SYSTEMS ANALYSIS AND BIG DATA REVEALS BENEFIT OF NEW ECONOMY SOLUTIONS AT MULTIPLE SCALES

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ABSTRACT: *Historical demographic, water resources and economic "big" data was examined and included in systems analysis to reveal the benefits of distributed solutions for household water efficiency and rainwater harvesting in Australian capital city regions. A policy requirement that new and renovated dwellings to meet water savings targets in Sydney has acted as an economic market mechanism to drive higher growth in household water savings of 48,440 ML since 2007, lower water tariffs, improved household welfare and more economically efficient utility water services. The estimated annual average economic savings to households and the water utility in Sydney was $218 m - $578 m and $58m -$881 m. These methods and insights have broader application for discovering the new economy benefits of water sensitive urban design approaches. This research presents the potential for multiple scales solutions, such as WSUD, to deliver a new economy of solutions that improve the performance of utilities and mitigate impacts on households.*

KEYWORDS: Systems Analysis, Big Data, Economics, Scales, Household Welfare, Utility costs, Cities

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1 INTRODUCTION

Cities and surrounding environments are part of a system. Urban services and outcomes should be understood and analysed as part of the system. Australian cities operate at multiple linked temporal and spatial scales, from household to region, and respond to evolving challenges and opportunities. Population growth is expanding areas, increasing densities of cities, and with greater climate variability is driving higher costs of services. In the old economy the services required by cities (such as water and energy) are mostly provided at a single centralised scale. This philosophy fosters provision of urban water services as essentially a transport industry that transfers water, wastewater and stormwater across increasingly long distances.[1]

The millennium drought revealed that decentralised approaches to increase local supply and water efficiency improved the performance of entire systems.[2] Simple strategies including household water efficiency and rainwater harvesting ensured that Australian cities did not run out of water. Solutions at multiple scales produce better overall response to variable challenges in cities. Nevertheless, centralised solutions are preferred and benefits of local strategies including water sensitive urban design (WSUD) are contested by the water industry. The Australian government's Productivity Commission, in 2011, recommended a reduced focus on water restrictions, water use efficiency and conservation in urban water system.[3] These distributed approaches were considered to be economically inefficient when compared utility water supplies. It was assumed that water efficient approaches at households had costs of $770/ML – $33,500/ML in comparison to the estimated costs of utility supply of $750/ML to $1,300/ML. In 2017, the Commission argued that water reuse, water use efficiency, water sensitive urban design and innovation has improved but it is difficult to measure and value benefits of these opportunities that may produce significant local and widespread effects on the urban water sector.[4]

An increased reliance on large scale centralised solutions such as desalination and water grids (long pipelines that connect regions and large scale supply solutions) was considered more efficient. However, the Queensland Audit Office (QOA) has established that the South East Queensland (SEQ) region inherited debt from the water grid is over $9.4 billion that corresponded with diminished economic efficiency of utility urban water supply.[5] It was assumed by the QAO that the regional water utility cannot service the debt due to decreased water use in households which reduced revenue accruing to the utility.

In contrast, Coombes et al., (2015) found that household water efficiency and rainwater harvesting reduced water use in SEQ and would decrease utility debt by over $3.5 billion in the period to 2050. Increased water use resulting from diminished household water efficiency and rainwater harvesting would drive higher utility debt and diminished household welfare from increased utility bills.[1] The economic efficiency of utility water supply was dominated by operational costs which were dependent on the volume of water demands. Similarly, the Westminster water utility in Colorado USA found that water conservation diminished the growth in water supply costs and associated household bills by 135% ($553/year). [6] Growth in household bills for utility water and sewerage services was reduced by 91% ($655/year). There are similar declines in the efficiency of water utilities with associated reductions in household welfare in North America.[7] These impacts on household welfare, dramatic increases in expenses and decline in economic efficiency of utility services are also experienced in the energy sector.[8]

The value and effect of distributed measures on households, utilities and governments is contested or uncertain. A long timeline of historical data and actions is available from Australian government agencies and water utilities that can now be used to investigate the impact of distributed solutions on the performance of urban water services. Systems analysis and forensic investigation of all available big data[9] was used to investigate the impact of household water efficiency and rainwater harvesting on water services to Australian capital city regions of South East Queensland, and Greater Sydney, Melbourne, Perth and Adelaide.

