Independent research and consulting

Effectiveness of rainwater harvesting for management of the urban water cycle in South East Queensland

For

The Association of Rotational Moulders Australasia

and

The Rainwater Harvesting Association of Australia

By

Dr. Peter Coombes

Independent research and consulting

70 Howden Street Carrington NSW 2294 ■ Tel: 0419 439 124 ■ thecoombes@bigpond.com ■ www.urbanwatercyclesolutions.com

About the Author

Dr Peter Coombes was the Managing Director of Bonacci Water, a conjoint Associate Professor of Integrated Water Cycle Management at the University of Newcastle, an Associate Professor of Chemistry and Biomolecular Engineering at Melbourne University and former chairman of the Stormwater Industry Association.

Peter is currently the managing director of Urban Water Cycle Solutions that operates as an independent research and consulting think tank.

He was one of the architects of the new Victorian government water policy Living Melbourne, Living Victoria; the recent report on water reform in the Greater Sydney region and restoration of Al Asfar Lake system in the historical city of Al Hasa.

Peter has served as a member of advisory group to the Prime Ministers Science, Engineering and Innovation Council, a member the advisory council on alternative water sources for the Victoria Government's Our Water Our Future policy, a member of the advisory panel on urban water resources to the National Water Commission, an advisor on alternative water policy to the United Nations and a research leader of innovative WSUD strategies in the eWater CRC.

His research interests include Integrated Water Cycle Management, Water Sensitive Urban design, hydrology, analysis of complex systems and molecular sciences including water quality. He has generated over 150 scientific publications and designed more than 120 sustainable projects including settlements that generate all of their water resources. Dr. Coombes was also a co-author of Australian Runoff Quality.

Executive Summary

The Queensland Government is currently considering changes to the Queensland Development Code MP 4.2 – Water Savings Targets and MP 4.3 – Alternative Water Sources – Commercial Buildings. Building Codes Queensland are conducting a cost benefit analysis of rainwater harvesting for new homes which will used to define the changes to the relevant Queensland development codes.

The Association of Rotational Moulders Australasia (ARMA) and the Rainwater Harvesting Association of Australia (AHAA) commissioned Dr Peter Coombes from Urban Water Cycle Solutions to develop a submission to the Queensland Government.

This investigation includes the results of independent monitoring programs (including the long term monitoring project that reported to the Queensland Water Commission and the Auditor General), the latest research results, recently investigations into reform of water policies (such as the Living Victoria policies) and continuous simulation of the performance of rainwater tanks within an integrated systems analysis. This report also provides a brief review of various claims made about the performance of rainwater tanks in the water industry.

This investigation summarises the results of independent long term monitoring of household water use in the South East Queensland to demonstrate the actual performance of the Queensland Development Code MP 4.2.

An overview of key independent water research, analysis and policy results are provided to clarify the actual performance of rainwater tanks. An integrated systems framework for South East Queensland was utilised to generate whole of water cycle responses to the use of rainwater tanks for inclusion in an investment economics analysis to understand the whole of society value of rainwater tanks.

The analysis in this study focuses on the benefits that rainwater tanks provide to water authorities, local and state government.

Key findings

The Queensland development Code MP 4.2 has:

1. Provided annual water savings of 21.2 to 11.3 GL
2. Generated economic benefits to the State of Queensland of $2,282 to $4,285 for dwellings with rainwater supply

Continuing the Queensland Develop Code MP 4.2 will:

3. Provide annual water savings of 57 GL to 107 GL by 2056
4. Defer regional augmentation by 4 years to 8 years
5. Generate economic benefits to the state of Queensland of $1,557 to $4,041 for dwellings with rainwater supply

Including rainwater supply to hot water services in Queensland Development Code MP 4.2 will:

6. Provide annual water savings of 136 GL by 2056
7. Defer regional augmentation by 12 years

8. Generate economic benefits to the state of Queensland of $6,720 for dwellings with rainwater supply

Inclusion of renovated dwellings in the Queensland Development Code MP 4.2 will:

9. Provide annual water savings of 79 GL to 190 GL by 2056
10. Defer regional augmentation by 6 years to 20 years
11. Generate economic benefits to the state of Queensland of $1,846 to $6,933 for dwellings with rainwater supply

An integrated systems perspective of the performance of rainwater tanks reveals:

12. Household with rainwater tanks provide benefits to the entire water cycle at multiple scales from household to neighbourhood to suburb to city to region. A majority of these benefits accrue to water authorities, whole of society, local and state governments.
13. Traditional analysis that only considers water savings at households excludes the majority of benefits created by use of rainwater tanks.
14. A common practice of using generic analysis techniques and average assumptions also grossly under-estimate yields from rainwater harvesting systems.
15. A singular focus on water savings at households and revenue earned by water authorities rather than whole of system reductions in operating costs provides an illusion that water authorities and household rainwater tanks are competitors

An independent and long term monitoring program of water use in households across South East Queensland demonstrates:

16. The water use behaviour of 50 households was monitored using mini smart meters during the period February 2009 to May 2010. Audits were also completed to accurately define the characteristics of each household. Each household also completed a water use diary.
17. Households without rainwater tanks had an average daily mains water demand of 514 litres and a per-capita daily demand of 139 litres.
18. Households using rainwater for outdoor use only had an average daily mains water demand of 383 litres and a per-capita daily demand of 117 litres – annual savings of 47.8 kL.
19. Households using rainwater for indoor and outdoor uses had an average daily mains water use of 268 litres and a per-capita demand of 63 litres – annual savings of 89.8 kL.
20. The performance of households using rainwater for indoor and outdoor uses exceeded the requirements of Queensland Development Code MP 4.2.
21. Rainwater tanks demonstrated resilience to changes in climate and water demands throughout the monitoring period.
22. Relatively small rainwater tanks (2 kL) and roof areas (50 m^2 to 100 m^2) generated the largest reductions in mains water use. This demonstrates that rainwater harvesting will be (and is) successful on smaller allotments.
23. Use of rainwater for indoor uses reduced peak daily and hourly mains water demands which will diminish impacts on and requirement for water distribution, pumping and treatment infrastructure.

An overview of independent research and development of policy for rainwater harvesting in new and renovated housing shows:

24. Defer the requirement to augment regional water supplies (new desalination plants and dams) at substantial economic savings.
25. Reduce the net present cost of operating water authorities from $57 to $6,371 for each household with a rainwater tank.
26. A 5 kL rainwater tank used to supply laundry, toilet and outdoor uses should reduce the net present costs of operating water authorities by at least $1,442 for each household with a rainwater tank.
27. Rainwater tanks are resilient to drought and climate change with negligible reductions in yield.
28. Diminish requirements for and the costs to manage detention basins and constructed wetlands.
29. Reduce the traditional lumpy and expensive "just in time" investment in water infrastructure and associated high finance costs.
30. Substantially reduce greenhouse gas emissions, carbon and land costs.

Independent long term monitoring of rainwater harvesting systems throughout Australia has revealed:

31. A majority of rainwater harvesting systems are compliant with Australian Drinking Guidelines for metals and elements.
32. The quality of rainwater supplied from hot water services was always compliant with Australian Drinking Water Guidelines. Laboratory experiments also demonstrate rapid death of pathogens in hot water services.
33. Surveys of people drinking rainwater prove that the health of people using rainwater is equal or better than the health of people drinking mains water.

Conclusions and recommendations

A. Households with rainwater tanks to supply indoor and outdoor water uses have exceeded the requirements of the Queensland development Code MP 4.2.

B. These households have provided annual water savings of 21.2 GL to 11.3 GL in the South East Queensland region at an economic benefit to the Queensland government of $2,282 to $4,285 for each household with a rainwater tank.

C. Continuing with the Queensland Development Code MP 4.2 will provide substantial economic benefits of $1,557 to $4,041 for each household with rainwater tanks and annual water savings of 57 GL to 107 GL by 2056.

D. Extending the MP 4.2 strategy to include use of rainwater in hot water services and installation of rainwater tanks for renovated housing with provide considerable economic benefits to the Queensland government of $1,846 to $6,933 for each household with rainwater tanks and annual water savings of 130 GL to 190 GL.

E. The whole of water cycle and society benefits of alternative strategies that are an essential part of an integrated and robust water strategy cannot be understood unless an integrated systems analysis perspective is adopted.

F. Similarly, the economic benefits of alternative strategies cannot be understood using partial analysis that excludes most of the benefits to Queenslanders.

G. It is recommended that the Queensland government utilised independent systems analysis of the entire water and investment economic cycles to fully understand the value of diverse and integrated strategies.

