Centralised and Decentralised Water Infrastructure: The Best of Both Worlds

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ABSTRACT
Over the past 100 years, the procurement of Australian water and wastewater infrastructure has been guided by centralised philosophies. Centralised philosophies describe the water trinity of potable supply, sewerage services and stormwater management. However in recent years it has become clear that this approach is not economically, socially or environmentally sustainable in its current form. Decentralised solutions such as rainwater tanks, wastewater treatment and reuse and water sensitive urban design (WSUD) have been shown to provide significant benefits that compliment the current centralised approach.

The aim of this paper is to highlight the comparative mains water savings, and reductions in wastewater flows and stormwater runoff at the allotment scale, with respect to centralised and decentralised water infrastructure approaches. The Probabilistic Urban Rainfall and Wastewater Reuse Simulator (PURRS) (Coombes, 2002) was used to simulate allotment scenarios based on 1 to 5 people households and 150, 200 and 300 m^2 roof areas for Sydney, Brisbane and Melbourne. Results show significant mains water savings and wastewater flow and stormwater runoff reductions at the allotment scale can be obtained from decentralised options and one must question our insistence on the current centralised approach.

Decentralised options are rarely considered by water authorities or government planners because they are skeptical on the benefits they provide. This skepticism may have an ulterior motive that will be a challenge to address. The centralised philosophy appears to be a function of the current vested interests in centralised management of water supplies, dividend returns to government from the sale of water and consultants that are dependent on the current centralised governance structure. This approach has led us away from sustainable water management over the past 100 years and unless decentralised alternatives are embraced and included within the future development of Australia's water infrastructure we will continue to place greater burdens on existing water supply catchments and remain susceptible to water shortages into the future.

Keywords: decentralised, rainwater harvesting, household water management, PURRS

1. INTRODUCTION

In Australia, analysis of regional water strategies carried out by State governments, water authorities and their consultants have found that insufficient water resources are available to meet increasing water demands that are a consequence of a growing population. These studies usually recommend demand management strategies coupled with large centralised engineering solutions including installation of desalination plants and large scale wastewater recycling schemes that sometimes require citizens to drink treated wastewater that will be stored in water supply reservoirs (Sydney Water, 2006; Hunter Water Corporation, 2004). It should be recognised that drinking water demand is only about 1% of total water use in a city (Coombes, 2002).

These types of studies typically dismiss decentralised solutions including rainwater harvesting as an option without critical analysis (Coombes, 2005). Since water demand and supply management are in part dependent on organisational culture, there is an increasing belief that urban water authorities are unnecessarily constrained by their historical developments, their internal arrangements and culture by current engineering paradigms (Engineering Australia, 2006). While there are many good reasons to organise service delivery into water supply, wastewater services and stormwater services, this compartmentalisation unduly influences the development of reform options (Engineering Australia, 2006). Typically, decision making reflects organisational structure and favours options promoted by key managers. As a result, reform deliberations revolve around a sub-set rather than all available options. The aim of this paper is to highlight (a) the significant benefits of decentralised water and wastewater options and, (b) the need to promote *both* centralised and decentralised approaches for creating sustainable water and wastewater infrastructure in Australia.

2. BACKGROUND

Consider a simple urban water balance at the allotment scale. Figures 1a and 1b show that the volume of stormwater runoff from an urban allotment is similar or greater than the volume of mains water supplied to the allotment. Note that the combined volume of stormwater and wastewater discharging from the allotment is considerably greater than the volume of mains water demand. Figures 1a and 1b were based on data used and described later in this paper.

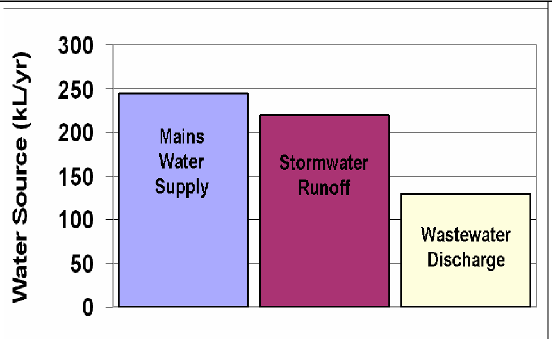

Figure 1a: **Average household water balance in Melbourne**

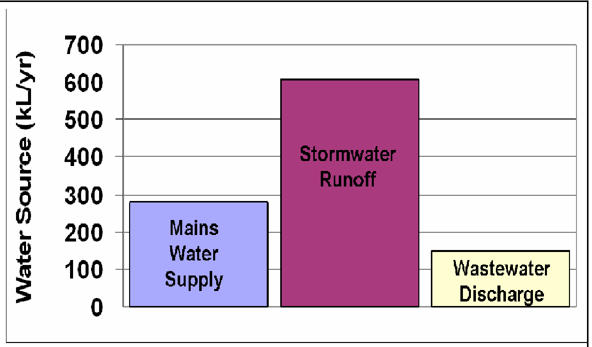

Figure 1b: **Average household water balance in Brisbane**

Thus there is a considerable excess of water available at the allotment and the magnitude of this excess of available water is dependent on location. Given that an excess of water is available at the decentralised scale (at the allotment), one must ask why our regional water supply strategies find that insufficient water is available and recommend large centralised solutions. This is explained by the simplified rainfall runoff curve for water supply catchments and residential roofs as shown in Figure 2 below (from Coombes, 2002).

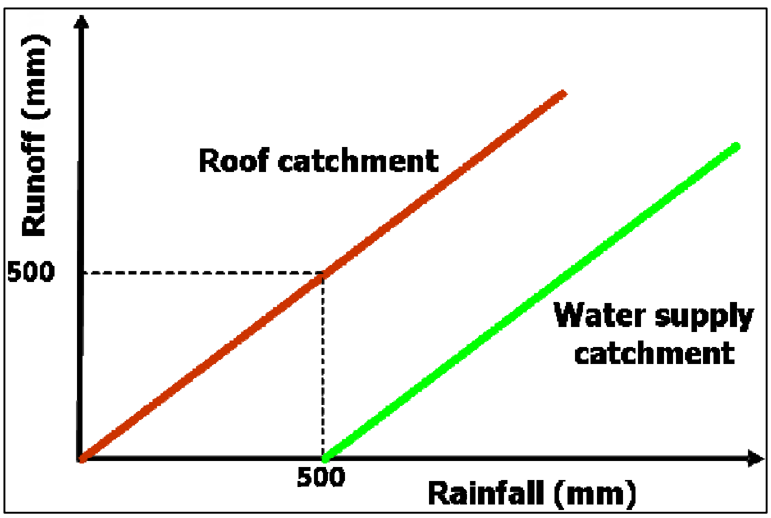

Figure 2: **Harvest efficiencies of natural and roof catchments**

Figure 2 shows that the efficiency of a water supply catchment is considerably less than a roofed catchment feeding a rainwater tank. It is also shown that in dry years (< 500 mm) the annual runoff in water supply catchments is insignificant. In these years water losses to the soil and atmosphere accounts for most of the rainfall and water supplies are almost totally dependent on water stored in dams from more bountiful years. In contrast the roofed catchment, being impervious, only experiences a small loss at the commencement of each rain event and is able to harvest the majority of rainfall. As a result, a rainwater tank can harvest significant volumes of water even during drought years. Roofs are more efficient than water supply catchments for harvesting rainwater. This result also indicates that roof catchments will be more reliable than water supply catchments in climate change scenarios.

