Water resources, stormwater and waterway benefits of water conservation measures for Australian capital cities

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Water conservation in households including rainwater harvesting and water efficient appliances made a profound contribution to Australian society by ensuring that many cities did not run out of water during the millennium drought. Nevertheless, as the memory of millennium drought fades, the value of sustainable households is contested. The society benefits of source control and water efficiency was investigated using audited metadata from national agencies and water utilities, peer reviewed research, selected case studies and a Systems Framework analysis of Australian capital cities. 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. 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. The case studies presented in this paper demonstrate that sustainable buildings and households operate as integrated systems to produce synergistic and accumulative benefits for water conservation, protection of waterways, improving the performance of infrastructure, and decreasing impacts on ecosystems.

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 their 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 in related areas, for infrastructure and operational finances, stormwater and energy management (Coombes, 2007; Byrne, 2013; Walsh et al. 2012). There is a professional tendency to reduce water efficiency to single components, a reductionist approach that considers rainwater harvesting, or front loading washing machines 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 entire system at any scale (household to region) (Coombes et al, 2015). In the context of this paper, the term ‘sustainable urban gardening’ refers to an approach that considers a range of environmental and human need considerations such as biodiversity, energy efficiency, nutrient recycling, local food production, health and wellbeing, and of course water conservation (Byrne, 2007; 2013). These factors can also be viewed as sustainability ‘goals’ that can help shape a particular landscape design response. Importantly, these goals need to be addressed with an integrated approach: by simply focusing on one element, a garden may inadvertently lead to a negative impact. The singular aim to reduce garden water use is an example of a negative approach.

Water conservation became a major priority in Australia within the gardening industry and broader community following the drought conditions that were experienced across much of the southern and south-eastern Australia during the first decade of this century (BOM, 2015). Some initial responses to water shortages were positive, such as promoting the use of low water use plants, especially native species which also provide biodiversity benefits, or the advancement of efficient irrigation systems which minimized water wastage. However a number of trends were not so positive, resulting in associated impacts that may not have been initially considered. For example the extensive use of paving and other hard surfaces to replace areas that were previously irrigated, or the substitution of lawn with synthetic turf, had other impacts. In both cases these responses may have led to a reduction in water use, but can also contribute to increased localised heating, additional stormwater runoff, as well as the use of materials with high embodied energy and an overall greater source of environmental impact. In the haste to promote low water use gardens, the landscaping and urban development industries often promoted designs as being 'sustainable' because they used less water, without consideration of the downstream impacts. What this also meant was that gardening activities that do require water, such as food gardens, are more likely to be excluded despite the fact they have a role to play in creating 'sustainable' urban living environments. Growing vegetables is a comparatively high water use gardening activity but it has significant health, social and environmental benefits through providing low-cost nutritious food with a low carbon footprint because it is consumed near to where it is grown. A holistic and sophisticated approach to how we design and manage our gardens is required if these spaces are going to genuinely contribute to improving the liveability and overall sustainability of urban environments in the face of a growing urban population and drying climate.

In many parts of the world the amount of water required to support gardens is substantial which often places strain on traditional water infrastructure. The introduction of demand management strategies, including watering restrictions, and consumer behaviour change programs that promote water efficient practices alone do not appear capable of resolving water security issues, and are in fact likely to limit broader sustainability outcomes which can be achieved at a local level through gardening for local food production, enhanced biodiversity, plus improved liveability and householder wellbeing through creation of favourable microclimates and providing close contact with nature. Urban stormwater runoff delivered from paved catchment via drainage networks is the primary cause of the poor condition of most of the developed world's 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 before urban development (Walsh et al. 2016). Achieving such regimes requires retention and harvesting of most impervious runoff to prevent it from flowing to the stream at all (Walsh et al. 2012). In this system, water savings are a large co-benefit of stream protection. This paper investigates the society benefits of source control and water efficiency by examining audited metadata from national agencies (such as the Bureau of Meteorology and the Bureau of Statistics), 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 professional advice and evidence is quite 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 large body of evidence that shows that water conservation remains a cost effective strategy (AWA, 2012; Coombes, 2012, Turner et al., 2016, Walsh, 2005). For the purposes of this paper we take an integrated water management approach to water efficiency including efficient use of water, use of alternative water sources such as stormwater, rainwater and recycled water, use of water efficient appliances and behavioural changes.

