Stormwater, waterway benefits and water resources benefits of water conservation measures for Australian cities

Peter J Coombes[1], Michael Smit[2], Josh Byrne[3], Christopher J Walsh[4]

[1]Urban Water Cycle Solutions, Newcastle, Australia
E-mail: thecoombes@bigpond.com

[2]Rainwater Harvesting Association of Australia, Brisbane, Australia

[3]Curtin University Sustainability Policy Institute (CUSP), Perth, Australia.

[3] School of Ecosystem and Forest Sciences, The University of Melbourne, Australia

Households with rainwater harvesting and water efficient appliances made a profound contribution to Australian society by ensuring that cities did not run out of water during the millennium drought. In spite of this, the value of sustainable households is contested as the memory of drought fades. This investigation used audited metadata from national agencies and water utilities, peer reviewed research, case studies and a systems analysis of Australian capital cities to define the benefits of sustainable buildings. The key findings of this study confirm that source control measures including rainwater harvesting, water efficient appliances and vegetable gardens at households makes a substantial contribution to the viability of water resources and ecosystems in Australian capital cities.

1. INTRODUCTION

Water efficiency is one element of a broader paradigm of working with natural systems to improve our quality of life. Many water efficient houses are also energy efficient, often include a productive food garden and improve water quality in catchments. Water efficiency is not an end in itself, it is a product of systems thinking and living sustainably, reducing our environmental impact to ensure there are sufficient resources for future generations. It is an inherently efficient paradigm that has synergistic benefits for ecosystems, infrastructure and operational finances, stormwater and energy management (Coombes, 2007; Byrne, 2013; Walsh et al. 2012). There is a tendency to reduce water efficiency to single components, a reductionist approach that considers rainwater harvesting, front loading washing machines, gardens or demand management behaviors in isolation. This approach reduces the pool of available solutions and reinforces past assumptions which may be quite wrong about the scales of the entire system (Coombes et al, 2015). Households with gardens also impact on biodiversity, energy efficiency, nutrient recycling, local food production, health and wellbeing, and water conservation (Byrne, 2007; 2013). These goals require an integrated approach: simply focusing on one element, a garden, may inadvertently lead to negative impacts such as singular aims to reduce garden water use.

Water conservation became a major priority in Australia during the Millennium drought. Some initial responses to water shortages were positive, such as use of low water use plants, especially native species with biodiversity benefits, or efficient irrigation systems. However some trends created impacts that were not envisaged. Extensive paving to replace irrigated landscapes or substitution of lawn with synthetic turf, had other impacts. These responses may have reduced water use, but also increased local heating, stormwater runoff and environmental impacts. Promotion of low water use gardens defined designs that use less water as ‘sustainable’ without consideration of downstream impacts. Urban stormwater runoff delivered from paved catchments via drainage networks is the primary cause of poor condition of urban creeks and rivers (Walsh et al. 2005). Protection and restoration of urban streams requires a paradigm shift in stormwater management to approaches that mimic the flow and water quality regimes of catchments prior to urban development (Walsh et al. 2016). Achieving these regimes requires retention and harvesting of most impervious runoff to prevent flows into streams (Walsh et al. 2012) and water savings are a significant co-benefit of stream protection. This paper investigates the society benefits of source control and water efficiency by examining audited metadata from national agencies and water utilities. This information was combined with peer reviewed research, selected case studies and a Systems Framework analysis of each capital city to reveal the water cycle and ecosystem benefits of source controls.

2. THE CASE FOR WATER EFFICIENCY AND SOURCE CONTROL

This is not a difficult case to argue. The evidence is clear that simple, effective water conservation measures are important and cost effective urban water solutions. This was widely recognized during the Millennium drought and there is a growing body of evidence showing that water conservation remains a cost effective strategy (AWA, 2012; Coombes, 2012, Turner et al., 2016, Walsh, 2005). The Australian experience of the millennium drought revealed that investment in water conservation options provided the cheapest, quickest and most effective contribution to managing demand during the drought (Coombes, 2012, Turner et al., 2016). Water conservation and local sources of water ensured that cities and towns did not run out of water (Coombes et al, 2012, Turner et al., 2016). This historical experience highlighted the importance of solutions that both increase local supply and reduce demand for mains water, and the effectiveness of strong demand management programs in uniting the community in meeting water saving targets.