In addition to the greater efficiency of roof catchments in comparison to water supply catchments, it is often the case that roofs in major urban areas on the coastal fringe of Australia receive greater rainfall depths. This fact is demonstrated in the following Figures 3a and 3b which compare rain falling on inland and urban catchments in South East Queensland and the Greater

Sydney region in New South Wales. Rainfall data was obtained from Bureau of Meteorology records for each area.

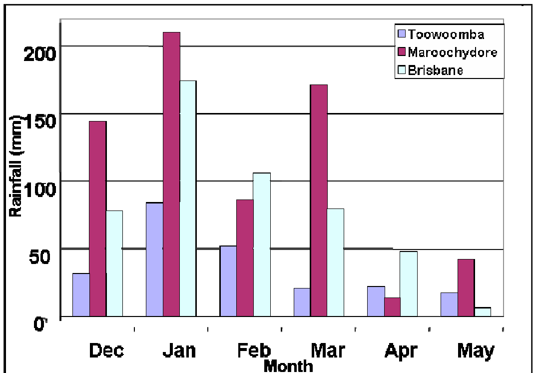

Figure 3a: Rainfall since December 2006 in the South East Queensland

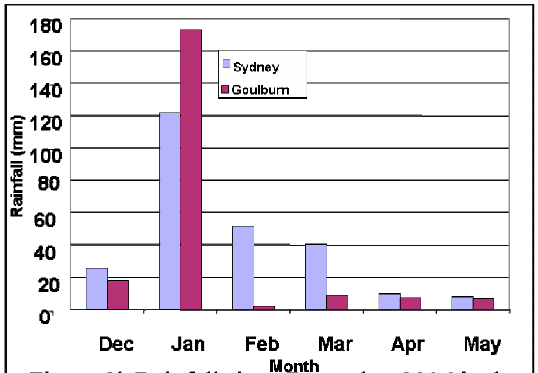

Figure 3b Rainfall since December 2006 in the Greater Sydney region

Figure 3a reveals that far greater rainfall in the highly populated areas of Maroochydore and Brisbane and considerably less rainfall at Toowoomba, located adjacent to the water supply catchment for Brisbane. Similarly in Figure 3b, albeit less significantly, more rainfall is available in the highly populated areas of Sydney than at Goulburn, which is within the water supply catchment for Sydney.

Fortunately, rainwater harvesting and wastewater reuse systems are becoming a new paradigm in sustainable urban water cycle management. The harvesting of rainwater provides the water supply and as a consequence generates the wastewater stream to be treated and reused. Therefore the volumes of water in the rainwater tank and wastewater system at a given time of day require accurate simulation, preferably at 6-minute time-steps (1/10 of an hour) (Lucas et al, 2006). Also, the relative impervious area on a given allotment will govern the volume of stormwater runoff for a specific integrated water cycle management (IWCM) option. Therefore, the timing and availability of harvested rainwater will directly impact on simulated mains water savings, wastewater flows and stormwater runoff.

Recent studies in Australia (Coombes et al, 2002; Coombes and Kuczera, 2003; Coombes 2005) and overseas (Vaes and Berlamont, 2001; Qiang, 2003; Villarreal and Dixon, 2005) have highlighted the significant cost and environmental benefits of decentralising and integrating water supply and wastewater reuse systems, particularly with respect to traditional designs. Traditionally designed supply, sewage and stormwater systems have environmental and cost limitations with respect to expanding urban areas and populations, available water sources and end-use water quality issues not previously envisaged by water authorities. Over the past decade, approaches to improve urban water cycle management have included water-saving devices inside the home, the use of rainwater tanks, reuse of treated wastewater and water sensitive urban design (WSUD) principles to manage stormwater runoff.

When several IWCM options are implemented in unison at an allotment scale, various levels of mains water savings, wastewater flow reductions and stormwater runoff reductions can be obtained. This study uses the PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator) (Coombes, 2002) model to continuously simulate demand management (water saving devices), the performance of rainwater harvesting and wastewater reuse to explore the reductions in mains water supply, wastewater discharges and stormwater runoff that are available at an allotment scale.

3. METHOD

Several IWCM options were evaluated in this study and are shown in Table 1. The simulations involving rainwater harvesting and wastewater reuse include a 5 kL rainwater tank and 6 kL wastewater storage respectively. Hypothetical allotment configurations used in this study are shown in Figure 4, that include houses with 150, 200 and 300 m^2 roof areas on 600 m^2 allotments, and including 75 m^2 of other impervious area (driveway, paths and so on).

Table 1: **IWCM strategies evaluated in this study**

STRATEGY	ABBREVIATION	OCCUPATION	ROOF AREA (m^2)
Demand Management only	DM only	1, 2, 3, 4, 5 people	150, 200, 300
Demand Management + Rainwater Tank	DM + RWT	1, 2, 3, 4, 5 people	150, 200, 300
Demand Management + Wastewater Reuse	DM + WW	1, 2, 3, 4, 5 people	150, 200, 300
Demand Management + Rainwater Tank + Wastewater Reuse	DM + RWT + WW	1, 2, 3, 4, 5 people	150, 200, 300