These locations were examined because they include water supply from desalination and different policies for household water efficiency and rainwater harvesting. All regions provided government incentives or subsidies to install water efficient appliances and rainwater harvesting during the Millennium drought between 2005 and

2009. The BASIX State Environmental Planning Policy was established in 2004 requiring a 40% reduction in household water use in new or renovated dwellings in Sydney. The Melbourne region was subject to the Five and Six Star housing efficiency policy that was implemented in 2005. This policy required new detached dwellings to choose either a solar hot water service or rainwater harvesting from a 50 m^2 roof connected to 2 kL rainwater tank that supplies toilet flushing. The SEQ region operated the MP4.2 and MP4.3 planning legislation, from 2008 to 2012, that required water efficient appliances and rainwater harvesting to supply clothes washers and toilets in new households.

The growth in household expenditure on utility water services, household welfare and utility water operating costs is examined to understand the economic efficiency of distributed solutions. This investigation aims to contribute to knowledge about this key question for water sensitive urban design – local actions provide whole of society benefits but what are the benefits and how do these benefits manifest across scales. This investigation also benefited from additional systems analysis of the urban water systems in each region that is reported by Barry and Coombes (2018).[10]

2 HOUSEHOLD WATER USE, WATER EFFICENT APPLIANCES AND RAINWATER HARVESTING

We examined historical household water use, and the installation of water efficient appliances and rainwater harvesting to understand the effects on urban water systems during period 2003 to 2016.

2.1 HOUSEHOLD WATER USE

Annual average household water use from 2003 to 2015 was derived from National Water Commission (NWC) [11], Bureau of Meteorology (BOM) [12] data and Utility Annual Reports by dividing total residential water use by number of connected residential properties in each year. Greater Melbourne was defined as the areas serviced by City West Water, South East Water and Yarra Valley Water. The SEQ region includes areas served by Urban Utilities, Unity Water, Gold Coast Water, Logan Water and Redlands Water. The results for Greater Sydney, Adelaide, Perth and Melbourne, and South East Queensland (SEQ) are shown in Figure 1.

Figure 1 shows that household water use in each region was reduced (SEQ 28%, Sydney 10%, Perth and Melbourne 5%) or only slightly increased in Adelaide (2%) since 2003.

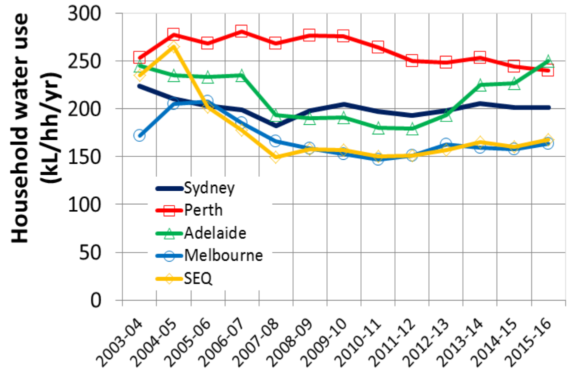

***Figure 1:** Historical average annual household water use for South East Queensland (SEQ), and Greater Sydney, Perth, Adelaide and Melbourne regions from 2003 to 2016.*

These reductions or small increase in average household water use were achieved in the context of substantial growth in dwellings in each region from 29.8% for SEQ to 14.9% for Sydney. The impact of water restrictions during the drought period from 2005 to 2009 is apparent from Figure 1 as small reductions in household water use in some regions. However, the overwhelming outcome is the stabilisation or reduction in average household water use over the entire period which indicates increased efficiency of household water use.

2.2 INSTALLATION OF WATER EFFICIENT APPLIANCES AND RAINWATER HARVESTING

Installation of rainwater harvesting and water efficient appliances was investigated to understand their contribution to more efficient household water use. The national surveys of household water use and conservation for 2007, 2010 and 2013 published by Australian Bureau of Statistics (ABS) in 2013 was examined for this task.[14] Detailed spatial information underpinning this publication was obtained in 2017 and analysed with spatial demographic data from ABS (such as Community Profiles) to define the installation of rainwater harvesting and water efficient appliances throughout each region. Data from the NSW government BASIX policy [13] and from surveys of industry sales were also utilised to determine the number of rainwater harvesting installations in each year.