3. HOUSEHOLD EXPENDITURE ON WATER AND UTILITY OPERATING COSTS

Total household expenditure for water and sewerage services for all water utilities were derived from data provided by the Bureau of Meteorology (BOM) (BOM, 2016). Total household expenditure on water has increased by $2 billion or 84% since 2007 and total household expenditure on water and sewerage has increased by $2.8 billion of 67%. Average annual water use has increased by 23%. However the pattern of household expenditure is not consistent across Australia. The BASIX program in NSW requires 40% water and energy savings on the design of all new houses compared to 2004 averages. Water savings are delivered by water efficient appliances, rainwater harvesting and sustainable gardens. BASIX was implemented in 2004 and has been operating for more than 10 years. We wanted to see if this major cumulative impact on supply and demand would be reflected in household bills and utility operating costs. So we separated the data. We restricted the data to average annual water bills and utility operating costs for connected properties to normalise differences in the number of connections and new connections. We also restricted the range to major water utility providers and we separated NSW major utilities, Sydney Water and Hunter Water, from major utilities in the rest of Australia as shown in Figure 1. The pattern of expenditure on operating costs by water utilities was determined for the same categories and is shown in Figure 2.

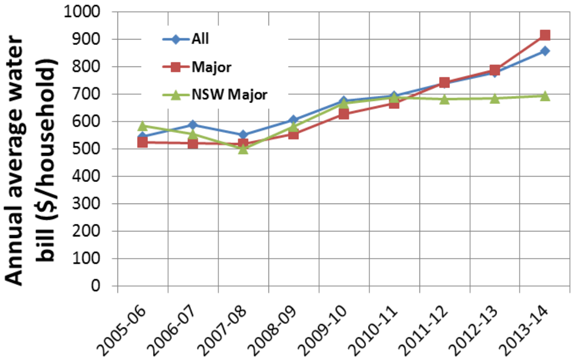

Figure 1: Average household water bills for all Australian water utilities, major Australian water utilities and NSW major water utilities.

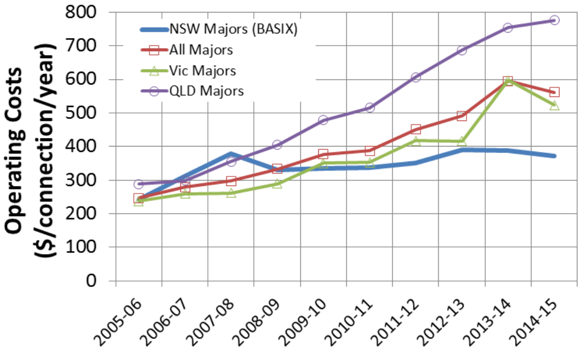

Figure 2: Water operating costs for utilities operating with mandates for sustainable buildings versus costs of other utilities (NWC, 2010; BOM, 2015).

Since 2005, average household water bills increased by 71% for all Australian utilities, by 91% for all Australian Major Utilities and for NSW major utilities household bills increased by 57%. There is a clear anomaly between household expenditure on water bills for the rest of Australia as compared to NSW. This potential relationship between water conservation and household expenditure provides 31% ($548 m) saving in household bills during the 2014/15 financial year. This equates to a reduction in water bills by $277 per household per year in 2014/15 and accumulative household benefits of $1,754 m since 2004. The driest year of the Millennium drought was 2006 and water levels in dams continued to fall during the period 2007 to 2009. While there were some increases in operating costs during this period it would be difficult to argue that water conservation campaigns generated an increase in operating costs. The increased operating costs in 2007-08 for NSW Major utilities were associated with expenditure for Sydney's desalination plant. However when water conservation programs were being wound back after the drought a number of east coast utilities show significant increases in operating costs per property. There is no evidence of significant economic savings following cessation of water conservation campaigns in 2009 to 11. Figure 2 also shows that growth in water operating costs of utilities in jurisdictions with BASIX legislation were significantly reduced in comparison to water operating costs of utilities in areas without mandates for sustainable buildings. The estimated cumulative savings for NSW Major utilities are $1,274 M by 2014 in comparison to All Major utilities. This represents an average saving in water operation costs in 2013/14 of $362 m ($183/property) or $1,282/property with rainwater harvesting and water efficient appliances.