1. Introduction

The Queensland Government is currently considering changes to the Queensland Development Code MP 4.2 – Water Savings Targets and MP 4.3 – Alternative Water Sources – Commercial Buildings. Building Codes Queensland are conducting a cost benefit analysis of rainwater harvesting for new homes which will used to define the changes to the relevant Queensland development codes.

The Association of Rotational Moulders Australasia (ARMA) and the Rainwater Harvesting Association of Australia (AHAA) commissioned Dr Peter Coombes from Urban Water Cycle Solutions to develop a submission to the Queensland Government. This report provides information and research results that addresses the following key issues:

- The contribution of urban rainwater tanks to managing the security and resilience of Queensland's water supplies;
- The whole of water cycle system benefits of rainwater tanks for management of the cost of infrastructure by deferral or delays in requirement to augment existing infrastructure, reducing the need to construct new infrastructure and reducing the impacts of stormwater runoff;
- The viability of rainwater tanks on small lots; and
- The performance of smaller roof catchments throughout Queensland – in particular in areas with higher rainfall

This investigation includes the results of independent monitoring programs (including the long term monitoring project that reported to the Queensland Water Commission and the Auditor General), the latest research results, recently investigations into reform of water policies (such as the Living Victoria policies) and continuous simulation of the performance of rainwater tanks using robust scientific methods. This report also provides a brief review of various claims made about the performance of rainwater tanks in the water industry.

In addition to the water saving initiatives specified in the Queensland Development Code, the current South East Queensland Water Strategy[1] outlines ongoing commitment to the following demand management policies:

- Target 200 - voluntary residential water use targets of 200 Litres/person/day;
- Encouragement of water efficiency for all new commercial and industrial buildings; and
- Local (off grid) water supplies for new homes, and most commercial and industry buildings.

These initiatives were expected to deliver reductions in water use of 35 GL/annum in 2026 and 60 GL/annum in 2056.

However, it is noted that residential water use in South East Queensland has reduced from 282 Litres/person/day in 2005 to 131 Litres/person/day during the period 2007 to 2009. Following the drought and severe water restriction, the residential water use in south East Queensland has increased to 163 Litres/person/day.[2]

These results imply that the total magnitude of residential water savings during the recent drought was about 150 GL/annum and the response to water restrictions generated approximately 45

[1] QWC (2010). South East Queensland water strategy. The Queensland Water Commission
[2] QWC (2011). South East Queensland water strategy – annual report. The Queensland Water Commission

GL/annum reductions in water use. Thus water efficient appliances, changes of behaviour and local water supply (including rainwater tanks) has produced about 105 GL/annum of water savings.

An estimated 236,000 homes use rainwater harvesting to supplement mains water supplies throughout South East Queensland.

Key processes:

This investigation summarises the results of independent long term monitoring of household water use in the South East Queensland to demonstrate the actual performance of the Queensland Development Code MP 4.2.

An overview of key independent water research, analysis and policy results are provided to clarify the actual performance of rainwater tanks.

An integrated systems framework for South East Queensland was utilised to generate whole of water cycle responses to the use of rainwater tanks for inclusion in an investment economics analysis to understand the whole of society value of rainwater tanks.

The analysis in this study focuses on the benefits that rainwater tanks provide to water authorities, local and state government.

2. Overview of impacts of rainwater harvesting on water cycle systems

The natural water cycle is profoundly changed by urban development and the hydraulic systems constructed to provide stormwater services to towns and cities. Typically, the area of impervious surfaces is increased, whilst natural watercourses are replaced with pipes and channels designed to be hydraulically efficient to expedite the removal of stormwater to downstream environments.

To date assessment of rainwater and stormwater harvesting in the South East Queensland area has been limited to generic assessment of potential yield at households using assumptions based on average water demands and climate inputs. This genre of assessment cannot recognise the potential of household rainwater tanks to provide a wide range of stormwater and water supply benefits. This oversight is due to the coarseness of the analysis and a failure to analyse households with rainwater tanks as part of water cycle systems that include water supply, stormwater management and demographics. An overview of the impacts of local rainwater harvesting on the urban stormwater system is shown in Figure 2.1

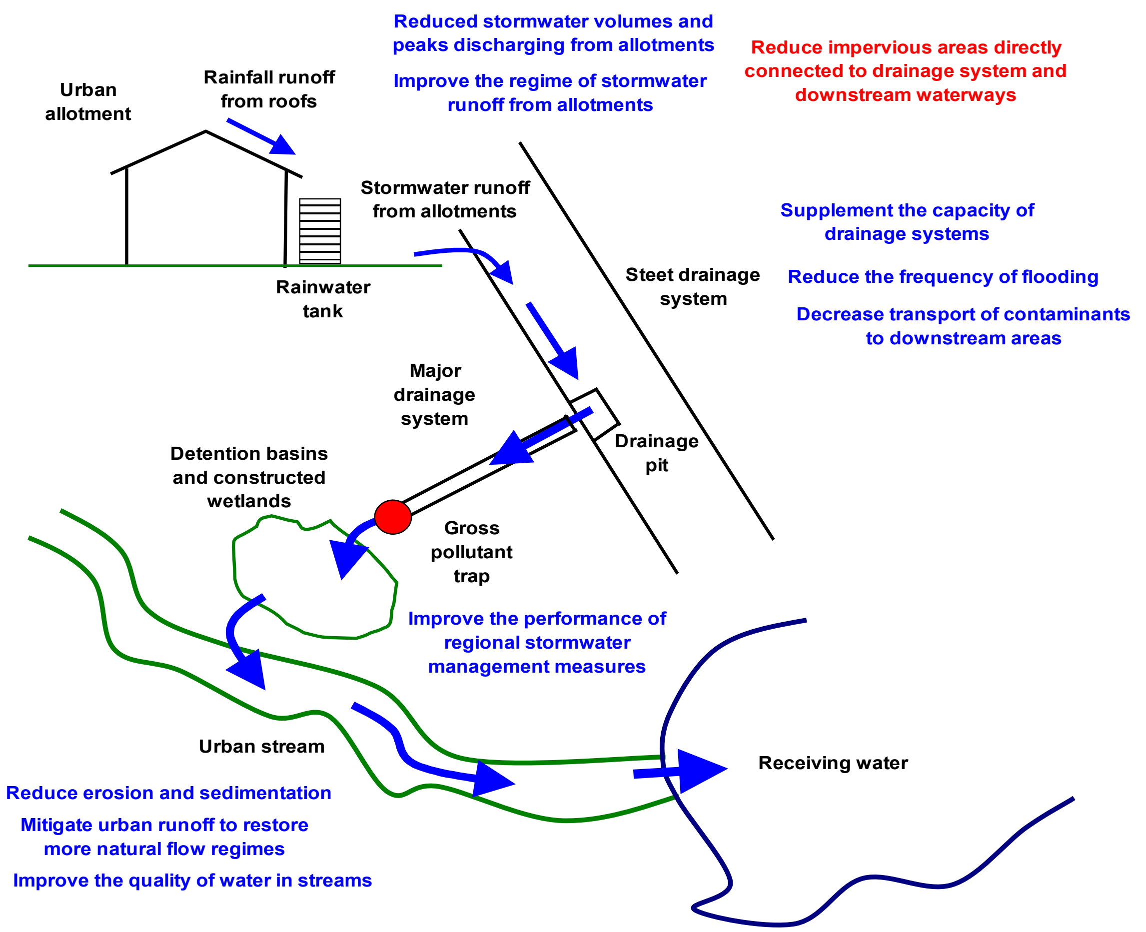

Figure 2.1: An overview of the impacts of rainwater tanks on the urban stormwater system

Figure 2.1 shows that use of rainwater tanks to collect rainfall runoff from roofs reduces the volumes of stormwater runoff and peak stormwater discharges from urban allotments. This will reduce the effective impervious area of each allotment and increase the capacity of urban stormwater management systems to manage local flooding.

The use of rainwater harvesting also reduces the frequency of stormwater runoff thereby improving stormwater runoff regimes that will combat the effects of urbanisation on waterway ecosystem health. A combination of reduced stormwater runoff volumes and reduced frequency of stormwater runoff from allotments with rainwater tanks also decreases transport of contaminants to waterways. These benefits accrue to local and state governments, and the community.

This study analyses the reduction in stormwater volumes discharging from allotments with rainwater harvesting to indicate improvements in stormwater runoff regimes and decreases in the transport of contaminants to waterways. In addition, peak stormwater discharges from allotments were used to indicate the contribution of rainwater harvesting to supplementing urban stormwater management systems, mitigating flooding and reducing erosion in waterways. These benefits accrue to local and state governments.