Examination of spatial detail underpinning the ABS 2013 publication provided amended results for

NSW, Queensland and Victoria. The dataset was also characterised by a high level of spatial variability, and revealed that capital city statistical regions in the publication do not correspond with water supply regions for each city. However, finer spatial detail in the dataset permitted a better approximation of the installation of water efficient appliances and rainwater harvesting across local government areas and within urban water supply regions. Results for installation of rainwater harvesting and connection of rainwater supplies to indoor uses in each water supply region are presented in Table 1.

Table 1: *Dwellings with rainwater harvesting and rainwater harvesting for indoor uses*

Region	Dwellings with rainwater harvesting (%)			Indoor uses in 2013 (%)
	2007	2010	2013	
Sydney	14	16.4	19.6	42
Melbourne	18.3	21.4	21.4	29
SEQ	19.8	28.8	27.9	31.7
Adelaide	38.7	27.3	34	29
Perth	9.5	7.2	9.4	32.6

The Sydney region experienced a 5.6% growth in rainwater harvesting and has a greater proportion of connection of rainwater harvesting (42%) to indoor uses. This is expected to generate greater rainwater yields. Both Melbourne (3.1%) and SEQ (8.1%) were subject to increases in rainwater harvesting, whilst Adelaide (-4.7%) experienced negative growth in rainwater harvesting. The proportion of Perth households installing rainwater harvesting was relatively static across the survey period (-0.1%). In 2013, Adelaide had the greatest proportion of dwellings with rainwater harvesting (34%) and Perth had the lowest proportion of rainwater Harvesting (9.4%).

The installation of dual flush toilets and the change in proportion of households with dual flush toilets are presented in Table 2.

Table 2: *Dwellings with dual flush toilets*

Region	Dwellings with dual flush toilets (%)			Change since 2007 (%)
	2007	2010	2013	
Sydney	66.6	81.8	85.7	19.1
Melbourne	80.2	88.7	90.8	10.6
SEQ	75.4	90.4	91.6	16.2
Adelaide	78.9	88.9	90.9	12
Perth	80.6	86.1	90.8	10.2

Table 2 shows that all regions experienced growth in the proportion of households with dual flush toilets. Sydney experienced the highest change (19.1%) and Perth had the lowest change (10.2%) in proportions of households with dual flush toilets since 2007. In 2013, SEQ had the greatest proportion of dwellings with dual flush toilets (91.6%) and Sydney had the lowest proportion of dual flush toilets (85.7%).

The installation of low flow showers and the change in proportion of households with low flow showers are presented in Table 3.

Table 3: *Dwellings with low flow showers*

Region	Dwellings with low flow showers (%)			Change since 2007 (%)
	2007	2010	2013	
Sydney	57.8	64.8	66.1	8.3
Melbourne	44.4	69.2	71.9	27.5
SEQ	49.8	76.9	79.4	29.6
Adelaide	48.7	64.2	68.9	20.4
Perth	42.4	62.1	66	23.6

Table 3 reveals that all regions experienced increased uptake of low flow showers with the highest change in SEQ (29.6%) and lowest change in Sydney (8.3%). In 2013, SEQ had the greatest proportion of dwellings with low flow showers (79.1%) and Perth had the lowest proportion of low flow showers (66%). The installation of water efficient clothes washers and the change in proportion of households with water efficient clothes washers are presented in Table 4. Note that survey data was not available for 2007.

Table 4: *Dwellings with water efficient clothes washers*

Region	Dwellings with water efficient clothes washers (%)		Change since 2010 (%)
	2010	2013	
Sydney	25.5	32	6.5
Melbourne	31	40.6	9.6
SEQ	32.1	34.4	2.3
Adelaide	34.8	44.7	9.9
Perth	32.3	43.3	11

Table 4 shows that Adelaide experienced the greatest change in dwellings with water efficient clothes washers (9.9) and SEQ had the lowest change (2.3%). In 2013, Adelaide had the greatest proportion of dwellings with water efficient clothes washers (44.7%) and Sydney had the lowest proportion (32%).

