The Institution of Engineers, Australia
28th International Hydrology and Water Resources Symposium
10 – 14 November 2003
Wollongong NSW

Analysis of the Performance of Rainwater Tanks in Australian Capital Cities

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Abstract:
The performance of 1kL to 10 kL rainwater tanks with mains water tickle topup used to supplement mains water supply for domestic toilet, laundry, hot water and outdoor uses was evaluated for Brisbane, Sydney, Melbourne and Adelaide. The PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator) model developed by Coombes and Kuczera (2001) was employed to continuously simulate the performance of rainwater tanks using synthetic pluviograph rainfall generated by the DRIP (Disaggregated Rectangular Intensity Pulse) event based rainfall model by Heneker et al. (2001). Depending on roof area and number of occupants in a household, the use of rainwater tanks resulted in annual mains water savings ranging from 18 kL to 55 kL for 1 kL rainwater tanks to 25 kL to 144 kL for 10 kL rainwaters tanks. The average retention volumes available in rainwater tanks prior to storm events ranged from 0.26 m^3 to 0.71 m^3 for 1 kL tanks to 2.34 m^3 to 8.4 m^3 for 10 kL tanks.

Keywords: rainwater tanks, mains water savings, stormwater runoff, climate, continuous simulation

1. INTRODUCTION

The use of roof runoff collected in rainwater tanks with mains water trickle topup to supplement mains water supplies for domestic consumption was shown by Coombes et al. [2002; 2002a] and Mitchell et al. [1997] to significantly reduce household mains water use. Indeed Coombes et al. [2002] found that the widespread introduction of 10 kL rainwater tanks for domestic hot water, toilet and outdoor uses will defer the requirement to augment the Lower Hunter and Central Coast water supply headworks systems by 28 to100 years.

Importantly Coombes et al. [2000; 2000a; 2002a] and Spinks et al. [2003; 2003a] found that the quality of water supply from rainwater tanks was acceptable for hot water, toilet, and outdoor uses. Spinks et al. [2003] confirmed that *E. Coli* and selected pathogens are rapidly eliminated from water heated to temperatures above 55°C by the processes of heat shock and pasteurisation. Note that ASNZ2500.2.4 requires that hot water systems be set to heat water to 60°C to eliminate *Legionella Spp.* from mains water.

Coombes et al. [2003] concluded that installation of 5 kL rainwater tanks for domestic hot water, toilet, laundry and outdoor uses will defer the requirement to augment the Sydney water supply headworks system by 21 – 84 years. Analysis of the impact of installing 10 kL rainwater tanks in the Upper Parramatta River catchment in Sydney revealed that the tanks will have on average 42% of their storage available for retention of stormwater prior to the 100 year average recurrence interval (ARI) storm events.

These studies into the effectiveness of rainwater tanks for water supply and stormwater management have focused on a narrow range of tank sizes (5 kL and 10 KL) operating in a temperate climate zone with seasonally uniform rainfall. This study evaluates the water supply and stormwater management impacts of rainwater tanks with capacities ranging from 1 kL to 10 kL in Adelaide, Brisbane, Melbourne and Sydney. The city of Adelaide has a temperate climate with winter rainfall, Melbourne and Sydney have temperate climates with uniform rainfall and Brisbane has a sub-tropical climate with summer rainfall [Heneker, 2002]. Brisbane and Sydney also experience greater annual rainfall depths in comparison to Adelaide and Melbourne.

2. Why Rainwater Tanks Can Defer the Requirement for New Dams

Before embarking on an assessment of the performance of domestic rainwater tanks, it is important to provide a process-based explanation of why rainwater tanks can defer major infrastructure for the provision of urban water cycle services.

Until recent times it was commonly assumed that rainwater tanks are of little benefit to the community because during drought the rainwater tank is empty and the consumer is totally reliant on mains water. This wisdom appears to be based more on belief than fact. There are a number of “hidden” processes by which rainwater tanks significantly reduce impact on water supply headworks systems. These are described below.

It is true that during drought major urban water supply systems rely on water storages. For example on the east coast of Australia droughts represent extended periods of below average rainfall. In the last 150 or so years the annual rainfall at Sydney's Observatory Hill has dipped a few times to between 600 to 700 mm. Figure 1 presents a schematic comparing the efficiency of a water supply catchment and a roofed catchment feeding a rainwater tank.

Plots of annual runoff against annual rainfall for water supply catchments typically display a threshold effect. Once annual rainfall falls below about 500 mm annual runoff in water supply catchments is insignificant. In such years evapotranspiration and infiltration accounts for virtually all of the rainfall and the water supply system is almost totally dependent on water stored from more bountiful years. In contrast the roofed catchment, being impervious, only experiences a small loss at the commencement of each rain event. In addition urban areas such as Sydney and the Central Coast in NSW typically receive more rainfall than water supply catchments. As a result, a rainwater tank can harvest significant volumes of water even during drought years.