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 supply and reduce demand for mains water, and the effectiveness of strong demand management programs in uniting all of the community in meeting water saving targets.

3 METADATA OF HOUSEHOLD EXPENDITURE ON WATER

The total household expenditure for water and sewerage services for all water utilities data was derived from BOM (2016) data and shown in Figure 1. 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%. Water use has increased by 23%. However the pattern of household expenditure is not consistent across Australia. The BASIX program in NSW requires a 40% water and energy savings on the design of all new houses compared to the 2004 average. These water savings are delivered 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. So we separated the data. We restricted the data to typical water bills for connected properties (average household water bill) 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 2.

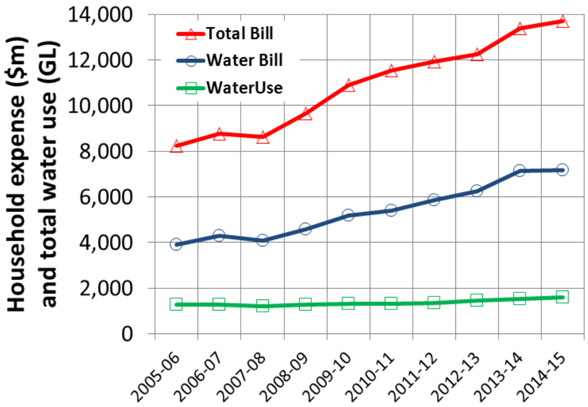

Figure 1: Household expenditure and residential water use

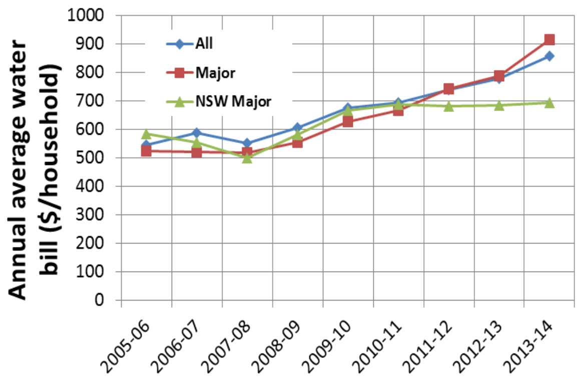

Figure 2: Average household water bills for all Australian water utilities, major Australian water utilities and NSW major water utilities.

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.

4 OPERATING COSTS OF WATER UTILITIES

The pattern of expenditure on operating costs by water utilities during and after recent drought is shown in Figure 3.

The driest year of the recent drought was 2006 and water levels in dams continued to fall during the period from 2007 to 2009. While there were some increases in operating costs during this period it would be difficult to argue that the massive water conservation campaigns run at that time generated an increase in operating costs. The increased operating costs in 2007-08 for NSW Major utilities were associated with expenditure on Sydney's desalination plant. However subsequent to the drought a number of east coast utilities saw significant increases in operating costs per property when water conservation programs were being wound back. There is no evidence of significant economic savings following cessation of water conservation campaigns in 2009-11. Figure 3 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 for all connected properties) or $1,282 per property with rainwater harvesting and water efficient appliances.