An overview of the impacts of local rainwater harvesting on the urban water supply systems is shown in Figure 2.2.

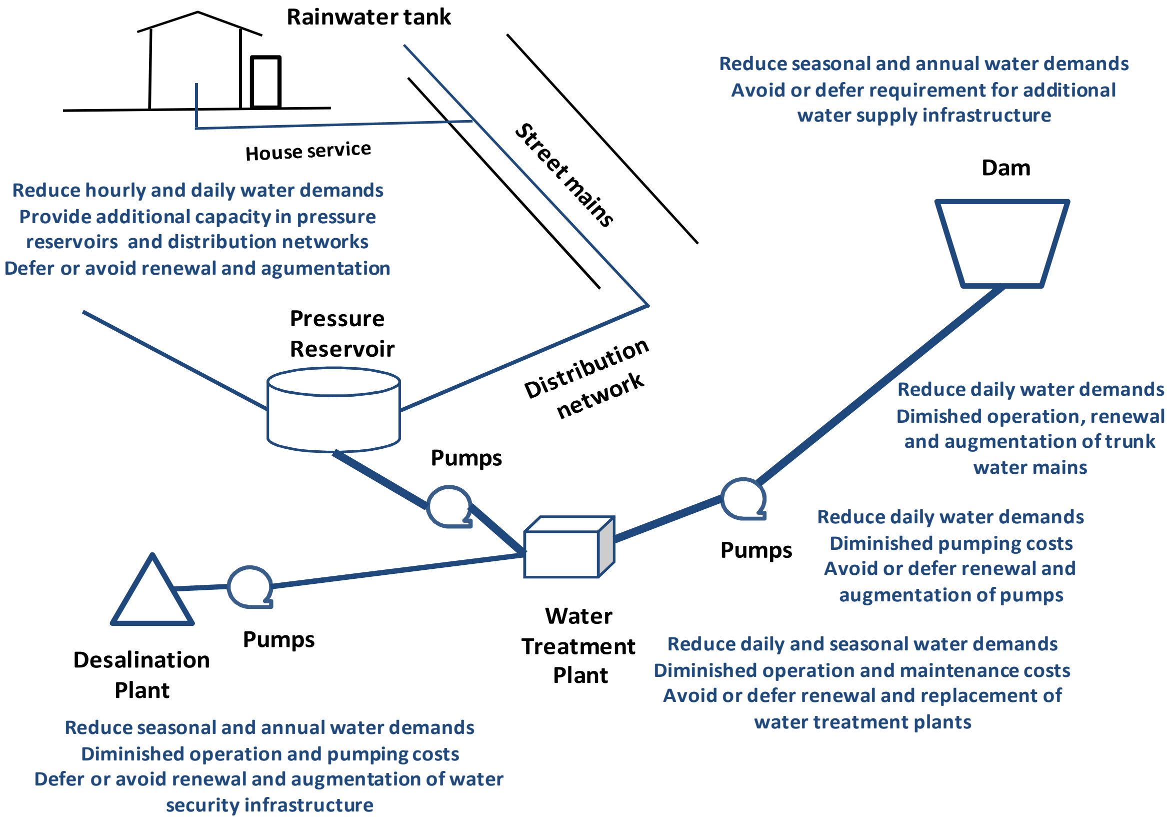

Figure 2.2: An overview of the impacts of rainwater tanks on urban water supply systems

Figure 2.2 demonstrates that the use of rainwater tanks to collect rainfall runoff from roofs reduces the daily, seasonal and annual demands for mains water and the peak water demands of urban allotments. These reductions produce benefits across multiple scales from a household to water distribution to trunk networks to water supply to water security systems.

Rainwater harvesting reduces demands for mains water at the household resulting in reduced water bills to the resident. However, reduced demand for mains water also reduces the operation and renewal costs of water treatment plants, pumps, pressure reservoirs and desalination plants. Importantly the reduced demands for mains water defers or avoids the need to replace or augment distribution systems, trunk networks, pressure reservoirs, desalination plants and dams. These substantial benefits accrue to water authorities and the Queensland government.

Key findings:

Household with rainwater tanks provide benefits to the entire water cycle at multiple scales from household to neighbourhood to suburb to city to region. A majority of these benefits accrue to water authorities, whole of society, local and state governments.

Traditional analysis that only considers water savings at households excludes the majority of benefits created by use of rainwater tanks.

A common practice of using generic analysis techniques and average assumptions also grossly under-estimate yields from rainwater harvesting systems.

A singular focus on water savings at households and revenue earned by water authorities rather than whole of system reductions in operating costs provides an illusion that water authorities and household rainwater tanks are competitors

3. Monitoring results from South East Queensland

Dr Peter Coombes (formerly from Bonacci Water) has undertaken detailed field investigations including monitoring of residential and non-residential water demands throughout South East Queensland (SEQ). This analysis was originally commissioned by the Queensland Water Commission (QWC). Approximately 50 households and businesses in the SEQ region were randomly selected for the survey. Mini smart meters were installed at each property and participants were asked to complete questionnaires about their households and businesses. Each household also completed a water use diary over a period of 30 days that outlined key water uses on each day. The results of the monitoring of residential water use are presented in this Section.

Approximately 325 households were invited to participate in this study (via email, telephone and letter drops). It is expected that a higher number of people received this invitation as those contacted directly were encouraged to forward on the details and recruit colleagues, family and friends. A total of 76 households from all areas throughout SEQ responded as willing to participate in the study. However, 31 of the households were excluded from the investigation due to water meters on their properties that were not compatible with the smart meter technology and 3 households did not ultimately complete the monitoring program.

Questionnaires and water use diaries were issued to participating households and water use was observed at 6 minute intervals at each household during the period February 2009 to May 2010. The average results for the houses without rainwater tanks, using rainwater for indoor and outdoor water uses, and for outdoor water uses only are presented in Figure 3.1.

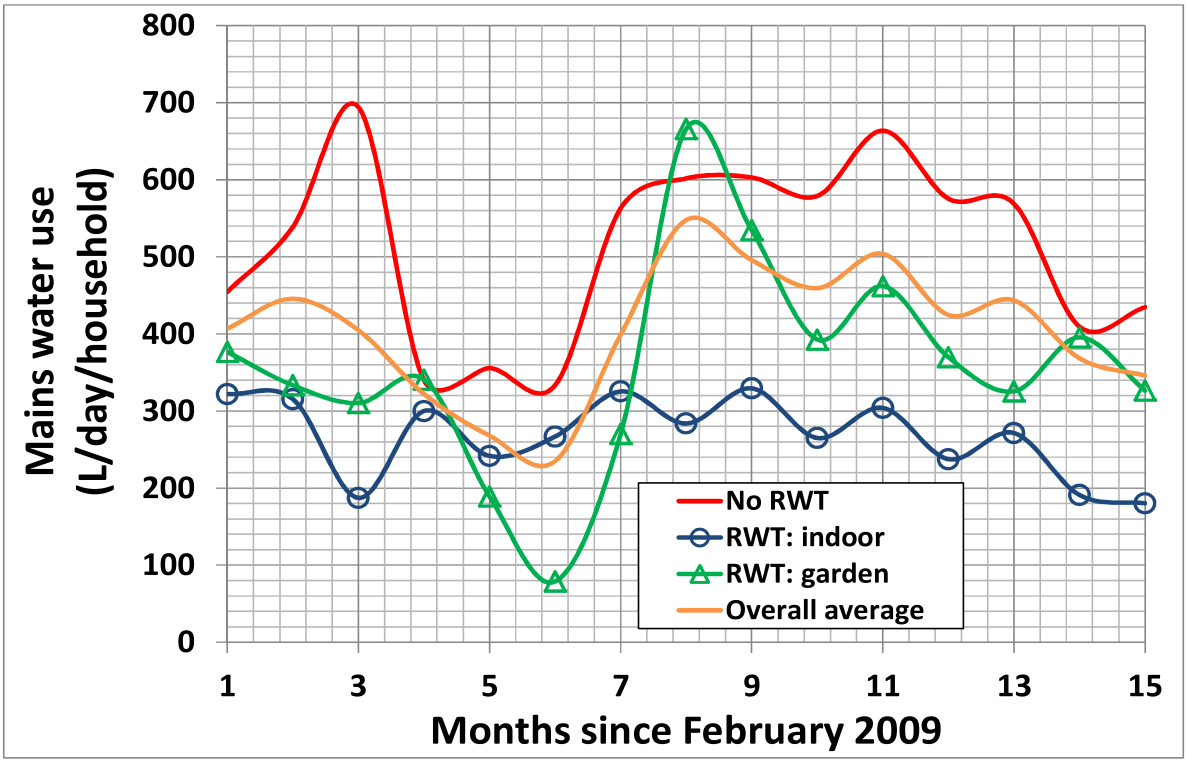

Figure 3.1: Summary of monitoring results for SEQ

Figure 3.1 demonstrates that households using rainwater for indoor and outdoor water uses, and for outdoor uses only used significantly less mains water than houses without rainwater tanks. The use of rainwater tanks has also reduced the seasonal variability of demands for mains water. This effect was particularly evident for households using rainwater for indoor and outdoor water uses. In addition, Figure 1 shows that the effectiveness of rainwater tanks for reducing mains water use was increased during the last few months of the monitoring period when rainfall returned to more normal patterns. Note that the monitoring period included high level water restrictions until April 2009, medium water restrictions to December 2009 and then permanent water conservation measures thereafter. A summary of the monitoring results are provided in Table 3.1.