4. RAINWATER HARVESTING AND WATER EFFICIENCY IN CITIES

Rainwater harvesting became a major source of water during the millennium drought. The Australian Bureau of Statistics (ABS, 2015) estimated that rainwater tanks supplied 156 GL of rainwater at a financial value of $500 million to households in 2013/14. Australian capital cities included more than 1.12 m rainwater harvesting systems. Rainwater yields estimated by the ABS were lower than the longitudinal observations from Coombes (2012) for rainwater tanks and water efficient appliances in South East Queensland. The Systems Framework by Coombes and Barry (2015), operating at 6 minute time steps, was used to simulate the performance of 5 kL rainwater tanks with 100 m^2 roof catchments and water efficient appliances in each capital city (Table 1). This approach incorporates climate dependent water demands, local climate and demographics, and was calibrated using data from water utilities (BOM, 2016). Water efficient appliances were categorised as change to dual flush toilets, front loading washing machines and water efficient showerheads as provided by ABS (2013).

Table 1: Rainwater yields, water efficiency and values in 2014 from systems analysis

Capital City	HHs with RW	RW (kL/yr)	WEA (kL/yr)	Total RW (ML/yr)	Total WEA (ML/yr)	RW value ($m)	WEA value ($m)	Total value ($m)
Sydney	249,900	70	49	17,493	25,948	50.4	75	125
Melbourne	376,900	53	31	19,976	10,051	67.7	34	102
Brisbane	237,600	66	25	15,682	12,963	51.1	42	93
Adelaide	165,800	43	26	7,129	2,751	30.6	12	42
Perth	51,600	54	50	2,786	6,928	5.5	14	19
Hobart	12,100	41	27	496	1,317	1.7	5	6
Darwin	6,384	61	34	389	841	0.9	2	3
Canberra	25,922	50	27	1,296	1,793	3.9	5	9
Total	**1,126,206**			**65,248**	**62,592**	**212**	**188**	**400**

Table 1 shows that total water savings from rainwater harvesting (RW) and water efficient appliances (WEA) was 128 GL at household (HH) savings in water use of $400 m in 2014 ($355/HH/year). Rainwater harvesting and water efficient appliances provide substantial benefits in Australian cities.

5. SOURCE CONTROL BENEFITS – GROUND TRUTH

So far this discussion has highlighted that contribution of rainwater harvesting and water efficient appliances on reducing water demands. The household is presented in this section as an integrated system that can provide multiple benefits. These additional systemic benefits of household systems which are explored by examination of observed household scale benefits from selected case studies.

6.1 Carrington in New South Wales

The Carrington house in Newcastle is situated on a small property (178 m^2) which includes a kitchen garden and monitoring of water and energy use, and costs for more than decade. A 5 kL rainwater tank captures rainwater from a 95 m^2 roof to supply all household water uses for two people. Rain falling on impervious surfaces is directed into the kitchen gardens rather than to street drainage. The observed performance of rainwater supply and water efficient appliances at the Carrington house was confirmed by water billing records from July 2003 to July 2016 as shown in Figure 3 and Table 2.