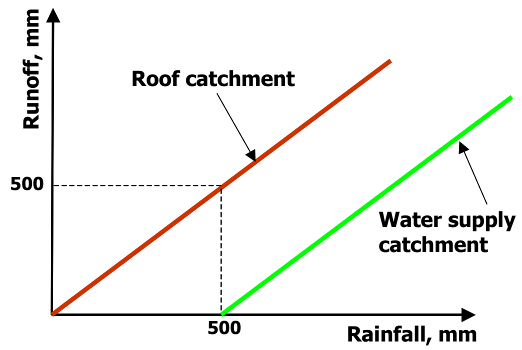

Figure 1. Harvest efficiencies of natural and roofed catchments.

Conventional wisdom assumes that rainwater tanks in urban areas only provide water for outdoor uses such as garden watering. As a result, the tank is only utilised during the growing season. If, however, the tank is used for toilet flushing, laundry and hot water, which represent a significant fraction (about 85%) of indoor usage, the tank is constantly being drawn down. This has two unexpected benefits. First, for small storm events much of the potential runoff is captured by the tank – that is why use of the rainwater tanks produces considerable reduction in stormwater runoff for small ARI storm events. Second, because toilet flushing, laundry water and hot water are sourced from the rainwater tank, the base load on the mains water system is reduced. As a result, reservoirs will fill more rapidly during periods of good streamflow. In headworks systems with over-year storage capacity, the reduction in base demand provides a buffer against the effects of droughts and growth in water demand due to population growth.

2. METHOD

The PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator) model [Coombes and Kuczera, 2001] was used in combination with the DRIP event based synthetic rainfall model [Heneker et al,. 2001] to evaluate the effectiveness of rainwater tanks in each city.

The PURRS model was used to analyse the performance of 1 kL to 10 kL rainwater tanks used to supply domestic hot water, toilet, laundry and outdoor uses. Continuous simulation of the performance of rainwater tanks was conducted at time steps of 5 minutes over a period of 100 years using synthetic pluviograph rainfall records generated by DRIP. Hot water, laundry and toilet use was estimated to be 85% of indoor water demand. When a water level in a rainwater tank falls below a minimum depth of 200 mm the tank is topped up with mains water to a minimum level at a rate of 30 litres per hour (Figure 2).

The performance of rainwater tanks connected to dwellings with roof areas of 100 m^2, 150 m^2 and 200 m^2 with 1 to 5 occupants was analysed in this study. The average annual reduction in mains water use and the average retention storage volume available prior to storm events is used to assess the performance of the rainwater tanks.

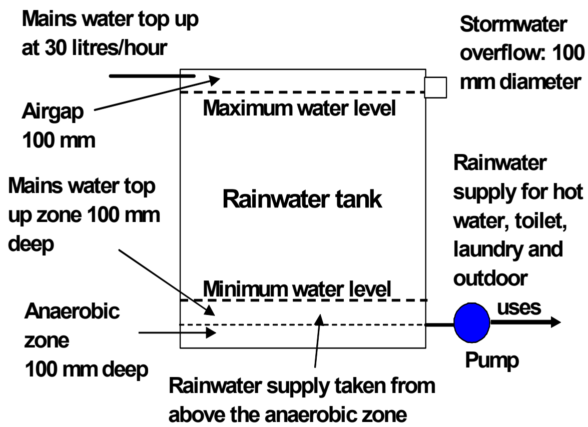

Figure 2: Elevation view of the rainwater tank

3. ADELAIDE

The performance of rainwater tanks in Adelaide was analysed using synthetic rainfall generated by DRIP based on the West Terrace pluviograph record [see Heneker, 2002 for details]. Adelaide has an annual rainfall depth of about 520 mm. Domestic water use for Adelaide shown in Table 1 was estimated using the results from Environment Australia [2001] and methods developed by Coombes et al. [2000].

3.1 Adelaide Water Savings

Mains water savings that resulted from the use of 1 kL to 10 kL rainwater tanks used to supply domestic hot water, toilet, laundry and outdoor uses are shown in Figures 3, 4 and 5. Figure 3 shows that rainwater tanks connected to roofs with an area of 100 m^2 produced average annual mains water savings of 17 kL (6%) to 25 kL (16%). Rainwater tanks connected to roofs with areas of 150 m^2 and 200 m^2 provide average annual mains water savings of 25 kL (9%) to 45 kL (29%) and 31 kL (11%) to 67 kL (39%) respectively (Figures 4 and 5).