Examination of the ABS survey data of water efficient appliances and rainwater harvesting at households revealed increased proportions of dwellings with rainwater harvesting (expect for Adelaide and Perth), dual flush toilets, low flow showers and water efficient clothes washers during the period 2007 to 2013. These results suggest an increased proportion of water efficient households in each region contributed to the stabilisation of reductions in average annual household water use over time.

3 SAVINGS FROM WATER EFFICIENT APPLIANCES AND RAINWATER HARVESTING

Each local government area, suburb in the regions has different numbers of dwellings, growth rates and climate processes which will impact on the quantum of water savings. Average water savings from rainwater harvesting and water efficient appliances for households in each city were estimated by Coombes et al., (2016)[2] as shown in Table 5.

Table 5: *Estimated average household water savings from rainwater harvesting and water efficient appliances.*

Region	Rainwater savings (kL/yr)		WEA savings (kL/yr)
	Indoor + outdoor	Outdoor only	
Sydney	70	48	49
Melbourne	53	37	33
SEQ	66	46	25
Adelaide	43	30	28
Perth	54	38	48

Table 5 shows results for households that use rainwater for outdoor uses only, and for indoor and outdoor uses. These results were derived from analysis of the performance of 5 kL rainwater tanks connected to 100 m^2 roof areas at a single location in each city. Indoor use was defined as rainwater supply to laundry and toilets. Detailed spatial analysis of household water demands, water efficient appliances, rainwater harvesting and numbers of dwellings in each local government area or suburb was also conducted by Barry and Coombes,[10] and included in the assessment of water savings for Perth, Melbourne and Sydney. The mains water savings from rainwater harvesting (Table 5) were combined with the numbers of dwellings from the ABS Community and Housing Profiles and the information in Table 1 to estimate water savings from rainwater harvesting for each region as shown in Figure 2. These results for rainwater savings were combined with numbers of dwellings, savings from water efficient appliances (WEA) in Table 5 and information in Tables 2 to 4 to estimate total water savings in each region shown in Figure 3.

The numbers of dwellings with rainwater harvesting and water efficient appliances in 2016 were determined as an extension of the trend from the period 2007 to 2013. Data from the NSW BASIX Policy[14] shows rainwater harvesting was installed in 80% of new dwellings and rainwater supplied indoor uses in 78% of those dwellings. This data was also incorporated in the estimates for the period 2013 to 2016 for Sydney. Industry sales data was also used to determine that 10% of new houses in Melbourne installed rainwater harvesting after 2013 in response to the Victorian Six Star Policy.

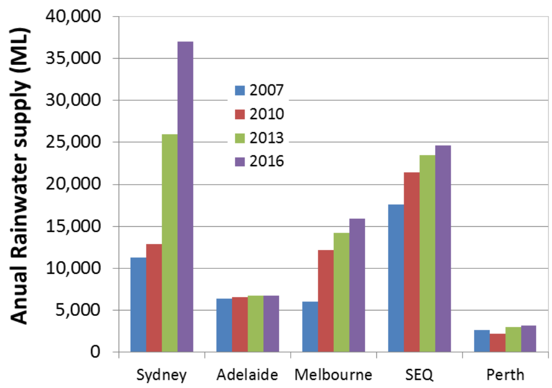

Figure 2: *Water savings from rainwater harvesting for each region*

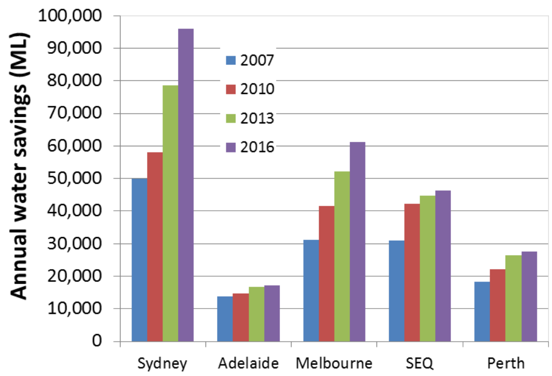

Figure 3: *Water savings from rainwater harvesting and water efficient appliances for each region*

Figure 2 shows all regions experienced growth in rainwater savings. Sydney, Melbourne and SEQ displayed higher growth in rainwater savings since

2007 that was driven by policies mandating or encouraging rainwater harvesting. Sydney had the greatest increase in annual rainwater savings of 27,730 ML (229%) since 2007 and Adelaide has the lowest increase in annual rainwater savings of 348 ML (5%).