Table 3.1: Summary of monitoring results from SEQ for the period February 2009 to May 2010

Household rainwater use	Number of houses	Average monthly water use (L/day)			Reduction (%)	Reduction (kL/annum)	Per-capita use (L/day)
		Average	Maximum	Minimum			
No Tanks	17	514	871	278	-	-	139
Indoor	11	268	428	125	48	89.79	63
Outdoor	14	383	725	263	24	47.82	117

Table 3.1 highlights that 17 households were not connected to rainwater tanks whilst 11 households used rainwater for indoor and outdoor uses, and 14 households only use rainwater for outdoor water uses. The average reduction in demands for mains water for households utilising rainwater for indoor and outdoor uses, and for outdoor uses was 89.79 kL/annum and 47.82 kL/annum respectively. The performance of households using rainwater for indoor and outdoor purposes was considerably in excess of the targets in the Queensland Development Code (MP 4.2).

The observed average per-capita water use from households without rainwater tanks of 139 Litres/person/day is slightly higher than the per-capita water use reported by the QWC for households during the drought of 131 Litres/person/day as expected. It is significant that the use of rainwater tanks has reduced per-capita water use to 117 and 63 Litres/person/day for outdoor, or indoor and outdoor uses respectively. This result is considerably less than the per-capita water use of 200 Litres/person/day targeted by the South East Queensland water strategy. The impact of household rainwater harvesting seasonal demands for mains water is demonstrated in Table 3.2.

Table 3.2: Impact of rainwater harvesting on seasonal mains water use throughout SEQ

Household rainwater use	Number of houses	Average monthly water use (L/day)			Reduction (%)	Household size (people)	Per-capita use (L/day)
		Average	Maximum	Minimum			
No tanks	17	514	871	278	-	3.7	139
Outdoor	14	383	725	263	24	3.3	117
Toilet & outdoor	4	296	425	192	42	3.5	84
Laundry & outdoor	2	225	271	130	56	5.5	41
Toilet, laundry & outdoor	5	254	376	121	51	5.2	49

Tables 3.1 and 3.2 reveal that the use of rainwater tanks has reduced average, maximum and minimum water uses. This demonstrates the resilience of the rainwater tanks for reduction in mains water demands throughout SEQ. In addition, Table 2 shows that the use of rainwater for laundry and outdoor uses, and toilet, laundry and outdoor uses produces the greatest reduction in demands for mains water. The observations of the impacts of different capacities of rainwater tanks in the survey are presented in Table 3.3.

Table 3.3: Mains water savings versus capacity of rainwater tanks

Tank size (kL)	Number	Average monthly water use (L/day)		
		Average	Maximum	Minimum
No tank	17	514	871	278
0 - 2	6	248	341	100
2 - 5	8	376	663	198
5 +	11	303	462	153

Table 3.3 shows that households with capacities of rainwater tanks less than 2 kL generated the lowest demands for mains water. Households with rainwater tanks larger than 5 kL provided the lower demands for mains water than tanks with capacities between 2 and 5 kL, and higher mains water demands than houses with rainwater tanks smaller than 2 kL. This result highlights that the performance of rainwater harvesting is dependent on water use from tank and roof area rather than the size of the rainwater tank.

Observations of the impacts of different roof areas connected to rainwater tanks in the survey are presented in Table 3.4.

Table 3.4: Impact of roof area connected to rainwater tanks

Connected roof area (m^2)	Number	Average monthly water use (L/day)		
		Average	Maximum	Minimum
No tank	17	514	871	278
< 50	3	388	513	281
50 - 100	6	304	439	79
100 - 150	5	338	492	192
150 - 200	5	292	574	114
>200	6	329	607	143

Table 4 shows that rainwater tanks connected to all roof areas produce significant reductions in demands for mains water. However, rainwater tanks connected to roof areas in the range of 50 to 100 m^2 and 150 to 200 m^2 produced lowest demands for mains water. This outcome highlights that the performance of rainwater harvesting is also primarily dependent on water demands from the rainwater tank and that relatively small roof areas can produce significant savings in mains water.

Information about peak daily and hourly water use is used to design water distribution infrastructure. The average per-capita peak daily and hourly water uses recording during the monitoring period is shown in Table 3.5.

Table 3.5: Per-capita peak water uses at households

Category	Peak water use (L/pp/minute)	
	Hour	Day
No tanks	1.64	0.36
Tanks - garden	1.74	0.19
Tanks - indoor	1.07	0.17

Table 3.5 shows that the use of rainwater tanks to supply indoor and outdoor water demands provides substantial reductions in peak hourly and daily water demands. This result indicates that the use of rainwater tanks will reduce impacts on or requirement for local and regional infrastructure including water distribution systems, pumping stations, water treatment plants and pressure reservoirs. It is noteworthy that limiting the use of rainwater to outdoor uses will not produce benefits for local distribution infrastructure.

The distribution of these results is demonstrated for peak hourly and daily mains water demands in Figures 3.2 and 3.3 respectively.

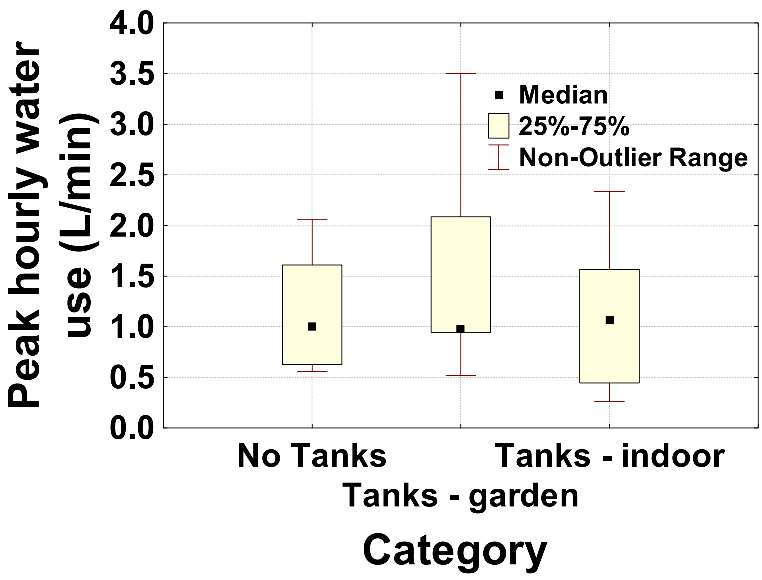

Figure 3.2: Per-capita peak hourly use

Figure 3.2 shows that the median values of per-capita peak hourly water use at households with and without rainwater tanks are similar. However, use of rainwater tanks for only garden watering shows a trend to increases peak hourly water use and the use of tanks for indoor uses show a significant trend to decreases in peak hourly water use.

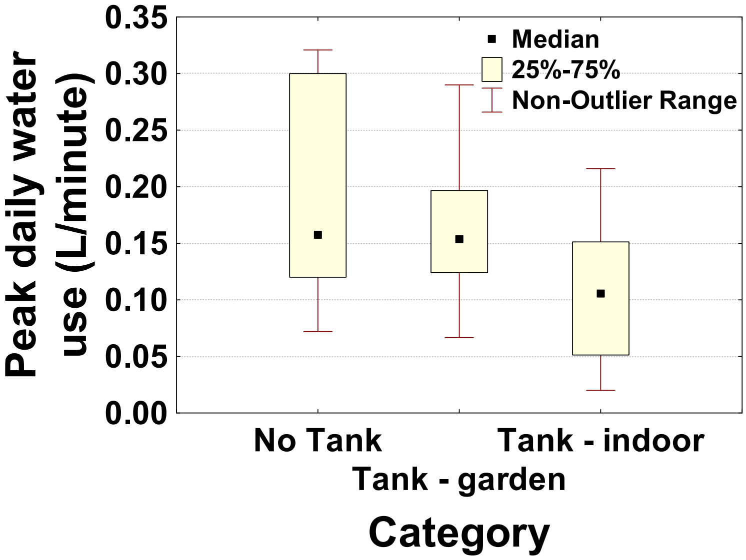

Figure 3.3: Per-capita peak daily use

Figure 3.3 reveals the use of rainwater tanks for indoor water uses significantly reduces peak daily water demands. Use of rainwater tanks for indoor uses will reduce impacts on water distribution, treatment and storage infrastructure.