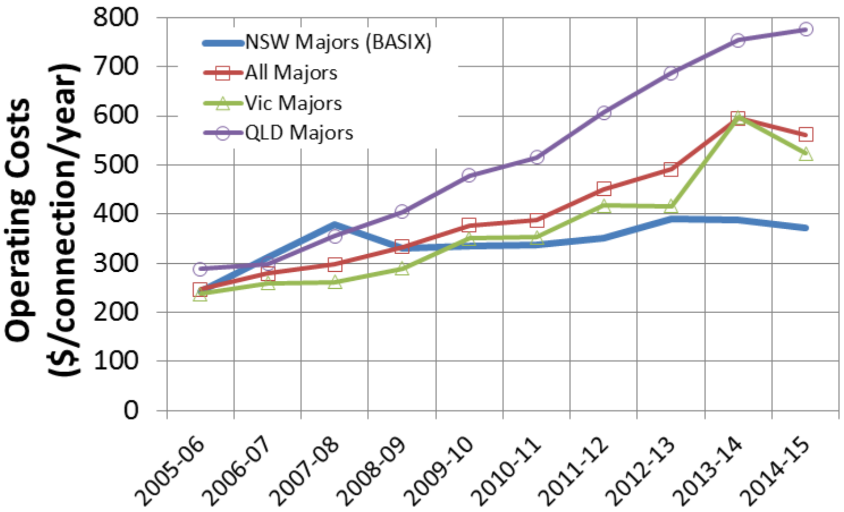

Figure 3: Water operating costs for utilities operating with mandates for sustainable buildings versus costs of other utilities (NWC, 2010; BOM, 2015).

5 RAINWATER HARVESTING AND WATER EFFICIENCY IN CITIES

One of the major alternative water sources that emerged during and since the drought was rainwater harvesting. The Australian Bureau of Statistics (ABS) estimated that rainwater harvesting systems supplied more than 156 billion litres (8% of total household use) at a saving to households of greater than $500 million in 2014 (ABS, 2015). Similar to reuse of recycled water and stormwater harvesting, rainwater harvesting needs to be carefully evaluated as a source of water used in conjunction with potable water in our cities. The number of rainwater harvesting systems (RW) in Australian capital cities, the ABS estimates of rainwater yields and value of that rainwater supply are shown in Table 1. However the yields calculated by the ABS are lower than the longitudinal observations from Coombes (2012) for rainwater tanks and water efficient appliances in South East Queensland. Table 1 shows savings achievable from existing rainwater harvesting systems in households (HH) although there is clearly potential to significantly increase the number of installations.

Table 1: Estimated rainwater (RW) yields and values for households (HH) in capital cities in 2014 (ABS, 2015)

Capital City	HHs with RW	Proportion HHs with RW (%)	Water savings (ML)	Estimated Value ($m)
Sydney	249,900	14.6	10,458	30.1
Melbourne	376,900	23.9	13,438	45.6
Brisbane	237,600	31	11,861	38.7
Adelaide	165,800	33.7	6,875	29.5
Perth	51,600	7.4	2,999	5.9
Hobart	12,100	13.5	590	2.1
Darwin	6,384	12	554	1.2
Canberra	25,922	21.3	1,296	2.8
Total	**1,126,206**	**20.4**	**47,726**	**155.9**

The Systems Framework by Coombes and Barry (2015) which operates at 6 minute time steps was also used to simulate the performance of rainwater tanks and water efficient appliances in each capital city. This approach has been verified for each capital city and 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 2 shows that the total water savings from rainwater harvesting (RWT) and water efficient appliances (WEA) was 128 GL at a household saving in water use of $400 m in 2013 ($355 per HH per year). The more comprehensive inputs to the systems analysis provide 30% greater rainwater savings for capital cities of 62,592 ML than the 47,726 ML estimated by ABS (2015). Nevertheless, either result indicates that rainwater harvesting and water efficient appliances provide substantial benefits in Australian capital cities.

Table 2: Rainwater yields, water efficiency and values in 2014 from systems analysis

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

6 SOURCE CONTROL BENEFITS – GROUND TRUTH

So far this discussion has highlighted that contribution of rainwater harvesting, water efficient appliances and sustainable gardens on reducing water demands during the Millennium drought, and reducing impacts on urban waterways. The household is presented as an integrated system that can provide multiple downstream benefits. Analysis using metadata revealed a large number of households in capital cities include rainwater harvesting and water efficient appliances. The water supply and economic impact of these houses was shown to be significant in the context of increasing household expenditure on utility water bills and operating costs in regions without programs for sustainable households. However, there is a range of 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 is the subject of monitoring for nearly 20 years. 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 the street drainage network. The performance of rainwater supply and water efficient appliances at Carrington house was confirmed by a decade of water billing records from Hunter Water Corporation from July 2003 to July 2016 as shown in Table 3.