Table 2: Water balance from long term monitoring of the Carrington dual water supply scheme

Criteria	Water use (kL/yr)	Proportion (%)
Leak detection and behaviour change	35	17
mains	48	24
rainwater	87	43
Water efficient appliances	34	17
Total (circa 1998)	204	100

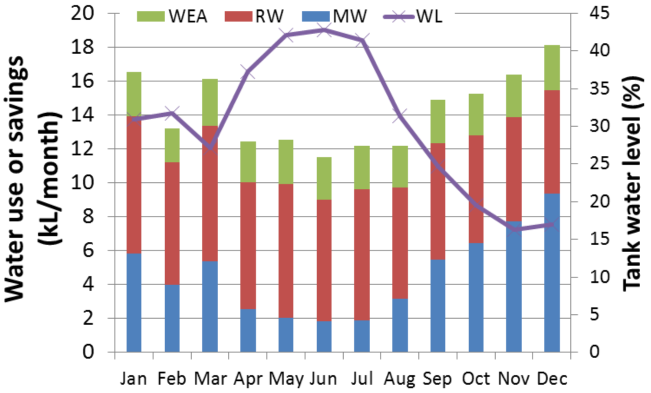

Figure 3: Long term behaviour of water efficient appliances (WEA), rainwater supply (RW), mains water supply (MW) and water levels (WL) in rainwater tank of the Carrington house

A combination of rainwater harvesting, water efficient appliances, leak detection and behaviour change has reduced mains water use by over 71% (147 kL/annum). The demand management response was achieved by lower pressures and flow rates delivered by the pump, a front loading clothes washer and a 4.5/3 litre flush toilet. Over 85% of stormwater runoff is retained on site by the rainwater tank and kitchen garden. Figure 3 shows a consistent rainwater supply throughout the year and water levels in the rainwater storage were constantly drawn down. The costs of rainwater supply ($0.58/kL) and with demand management ($0.13/kL) are substantially less than mains water supply ($2.22/kL). Monitoring of the energy balance of the entire household revealed a 15% reduction in electricity use due to the water strategy and the household uses 7% less energy than an equivalent household in the region. The addition of solar panels has further reduced net energy use by 61%.

6.2 Fremantle Western Australia

A detached dwelling located on a 700 m^2 block in the Perth suburb of Hilton in Western Australia includes water and energy management with local energy supply from solar panels and a comprehensive monitoring program. The house has four residents and includes rainwater (RW) supply and greywater (GW) collection from all GW sources (excluding kitchen sink and dishwasher). Rainwater supplies all internal demands via filtration and UV disinfection, with back up from mains water (MW). Garden irrigation demands are met by GW and groundwater (GndW) via a bore which is replenished by onsite stormwater infiltration. Water efficient plumbing fixtures were installed throughout. A data dashboard with real-time user feedback on water and energy uses was also installed to inform responsible behaviors. The landscape includes trees and vines that enhance the thermal performance of the solar passive designed home. Onsite food production is supported by composting systems and a nursery. Results for household water use for the Case Study Site (CS3), Perth Average and Perth Average with Bore, the local Suburb Average is provided in Figure 4. Rainwater (RW) and mains water (MW) use for internal household demands and rainwater storage volumes across the year are presented in Figure 5. Total mains water use for the site (CS3) was 29 kL/annum compared to 313 kL/annum for Perth Average with Bore, 363 kL/annum for the Perth Average, and 214 kL/annum for the local Suburb Average. Rainwater supplied 78 kL/annum (73%) of indoor use from the 18 kL storage with a roof catchment of 200 m^2 during 10 months of the year. Total indoor water use was 57% and 14% less than Perth Average and local Suburb Average, respectively.