Key findings:

The water use behaviour of 50 households was monitored using mini smart meters during the period February 2009 to May 2010. Audits were also completed to accurately define the characteristics of each household. Each household also completed a water use diary.

Households without rainwater tanks had an average daily mains water demand of 514 litres and a per-capita daily demand of 139 litres.

Households using rainwater for outdoor use only had an average daily mains water demand of 383 litres and a per-capita daily demand of 117 litres – annual savings of 47.8 kL.

Households using rainwater for indoor and outdoor uses had an average daily mains water use of 268 litres and a per-capita demand of 63 litres – annual savings of 89.8 kL.

The performance of households using rainwater for indoor and outdoor uses exceeded the requirements of Queensland Development Code MP 4.2.

Rainwater tanks demonstrated resilience to changes in climate and water demands throughout the monitoring period.

Relatively small rainwater tanks (2 kL) and roof areas (50 m^2 to 100 m^2) generated the largest reductions in mains water use. This demonstrates that rainwater harvesting will be (and is) successful on smaller allotments.

Use of rainwater for indoor uses reduced peak daily and hourly mains water demands which will diminish impacts on and requirement for water distribution, pumping and treatment infrastructure

4. Research results

The performance of rainwater tanks has been subject to a range of key research and policy investigations that are often not considered in debates about using rainwater in households in a policy setting. This Section provides an overview of key independent research and policy outcomes that have influenced the use of rainwater harvesting in government policy.

4.1 Augmentation of regional water supplies

The impact of Integrated Water Cycle Management approaches on the security of regional water supplies in Sydney was analysed prior to 2003 as part of the process of developing the BASIX State Environmental Planning Policy for New South Wales. This research was subject to peer review and published by the Australian Water Association and Engineers Australia.[3] This study highlighted the synergistic impacts of supply and demand management approaches on the security of regional water supply systems.

Impacts on the Greater Sydney system were examined by the study. The installation of 5 kL rainwater tanks to supply hot water, toilet, laundry and outdoor uses with or without demand management measures to new and existing dwellings at rates of 1% and 2% per annum will defer augmentation by 21 to 84 years. If the acceptable annual probability of water restrictions is increased to 5% these scenarios will defer the requirement to construct Welcome Reef Dam or a desalination plant beyond 2090. The scenarios with rainwater tanks provided net present benefits up to $774 million.

Earlier research demonstrated that the use of rainwater tanks will defer the requirement to augment the Lower Hunter and Central Coast water supply headworks systems by 28 to 100 years.[4] These strategies also produced net present benefits of up $78 million and up to $47 million respectively for the Hunter and Central Coast regions respectively. Note that the full costs of installing and operating rainwater tanks were included in this analysis. However, the investment analysis only counted the benefits of deferring regional water security infrastructure and household water use.[5]

Even though this study demonstrates that the economic performance of rainwater tanks is robust from a whole of society perspective, it in fact was biased against rainwater tanks. The investigation has not valued the environmental benefit associated with delaying the construction of dams or desalination plants to augment water supply and from reduced stormwater discharges to the receiving environment, and the cost savings from a reduced requirement for water distribution and treatment infrastructure.

4.2 Operation of water authorities

[3] Coombes P.J., (2005). Integrated water cycle management – analysis of resource security. Water. Journal of the Australian Water Association. March. pp 21 – 26.

[4] Coombes P.J., G. Kuczera, J.D. Kalma and J.R.Argue, (2002). An evaluation of the benefits of source control measures at the regional scale. *Urban Water.* 4(4). London, UK.

[5] Coombes P.J., and G. Kuczera, (2003). A Sensitivity Analysis of an Investment Model Used to Determine the Economic Benefits of Rainwater Tanks. 28th Hydrology and Water Resources Symposium. Engineers Australia.

During 2005 the New South Wales Department of Energy and Utilities commissioned an investigation of the impacts of rainwater tanks on the costs to operate regional water authorities for twelve regions across New South Wales from Broken Hill and Tweed Heads. This investigation was used as part of the evidence for extending the BASIX SEPP to all of New South Wales and was ultimately subject to peer review and published by Engineers Australia.[6] Rainwater was used to supply laundry, toilet and outdoor uses in all new houses and 2% of existing houses per annum.

This study revealed that water savings resulting from the use of rainwater tanks to supplement mains water supplies for toilet, laundry and outdoor uses was considerable in most areas of NSW, ranging from 11 kL for a 1 kL tank at Broken Hill to 158 kL for a 10 kL tank at Tweed Heads. The results also reveal that the use of small rainwater tanks produced considerable mains water savings in relatively low rainfall areas, rainwater yield from the tanks increases with increasing water demands and larger roof areas supplying tanks. The optimum sized rainwater tank was between 2 and 5 kL. Indeed, it was observed that a design to increase yields from rainwater tanks should endeavour to increase water demands from tanks and connected roof areas prior to increases in the capacity of rainwater tanks.

Analysis of the economics of rainwater tanks from the perspective of the householder reveals the cost of rainwater ranges from $7.95/kL at Broken Hill to $0.88/kL at the Central Coast region of NSW. The household scale cost of rainwater supply is also dependent on the price of mains water. However, this detailed investigation has revealed that the widespread installation of rainwater tanks used to supplement mains water supplies for domestic laundry, toilet and outdoor uses can also produce considerable reductions in operating costs and greenhouse gas emissions of regional water systems supplying cities that range from a present value of $57 to $6,371 per household installing a rainwater tank. These benefits are dependent on the average annual rainfall depth, distance from the coast, and availability of reliable operational and augmentation data of a regional water system.

In addition, considerable improvement in the security of regional water supplies was observed for all coastal cities. The widespread use of rainwater tanks reduces the energy use for operating regional water supplies and associated greenhouse gas emissions by reducing dependence on pumping from water sources, water treatment, asset replacement and desalination. The use of mains water bypass in rainwater harvesting systems produced greater reductions in greenhouse emissions than rainwater tanks with mains water top up.

It was also acknowledged that the addition of asset management and replacement data in this study will reveal greater opportunities. Nevertheless, the major contribution of this study is the revelation of the importance of including rainwater tanks or, indeed, any other decentralised water management option in analysis of the operation of regional water systems to provide a realistic understanding of the benefits of decentralised water management strategies in cities.

An estimate for the net present economic savings (9% discount rate and 50 year planning horizon) accruing to a regional water authority for reduced operating costs was provided by the flowing equation:

$$Savings = 0.88ARD + 96TS \quad \text{.......(1)}$$

[6] Coombes P.J. (2008). Energy and economic impacts of rainwater tanks on the operation of regional water systems. Australian Journal of Water Resources. Vol. 11, No. 2. pp177 – 192.

Where ARD is average annual rainfall depth and TS is tank size.

Given that annual average rainfall in Brisbane is 1,093 mm and assuming tank size of 5 kL in Equation 1 results in a net present value of $1,442/household for the reduction in the operating costs of a regional water authority. Use of rainwater harvesting to supply laundry, toilet and outdoor uses in Brisbane will reduce the net present costs to operate water authorities by at least $1,440/household.

4.3 Impact of climate variation and change

During 2006 an investigation was conducted that compares the impact of historical variations in climate and predicted climate change for 2030 on runoff into dams and the yield from 3 kL rainwater tanks supplying laundry, toilet and outdoor uses in Australian capital cities of Brisbane, Melbourne, Perth and Sydney. These results of these investigations were published by the Prime Minister's Science, Engineering and Innovation Council working group[7] and by Engineers Australia.[8]

This study analysed the relative efficiencies of runoff into dams supplying Brisbane, Melbourne, Perth and Sydney, and of rainwater harvesting in those cities. It was shown that both respond differently to drought and climate change forcing, with decentralised rainwater harvesting systems in cities exhibiting a more uniform performance across these stressors.

The impact of natural variations in climate is considerable, with the inland catchments that supply cities exhibiting a disproportionate decrease in yield in response to rainfall reductions, as compared to rainwater tanks in the cities. A 50% decrease in median rainfall at each location results in a 60% to 85% reduction in runoff to dams and a 15% to 30% reduction in yield from 3 kL rainwater tanks.