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 that delivered additional mains water savings of 4% (8 kL/annum), 12% (24 kL/annum) and 1% (2 kL/annum) respectively. Over 85% of stormwater runoff is retained on site by the rainwater tanks and the kitchen garden. The long term performance of the household water balance is presented in Figure 4.

Table 3 Water balance results 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**

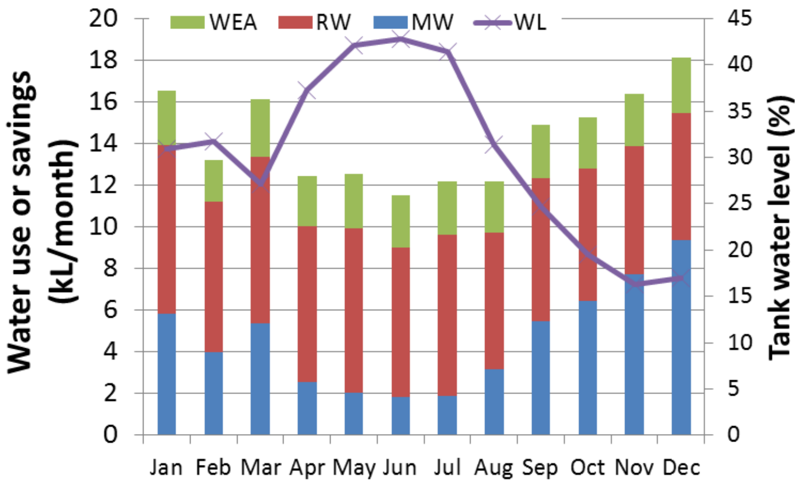

Figure 4: Long term behaviour of water efficient appliances (WEA), rainwater supply (RW), mains water supply (MW) and water levels (WL) in rainwater tank of the Carrington house

Figure 4 shows a reasonable consistent rainwater supply throughout the year and water levels in the rainwater storage were constantly drawn down. The analysis also reveals that the costs of rainwater supply ($0.58/kL) and with demand management ($0.13/kL) are substantially less that the costs of mains water supply. Note that the avoided cost of not having to purchase mains water were not counted and the full costs of the clothes washer were counted – thus the economic results are conservative. By comparison the water usage charge by Hunter Water Corporation is $2.22/kL. In addition, monitoring of the energy balance for the entire household revealed a 15% reduction in electricity use at the site in response 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 nett energy use by 61%. These results are based on meticulously detailed data on material costs, energy and water costs and detailed (hourly) monitoring over more than a decade. The results are incontrovertible. It is important to note however the technology is remarkably simple and the house operates as a connected system.

6.2 Fremantle Western Australia

A single residential detached dwelling located on a 700 m^2 block in the Perth suburb of Hilton in Western Australia included an integrated water management strategy, energy management including solar panels for local energy supply and a comprehensive monitoring program. The local climate is Mediterranean and the soil type is coarse sand. The house has four residents and was built in 2013 to include rainwater (RW) supply and greywater (GW) collection from all GW sources (excluding kitchen sink and dishwasher). The property was serviced by RW for all internal demands via filtration and UV disinfection, with back up from mains water (MW) provided by the Water Corporation. Garden irrigation demands were serviced by both 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 daily water use by source (as well as a range of other household operational parameters, such electricity and gas usage) was also installed with the aim of informing responsible consumption patterns.

The landscape was designed to create family spaces for outdoor living and play spaces for young children. Strategic placement of trees and vines enhance the thermal performance of the solar passive designed home. Food production is a major theme, with adequate space to set aside for growing fruits and vegetables, as well as composting systems and nursery included to support these activities. The garden is managed organically through natural pest and disease control and consideration of healthy urban biodiversity more broadly. Results for the household water use by source for the Case Study Site (CS3), the Perth Average and Perth Average with Bore, as well as the local Suburb Average is summarised in Figure 5. Rainwater (RW) use is compared to MW use for internal house demands for the Case Study Site by month, as well as the rainwater storage volume across the year in Figure 6.
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. The site made use of 78 kL/annum of RW for indoor water use from the 18 kL storage with an effective roof catchment of 200 m2 during 10 months of the year, which satisfied 73% of indoor water demand. The total indoor water use at the Case Study Site was 57% and 14% less than the Perth Averages and the local Suburb Average respectively. External water use at the site was less than the Perth Average with Bore but higher than the Perth Average and the local Suburb Average (131 kL/annum compared with 506kL/annum, 116kL/annum, and 90kL/annum).