Table 1. Estimated average daily household water use in the city of Adelaide

	Average water use (Litres per day)					
	Outdoor	Inhouse (number of occupants)				
Month		1	2	3	4	5+
January	470	193	339	484	630	776
February	459	187	333	478	624	770
March	458	194	339	485	631	776
April	378	180	326	471	617	763
May	168	184	330	475	621	767
June	171	171	317	463	608	754
July	188	170	316	461	607	753
August	266	175	321	466	612	758
September	396	179	324	470	616	761
October	634	181	327	473	618	764
November	638	185	331	476	622	768
December	569	183	329	475	620	766

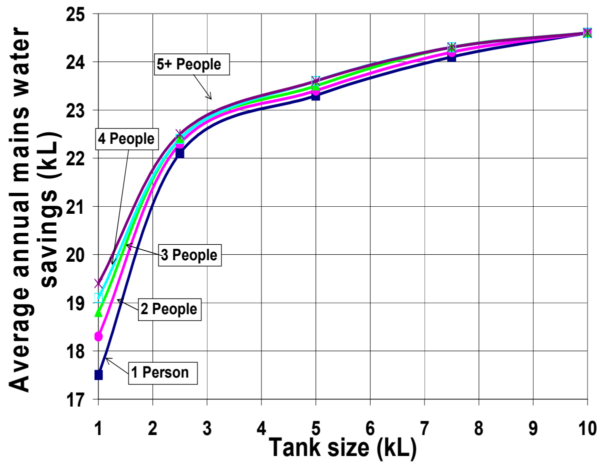

Figure 3: Mains water savings at dwellings with 100 m^2 roof areas in Adelaide

Mains water savings provided by the rainwater tanks are shown to increase with larger roof areas. Significantly, small rainwater tanks with volumes of 1 kL to 5 kL produce the majority of mains water savings. Indeed increases in water savings diminish with larger tank sizes especially for the smaller roof area of 100 m^2 and dwellings with 4 and 5 occupants.

The results show greater mains water savings with increases in numbers of occupants. Higher water demand from greater numbers of occupants in dwellings draws down water levels in the rainwater tanks more often allowing greater capture of rainwater. The impact of this phenomenon on mains water savings is limited by the availability of rainfall and the different temporal patterns of water demand and rainfall. Dwellings with 5 occupants do not show significantly greater mains water savings than dwellings with 3 and 4 occupants showing that supply from the rainwater tank is also limited by rainfall depth, tank volume and roof areas.

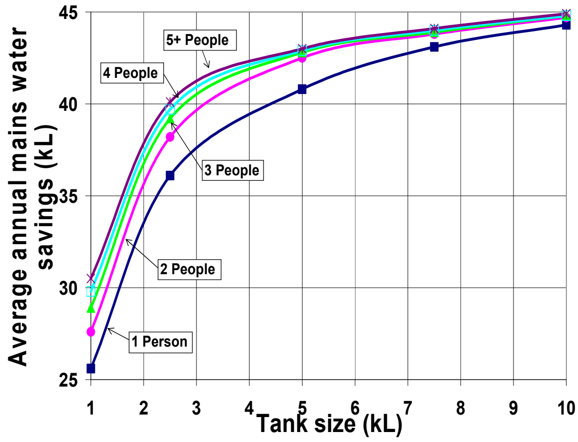

Figure 4: Mains water savings at dwellings with 150 m^2 roof areas in Adelaide

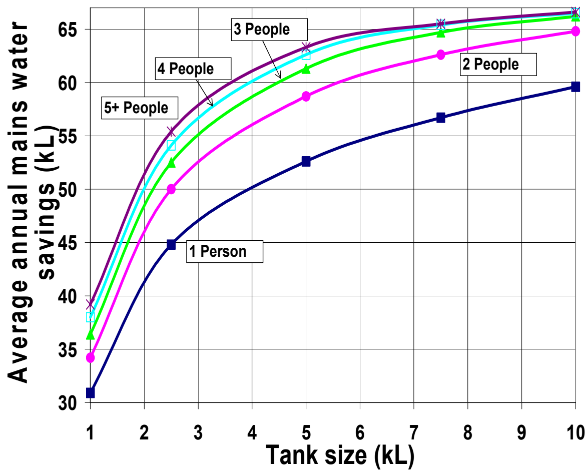

Figure 5: Mains water savings at dwellings with 200 m^2 roof areas in Adelaide

Figure 6 shows the average proportion of rainwater tank volume available for retention of roof water prior to storm events in Adelaide. It is noted that in this study a storm event is defined by a dry spell of 2 or more hours.