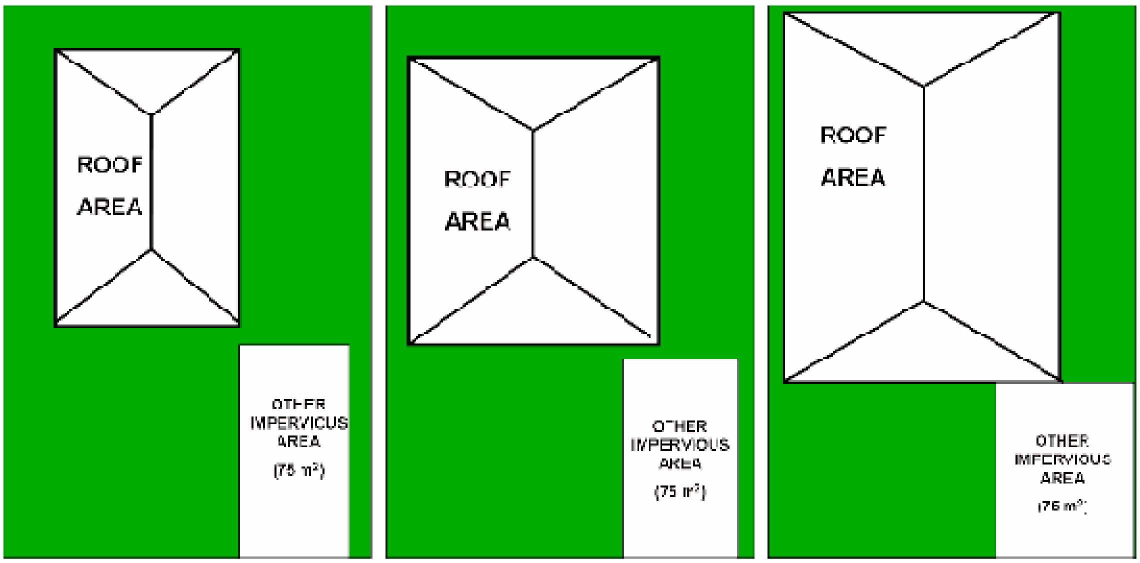

Figure 4: **Allotment areas and impervious areas used for each scenario**

3.1. Climate data

The IWCM strategies were continuously simulated in Sydney, Melbourne and Brisbane using climate data, including pluviograph rainfall (6 minute intervals); sourced from the Australian Bureau of Meteorology (BOM). The annual average rainfall depths, rainfall distribution, length of rainfall record and water demand distribution for each location are shown in Table 2. This data will be referred to during discussion to highlight the effect that rainfall depth, distribution of water demand and rainfall, have on mains water savings, wastewater flow and stormwater runoff volumes.

Table 2: **Annual average rainfall, relative rainfall depth, and rainfall and water demand distribution with the number of years used in the continuous simulation**

LOCATION	ANNUAL AVERAGE RAINFALL (mm)	RELATIVE RAINFALL DEPTH/ DISTRIBUTION	WATER DEMAND DISTRIBUTION	YEARS OF SIMULATION
Sydney Observatory Hill	1199	High - Uniform	Summer	86
Melbourne Regional Office	645	Low - Uniform	Summer	76
Brisbane Airport	1093	High - Summer	Summer	83

3.2. Water demand

All simulations used water demand data that was derived for 1, 2, 3, 4 and 5 person households. Table 3 summarises the indoor, outdoor and total water demands used during simulation of each IWCM option. Values for indoor and total demand are with respect to the number of people (left to right, 1 to 5 people) and outdoor use for a 600 m^2 allotment was considered constant regardless of the number of people.

Table 3: **Indoor, outdoor and total water demands used in this study**

LOCATION	No of PEOPLE	INDOOR (kL/day)	OUTDOOR (kL/yr)	TOTAL DEMAND (kL/yr)
Sydney	1,2,3,4,5	0.23, 0.43, 0.64, 84, 1.06	58.8	142.4, 215.4, 292, 365, 445.3
Melbourne	1,2,3,4,5	0.14, 0.28, 0.41, 0.55, 0.68	49.9	102.2, 153.3, 200.8, 251.9, 299.3
Brisbane	1,2,3,4,5	0.10, 0.19, 0.32, 0.47, 0.58	94.1	131.4, 164.3, 211.7, 266.5, 306.6

The demand management (DM) option includes the use of water efficient toilets, shower roses and washing machines. In the demand management and rainwater harvesting (DM + RWT) option, rainwater harvesting supplies outdoor, toilet, laundry and hot water uses. Alternatively, the demand management and wastewater reuse (DM + WW) option involved using treated wastewater for outdoor and toilet uses. In the DM + RWT + WW option, the rainwater tank supplies laundry and hot water use with treated wastewater supplying outdoor and toilet uses.

3.3. Selected Model

The Probabilistic Urban Rainfall and wastewater Reuse Simulator (PURRS) by Coombes (2002) was designed specifically to evaluate rainwater harvesting and wastewater reuse at an allotment scale. Continuous simulation of the performance of allotment scale IWCM options was conducted using 6-minute time-steps and rainfall with lengths shown in Table 2. The PURRS employs climate dependent water demands derived from Table 3. The diurnal water demand pattern used to disaggregate water demand into 6-minute time-steps and the tank configuration used in the simulations are shown in Figure 5.

In the model, rainfall was directed from roofs via first flush devices with a volume of 20 L to the rainwater tanks. An initial loss of 0.5 mm was assumed from the roofs. The rainwater tanks are topped up by mains water at a rate of 40 L/hr when the water levels were drawn below a minimum water level located 0.3 m from the base of the tank (Figure 5B). Full details of the PURRS model can be found in Coombes (2001).

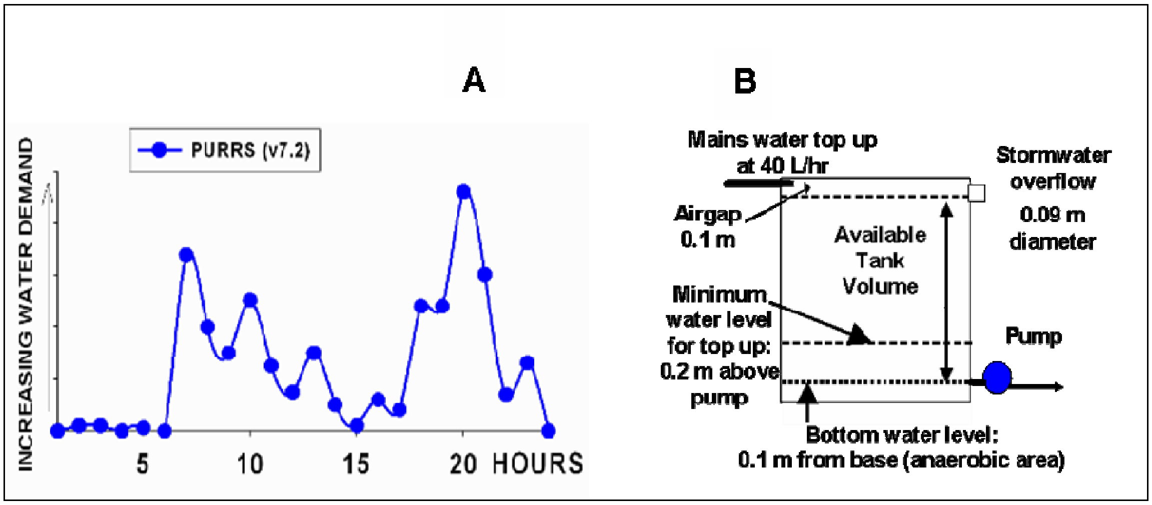

Figure 5: **(A) Diurnal water demand pattern and (B) Tank configuration as used in PURRS**