Figure 3 demonstrates that all regions experienced growth in annual water savings from rainwater harvesting and water efficient appliances since 2007. Sydney had the highest growth in water savings of 46,440 ML (93%) and Adelaide had the lowest growth in water savings of 3,253 ML (23%). This analysis has demonstrated that local solutions such as water efficient appliances and rainwater harvesting at dwellings has made a substantial contribution to reducing potential growth in water demand in each region. The magnitude of household savings and the rate of growth in those savings is different for each region.

4 HOUSEHOLD WELFARE AND UTILITY OPERATING COSTS

Household expenditure on utility water services impacts on household disposable income which influences household welfare and ultimately consumption in the economy. Household welfare was considered a macro-economic indicator of economic efficiency of water utilities in each region. Utility water operating costs were found by Coombes et al., (2015) to be a dominant proportion of the costs of providing urban water services and a measure of the efficiency of utility services.[1] Water operating costs are considered a micro-economic indicator of utility performance in this investigation.

4.1 NATIONAL CONSUMER EXPENSES AND URBAN WATER USE

National results for total consumer (Total Bill) and household expenditure (Total Household Bill) on utility water and sewerage services, and total urban water use (Water Use) was derived from BOM[11] and NWC[12] data as shown in Figure 4.

Figure 4 reveals that total expenditure on urban water services increased by 95% ($6,695 million) and household expenditure increased by 116% ($5,450 million) for a 3% (88 GL) increase in utility supply. The change in Consumer Price Index (CPI), a measure of the changing value of money over time or inflation, during the same period was 38%.[15] Determination of the present values of national expenses (adjusted for inflation effects) for all urban water and sewerage services reveals a 41% real decline in economic efficiency. These results indicate that the historical national average real marginal cost of urban water services was $46/kL. This is a significant national average loss of economic efficiency of utility water services to urban areas.

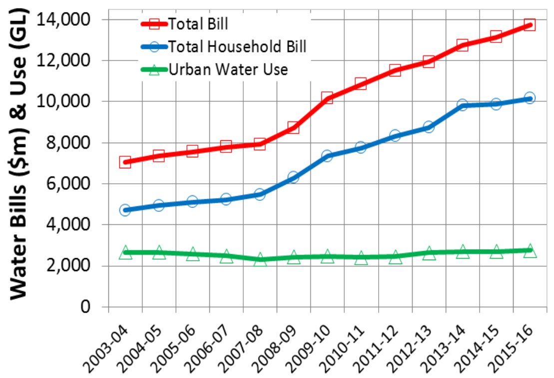

***Figure 4:** National expenditure for all connections (Total Bill) and households (Total Household Bill) on utility water services and urban water use.*

Figure 4 reveals that household expenses are a substantial proportion of the total consumer revenue paid for urban water and sewerage services. The proportion of household expenses has increased from 67% to 74% whilst the proportion of household water use has declined from 61% to 60% of total urban water use. Households are paying a greater proportion of urban water revenue. National results for household expenditure on utility water and sewerage services (Total Household Bill), household expenditure on utility water services (Household Water Bill) and household water use were also derived from BOM[11] and NWC[12] data and shown in Figure 5.

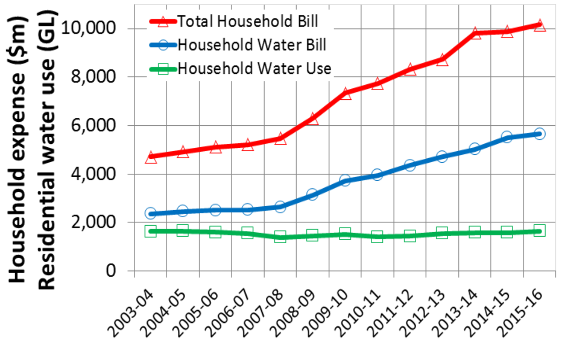

***Figure 5:** National expenditure by households on utility water and sewerage services and household water use.*

Figure 5 highlights that household water bills increased by 140% ($3,290 million) for a 1.7% (28 GL) increase in household use of utility water services. These results represent a real increase in household expense for utility water services of 74% and a real historical marginal cost of $85/kL for utility water supply to households. The historical real marginal cost for utility water and sewerage services to households was $140/kL. These results for real increases for total consumer and household expenses, and historical marginal costs of utility services represent a substantial loss in economic efficiency from a national perspective.