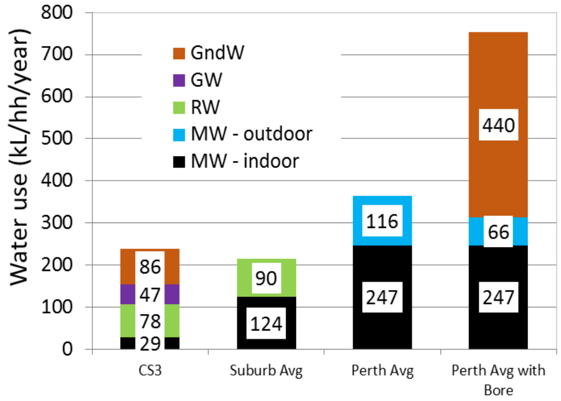

Figure 5: Water use by source at the site (CS3), for Perth and local suburb

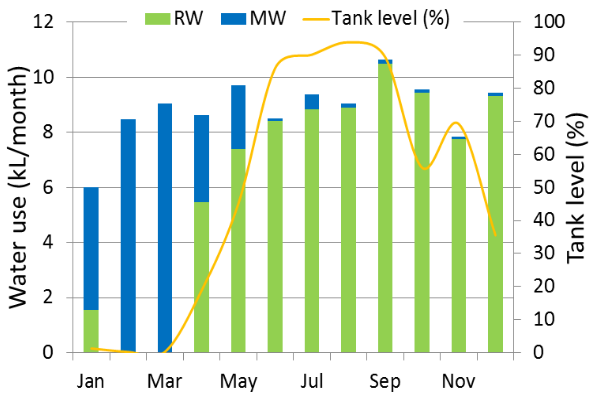

Figure 6: Rainwater versus mains water use for internal demands by month

The site does not use mains water outdoors but instead makes primary use of ground water. It uses 84kL/annum of ground water, which is 81% less than the ground water use of the Perth Average with Bore, and it is complemented by the use of 47 kL/annum of grey water. All stormwater is retained on site for harvesting or natural processes such as 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

An integrated stormwater management system was established as part of the renovation of a 121 m^2 house on a 160 m^2 property in the inner-Melbourne suburb of Richmond. The system consists of two 2.75 kL slimline tanks which collect rainwater (via charged downpipes) from all but 4 m^2 of the roof, and is plumbed into the toilets and washing machine in the 4 person household (with an automatic switch to mains supply when the rainwater storage empties). The tank overflows to a 2.9 m^2 vegetable rain-garden (Tom et al., 2013) in the rear courtyard, which overflows to a similar 2.1 m^2 garden at the front of the house. The front rain-garden also receives runoff from the 4 m^2 of roof that does not drain to the tank. This garden overflows to the stormwater drainage network at the curb, permitting monitoring of overflow events from the property. The system is not instrumented, but all periods of tank emptying were recorded, 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 about 500 m from the house, was calibrated to the monitoring data to estimate behaviour of the system. The system has operated from August 2014, and its performance has evolved as plants in the gardens have grown (particularly the large passionfruit vine that grew across the tank and continues to grow along the north facing wall of the house, providing thermal efficiency and amenity benefits of a green wall). Over one year, the system provided 40 kL of rainwater, accounting for one-third of the household water usage. The tank has provided water at >98% reliability, with two short periods when it emptied in April and October 2015. Neither rain-garden has completely emptied (although the nearly empty front rain-garden was augmented with water from the charged downpipes in January 2016), and both have supported large crops of healthy plants that required no irrigation.

The primary motivation of the system was to minimize the impact 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 from the property to the council drainage network (Figure 7). This Figure shows that performance of the system (as measured by the reduction in frequency and magnitude of overflows) has improved over time, as the area covered by the plants in the rain-gardens grew, and they consumed more water. According to the principles proposed by Walsh et al. (2012, 2016), a small proportion (10-20%) of runoff from the site should be allowed to filter into the soil (or filtration systems that mimic soil processes). However, 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.