4. RESULTS

Results are presented as mains water savings, wastewater flows and stormwater runoff in kL/yr for each location. The rainwater tank and wastewater treatment facility were assumed to have capacities of a 5kL and 6 kL respectively. The results for each location are presented in a series of Figures. In each Figure, columns represent mains water savings, wastewater flows and stormwater runoff (all in kL/yr) from left to right and rows represent increasing roof areas from top to bottom. Mains water savings expressed as a percentage of total water demand are also shown in a separate Table for each location.

Figure 6 shows results for Brisbane. Mains water savings significantly improved with increasing occupancy for all IWCM options except the DM only scenario, which provided small mains water savings. In Brisbane, annual average mains water savings for 1 to 5 person households with 150 m^2 roof areas ranged from approximately 6 kL to 27 kL for the DM only, 39 kL to 176 kL for the DM + WW, 75 kL to 121 kL for the DM + RWT and 96 kL to 242 kL for the DM + RWT + WW scenarios. Annual average mains water savings for 1 to 5 person households with 300 m^2 roof areas ranged from approximately 39 kL to 176 kL for the DM + WW, 87 kL to 147 kL for the DM + RWT and 104 kL to 251 kL for DM + RWT + WW scenarios.

Annual average mains water savings increased with larger roof areas for DM + RWT and DM + RWT + WW strategies but were independent of roof area for the DM only and DM + WW scenarios. Mains water savings from the DM + WW scenarios are lower than DM + RWT scenarios for 1 and 2 person households because total water demand could not be satisfied by the wastewater produced.

Annual average wastewater discharges for 1 to 5 person households with 150 m^2 roof areas ranged from approximately 0 kL to 28 kL for DM + RWT + WW and DM + WW scenarios, and 34 kL to 191 kL for DM only and DM + RWT scenarios. Variations in roof area were observed to have no influence on wastewater discharges. Significant reductions in wastewater flows were observed for IWCM options that included wastewater reuse strategies, however the use of rainwater tanks did not influence wastewater flows.

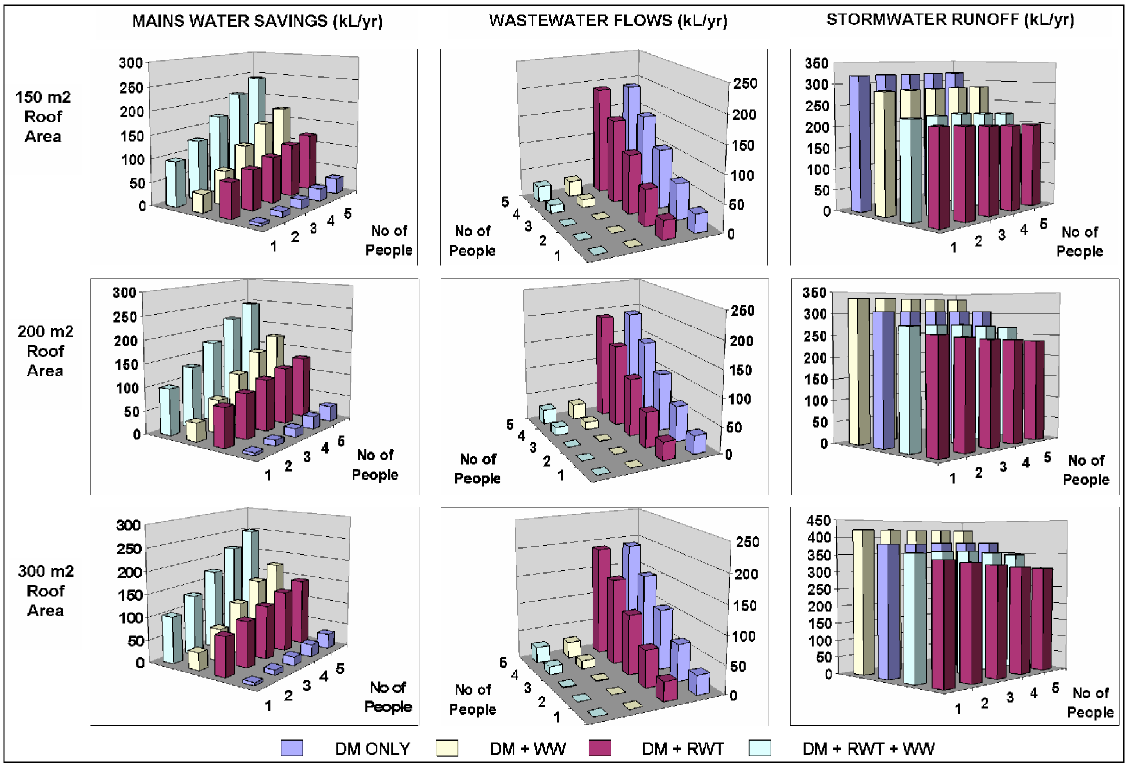

Figure 6: **Mains water savings, wastewater flows and stormwater runoff in Brisbane**

Annual average stormwater runoff volumes generally decreased with increasing occupancy for the DM + RWT and DM + RWT + WW scenarios, and remained relatively constant across 1 to 5 person households for the DM only and the DM + WW scenarios. Annual average stormwater runoff for 1 to 5 person households with 150 m^2 roof areas was approximately 286 kL for DM only and DM + WW scenarios, and ranged from 218 kL to 198 kL for the DM + RWT and 229 kL to 221 kL for DM + RWT + WW scenarios. Stormwater runoff for 1 to 5 person households with 300 m^2 roof areas was approximately 421 kL/yr for DM only and DM + WW scenarios, and ranged from 340 kL/yr to 307 kL/yr for the DM + RWT and 356 kL/yr to 346 kL/yr for DM + RWT + WW scenarios. The DM + RWT + WW scenario created larger SWR volumes than the DM + RWT scenario for all roof areas.