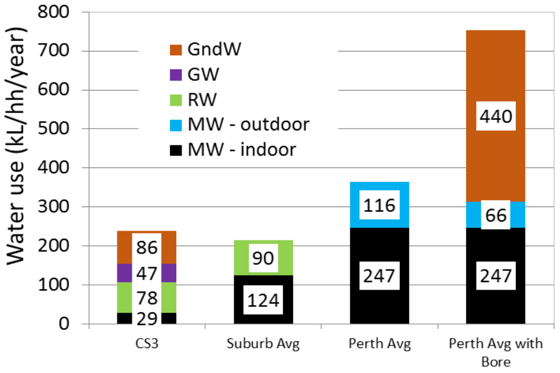

Figure 4: Water use by source at the site (CS3), for Perth and local suburb

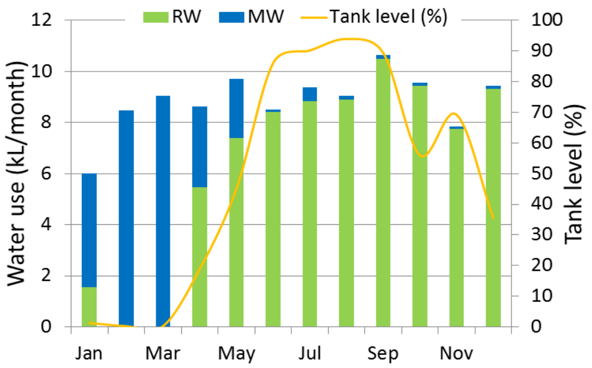

Figure 5: Rainwater versus mains water use for internal demands by month

External water use was less than Perth Average with Bore but higher than Perth Average and the local Suburb Average (131 kL/annum compared with 506kL/annum, 116 kL/annum, and 90 kL/annum). Outdoor use is supplied by 84 kL/annum of ground water (81% less than ground water use of Perth Average with Bore) and is complemented by 47 kL/annum of grey water. All stormwater is retained on site for harvesting or infiltration. The observed peak energy use of the rainwater pump was 1,540 kWh/ML. However, monitoring of the household energy balance revealed a 53% reduction in energy consumption compared to equivalent Perth households and when the local energy produced by the solar panels is considered, the house produces 2,100 kWh/year more than energy that is uses.

6.3 Richmond in inner-city Melbourne

A 121 m^2 house with 4 residents on a 160 m^2 property in the inner-Melbourne suburb of Richmond includes two 2.75 kL slimline tanks to collect rainwater from the roof to supply toilets and washing machine (with an automatic switch to mains supply when the rainwater storage empties). The tanks overflow to a 2.9 m^2 vegetable rain-garden (Tom et al., 2013) which overflows to a similar 2.1 m^2 garden at the front of the house. The front rain-garden receives runoff from a 4 m^2 roof area that does not drain to the tank. This garden overflows to street drainage at the curb, permitting monitoring of overflow events. The system is not instrumented, but tank emptying and overflow events were recorded opportunistically, usage patterns noted, and water depths in the two raingardens and the tank were recorded irregularly. A daily time-step mass balance model (http://urbanstreams.net/tools/EBcalc/) using daily rainfall data from a Melbourne Water rain gauge (500 m from the house) was calibrated to the monitoring data to estimate behaviour of the system. The performance of the system has evolved since as plants in gardens have grown (particularly the large passionfruit vine that grew across the tank and along the north facing wall of the house, providing thermal efficiency and amenity benefits of a green wall). During the year, the system provided 40 kL of rainwater, accounting for one-third of household water demand. The tank has provided rainwater at >98% reliability, with two short periods when it emptied in April and October 2015. Neither rain-garden has completely emptied whilst supporting large crops of healthy plants that did not require irrigation. The primary motivation of the system was to minimize impacts of the property on the downstream waterway, the Yarra River. The system retained >80% of the property's runoff, greatly reducing the frequency of runoff to street drainage (Figure 6).

Figure 6 shows that performance of the system (reduction in frequency and magnitude of overflows) has improved over time in response to the growth of plants in the rain-gardens that increased water use. Walsh et al. (2012, 2016) proposed that a small proportion (10-20%) of runoff should be allowed to filter into the soil (to mimic soil processes). The high density context of the site, with constructions on all boundaries precluded infiltration. Nevertheless, the system demonstrates that appropriate volume reduction is possible on high-density developments, to increase the feasibility of high-performance infiltration systems on public land downstream to retain runoff from roads that will also be required to protect downstream waterways. A common reservation about stormwater source control measures is the space that they use, but integration into productive and attractive garden space, means that the rainwater tank (<1% of property area) is the only component taking space that does not provide other uses to the property. The effective area of rain-gardens including and 'green-wall' vine is about 10% of property area. The system added about $8,000 to renovation costs, thereby adding $400 pa to mortgage repayments (and less than $15/year in pump electricity costs).

