure 30: Available retention storage in rainwater tanks connected to a 50 $m^2$ roof area

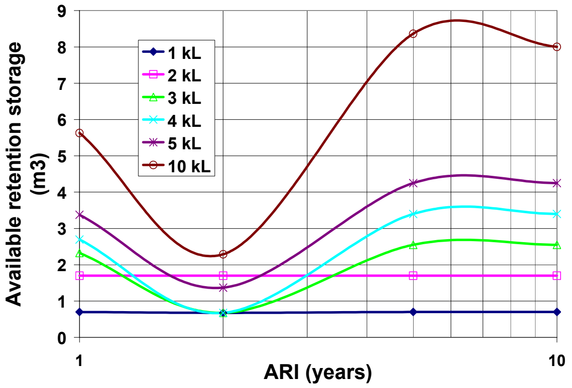

Figure 31: Available retention storage in rainwater tanks connected to a 100 $m^2$ roof area

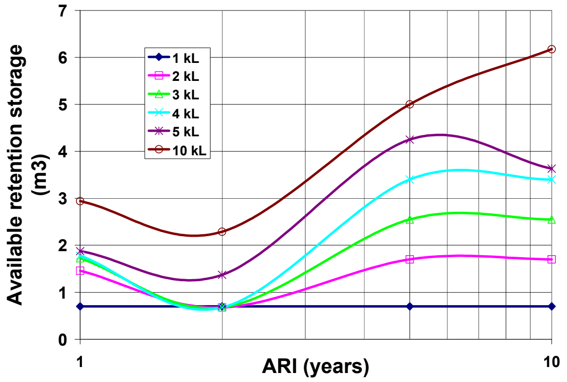

Figure 32: Available retention storage in rainwater tanks connected to a 150 $m^2$ roof area

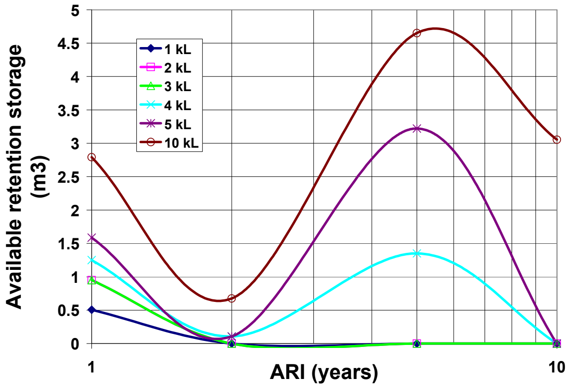

Figure 33: Available retention storage in rainwater tanks connected to a 200 $m^2$ roof area

The available storage volumes in rainwater tanks in Sydney ranged from 0 $m^3$ to 8.25 $m^3$ (Figures 30, 31, 32 and 33). Available storages in tanks were seen to decline with increases in roof areas connected to rainwater tanks. A characteristic of the results for Sydney is that available storages in tanks are at a minimum for rain events with a 2 year ARI for a given roof area less than 200 $m^2$. Higher rainfall depths and more intense rainfall patterns in Sydney may be a driver for this result.

Available storages in smaller rainwater tanks (1 kL and 2 kL) connected to roof areas less than 200 $m^2$ were observed to be limited by tank capacity whilst available storages in larger tanks was limited by water demands. Figure 33 highlights that available storages in rainwater tanks were also dependent on tank size with smaller tanks connected to 200 $m^2$ roofs unable to provide retention storage for rain events with ARIs greater than 2 years. The variation in available storage volumes with household size for 3 kL rainwater tanks is shown in Figures 34, 35, 36 and 37.

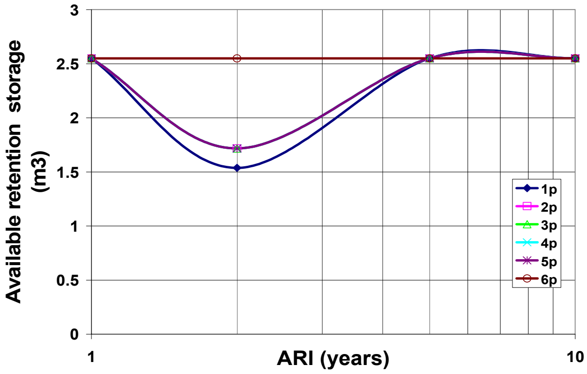

Figure 34: Available retention storage in 3 kL rainwater tanks connected to 50 m$^2$ roof areas