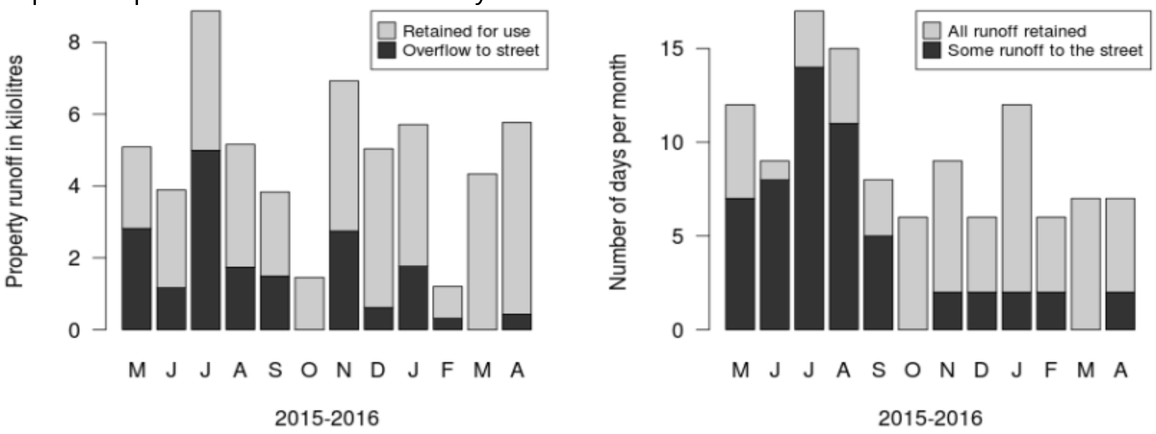

Figure 4: A: The total volume of runoff produced and retained. B: Number of days over the last year that property would have produced runoff to the street without the system is the total height of each bar. Each bar is separated into the number of days in which all runoff was retained, and the number of days in which some runoff overflowed to the street.

A common reservation about stormwater source control measures is the space that they use, but the integration of the stormwater management system into productive and attractive garden space, means that the rainwater tank (taking up less than 1% of the property) is the only component that is taking space that does not provide other uses to the property. The effective area of the rain-gardens including the 'green-wall' vine is likely to approach 10% of the property area. The system added about $8,000 to the renovation costs, thereby adding $400 pa to mortgage repayments (and less than $15 per year in pump electricity costs). For that expense, it has provided to date $95 per year from rainwater, more than $350 per year of vegetables, and unaccounted (and growing) savings in energy costs to the house through increased thermal efficiency. Consumption of electricity was since the renovation and was reduced by over 31% by installation of the 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).

7 STORMWATER BENEFITS FROM WATER CONSERVATION

Discussion about the contribution of sustainable houses is often focused on the water conservation outcomes. However, when these houses include rainwater harvesting and vegetable gardens, they also provide stormwater benefits that reduce impacts on waterways. The Systems Framework by Coombes and Barry (2015) was utilized to evaluate the impacts of reduced runoff generated by existing household rainwater harvesting systems on contaminant loads discharging to waterways in each city as shown in Table 4. This analysis also examined (results shown in brackets) the additional reductions in contaminant loads that would be created if all houses with rainwater harvesting also utilize rainwater overflows and stormwater runoff in vegetable gardens as described in the ground truth section. It was assumed that each household included 5 m^2 of vegetable gardens.

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

8 WATER SECURITY BENEFITS FROM WATER CONSERVATION

Demand for mains water is substantially diminished by households with rainwater harvesting and water efficient appliances. The reduced demand profiles can defer and lessen the need for water security infrastructure. Systems analysis of capital cities are summarised 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 requirement for water security infrastructure in each capital city created by existing rainwater harvesting and water efficient appliances in households was estimated using the Systems Framework by Coombes and Barry (2015) and are presented in Table 5.