Water levels in the rainwater tanks used to supply indoor uses are constantly drawn down as shown in Figure 6. Scenarios with the smallest roof areas of 100 m^2 have the largest retention storage available prior to storms ranging from 64% (0.64 m^3) – 71% (0.71 m^3) for

1 kL rainwater tanks to (82%) 8.18 m^3 – 84% (8.4 m^3) for 10 kL rainwater tanks whilst tanks connected to the dwelling with the 200 m^2 roof and one occupant provided the smallest retention storages of 36% (0.36 m^3) to 46% (4.64 m^3) for the 1 and 10 kL rainwater tanks respectively.

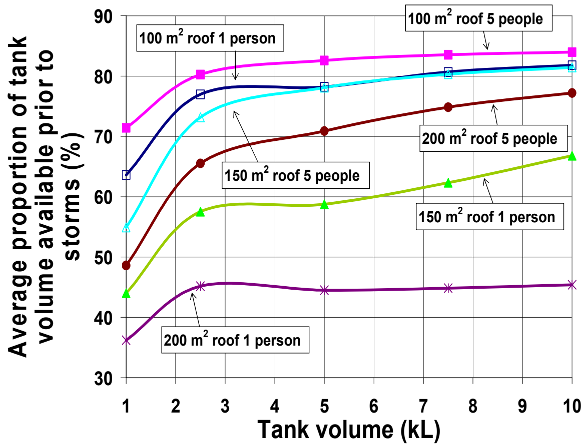

Figure 6: Average retention storage available prior to storm events in Adelaide

Average retention storages available in a rainwater tank prior to storm events increases with tank volume and the number of occupants in dwellings. A reduced volume of retention storage in tanks is available for larger roof areas although considerable stormwater retention is provided by most tank sizes. A 5 kL rainwater tank in Adelaide will on average provide 43 kL/ annum mains water savings and retention storage of 80% (4 m^3) prior to storm events.

4. BRISBANE

The performance of rainwater tanks in Brisbane was analysed using 100 years of synthetic rainfall generated by DRIP based on the central Brisbane pluviograph record with an annual rainfall depth of about 1110 mm [see Heneker, 2002 for details]. Domestic water use for Brisbane shown in Table 2 was estimated from Environment Australia [2001] using methods developed by Coombes et al. [2000].

4.1 Brisbane Water Savings

Mains water savings resulting from the use of rainwater tanks used to supply domestic hot water, toilet, laundry and outdoor uses in Brisbane are shown in Figures 7, 8 and 9.

Rainwater tanks connected to roofs with areas of 100 m^2, 150 m^2 and 200 m^2 produced average annual mains water savings of 31 kL (20%) to 85 kL (27%), 37 kL (26%) to 119 kL (38%) and 40 kL (29%) to 144 kL (45%). Substantial mains water savings of 12% - 74% were produced by the use of rainwater tanks. The greater mains water savings in Brisbane in comparison to Adelaide was due to the larger rainfall depth in Brisbane.

Table 2. Estimated average daily household water use in the city of Brisbane

	Average water use (Litres per day)					
	Outdoor	Inhouse (number of occupants)				
Month		1	2	3	4	5+
January	409	130	230	380	541	701
February	399	131	221	392	522	653
March	370	117	234	351	508	585
April	328	111	223	344	506	597
May	146	115	200	355	540	626
June	148	113	216	359	472	565
July	164	115	209	324	518	623
August	232	119	197	296	494	593
September	344	118	196	294	493	591
October	551	113	226	339	452	565
November	554	103	205	338	431	614
December	495	121	243	364	485	607