4.2 REGIONAL HOUSEHOLD EXPENSE FOR UTILITY WATER SERVICES

The magnitude and patterns of household expenditure for utility water services are unlikely to similar across Australia. Household expenses for utility water services is presented for Sydney, SEQ, Melbourne, Adelaide and Perth regions in Figure 6.

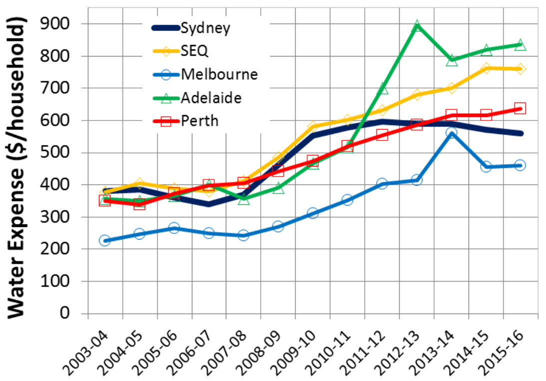

Figure 6: *Regional average annual expenditure by households on utility water services in Sydney, SEQ, Melbourne, Adelaide and Perth regions*

Figure 6 shows all regions are subject to increases in annual household expenses for utility water services. The trend for average annual household expenses for Sydney is different to the other regions with household expenses stabilising and declining after the 2009-10 financial year. This result is consistent with the greater and more substantial increases in household water savings of 46,440 ML (93%) in Sydney that is presented in Figure 3. The nominal (actual) and real (adjusted for inflation) changes in household expenses for utility water services is summarised in Table 6 for each capital city region.

Table 6: *Nominal and real changes in household expenses for utility water services for Sydney, Melbourne, SEQ, Adelaide and Perth*

Region	Change in household water expense			
	Nominal		Real	
Sydney	$180	47%	$35	7%
Melbourne	$236	104%	$150	48%
SEQ	$381	101%	$237	45%
Adelaide	$479	134%	$343	70%
Perth	$285	81%	$151	31%

Table 6 reveals that Sydney households experience the smallest real increase in household expenses for utility water services of $35 (7%). The remainder of the regions were subject to higher increases in real household expenses for utility water services ranging from $151 (31%) for Perth to $343 (70%) for Adelaide.

Median available household income (AMI) in each region was defined using the ABS Population and Housing[16] data as median income less taxation (disposable income) less mortgage or rent expenses. The proportion of household water expense (HWE) of available income was defined as (HWE/AMI). Increased real impact on household welfare was defined the change in real household water expense (HWE) divided by available household income (AMI). These values are summarised in Table 7.

Table 7: *Available median income (AMI), utility water expense (HWE) and real effect on households in Sydney, Melbourne, SEQ, Adelaide and Perth*

Region	AMI ($/yr)	HWE ($/yr)	HWE /AMI (%)	Change HWE/ AMI (%)
Sydney	41,530	560	1.35	0.08
Melbourne	39,180	461	1.18	0.38
SEQ	39,090	461	1.95	0.61
Adelaide	33,130	836	2.52	1.04
Perth	40,120	636	1.58	0.38

Table 7 shows that household expense for utility water services were the lowest proportion of available household income in Melbourne (1.18%) and highest proportion is in Adelaide (2.52%). Sydney was subject to the smallest change in household expense as a proportion of available income (0.08%) and the largest increase was experienced by Adelaide (1.04%). The increased proportion of available household income spent on utility water services reduces the funds available for consumption of goods in the economy which impacts on the gross domestic product (GDP) and household welfare.

Mack and Wrase (2017) highlight that the American Environment Protection Agency recommends that expenses for utility water services should be less than 2% of median household income.[7] Household expenses in Adelaide may exceed this criteria. However, the impact on lower income households (gross weekly household income of $650) in each region is significant – for example, household expense on utility water services is greater than 2.3% of available income in 17% of Sydney households and greater than 10.5% in 23% of Adelaide's households, and the changed impact since 2003 is 0.4% of available income in Sydney and 4.3% of available income in Adelaide.