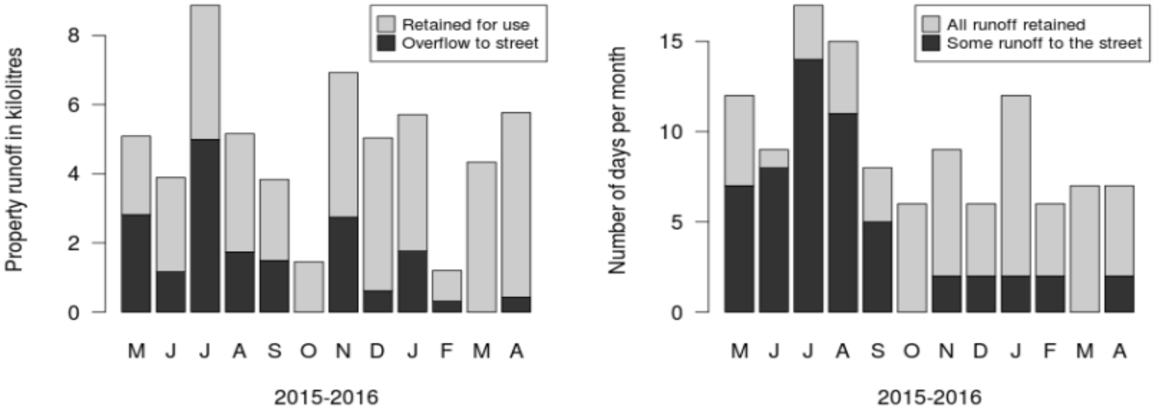

Figure 6: A: The total volume of runoff produced and retained. B: Number of days in which all runoff was retained, and the number of days in which some runoff overflowed to the street.

For that expense, it has provided to date $95/year of rainwater, more than $350/year of vegetables, and unaccounted (and growing) savings in energy costs through increased thermal efficiency. Consumption of electricity has remained stable since the renovation and is reduced by over 31% by installation of solar panels. Arguably, the system is providing stream protection services that are nominally funded by the $95 Melbourne Water waterways and drainage charge that the property attracts. The combined public and private benefits of the system (greater than $540/year) therefore greatly exceed its costs ($415/year).

6. STORMWATER BENEFITS FROM WATER CONSERVATION

Discussion about sustainable houses is often limited to water conservation outcomes. However, inclusion of rainwater harvesting and vegetable gardens also provide stormwater benefits that reduce impacts on waterways. The Systems Framework by Coombes and Barry (2015) was utilized to evaluate impacts of reduced runoff of existing household rainwater harvesting systems on contaminant loads discharging to waterways (Table 4). This analysis also examined (shown in brackets) reductions in contaminant loads created if all houses with rainwater harvesting capture rainwater overflows and stormwater runoff in 5 m^2 vegetable gardens (see ground truth section).

Table 4: Estimated reductions in stormwater runoff and pollutant loads for 2014

Capital City	Reduced runoff (ML/yr)	Reduced pollutant loads (Tonnes/yr)		
		TSS	TP	TN
Sydney	17,493	4,523 (7,790)	8.5 (11.1)	54.5 (96.6)
Melbourne	19,976	3,807 (26,681)	7.5 (34.3)	52.4 (258.9)
Brisbane	15,682	2,756 (9,098)	5.5 (11.5)	36.1 (113.1)
Adelaide	7,129	829 (6,460)	1.7 (9.0)	11.8 (65.5)
Perth	2,786	630 (773)	1.2 (1.1)	7.84 (9)
Hobart	496	122 (361)	0.24 (0.5)	1.56 (4.7)
Darwin	389	144 (178)	0.26 (0.7)	1.47 (2)
Canberra	1,296	233 (2,162)	0.47 (1.0)	5.96 (22.5)
Total	**65,248**	**13,044 (53,501)**	**25 (69)**	**172 (572)**

Table 4 shows that existing household rainwater harvesting systems produced substantial reductions in stormwater runoff volumes and contaminant loads discharging to waterways in capital cities. These results indicate a significant contribution to the health of waterways. However, the synergistic benefits of these household systems are substantially greater when rainwater harvesting systems are combined with vegetable gardens that accept stormwater runoff and rainwater overflows.