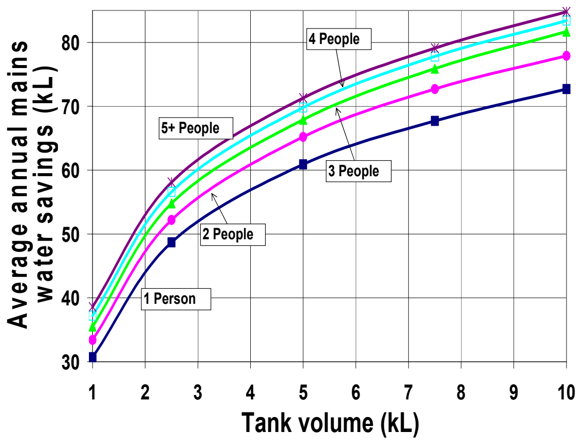

Figure 7: Mains water savings at dwellings with 100 m^2 roof areas in Brisbane

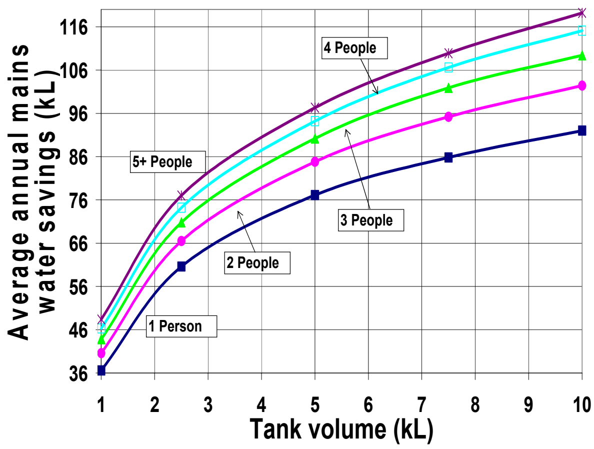

Figure 8: Mains water savings at dwellings with 150 m^2 roof areas in Brisbane

Figure 10 shows the average proportion of rainwater tank volume available for retention of roof water prior to storm events in Brisbane.

Dwellings with roof areas of 100 m^2 have retention storages available prior to storms ranging from 38% (0.38 m^3) – 48% (0.48 m^3) for 1 kL rainwater tanks to 56% (5.58 m^3) – 71% (7.07 m^3) for 10 kL rainwater tanks whilst tanks connected to the dwelling with the 200 m^2 roof and one occupant provided retention storages of 26% (0.26 m^3) to 32% (3.24 m^3) for the 1 and 10 kL rainwater tanks respectively.

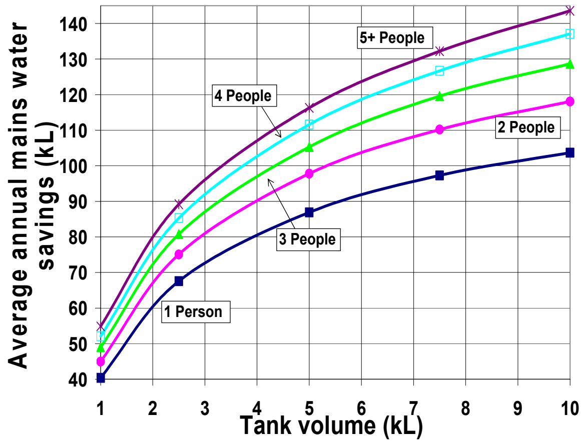

Figure 9: Mains water savings at dwellings with 200 m^2 roof areas in Brisbane

The higher annual rainfall depth in Brisbane resulted in decreased storage volumes in rainwater tanks available prior to storm events in comparison to the storages available in Adelaide.

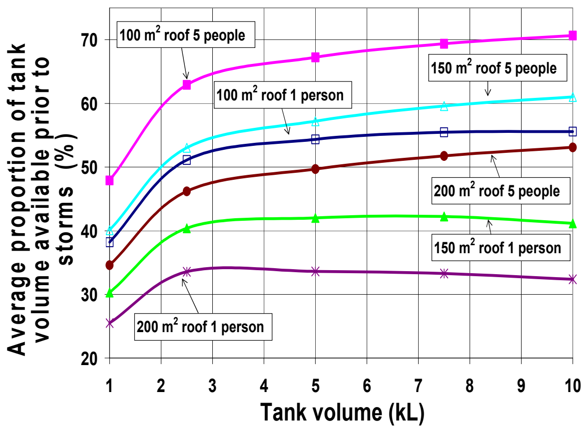

Figure 10: Average retention storage available prior to storm events in Brisbane

5. MELBOURNE

The performance of rainwater tanks in Melbourne was analysed using 100 years of synthetic rainfall generated by DRIP based on a pluviograph record with an annual rainfall depth of about 663 mm [see Heneker, 2002 for details]. Domestic water use for Melbourne shown in Table 3 was estimated from Environment Australia [2001] using methods developed by Coombes et al. [2000].

5.1 Melbourne Water Savings

Table 3. Estimated average daily household water use in the city of Melbourne

	Average water use (Litres per day)					
	Outdoor	Inhouse (number of occupants)				
Month		1	2	3	4	5+
January	243	158	298	436	575	715
February	247	151	290	429	567	706
March	243	159	298	437	576	715
April	212	142	281	420	559	698
May	166	159	298	437	576	715
June	122	153	292	430	569	708
July	131	148	287	426	565	703
August	179	144	283	421	560	699
September	217	146	285	423	562	701
October	262	156	296	434	573	713
November	295	157	296	435	574	713
December	347	154	293	432	571	710

Mains water savings that resulted from the use of rainwater tanks used to supply domestic hot water, toilet, laundry and outdoor uses in Melbourne are shown in Figures 11, 12 and 13.