Rainwater yields from 3 kL tanks in the cities were more resilient to the potential for climate change than runoff into dams supplying the cities. Reductions in runoff from the worst case climate change scenario ranged from 19% to 53%, while reductions in yields from rainwater tanks were 5% to 8%. Yields from rainwater tanks in cities were also more resilient to droughts than runoff into dams. This research highlighted the potential for rainwater tanks in cities to supplement water supply from dams during droughts and to buffer the expected impacts of climate change.

This investigation highlighted that runoff into Wivenoe Dam is highly dependent on natural variation in rainfall. Median annual rainfall and runoff at Wivenoe Dam was 846 mm and 224 GL, respectively. In contrast, yields from 3 kL rainwater tanks in Brisbane display less dependence on variation in rainfall than runoff into Wivenhoe Dam supplying Brisbane. Median annual rainfall and yield from 3 kL rainwater tanks in Brisbane was 1068 mm and 67 kL, respectively.

Median annual runoff into Wivenhoe Dam from the worst case scenario for climate change in 2030 was 181 GL, which represents a 19% reduction in runoff. While median annual yields from rainwater tanks in Brisbane from the worst case scenario for climate change in 2030 were 63 kL, which represents a 5% reduction in yield.

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[7] PMSEIC, (2007), Water for Our Cities: building resilience in a climate of uncertainty, Report of the Prime Minister's Science, Engineering and Innovation Council working group, Australian Government, Canberra.

[8] Coombes P.J. and M.E. Barry (2008). The relative efficiency of water supply catchments and rainwater tanks in cities subject to variable climate and the potential for climate change. Australian Journal of Water Resources. Vol. 12, No.2.

The relative efficiency of traditional water supply catchments and rainwater tanks supplying Brisbane is highlighted by the response to a 50% decrease in median annual rainfall of a 60% reduction in runoff into Wivenhoe Dam and a 15% reduction in yield from a 3 kL tank. These results explain the negligible reductions in yield from rainwater tanks in South East Queenland during the recent drought. The reduction in medium annual rainfall throughout South East Queensland was less than 20% which corresponds to an expected reduction in yield from rainwater tanks of 6%.

4.5 Stormwater management and waterways

Urban development and traditional drainage produces substantial increases in stormwater runoff in comparison to existing conditions. Analysis of three catchments in the growth corridor for Melbourne at Armstrong analysed the use of 3 kL and 5 kL rainwater to supply household laundry, toilet and outdoor uses.[9] The Options using rainwater tanks, 2a and 2b, reduced stormwater runoff volumes from the developed case by 16% and 17% respectively. Options that employ bio-retention systems with rainwater tanks, 3a and 3b, reduce stormwater runoff volumes from the urban development by 23% and 25% respectively.

Options using rainwater tanks and bio-retention were designed in accordance with best practice guidelines. However substantial increases in stormwater runoff volumes were simulated in comparison to runoff volumes discharging from existing catchments. This result shows that the rainwater tanks and bio-retention systems will not reduce environmental flows to less than existing flows. The requirement for stormwater detention basins and constructed wetlands in each catchment for each Option is shown in Figures 4.1 and 4.2 respectively.

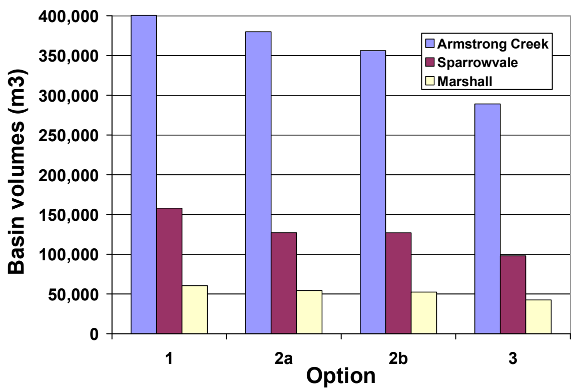

Figure 4.1: Requirement for detention basins

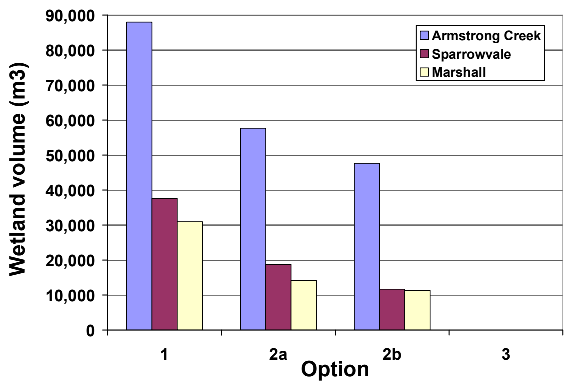

Figure 4.2: Requirement for constructed wetlands

Figure 4.1 shows that rainwater tanks reduce the volumes (9% to 13%) and land areas (9% to 13$) of detention basins required to manage stormwater peak discharges from the developed catchments. A combination of rainwater tanks and linear bio-retention provides substantial reductions in the requirement for centralised infrastructure with reductions requirement for detention basins and land area of 31%.

9 Coombes P.J., (2009). Integrated water cycle management at Armstrong Creek – towards targets for sustainable development. WSUD 2009 Conference. Engineers Australia.

Figure 4.2 reveals that the use of rainwater tanks will almost halve the requirement for constructed wetlands (42% to 55%) and land area (42% to 55%) required to meet stormwater best practice guidelines. The combined use of rainwater tanks and linear bio-retention eliminates the requirement for constructed wetlands to meet best practice stormwater quality guidelines.

The use of 3 kL and 5 kL rainwater tanks provided net present benefits of $13.1 million and $20.8 million respectively. A combination of rainwater tanks and bio-retention measures provides a net present value of $99 million to $129 million.

4.6 Integrated systems analysis to create government policy

Traditional analysis of opportunities for water supply does not consider the entire water cycle or count all costs and benefits throughout a metropolis. Sydney Water Corporation (SWC) commissioned an Alternative Water Strategy for Greater Sydney.[10] The purpose of this investigation is to provide an alternative view of the potential for water cycle management throughout the Greater Sydney region and the role of SWC. This study employed an integrated systems approach to analysing the performance of integrated water cycle management Options throughout the Greater Sydney region.

This unique investigation developed a "bottom up" integrated systems analysis of Greater Sydney region that included the whole of society spatial information from across Sydney. The investigation provided a range of insights including that it was likely that Sydney will not evolve as a uniform spatial or temporal process. This creates considerable uncertainty for the provision of traditional centralised strategies for management of water and sewage.

The increasing movement and accumulation of water, wastewater and stormwater throughout expanding or aging networks of infrastructure are the greatest challenge facing SWC. The increasing age, and declining capacity and condition of assets is expected to escalate the cost of managing the assets.

Importantly the Greater Sydney region is subject to considerable spatial and temporal behaviour that creates considerable risks for the traditionally lumpy "just in time" nature of providing centralised infrastructure. Continuous investment of smaller scale strategies including rainwater harvesting provided are more resilient water strategy to economic and climate shocks.

Strategies involving rainwater harvesting also provided considerable additional benefits including reductions in stormwater runoff that improved urban stormwater quality and reduced risk of flooding. These considerable stormwater benefits include diminished nuisance flooding in urban areas which avoids the expense of upgrading stormwater infrastructure. In addition, significant improvements in the health of waterways were expected.

Rainwater harvesting reduced reliance on desalination plants, the need to treat water and requirement to transfer water across long distances throughout the city. This resulted in large reductions in greenhouse gas emissions, and the costs to operate, renew and extend water distribution systems. Similarly, this strategy also delayed the requirement to augment the regional water supply system.

[10] Coombes P.J., and Bonacci Water (2011). Sydney Water alternative water strategy – a vision of what is possible and a road map to get there. Report for the board of Sydney Water Corporation.

The most significant benefit of a continuous strategy to install rainwater harvesting and water efficient appliances was the elimination of expensive lumpy "just in time" investment in centralised infrastructure and associated finance costs. Importantly, lumpy investment strategies also eliminate the flexibility of water planning for long periods.

The Victorian government has implemented the Living Melbourne, Living Victoria policy that utilised similar integrated systems analysis to understand the full range of benefits to society. This investigation provided systems analysis of the water cycle for Greater Melbourne and advice in support of the Ministerial Advisory Council (MAC).[11] This process aimed to generate discussion and deeper understanding of the detailed transactions that drive water cycle management throughout the region.

Building scale Options that combined rainwater harvesting and water efficient appliances were found to substantially mitigate the challenges of variable population and climate. These alternative Options generate substantial reductions in water demand, wastewater discharges and stormwater runoff.