7. WATER SECURITY AND GREENHOUSE GAS BENEFITS

The reduced demand profiles of houses with rainwater harvesting and water efficient appliances can defer and diminish requirement for water security infrastructure. Systems analysis of capital cities were provided by Coombes and Barry (2014) for Melbourne, Coombes (2012) for Sydney, Coombes and Lucas (2007) for Perth, and Coombes et al. (2015) for South East Queensland. The net present value of deferred water security infrastructure created by existing rainwater harvesting and water efficient appliances was estimated using the Systems Framework by Coombes and Barry (2015). Reductions in greenhouse gas emissions generated by rainwater harvesting and water conservation was evaluated using published values for water distribution from BOM (2015) and NWC (2010). The analysis counted the cumulative emissions of transferring water from bulk sources via retail distribution networks to households (Utility Energy in Table 5). Where a region includes multiple water retailers (Melbourne and Brisbane), the weighted average of water distribution emissions was used in the analysis. Energy use of rainwater pumps and household hot water services was assumed to be 1.54 kWh/kL and 31.6 kWh/kL (Gurung et al., 2016). Two Options were analysed: Rainwater supply was assumed to increase household energy use (With RW energy) and, from the ground truth section, rainwater supply does not increase household energy use. Each option assumes that water efficient appliances reduce household energy use. The security value and reductions in greenhouses gas emissions created by existing sustainable households for each city is shown in Table 5.

Table 5: Security value, energy demand and reductions in greenhouse gas emissions provided by water conservation for cities in 2013/14

City	Security Value ($m)	Utility energy (kWh/ML)	RW & WEA Nett GHG savings (tonnes CO_2)	
			With RW energy	Without RW energy
Sydney	69	373	128,740	151,369
Melbourne	86	54	38,843	73,605
Brisbane	139	2,447	101,027	120,106
Adelaide	31	2,031	14,823	20,971
Perth	89	3,163	53,369	56,630
Hobart	21	2,458	1,442	1,534
Darwin	3	423	2,985	3,326
Canberra	45	233	8,447	10,123
Total	**483**		**349,675**	**437,663**

Table 5 reveals that rainwater harvesting and water efficient appliances provided substantial water security benefits in each capital city. Water security benefits were $429 for each property with rainwater harvesting and water efficient appliances. Rainwater harvesting and water efficient appliances also provided substantial reductions in greenhouse gas emissions (349,675 – 437,633 tonnes) during 2013/14 by reducing energy required to treat and transfer mains water to households, and reducing energy used for heating water and operating appliances. The average annual reduction in greenhouse gas emissions of sustainable households was 0.31–0.39 tonnes of CO_2 equivalents. These greenhouse gas benefits will be greater in situations where use of desalination increases.

8. CONCLUSIONS

This investigation utilised audited data published by government agencies and water utilities, peer reviewed research and data published by the authors, and systems analysis of capital cities to highlight the "hidden" benefits of sustainable buildings with rainwater harvesting, water efficient appliances and vegetable gardens. It is well documented that water efficient buildings and households made an important contribution to Australian society by ensuring that many Australian cities did not run out of water during the millennium drought. Nevertheless, as the memory of the drought diminishes, arguments abound that sustainable buildings with rainwater harvesting and water efficient appliances are ineffective and not economically viable in comparison to centralised options. The key findings of this investigation confirm the substantial contribution of sustainable buildings to improving the performance of water cycle infrastructure and ecological systems in cities. The case studies presented in this paper demonstrate that sustainable buildings operate as integrated systems to produce synergistic and accumulative benefits to reduce consumption of grid energy and water resources; diminish stormwater runoff and impacts on waterways; provide local food and amenity, and generate local energy and water resources. The benefits are clear and well documented over an extended period of time, and easily outweigh implementation costs. The authors suggest that the adoption of widespread water efficiency and water conservation measures as a component of urban planning is in the public interest. Moreover, this investigation highlights that the potential contribution of sustainable buildings and households to Australian society is greater that the substantial historical benefits revealed by this investigation.