Rainwater tanks connected to roofs with areas of 100 m^2, 150 m^2 and 200 m^2 produced average annual mains water savings of 20 kL (18%) to 30 kL (9%), 29 kL (26%) to 55 kL (16%) and 35 kL (31%) to 81 kL (24%). Mains water savings ranged from 7% to 27% of total household water use for a dwelling with a roof area of 100 m^2 to savings of 13% to 67% for a dwelling with a 200 m^2 roof.

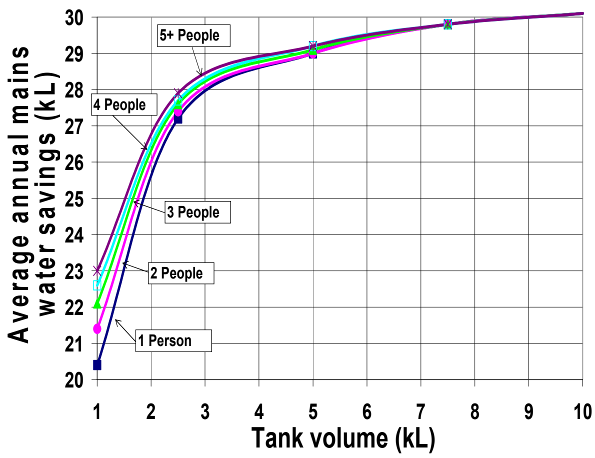

Figure 11: Mains water savings at dwellings with 100 m^2 roof areas in Melbourne

Figures 11, 12 and 13 show that rainwater tanks with volumes of 1 kL provide significant mains water savings. Similar to the results for Adelaide the magnitude of increases in mains water savings diminishes with greater tank sizes due to limited roof water supply. A 5 kL rainwater tank appears to be the optimum size for providing mains water savings. A rainwater tank with a volume of 5 kL will on average supply 29 kL to 75 kL of rainwater per annum to a household.

Figures 12 and 13 show that for households with roof areas of 150 m^2 and 200 m^2 mains water savings increase with the number of occupants although increases in yield from the tanks decrease with increasing tank size and greater numbers of occupants. The combination of roof area and low rainfall depth produces an upper limit on potential mains water savings for a given tank size. Nonetheless, even in the temperate low rainfall climate in Melbourne, the use of rainwater tanks produce considerable mains water savings.

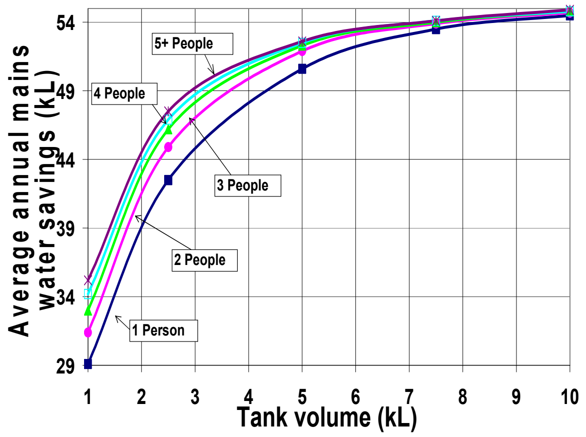

Figure 12: Mains water savings at dwellings with 150 m^2 roof areas in Melbourne

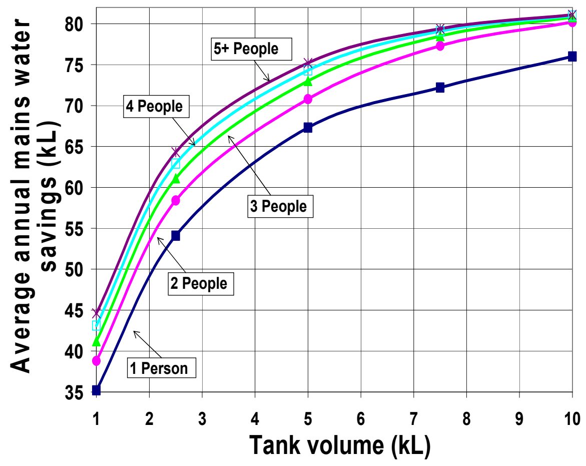

Figure 13: Mains water savings at dwellings with 200 m^2 roof areas in Melbourne

Figure 14 shows that average proportion of rainwater tank volume available for retention prior to storm events range from 36% (0.36 m^3) – 61% (0.61 m^3) for 1 kL rainwater tanks to 49% (4.90 m^3) – 84% (8.36 m^3) for 10 kL rainwater tanks. Similar to the results for Adelaide, greater retention storages are available in rainwater tanks prior to storm events in Melbourne in comparison to Brisbane due to the lower annual rainfall depth.