Table 6 shows mains water savings in Brisbane as a percentage of total allotment water demand. The DM only scenario reduced mains water use by 4.7% to 10.4% for 1 to 5 person households respectively. Significant reductions in mains water use were achieved using rainwater harvesting and wastewater reuse strategies. For 1 to 5 person households with 150 m^2 roof areas the DM + RWT scenario reduced mains water use by 61.5% to 42 %, and by 64.1% to 46.5% for 300 m^2 roof areas. Mains water savings were observed to decrease with increasing occupancy and increased mains water savings were observed with respect to increasing roof area for a given occupancy. The DM + WW scenario reduced mains water use by 28.7% to 55.6% for 1 to 5 person households respectively and no increase in mains water savings was observed with larger roof areas. The DM + RWT + WW scenario provided the greatest reductions in mains water use for all occupancies and roof areas. For 1 to 5 person households with 150 m^2 roof areas the DM + RWT + WW scenario reduced mains water use by 70.5% to 76.3 % and by 76.3% to 79.2% for the 300 m^2 roof areas.

Table 6: **Percentage Main Water Savings in Brisbane**

		No of People				
BRISBANE	**Roof Area (m^2)**	**1**	**2**	**3**	**4**	**5**
DM only	150,200,300	4.7	6.8	8.5	9.8	10.4
DM + RWT	150	54.7	49.6	44.9	40.6	38.3
DM + RWT	200	61.5	56	50.7	44.4	42
DM + RWT	300	64.1	59	53.9	49.1	46.5
DM + WW	150,200,300	28.7	41.9	52.1	55	55.6
DM + RWT + WW	150	70.5	73.9	77.6	77.2	76.3
DM + RWT + WW	200	73.3	77	79.7	79.9	77.7
DM + RWT + WW	300	76.3	78	80.3	79.9	79.2

Figure 7 shows results for Melbourne. Mains water savings were seen to increase with greater occupancy for all IWCM options except DM only which provided small mains water savings. In Melbourne, annual average mains water savings for 1 to 5 person households with 150 m^2 roof areas ranged from approximately 8 kL to 38 kL for DM only, 49 kL to 151 kL for DM + WW, 68 kL to 116 kL for DM + RWT and 86 kL to 220 kL for DM + RWT + WW scenarios. Annual average mains water savings for 1 to 5 person households with 300 m^2 roof areas ranged from approximately 49 kL to 151 kL for DM + WW, 78 kL to 158 kL for DM + RWT and 89 kL to 237 kL for DM + RWT + WW scenarios.

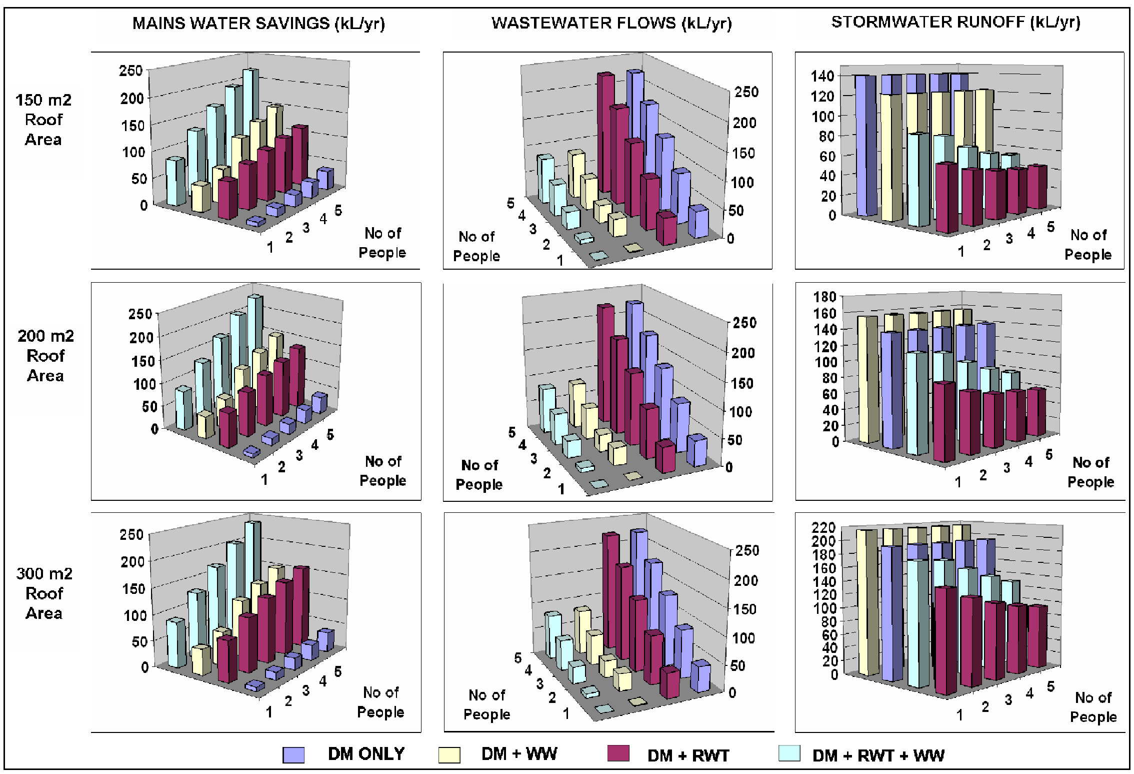

Figure 7: **Mains water savings, wastewater flows and stormwater runoff in Melbourne**

Mains water savings increased with larger roof areas for DM + RWT and DM + RWT + WW strategies and was independent of roof area in the DM only and DM + WW scenarios. Mains water savings from implementing DM + WW are lower than DM + RWT for 1 and 2 person households because water demand can not be satisfied by the wastewater produced. Alternatively for scenarios with 150 m^2 roof areas and occupancies higher than 2 people the DM + WW scenario produced higher mains water savings than the DM + RWT scenarios.

Wastewater discharges increased with increasing occupancy for all IWCM options (as expected). Annual average wastewater discharges for 1 to 5 person households with 150 m^2 roof areas ranged from approximately 0 kL to 84 kL for DM + RWT + WW and DM + WW scenarios, and

47 kL to 224 kL for DM only and DM + RWT scenarios. Variations in roof area were observed to have no influence on wastewater flows. Significant reductions in wastewater flows were observed for IWCM options that included wastewater reuse (WW) strategies and the use of rainwater tanks did not influence wastewater discharges.