The building scale Options provided significant reductions in the cost of providing water and wastewater services that include reduced transfer costs of providing water and sewage services. It was also found that the full costs (and benefits) of projects for water cycle management are not currently considered. This is likely to create bias in decision making processes towards augmentation using large scale infrastructure.

The most significant recommendation of the policy was to eliminate "lumpy" expenditure for large scale centralised infrastructure wherever possible. There was significant value in avoiding investment in large scale infrastructure by utilising timely investment in smaller scale local infrastructure as required.

This building scale policy process investigated use of rainwater harvesting from small roof areas (100 m^2) into 5 kL rainwater tanks to supply laundry, toilet and outdoor uses installed in all new and redeveloped buildings. The rainwater harvesting strategy was combined with water efficient appliances.

The building scale policy produced substantial delays in requirement to augment regional water security infrastructure by 9 years for a high emissions climate change scenario and by 19 years for a low emissions climate change scenario. Importantly, this option eliminated one of the three augmentations required for the business as usual option. In addition, the building scale option eliminated requirement for augmentation generated by a high population growth scenario.

This option generated reductions in annual water demands, wastewater discharges and stormwater runoff volumes in 2050 by 28%, 15% and 8% respectively. In addition, the building scale option produced a 40% reduction in greenhouse gas emissions that was generated by a reduced requirement to transport water across Greater Melbourne and avoided use of water from desalination plants.

The buildings scale option also reduced the cumulative costs of providing water, wastewater and stormwater services up to 2050 by $9 billion, $8 billion and $3 billion respectively. The cumulative

[11] Coombes P.J., and Bonacci Water (2012). Living Melbourne Living Victoria – Modelling in support of the Living Victoria Ministerial Advisory Council.

savings from reduced requirement for developable land for stormwater management was $6.2 billion.

Reductions in net present costs of requirement for infrastructure for water supply, wastewater and stormwater was 5%, 11% and 6% respectively. The resultant diminished net present costs for provision of land for stormwater management was 12%.

4.7 Quality of rainwater supplies and health risks

A longitudinal study was conducted by the author and others to examine the performance of rainwater harvesting systems throughout the eastern and southern states of Australia. Samples collected from different locations in rainwater harvesting systems at about 50 sites around Australia over a period of four years were analysed for water quality as indicated by elements and microbiology. The magnitude of this research program is unprecedented and an overview of the results is presented in this Section.

The majority of samples (83%) were within guideline values for all 26 elements examined. A majority of tanks (89%) were compliant with guidelines for the number of samples collected.[12] Five systems out of 44 were found to have more than one elevated level for a particular element, and a further 17 systems demonstrated a single elevated level of a particular element which may be the result of weather events, or sampling or measurement error. Due to the bioaccumulation potential of some elements, in particular lead, particular attention was paid to those sites at which elevated levels of metals were observed in more than a single sample.

Five rainwater harvesting systems were found to have more than one elevated level for a particular element, two with nickel, two with lead, and one bladder tank with arsenic. However, most of these sites did not utilise rainwater for drinking purposes which rendered assessment against drinking water guidelines a redundant exercise. In particular, measurements at a taps connected to the exterior of rainwater tanks were the origin of most of the elevated levels for nickel and lead.

While roof harvested rainwater has the potential to acquire contaminants from both external and internal pollution sources, the majority of rainwater complies with ADWG for metals and other elements. At sites where rainwater quality may not be fit for potable uses, measures can be taken to improve water quality.

It is noteworthy that the guideline value for lead is based on consumption of one litre of water per day, and calculated to ensure that those sub-populations most at risk from lead (pregnant women, children, and infants) do not receive total concentrations from food, dirt, and dust (which represent 80% of average daily lead intake), and water combined which exceed safe levels. This standard is based on continuous dosing of lead in drinking water supplies. No location in this longitudinal study was subject to continuous elevated loads of any element at any location.

Of the 5 systems which demonstrated more than one elevated level of a particular metal, only two had the potential to detrimentally affect human health as indicated by Australian Drinking Water guidelines. At one of these sites, it may be possible for the occupants to simply avoid using the

[12] Morrow A., P.J. Coombes, H. Dunstan, C. Evans and A. Martin, (2007). Elements in tank water – comparisons with mains water and effects of locality and roofing materials. 13th International Rainwater Catchment Systems and 7th International Water Sensitive Urban Design Conference. Engineers Australia.

internal hot tap and the external tank tap for drinking and cooking purposes, since the internal cold tap was within lead guideline values for the whole sampling period. At the second of these sites, an inline filter may be the best option for improving the quality of the harvested rainwater.

The concept that domestic rainwater storage tanks may host sustainable microbial ecosystems has not previously been addressed. The bacterial diversity, cultivated from more than 80 samples from 22 tanks at various locations across eastern Australia, is presented as prima facie evidence for the potential operation of a functional micro-ecology within rainwater storage systems.[13] Cultivated isolates were found to comprise members of four major bacterial divisions; Proteobacteria, Firmicutes, Actinobacteria and Bacteroidetes, including more than 200 species from 80 different genera. The pattern of abundance distribution was typical of that observed in most natural communities, comprising a small number of abundant taxa and a multitude of rare taxa, while the specific composition resembled that previously described in a number of natural aquatic systems. Although Proteobacteria from α, β and γ sub-classes were dominant, a set of core taxa comprising representative genera from all four phyla could be identified.

Coliform and other species specifically associated with faecal material comprised about 15% of the species identified and only represented 1.5% of the total average abundance of bacteria. The composition of the cultivated populations and scope of diversity of present bacteria suggested that rainwater tanks may support functional ecosystems comprising complex communities of environmental bacteria which may have beneficial implications for the quality of harvested rainwater.

Although faecal deposition was considered a primary pathway by which bacteria might enter rainwater tanks, identified members of the Enterobacteriaceae family (which included ten coliform groups) were neither persistent nor abundant in these samples. Since the survivability of coliform groups on the catchment surface is unlikely to differ substantially from that of other non-sporing gram negative Proteobacteria (Pseudomonas, Sphingomonas, Acidovorax), two possible explanations for their comparatively low occurrence and abundance seem likely. Either the incidence of faecal deposition on the roof catchments was low relative to contributions from other sources or pathways or, organisms of faecal origin may simply be less tolerant of the oligotrophic tank conditions than non-enteric groups commonly found in other aquatic systems. The latter may result in their competitive exclusion, representing a means by which the operation of a resident ecosystem may facilitate maintenance of water quality in tanks.

Nutrient cycling and other metabolic activities of the resident communities may also have beneficial consequences for the chemical quality of tank water. Contamination of roof harvested rainwater with halogenated, aromatic and heavy metal pollutants has been identified as potentially problematic in urban settings while contamination with pesticides may be of concern in rural environs. Many of the bacterial groups frequently detected in this study including Pseudomonas, Sphingomonas, Bacillus, Arthrobacter and Rhodococcus, have demonstrated a capacity to degrade such compounds, or otherwise facilitate their removal from rainwater.

Aside from the obvious benefits, such activity within rainwater tanks may carry implications with regard to the treatment of stored rainwater. Any potential bio-remedial capacity of resident

[13] Evans C. A., P.J. Coombes, H. Dunstan and T. Harrison (2009). Extensive bacterial diversity indicates the potential operation of a dynamic micro-ecology within domestic rainwater storage systems. Science of the Total Environment. Vol. 407. pp 5206 – 5215.

populations would provide a case for their retention within the tank, rather than elimination via disinfection for example, especially in adequately maintained systems where pathogenic risk is considered minimal. At sites with higher risk of pathogenic load, and where the stored water is used for drinking, treatment may include post-tank measures such as UV disinfection or passage through a domestic hot water service rather than chemical disinfection of the tank itself.

The scope of bacterial diversity present, the general abundance distribution, and the resemblance of the composition to that of other aquatic systems, has indicated the likely existence of definable micro-ecosystems within rainwater tanks. The functional operation of a stable micro-ecology, dominated by well adapted core resident groups, may have beneficial implications with regard to the regulation and maintenance of both the microbial and chemical quality of roof harvested rainwater.

System design, maintenance practices and recommendations regarding safe domestic utilisation of harvested rainwater are currently guided by a limited understanding of the relationship between roof catchment contamination, 'in-tank' processes and end product quality. Investigation of bio-reactor processes, facilitated by diverse microbial communities, may provide valuable insight into this relationship.