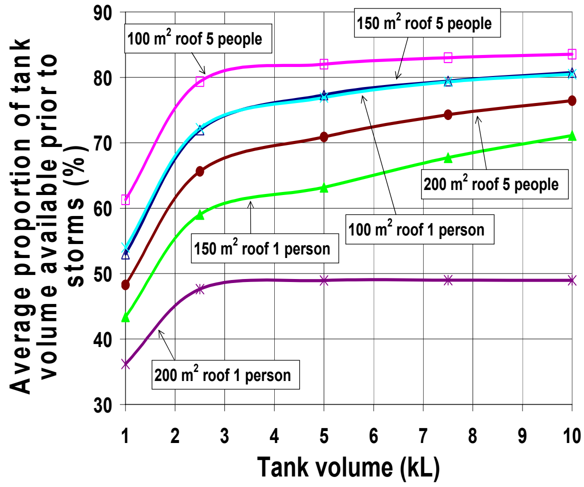

Figure 14: Average retention storage available prior to storm events

A 5 kL rainwater tank in Melbourne will on average provide 52 kL/annum mains water savings and an average retention storage of 3.7 m^3 prior to storm events.

6. WESTERN SYDNEY

The performance of rainwater tanks in Sydney was analysed using 100 years of synthetic rainfall generated by DRIP based on the North Ryde pluviograph record with an annual rainfall depth of about 959 mm [see Coombes et al., 2002 for details]. Domestic water use for Western Sydney shown in Table 4 was estimated from Environment Australia [2001] using methods developed by Coombes et al. [2000].

Table 4. Estimated average daily household water use for Western Sydney

	Average water use (Litres per day)					
	Outdoor	Inhouse (number of occupants)				
Month		**1**	**2**	**3**	**4**	**5+**
January	303	236	453	670	887	1104
February	311	229	447	664	881	1098
March	287	237	454	671	888	1105
April	239	229	446	663	880	1097
May	176	237	454	671	888	1105
June	121	222	439	656	874	1091
July	128	219	436	653	870	1087
August	204	223	440	657	874	1091
September	256	232	449	666	884	1101
October	316	237	454	671	888	1105
November	363	233	450	667	885	1102
December	419	235	452	669	886	1103

6.1 Western Sydney Water Savings

Mains water savings that resulted from the use of rainwater tanks used to supply domestic hot water, toilet, laundry and outdoor uses in

Western Sydney are shown in Figures 15, 16 and 17.

Rainwater tanks connected to roofs with areas of 100 m^2, 150 m^2 and 200 m^2 produced average annual mains water savings of 25 kL (16%) to 56 kL (11%), 32 kL (20%) to 87 kL (17%) and 37 kL (23%) to 114 kL (22%) respectively. Mains water savings ranged from 6% to 33% of total household water use for a dwelling with a roof area of 100 m^2 to savings of 10% to 58% for a dwelling with a 200 m^2 roof. Mains water savings provided by the rainwater tanks increase with larger roof areas. Moreover tanks with volumes in the range 1 kL to 5 kL produce the majority of mains water savings.

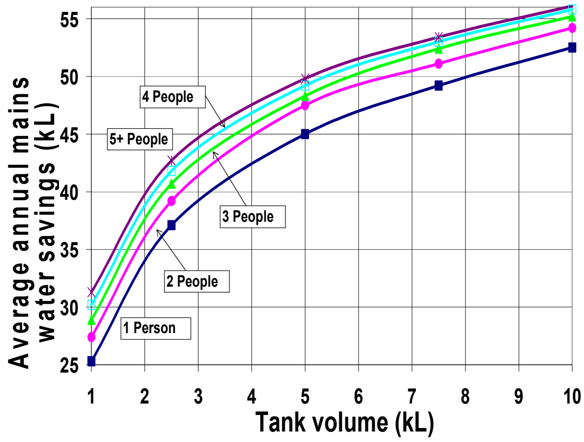

Figure 15: Mains water savings at dwellings with 100 m^2 roof areas in Western Sydney

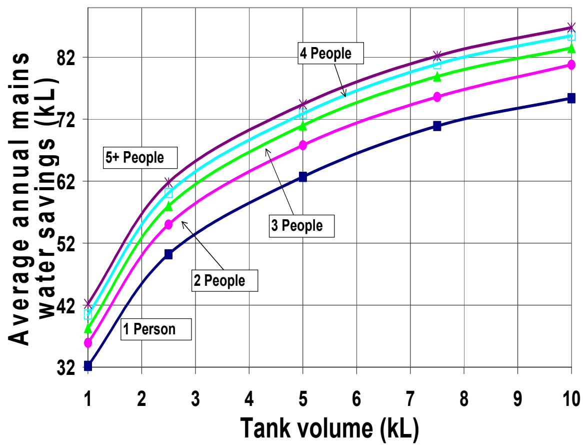

Figure 16: Mains water savings at dwellings with 150 m^2 roof areas in Western Sydney

Similar to the results from Adelaide and Melbourne, increases in mains water savings decline with greater numbers of occupants. Although the annual rainfall depth in Western Sydney (959 mm) is greater the ability to supply water demand is limited due to higher water demand.