Annual average stormwater runoff volumes generally decreased with increasing occupancy for the DM + RWT and DM + RWT + WW scenarios and remained relatively constant across 1 to 5 person households for the DM only and the DM + WW scenarios. Annual average stormwater runoff volumes for 1 to 5 person households with 150 m^2 roof areas was approximately 122 kL for DM only and DM + WW scenarios, ranged from 63 kL to 116 kL for DM + RWT and 86 kL to 220 kL for DM + RWT + WW scenarios. Whilst annual average stormwater runoff volumes for 1 to 5 person households with 300 m^2 roof areas was approximately 216 kL for DM only and DM + WW scenarios, ranged from 78 kL to 158 kL for DM + RWT and 89 kL to 237 kL for DM + RWT + WW scenarios. The DM + RWT + WW strategy created larger stormwater runoff volumes than the DM + RWT scenarios for all roof areas.

Table 7 shows mains water savings as a percentage of total allotment water demand in Melbourne.

Table 7: **Reductions in mains water demand in Melbourne**

		No of People				
MELBOURNE	**Roof Area (m^2)**	**1**	**2**	**3**	**4**	**5**
DM only	150,200,300	7.8	10.1	11.3	12.0	12.4
DM + RWT	150	65.1	54.8	47.3	41.9	37.9
DM + RWT	200	71.8	62.7	55.2	48.3	44.7
DM + RWT	300	75	67.5	61.4	56.1	51.7
DM + WW	150,200,300	47.2	42	54.1	51.3	49.4
DM + RWT + WW	150	82.1	83.2	80.6	76.3	72
DM + RWT + WW	200	83.4	83.8	81.8	79.9	75.1
DM + RWT + WW	300	84.7	83.9	82.2	79.9	77.6

The DM only scenarios reduced mains water use by 7.8% 12.4% for 1 to 5 person households respectively. Significant reductions in mains water use were achieved using rainwater harvesting and wastewater reuse strategies. For 1 to 5 person households with 150 m^2 roof areas the DM + RWT scenario reduced mains water use by 65.1% to 37.9% and by 75% to 51.7% for 300 m^2 roof areas. Reductions in annual average mains water savings were observed to decrease with increasing occupancy and increased reductions in mains water savings were observed with respect to increasing roof area for a given occupancy. The DM + WW scenario reduced mains water use by 42% to 54.1% for 1 to 5 person households respectively and the DM + RWT + WW scenario provided the greatest reductions in mains water use for all occupancies and roof areas. For 1 to 5 person households with 150 m^2 roof areas the DM + RWT + WW scenario reduced mains water use by 83.2% to 72% and by 84.7% to 77.6 % for 300 m^2 roof areas.

Figure 8 shows results for Sydney. Annual average mains water savings significantly increased with increasing occupancy for all IWCM options except DM only, which provided minimal mains water savings. In Sydney, mains water savings for 1 to 5 person households with 150 m^2 roof areas ranged from approximately 13 kL to 60 kL for DM only, 77 kL to 219 kL for DM + WW, 84 kL to 164 kL for DM + RWT and 119 kL to 307 kL for DM + RWT + WW scenarios.

Annual average mains water savings for 1 to 5 person households with 300 m^2 roof areas ranged from approximately 13 kL to 60 kL for DM only, 77 kL to 219 kL for DM + WW, 98 kL to 201 kL for DM + RWT and 121 kL to 329 kL for DM + RWT + WW scenarios. Mains water savings increased with larger roof areas for DM + RWT and DM + RWT + WW strategies. Mains water savings from implementing the DM + WW strategy were comparable to DM + RWT scenario for 1 and 2 person households because water demand was satisfied by the wastewater produced.

Wastewater discharges increased with increasing occupancy for all IWCM options (as expected). Annual average wastewater discharges for 1 to 5 person households with 150 m^2 roof areas ranged from approximately 0.2 kL to 150 kL for DM + RWT + WW and DM + WW scenarios and 71 kL to 347 kL with DM only and DM + RWT scenarios. Variations in roof area were observed to have no influence on wastewater flows. Significant reductions in wastewater flows were observed for IWCM options that included wastewater reuse strategies and the use of rainwater tanks did not influence wastewater flows.

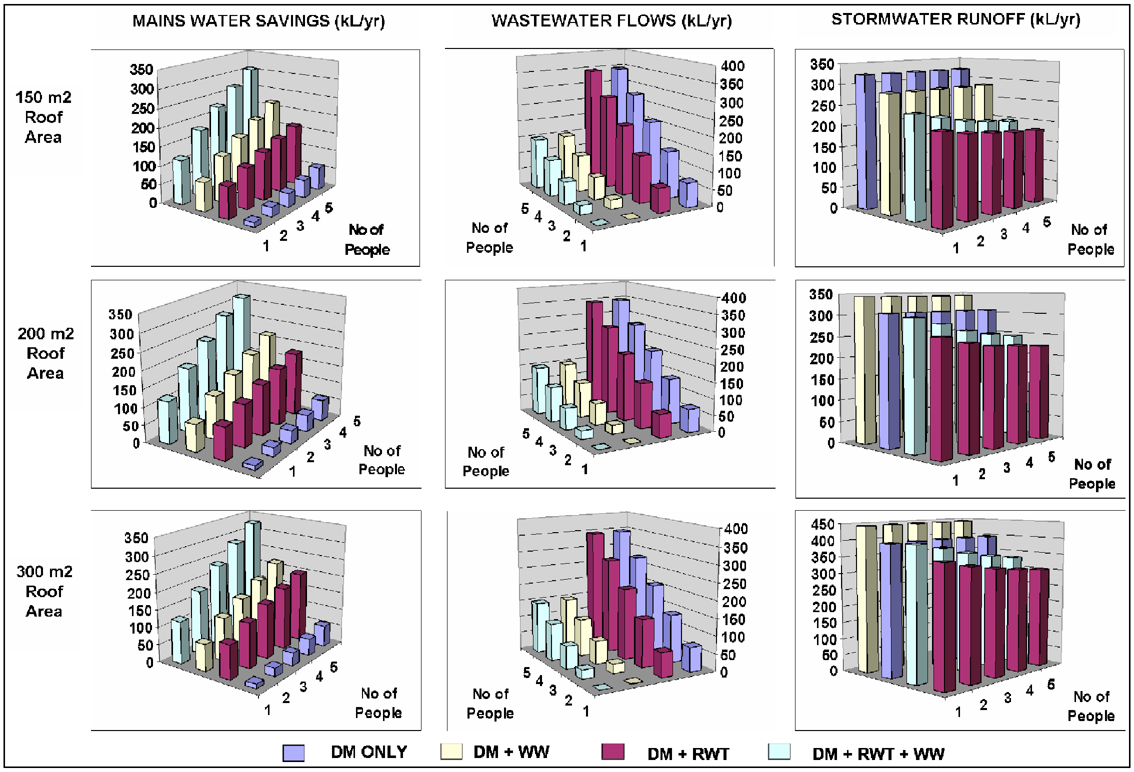

Figure 8: **Mains water savings, wastewater flows and stormwater runoff in Sydney**