Table 5: Net present value of water security provided water conservation for cities in 2014

Capital City	Total savings (ML/yr)	Security Value ($m)
Sydney	43,441	69
Melbourne	30,027	86
Brisbane	28,645	139
Adelaide	9,880	31
Perth	9,714	89
Hobart	1,813	21
Darwin	1,230	3
Canberra	3,089	45
Total	**127,839**	**483**

Table 5 reveals that existing rainwater harvesting and water efficient appliances have provided substantial water security benefits in each capital city by deferring the requirement to augment water security infrastructure. Water security benefits of $429 for each property with rainwater harvesting and water efficient appliances.

9 GREEN HOUSE GAS BENEFITS OF WATER CONSERVATION

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 considered the cumulative average emissions of transferring water from bulk sources via retail distribution networks to households (shown as Utility distribution in Table 6). In situations where a region includes multiple water retailers (such as Melbourne and Brisbane), the weighted average of water distribution emissions for the region was used in the analysis. Energy use of rainwater pumps and household hot water services was assumed to be 1.54 kWh/kL (see ground truth section) 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, in accordance with the ground truth sections of this paper, rainwater supply does not increase household energy use. Each option assumes that water efficient appliances reduce household energy use in the analysis. The reductions in greenhouses gas emissions created by households with rainwater harvesting and water efficient appliances for each city is shown for the existing water supply systems in 2014 in Table 6.

Table 6: Energy demand and reductions in greenhouse gas emissions from water conservation for cities in 2014

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

Table 6 shows that rainwater harvesting and water efficient appliances provided substantial reductions in greenhouse gas emissions (349,675 – 437,633 tonnes) during 2014 by reducing the energy required to treat and transfer mains water to households, and reducing energy used in households for heating water and operating appliances. It is noteworthy that additional use of desalination increases utility distribution energy use by up to 3,600 kWh/ML. The average annual reduction in greenhouse gas emissions created by 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.

10 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 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.

Australian households have been subject to rapidly increasing expenditure on utility water bills and water utilities are experiencing dramatic escalation in operating costs. However, buildings with rainwater harvesting and water efficient appliances reduce these cost burdens. In 2014, more than 1.12 million households in capital cities included rainwater harvesting and water efficient appliances to provide over 125 GL of water savings at a value of greater than $400 million to households. These average annual savings in reduced water bills are $355 per household.

These sustainable buildings reduce the requirement for water utilities to store (or manufacture), treat and transfer water to households. Comparison of the performance of major water utilities in New South Wales versus major utilities in remainder of Australia indicate that the water operating costs of water utilities have reduced by $1,282/household/year for buildings with rainwater harvesting and water efficient appliances during 2014. This equates to an annual saving of $183 for each household connected to water utilities. In addition, sustainable households provided net present benefits for water security of over $483 million in 2014. The water security benefit of sustainable buildings was more than $429/household in 2014.

Households with rainwater harvesting and water efficient appliances in our capital cities also reduced greenhouse gas emissions by up to 350,000 tonnes in 2014. This outcome was generated by reduced treatment and transfer of mains water to households, changes in water flowrates and pressures in households, and reduced flowrates through household hot water services. However, this estimation does not consider that sustainable households may reduce energy use by a greater amount than the energy required for a rainwater pump and local production of food reduces the carbon footprint of our food supplies. In this situation the annual reductions in greenhouse gas emissions created by sustainable households during 2014 may be considerably greater than 438,000 tonnes.

The contribution of buildings with rainwater harvesting and water efficient appliances to protection of urban waterways were highlighted by substantial reductions in stormwater runoff volumes (65 GL) and contaminant loads (TSS: 13,040 tonnes/year; TP: 25 tonnes/year; TN: 172 tonnes/year) in 2014. However, inclusion of vegetable gardens (or rain gardens) in the stormwater treatment train provide substantial further decreases in contaminant loads (TSS: 53,500 tonnes/year; TP: 69 tonnes/year; TN: 572 tonnes/year) in 2014.

Sustainable buildings and households have produced financial savings and amenity benefits to occupants, and reduced impacts on water cycle infrastructure and ecosystems. 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 source control strategies is clearly 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.

11 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).The case for water efficiency. AWA Position Paper. Australian Water Association.

BOM, (2015). Urban NPR full dataset 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.