9. REFERENCES

ABS (2013). *Environment, Water Use and Conservation 2013*, 4602.0 Australian Bureau of Statistics.

ABS (2015). Water Account Australia, 2013-14, 4160.0 Australian Bureau of Statistics.

AWA, (2012).T*he case for water efficiency.* AWA Position Paper. Australian Water Association.

BOM, (2015). *Urban NPR 2014-15*, Bureau of Meteorology. Commonwealth Government of Australia.

Byrne, J, (2007). *The Green Gardener,* VIC, Penguin.

Byrne, J, (2013). *Small Space Organics,* VIC, Hardie Grant Books.

Coombes P.J., (2007). *Energy and economic impacts of rainwater tanks on the operation of regional water systems.* Australian Journal of Water Resources. 11(2), 177-191.

Coombes P.J., Want, S., and Colegate, M., (2012). *Development of Policies for Water Cycle Reform in Greater Melbourne and Sydney.* Water and Climate – policy implementation challenges. Canberra.

Coombes P.J., Smit, M., and MacDonald G., (2015). *Resolving boundary conditions in economic analysis of distributed solutions for water cycle management.* Australian Journal of Water Resources. Engineers Australia.

Coombes P.J. and Barry M.E., (2015). *A systems framework of big data for analysis of policy and strategy,* 2015 WSUD & IECA Conference, Engineers Australia, Sydney.

Coombes P.J., and Barry M.E., (2014) *A systems framework of big data driving policy making – Melbourne's water future.* OzWater14 Conference. Australian Water Association. Brisbane.

Coombes P.J., (2012). *Insights into household water use behaviours throughout South East Queensland during drought.* 34th Hydrology and Water Resources Symposium, Sydney, NSW

Coombes P. J., and Lucas S. A., (2006). *Towards sustainable water strategies in the Perth region of Western Australia: inclusion of decentralised options,* Hydropolis Conference, Perth, Western Australia

Gurung R.T., Stewart R.A., Beal C.D., and Sharma A.K., (2016). *Investigating the financial implications and viability of diversified water supply systems in an urban water supply zone.* Water Resource Management. Springer.

NWC, (2010). *National performance reports – urban water utilities,* National Water Commission, Canberra.

Tom, M., Richards, P.J., McCarthy, D.T., Fletcher, T.D., Farrell, C., Williams, N.S., Milenkovic, K., 2013. *Turning (storm) water into food; the benefits and risks of vegetable raingardens,* Novatech 2013, 8th International Conference on Sustainable Techniques and Strategies in Urban Water Management.

Turner, A., White, S., Chong, J., Dickinson, M.A., Cooley, H. and Donnelly, K., 2016. *Managing drought: Learning from Australia,* prepared by the Alliance for Water Efficiency, the Institute for Sustainable Futures, University of Technology Sydney and the Pacific Institute for the Metropolitan Water District of Southern California, the San Francisco Public Utilities Commission and the Water Research Foundation.

Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M., Morgan, R.P., 2005. *The urban stream syndrome: current knowledge and the search for a cure.* J. N. Am. Benthol. Soc. 24, 706–723.

Walsh, C.J., Booth, D.B., Burns, M.J., Fletcher, T.D., Hale, R.L., Hoang, L.N., Livingston, G., Rippy, M.A., Roy, A.H., Scoggins, M., Wallace, A., 2016. *Principles for urban stormwater management to protect stream ecosystems.* Freshwater Sci. 35, 398–411.

Walsh, C.J., Fletcher, T.D., Burns, M.J., 2012. *Urban stormwater runoff: a new class of environmental flow problem.* PLoS ONE 7(9), e45814.