Stormwater runoff volumes generally decreased with increasing occupancy for the DM + RWT and DM + RWT + WW scenarios, and remained relatively constant across 1 to 5 person households for the DM only and the DM + WW scenarios. Annual average stormwater runoff for 1 to 5 person households with 150 m^2 roof areas was approximately 285 kL for DM only and DM + WW scenarios, ranged from 213 kL to 181 kL for DM + RWT and 243 kL to 197 kL for DM + RWT + WW scenarios. Whilst annual average stormwater runoff for 1 to 5 person households with 300 m^2 roof areas was approximately 443 kL for DM only and DM + WW scenarios, ranged from 358 kL to 303 kL for DM + RWT and 400 kL to 334 kL for DM + RWT + WW scenarios. The DM + RWT + WW scenarios created larger stormwater runoff volumes than DM + RWT scenarios for all roof areas.

Table 8 shows mains water savings as a percentage of total allotment water demand for Sydney.

Table 8: **Percentage Main Water Savings in Sydney**

		No of People				
SYDNEY	**Roof Area (m^2)**	**1**	**2**	**3**	**4**	**5**
DM only	150,200,300	8.7	10.9	11.9	12.5	12.9
DM + RWT	150	58.6	48.7	42.6	38.4	35.3
DM + RWT	200	64.8	54.5	47.8	42	38.7
DM + RWT	300	68.1	58.2	51.6	46.9	43.3
DM + WW	150,200,300	53.9	55.5	51.4	48.9	47.3
DM + RWT + WW	150	82.7	80.5	74.9	70.1	66.4
DM + RWT + WW	200	83.6	81.8	77.1	74.3	68.5
DM + RWT + WW	300	84.2	82.2	78.1	74.3	71

The DM only scenario reduced mains water use by 8.7% to 12.9% for 1 to 5 person households respectively. Significant reductions in mains water use were achieved using rainwater harvesting and wastewater reuse strategies. For 1 to 5 person households with 150 m^2 roof areas the DM + RWT scenario reduced mains water use by 58.6% to 35.3% and by 68.1% to 43.3% for 300 m^2 roof areas. Annual average mains water savings were observed to decrease with increasing occupancy and increased mains water savings were observed with respect to increasing roof area for a given occupancy. The DM + WW scenario for 1 to 5 person households reduced mains water use by 47.3% to 55.5 %. The DM + RWT + WW scenario provided the greatest reductions in mains water use for all occupancies and roof areas. For 1 to 5 person households respectively and for 150 m^2 roof areas the DM + RWT + WW scenario reduced mains water use by 82.7% to 66.4 % and by 84.2% to 71% for 300 m^2 roof areas.

5. DISCUSSION

The results indicate that significant mains water savings can be gained at the allotment scale for an array of IWCM strategies, particularly for options that embrace rainwater harvesting and wastewater reuse. Also, results indicate that there is not a water shortage as publicised by the water industry, only gross inadequacies in the centralised approaches used by the water industry.

The DM only scenarios provided relatively small mains water savings and no significant reductions in either wastewater flows or stormwater runoff. Alternatively the DM + RWT scenarios significantly decreased mains water use and decreased stormwater runoff although had no influence on wastewater discharges. The DM + WW scenarios significantly decreased mains water use and wastewater flows, but had no influence on stormwater runoff. The DM + RWT + WW scenario provided the greatest mains water savings, reductions in wastewater discharges with significant reductions in stormwater runoff.

Furthermore, the sum of individual benefits gained from individual IWCM options does not equal the simulated total. For example, mains water savings for (DM + RWT) + (DM + WW) does not equal mains water savings for DM + RWT + WW. This is likely to be a function of rainwater tank and wastewater storages competing for indoor/outdoor demand and the influence of the climatic regime of the location.

The IWCM strategies at the locations evaluated, namely Brisbane, Melbourne and Sydney, resulted in a range of mains water savings, wastewater flow and stormwater runoff reductions. These locations also have a diversity of climatic regimes and water demands that influenced the relative benefits to be gained from a given IWCM option. Figure 9 shows average monthly rainfalls and average monthly water demands for Brisbane, Melbourne and Sydney.

The difference between mains water savings at each location can be partially explained by the relative rainfall and water demand patterns shown in Figure 9. Annual rainfall and water demand patterns are similarly matched in Sydney, Brisbane and to a lesser extent Melbourne. At these locations, rainfall maxima generally coincide with high water demands and rainfall minima coincide with low water demands. However, the mains water savings observed cannot be explained solely by the climatic regime. As such, the influence of water demand on yields from rainwater tanks for a specific annual rainfall depth allows further explanation of the differences in mains water savings between Sydney, Brisbane and Melbourne. For example, Melbourne and Brisbane have relatively lower water demands than Sydney, although Brisbane has significantly greater rainfall than Melbourne or Sydney.

As such, rainwater tank options in Brisbane would be expected to provide greater mains water savings than in Melbourne – but this was not always the case. Inspection of water demand at lower occupancies show that Melbourne experiences larger indoor water demands than Brisbane, meaning that yields from tanks in Melbourne was greater than rainwater yields in Brisbane for lower household occupancies. As a result, rainwater tank options provided greater relative mains water savings in Melbourne than Brisbane for lower occupancy; however the difference between mains water savings between Melbourne and Brisbane diminished with increasing occupancy and roof area.

In contrast, Sydney has a moderate rainfall annual depth but a relatively large water demand compared to Melbourne and Brisbane. Therefore, since Sydney experiences significantly higher water demands then it follows that rainwater tank drawdown would also be at a maximum. Even though there is relatively less rainfall in Sydney than Brisbane, the scenario of moderate rainfall with good correlation between rainfall distribution and water demand distribution, and high water demand, means rainwater tanks provide comparable mains water savings to Brisbane.