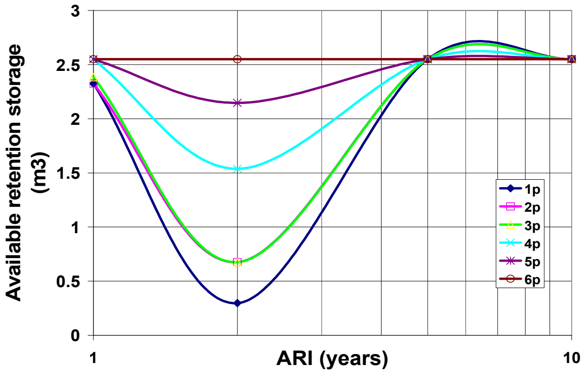

Figure 35: Available retention storage in 3 kL rainwater tanks connected to 100 m$^2$ roof areas

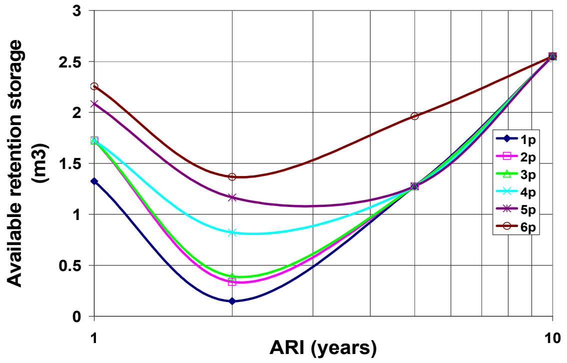

Figure 36: Available retention storage in 3 kL rainwater tanks connected to 150 m$^2$ roof areas

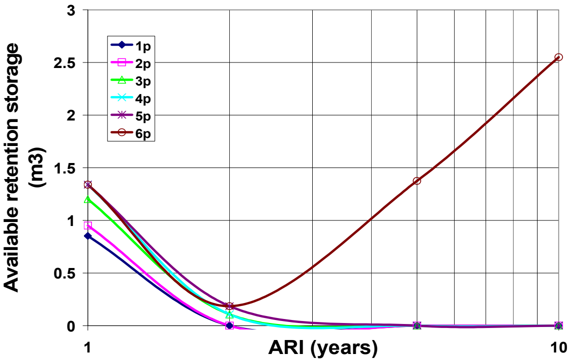

Figure 37: Available retention storage in 3 kL rainwater tanks connected to 200 m$^2$ roof areas

The available storages in rainwater tanks in Sydney are shown to be dependent on household size and, therefore, water demands in Figures 34, 35, 36 and 37. Minimum available storage volumes at rain events with 2 year ARI was observed. This effect was limited by tank capacity for larger household sizes and smaller connected roof areas. Figure 37 shows a decline in available storage volumes with increases in the ARI of rain events and an increase in available storage volumes for 6 person households beyond rain events with 2 year ARIs.

## 4. DISCUSSION

The results presented in this paper are a portion of a wider study to examine the impacts of rainwater tanks on water cycle management throughout Australia and are subject to further contextual analysis. This paper provides a preliminary snapshot of the likely storage volumes available in rainwater tanks prior to storm events of a given frequency and some insight to the influences on available storages at different locations.

### 4.1 Preliminary results

Available storage volumes in rainwater tanks in Adelaide, a city subject to a winter rainfall pattern with relatively low average annual rainfall depths, was dependent on tank size and water demand drawn from tanks. The available storage volumes were limited by the capacity of smaller tanks and by water demands for larger tanks. Available storage volumes increase with the ARI of rain events suggesting that these larger events occur during dryer periods when water levels in tanks are drawn down. A weak dependence between roof area and available storages was observed for Adelaide because water demand from tanks were seen to overwhelm the inflow of roof runoff into tanks. Household size was seen to have influence on available storage volumes for more frequent storm events and for larger roof areas.

Brisbane is subject to summer rainfall patterns with relatively high average annual rainfall depths. Available storage volumes in tanks at this location were dependent on tank capacity, ARI of storm events, roof area and household size. Available storage volumes in tanks was seen to diminish with increases in roof area due to roof runoff inflows to tanks overwhelming water demands drawn from tanks connected to larger roof areas. Household size was observed to influence available storage volumes for larger roof areas connected to tanks.