The expense of utility water services in lower income households was greater than 9.6%, 8% and 5.8% of available income in SEQ, Perth and Melbourne. The impact of real increases in utility water expenses on lower income households was 3%, 1.9% and 1.9% of household available income for SEQ, Perth and Melbourne.

The economic efficiency of utility water supply, as defined by household expenditure, has declined in all of the regions which impacts on household welfare and gross domestic product. These impacts are substantially reduced in Sydney that has the highest growth in water savings due to water efficient appliances and rainwater harvesting.

These results indicate that higher growth in water savings has driven down utility water tariffs (Sydney has the second lowest usage and lowest fixed utility water changes) which has reduced household expenses for utility water services across the entire Sydney region relative to other regions. This provides additional benefit of reduced utility water expenses to low income households.

4.3 REGIONAL IMPACTS ON WATER OPERATING COSTS

The change of utility water operating costs per connection, during the period 2003 to 2016, was examined to understand the efficiency of the urban water systems in each region as shown in Figure 7.

Figure 7 shows that utility operating costs of providing water services has increased across all regions since 2003. The lowest and highest increases in utility water operating costs were in Sydney (59%) and SEQ (269%).

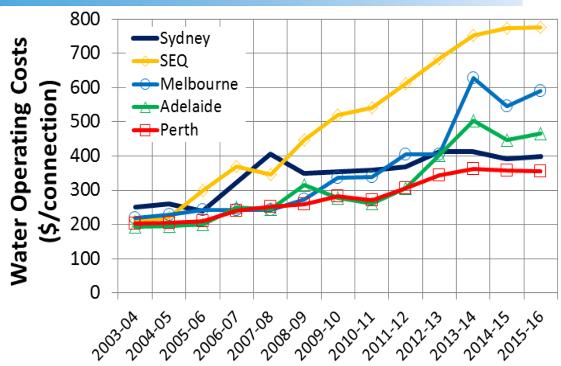

Figure 7: *Regional utility operating costs in Sydney, SEQ, Melbourne, Adelaide and Perth regions*

The nominal and real changes utility water operating costs per connection for each region is presented in Table 8.

Table 8: *Nominal and real changes in utility water operating costs per connection for Sydney, Melbourne, SEQ, Adelaide and Perth*

Region	Change in operating costs			
	Nominal		Real	
Sydney	$148	59%	$53	15%
Melbourne	$361	158%	$273	85%
SEQ	$565	269%	$485	167%
Adelaide	$271	140%	$197	73%
Perth	$162	76%	$81	28%

Table 8 demonstrates that SEQ (167%), Melbourne (85%) and Adelaide (73%) have experienced substantial real increases in operating costs since 2003. Sydney (15%) and Perth (28%) had the significantly lower real increases in water operating costs. Sydney experiences a different pattern of growth in water in utility water operating expenses that stabilises after the 2007-08 financial year that consistent with the growth in household water savings (Figure 3). In contrast, the SEQ region is subject to a high growth in water utility operating costs that may be driven by implementation of a regional water grid after 2008.

5 DISCUSSION

This study aimed to understand the effect of distributed local solutions, such as household water efficiency and rainwater harvesting, on the economic efficiency of urban water services in selected capital city regions. The changes in household expenses for utility water services, household welfare, historical marginal costs and the water operating costs of water utilities were characterised as describing economic efficiency. A fairly long timeline (2003 – 2016) of demographic, economic and water resources data was examined.

Analysis of all urban water systems in Australia revealed a 41% average increase in real revenue for water and sewerage services and a 3% increase in total urban water supply. The average historical marginal costs (2003 – 2016) were $46/kL for urban water supply. The total revenue earned by urban water utilities has increased substantially in real terms and the economic efficiency of utility urban water services has declined from a national perspective.

The proportion of urban water revenue paid by households has increased from 67% to 74%. Total household water use has declined from 61% to 60% of national urban water use. Households provided a 74% real increase in revenue for water and sewerage services and the real marginal cost of providing these services to households was $140/kL. These results indicate substantial economic inefficiency of utility water services and it is unlikely that distributed solutions are not competitive – on average, a medium run marginal cost of distributed alternative supply of less than $140/kL would be more efficient.