For all locations, significant reductions were observed in wastewater discharges for DM + WW and DM + RWT + WW scenarios. The DM only and DM + RWT scenarios provided no significant decreases in wastewater discharges. The implications for reducing wastewater flows are both economic and environmental. For example, lower wastewater flow means pipe networks and wastewater treatment plants can be smaller and will use less energy. Also, reduced wastewater discharges means reduced contaminant loads to natural waterways that can preserve water quality in sensitive urban areas.

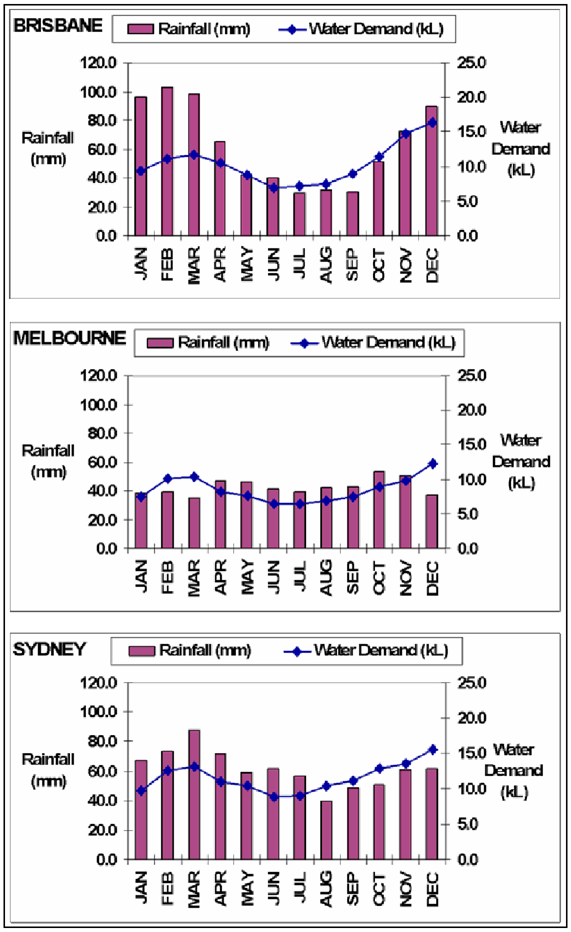

Figure 9: **Average monthly rainfall (mm) and Average monthly water demand (kL) for Brisbane, Melbourne and Sydney**

For all locations, significant reductions were observed in stormwater runoff for the DM + RWT and DM + RWT + WW scenarios. However the DM + RWT scenarios provided greater stormwater runoff reductions than the DM + RWT + WW scenarios. This was due to wastewater reuse accounting for water demands that would have previously been sourced from the rainwater tank (DM + RWT), thus decreasing the yield from the tank which in turn increases the frequency of overflows. Therefore, more stormwater runoff would be expected from a DM + RWT + WW strategy than a DM + RWT strategy. Reducing stormwater runoff also has economic and environmental implications. For example, lower stormwater runoff means drainage networks and detention basins can be smaller and will require less maintenance. Also, reduced stormwater runoff means reduced contaminant loads to natural waterways, which will preserve water quality in many urban areas.

It is also interesting to note that cumulative benefits are not equal to the sum of individual IWCM options. The sum of individual IWCM options does not equal the simulated total because allotment systems "compete" for water from a given storage. For example, when WW is included in a DM + RWT simulation, the yield from the rainwater tank is reduced because wastewater is usually used for outdoor purposes (the highest allotment scale demand). This outdoor use would have been previously sourced from the rainwater tank.

As a result, the harvestable rainwater yield is reduced, reducing the potential yield from the rainwater tank. When wastewater is used for indoor purposes as well as outdoor, the rainwater tank will effectively supplement the available wastewater storage for those uses during periods of high water demands, further reducing the yield from the rainwater tank.

Therefore, further economic considerations may want to be made prior to implementing wastewater treatment and reuse options in areas with adequate rainfall. Interestingly, this scenario typifies many coastal cities containing medium to high density urban development and one must wonder why wastewater treatment and reuse is being touted as the optimal solution to water shortages, particularly on the east coast of Australia. Augmentation of new supply headworks in the Sydney region could be deferred by up to 90 years if a 2 % annual uptake of rainwater tanks were introduced and where rainwater was used for outdoor, toilet, laundry and hot water uses (Coombes, 2005).

6. CONCLUSIONS

This study has highlighted that at the allotment scale there is more than enough water to satisfy water demand and that decentralised approaches, climatic regime and water demand significantly impact on mains water savings, wastewater flows and stormwater runoff. Of the four IWCM options considered, the use of water efficient appliances alone impacted slightly on mains water savings and had negligible impact on reducing wastewater discharges and stormwater runoff. In comparison the DM + RWT strategies significantly increased mains water savings and reduced stormwater runoff, but had negligible impact on wastewater discharges.

Alternatively the DM + WW strategies significantly increased mains water savings and reduced wastewater flows, but had negligible impact in reducing stormwater runoff. The DM + RWT +WW strategies provided the greatest mains water savings and significant reductions in wastewater flows and stormwater runoff, however the extra mains water savings gained from including relatively expensive wastewater treatment and reuse may not warrant the additional expenditure. In contrast, urban developments in areas with sensitive waterways are likely to justify costs to reduce wastewater flows to the environment and the DM + RWT + WW option may be preferred.

Continuous simulation allows intra-daily rainwater tank configuration to be determined, providing the necessary insight to evaluate rainwater harvesting under different climate regimes and water demands. The "competition" for water for indoor/outdoor uses from either the wastewater storage or rainwater tank explained why the sum of individual IWCM options does not equal the simulated total mains water savings.

The continuous simulation of rainwater tank drawdown in conjunction with intra-daily rainfall and water demand provided a realistic model of rainwater tank storage available for intra-daily rainfall entering the tank and water demand leaving the tank. As a result, the influence of climatic regime and water demand on the efficacy of the selected IWCM options was highlighted. All locations had uniform or spring and summer distribution of moderate to high rainfall and all water demands have spring and summer distributions. The use rainwater harvesting at these locations provided the greatest mains water savings.

Results from this study provide compelling evidence for the implementation of allotment scale IWCM options, particularly rainwater tanks, in the sustainable management of catchment water resources under mounting pressure from increasing populations and climate change. Decentralised options compliment centralised infrastructure by conserving catchment water supply and reducing urban stormwater runoff. The best of both worlds can be utilised to preserve regional storages and optimise rainwater harvesting and therefore must be equally considered in procurement of Australia's future water management strategies.

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