The average proportion of a rainwater tank volume available for roof water retention prior to storm events in Western Sydney is shown in Figure 18.

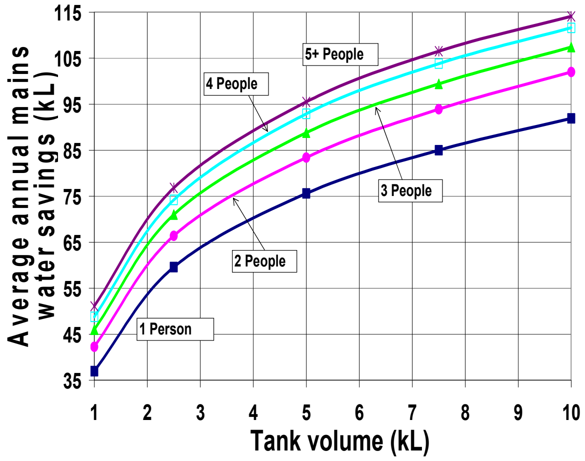

Figure 17: Mains water savings at dwellings with 200 m^2 roof areas in Western Sydney

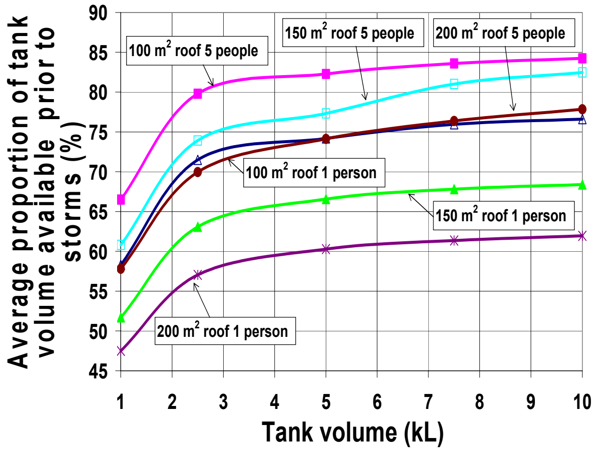

Figure 18: Average retention storage available prior to storm events in Western Sydney

Figure 18 shows that the average proportion of rainwater tank volume available for retention prior to storm events range from 48% (0.48 m^3) – 67% (0.67 m^3) for 1 kL rainwater tanks to 62% (6.2 m^3) – 84% (8.42 m^3) for 10 kL rainwater tanks. Similar to the results for Brisbane, smaller retention storages are available in rainwater tanks prior to storm events in Western Sydney than in Melbourne and Adelaide – this is due to the higher annual rainfall depth.

A 5 kL rainwater tank in Western Sydney will on average provide 71 kL/annum mains water savings and an average retention storage of 3.7 m^3 prior to storm events.

7. CONCLUSIONS

This study analysed the impact of collecting roof runoff in rainwater tanks with volumes from 1 kL to 10 kL that have mains water trickle topup used to supply domestic hot water, toilet, laundry and outdoor uses in Adelaide, Brisbane, Melbourne and Sydney. The water supply and stormwater benefits derived from the use of rainwater tanks are dependent on rainfall depth, domestic water use, tank volume and roof area.

The use of rainwater tanks resulted in considerable mains water savings in each city. Brisbane and Sydney with larger annual rainfall depths provided greater yields from the rainwater tanks. Significant retention volumes were found to be available in rainwater tanks prior to storm events in each city. Rainwater tanks will reduce stormwater peak and volumetric discharges from roof areas; especially for larger tank volumes. The largest retention volumes were available in Adelaide and Melbourne that have lower annual rainfall depths. Mains water savings increased with tank volume, number of occupants in dwellings and roof areas. In lower rainfall climates (Adelaide and Melbourne) and for smaller roof areas (100 m^2) increases in mains water savings diminish with larger tank volumes and greater numbers of occupants in dwellings.

For the cities examined in this study increases in water supply benefits from rainwater tanks diminished with larger tank volumes while stormwater management benefits increased with tank volume. In each city the optimum sized rainwater tank seemed to be about 5 kL for mains water savings whilst 10 kL rainwater tanks provided the greatest stormwater retention volumes. An important phenomenon is revealed by this study, unlike the design of reservoirs which require maximising water storage, the design of rainwater tanks with mains water trickle top up should aim to drawn down water levels in the tanks as often as possible.

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