The available storage volumes in rainwater tanks in Melbourne, a city subject to an even distribution of rainfall throughout the year and relatively low average annual rainfall depth, were dependent on tank size, roof area connected to tanks, household size for 100 $m^2$ and 150 $m^2$ roof areas connected to tanks, and the ARI of storm events. Available storage volumes were seen to increase with ARI of storm events for smaller roof areas to a maximum for rain events with a 5 year ARI. The maxima of available storage volumes vary with ARI of rain events and declines thereafter for larger roof areas.

Sydney experiences a relative high average annual rainfall depth that is distributed fairly evenly throughout the year. Available storage volumes in rainwater tanks located in Sydney were observed to be dependent on tank size, household size, roof area and the ARI of rain events. Available storage volumes in tanks were observed to decline with increases in connected roof areas and increase with ARI of rain events after reaching a minimum at rain events with an ARI of 2 years. These storage volumes were seen to decline for rain events with 10 year ARI for 200 $m^2$ roof areas.

## 4.2 Comments on method

The authors have developed the virtual storage method over a long period (see Coombes, 2002; Hardy et al., 2004) and have an emerging understanding of the behaviour of the method. This study utilised a fixed search interval (5 $m^3$) and space (up to 100 $m^3$) due to time constraints. This may have introduced some uncertainty about the results at the tails of the analysis because it became apparent that the search interval and space needed to be different at each location.

## 4.3 Comparison to design storms

This study has used continuous simulation using real rainfall sequences to determine the available storage volumes in rainwater tanks prior to rain events. These results are required for use in models using design storms to evaluate the effectiveness of stormwater management strategies. However the relationship between real storms and design storms is uncertain (Kuczera & Coombes, 2001). Design storms do not have volumes or temporal patterns consistent with real storms. Kuczera & Coombes (2002) revealed the marked differences in shape (hydrographs with one, two and three peaks), duration and volumes (39 mm to 217 mm) between real storms and design storms in Sydney. In any event, Coombes (2002) showed that the virtual storage method under-estimated the available storage volumes in the Newcastle region and suggested that the method may be conservative. Additional research is being undertaken to link the method to design storms at each location.

# 5. CONCLUSIONS

The use of design storms is current Australian practice for design of stormwater management strategies. Thus evaluation of the impact of rainwater tanks on the performance of stormwater management systems is reliant on understanding of the storage volumes available in tanks prior to storm events of a given ARI. This study has used continuous simulation, historical rainfall sequences and a unique method utilising virtual storages to determine storage volumes available in rainwater tanks prior to rain events of a given ARI.

Available storages in rainwater tanks prior to rain events were found to vary with climate at each location. The seasonality of rainfall patterns at each location which is a strong component of the balance between the timing of water demands and rainfall throughout a year has a strong influence on the magnitude of available storage volumes. This was highlighted by the larger available storages in tanks located in Brisbane that resulted from a summer rainfall pattern that consistent with expected higher water demands during the same period. In contrast, the lower available storage volumes in Adelaide were due to higher water demands occurring in summer which was inconsistent with the winter rainfall pattern at that location. Whilst the larger available storage volumes in tank located in Sydney resulted from the higher indoor water demands that balanced the more even seasonal distribution of rainfall at that location.

Available storage volumes in rainwater tanks prior to rain events at each location was observed to increase with tank capacity, household size and the ARI of rain events, and to decrease with increases in connected roof areas at each location. The variation in these parameters was seen to be conditioned on local climate and water demand patterns. Clearly the optimum use of rainwater tanks as part of a stormwater management strategy will be dependent on careful consideration of the key variables; local climate and water use patterns, the selected end use of rainwater, tank size and roof area.

Whilst this paper has provided important insight into the design of rainwater tanks for stormwater management, the results are limited by the presentation of a single rainwater use strategy and the relationship between these results using real rainfall sequences and design storms has only been implied. It is also suggested that the search interval and space used in the virtual storage method will need to be further explored to increase the robustness of the results. Additional work in this ongoing research programme has targeted a wide range of end uses for rainwater, analysis of the links between design storms and real rainfall at each location, and perfecting the virtual storage method .

## 6. ACKNOWLEDGEMENT

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