It is accepted that regional characteristics and economies of scale of urban water utilities may be vastly different to the national average performance. So the behaviour of urban water systems in capital city regions that also include desalinated water supplies was examined. Average annual household water use was found to decline or stabilise in the South East Queensland, and Greater Sydney, Melbourne, Adelaide and Perth regions. The improved or stable efficiency of annual average household water use was experienced in the context of considerable dwelling growth in each region. It would seem that water use efficiency of housing stock is improving in most regions.

Multiple layers of historical (2007 – 2013) and spatial (suburbs, local government areas, statistical regions) information about demographics, and numbers of dwellings with water efficient appliances and rainwater harvesting was combined to understand the changes in household water efficiency in each region. All of the selected capital city regions were subject to increases in the proportion of houses with water efficient appliances. Greater proportions of dwellings in Sydney, Melbourne and SEQ included rainwater harvesting. A significantly higher proportion of rainwater harvesting systems in Sydney were supplying household indoor uses. The increased numbers of water efficient houses are contributing to reduced or stable average household water use in each region.

This information was combined with observed residential water at each suburb or local government area in systems analysis[9,10] to quality the water savings from rainwater harvesting and water efficient appliances. All regions yielded significant water savings at households but the Sydney region displayed the largest growth in household savings (46,440 ML) since 2007. Substantial real increases in average annual household expenditure on utility water services of 31% ($151) to 70% ($343) were experienced across the regions. Households in the Sydney region only experienced a 7% ($35) real increase in expenditure on utility water services and the growth in household expenses for utility water services stabilised and declined after the 2009-10 financial year.

Real increases in household expenses for utility water services were shown to impact on available income and associated household welfare in each region. Reduced disposable income will also reduce consumption in the local economies. The impacts of changes in utility water expenses on household welfare were lowest in Sydney. The overall reduction in household water use due to water efficient appliances and rainwater harvesting has also produced lower tariffs for water services in Sydney that benefit all households. Examination of the utility water operating costs revealed real increases in operating costs in all regions ranging from 15% ($52/connection) in Sydney to 167% ($485/connection) in SEQ. Sydney also experiences a different pattern of growth in utility water operating costs that stabilises after to 2007-08 financial year.

The household water savings in the Sydney region and associated economic benefits are substantially greater than the other regions that rely on minimum standards or short term subsidies for water efficiency and optional local water supply solutions such as rainwater harvesting. The Sydney region is also subject to the lowest growth in household expenditure for utility services and in utility water operating costs. This has produced economic benefits for all households via lower water tariffs.

New and renovated dwellings in the Sydney region are required by the BASIX State Environmental Planning Policy to reduce water use by 40% in comparison to a reference year. This policy intervention has acted as a market mechanism to create widespread local scale competition for water services via household water efficiency and rainwater harvesting. This competition has improved the economic efficiency of utility water supply by reducing operating costs and household expenditure relative to other regions. The average annual economic value relative to the other regions for reduced utility water operating costs are $53 m - $810 m and for household expenditure are $218 m - $578 m. It is noteworthy that the values of water saving at households were not included in this analysis. The household benefits revealed in this investigation are produced by lower utility tariffs that result from distributed water savings.

This investigation has shown that household water efficiency and rainwater harvesting – distributed solutions – provide benefits to households, water utilities and whole of society. These distributed approaches improve the economic efficiency of the entire urban system. These methods and insights have application to understanding the value of a wide range distributed or multiple scale solutions that characterise Water Sensitive Urban Design approaches. The results in this investigation suggest that an opportunity of a new economy of solutions at multiple scales. However, as shown by Barry and Coombes (2017), understanding the benefits and opportunities of multiple scale solutions requires detailed bottom up investigation of data and systems analysis. Use of top down averages or assumptions provides an illusion of minimum benefit from distributed solutions.

6 CONCLUSION

Systems analysis of historical demographic, water resources and economic data has revealed the benefits of distributed solutions for household water efficiency and rainwater harvesting. A policy requirement for new and renovated dwellings to meet water savings targets in Sydney has acted as an economic market mechanism to drive higher household water savings, lower water tariffs, improved household welfare and more economically efficient utility water services. These methods and insights have broader application in discovering the new economy benefits of water sensitive urban design approaches.

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