Thermal inactivation analyses were carried out on eight species of non-spore-forming bacteria in a water medium at temperatures relevant to domestic hot water systems (55 to 65 ◦C), and susceptibilities to heat stress were compared using D-values.[14] The D-value was defined as the time required to reduce a bacterial population by 90% or 1 log reduction. The results found that both tested strains of Enterococcus faecalis were the most heat resistant of the bacteria studied, followed by the pathogens Shigella sonnei biotype A and Escherichia coli O157:H7, and the non-pathogenic E. coli O3:H6. Pseudomonas aeruginosa was found to be less resistant to heat, while Salmonella typhimurium, Serratia marcescens, Klebsiella pneumoniae and Aeromonas hydrophila displayed minimal heat resistance capacities. At 65 ◦C, little thermal resistance was demonstrated by any species, with log reductions in concentration occurring within seconds. The results of this study suggested that the temperature range from 55 to 65 ◦C was critical for effective elimination of enteric or pathogenic bacterial components and supported the thesis that hot water systems should operate at temperatures greater than of 55 ◦C.

These research programs also considered the relative significance of airborne environmental micro-organisms to roof catchment contamination and the issue of tank water quality.[15] This investigation into the influence of weather on roof water contamination conducted at an urban housing development in Newcastle on the east coast of Australia. Samples of direct roof runoff were collected during a number of separate rainfall events and microbial counts were matched to climatic data corresponding to each of the monitored events. The magnitude of a range of parameters in roof runoff was found to be influenced of both wind speed and direction. This study also investigated the microbial diversity of rainwater harvesting systems. The results indicate that the composition of organisms present varied considerably from source to source and throughout the collection system. In all cases evidence of faecal contamination was found to be negligible.

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[14] Spinks A.T., H. Dunstan, T. Harrison, P.J. Coombes and G. Kuczera, (2006). Thermal inactivation of water-borne pathogenic and indicator bacteria at sub-boiling temperatures. Water Research, Vol. 40, pp 1326 – 1332.

[15] Evans C.A., P.J. Coombes, H. Dunstan and T. Harrison, (2007). Identifying the major influences on the microbial composition of roof harvested rainwater and the implications for water quality. Water Science and Technology. Vol. 55, No. 4, pp 245 – 253.

The sparse evidence of faecal contamination was not surprising given the lower temperature, nutrient poor and consequently highly competitive tank environment would no doubt favour environmental organisms over enteric species adapted to the warmer, nutrient rich digestive tracts of animals. Thus, airborne environmental organisms, prominent in roof water, would likely be important to processes occurring within the tank. While the exact nature of such processes are likely to include biofilm formation and nutrient cycling, and extends to sequestration of trace metals, breakdown of organic contaminants and competitive exclusion of pathogens. In this respect environmental micro-organisms may have beneficial rather than adverse impacts, and their potential role in regulating tank water quality is potentially significant.

Microbial properties of harvested rainwater were assessed at two study sites at Newcastle on the east coast of Australia.[16] The investigation monitored daily counts of heterotrophic bacteria (HPC), total coliforms and E. coli during a mid-winter month (July). Immediately after major rainfall events, increases in bacterial loads were observed at both sites, followed by gradual reductions in numbers to prior baseline levels within 7 days. Baseline HPC levels ranged from 500–1000 cfu/mL for the sites evaluated, and the loads following rain peaked at 3590–6690 cfu/mL. Baseline levels of total coliforms ranged from 0–100 cfu/100 mL and peaked at 480–1200 cfu/100 mL following rain. At Site 1, there was no evidence of E. coli loading associated with rain events, and Site 2 had no detectable E. coli colonies at baseline, with a peak load of 17 cfu/100 mL following rain which again diminished to baseline levels. It was concluded that rainfall events contributed to the bacterial load in rainwater storage systems, but processes within the rainwater storage ensured these incoming loads were not sustained.

Although most studies find Coliform bacteria in rainwater storages and over 3 million Australians rely on rainwater for drinking water supplies only a small number of health concerns have been attributed to rainwater supplies. It is noted that the epidemiological study by Heyworth and subsequent research found that drinking rainwater posed a lesser health risk than drinking mains water in South Australia. A relationship between the presence of Coliform bacteria in rainwater tanks and frequency of illness has not been established.

The research journey of the author at the University of Newcastle provides some key insights into water quality processes in rainwater tanks and highlights the need for continuing scientific endeavour to replace myths and agendas with facts about this important water source.

The importance of applied research into the performance of carefully monitored demonstration sites is established by the key observations from the Figtree Place, Maryville and Carrington housing projects. Monitoring of these projects revealed the existence of a rainwater treatment train that includes first flush devices, the rainwater tank and domestic hot water services. In addition establishment of these projects exposed many myths and assumptions about the quality of rainwater. Significantly, limited knowledge about the microbial processes in rainwater tanks was revealed.

One of the dominant processes in the rainwater treatment train appears to be flocculation of organic, metallic and chemical parameters at the tank water surface with subsequent settlement of flocs to the bottom of the tank or attachment to walls in the tank. Ongoing analysis, resulting from

[16] Martin A., P.J. Coombes, T. Harrison and H. Dunstan, (2010). Changes in abundance of heterotrophic and coliform bacteria resident in stored water bodies in relation to incoming bacterial loads following rain events. Journal Environmental Monitoring. Vol. 12, pp 255 – 260

this initial observation, has revealed that biofilms do exist in rainwater tanks and that a core group of environmental bacteria such as *Bacillus Spp.* are likely to form biofilms in rainwater tanks.

Monitoring of the demonstration projects also led to a discovery that domestic hot water services set at temperatures greater than 52°C consistently eliminated bacteria from rainwater. This discovery led to laboratory experiments into the impact of hot water on the viability of selected pathogens. Potentially pathogenic bacteria were observed to be rapidly eliminated from rainwater at temperatures of 60°C or greater.

The use of Polymerase Chain Reaction (PCR) processes to determine the DnA of bacteria found in rainwater has increased concerns about the efficacy of the use of traditional coliform indicator organisms to determine the safety of rainwater supplies. Preliminary experiments confirmed that bacteria other than Fecal Coliforms, Total Coliforms and *E.Coli* can grow on commercially approved media. This indicates that the use of approved Coliform indicator tests can potentially result in a misleading view that rainwater supplies are unsafe.

Key findings:

A policy that requires rainwater harvesting in new and renovated housing:

Defer the requirement to augment regional water supplies (new desalination plants and dams) at substantial economic savings.

Reduce the net present cost of operating water authorities from $57 to $6,371 for each household with a rainwater tank.

A 5 kL rainwater tank used to supply laundry, toilet and outdoor uses should reduce the net present costs of operating water authorities by at least $1,442 for each household with a rainwater tank.

Rainwater tanks are resilient to drought and climate change with negligible reductions in yield.

Diminish requirements for and the costs to manage detention basins and constructed wetlands.

Reduce the traditional lumpy and expensive "just in time" investment in water infrastructure and associated high finance costs.

Substantially reduce greenhouse gas emissions, carbon and land costs.

Independent long term monitoring of rainwater harvesting systems throughout Australia have revealed:

A majority of rainwater harvesting systems are compliant with Australian Drinking Guidelines for metals and elements.

The quality of rainwater supplied from hot water services was always compliant with Australian Drinking Water Guidelines. Laboratory experiments also demonstrate rapid death of pathogens in hot water services.

Surveys of people drinking rainwater prove that the health of people using rainwater is equal or better than the health of people drinking mains water.

5. Analysis of the benefits of rainwater harvesting from the perspective of the entire water cycle

This study employed the integrated systems approach to analysing the performance of the water cycle management Options that was developed for the South East Queensland region over the last few years by the author. The approach was used to generate understanding of the response of the water cycle systems throughout South East Queensland to traditional and alternative strategies including rainwater harvesting at households.

This unique integrated systems analysis uses the same methods and principles used in the systems analysis of the Victorian government's Living Melbourne Living Victoria policy and for the Board of Sydney Water Corporation. The systems analysis for South East Queensland is subject to ongoing development and should be published in full during this year.

This unique analysis is dependent on detailed inputs, such as demographic profiles, and linked systems that accounts for water supply, sewage, stormwater and environmental considerations.

The systems analysis was constructed from the basic elements (the lot scale inputs) that drive system behaviours and account for first principles transactions within the system to allow simulation of spatial performance of the system. Biophysical systems in the region were constructed using three basic components:

- Sources - Regional and local water sources, catchments and waterways
- Flux – transport and treatment of water, sewage and stormwater throughout the region
- Sinks – Stormwater runoff and wastewater disposal to waterways

The analysis is anchored by a regional framework of key trunk infrastructure, demand nodes, discharge points, waterways and regional sources of water in the systems model.

Major water distribution, stormwater, sewage, demographic, climate and topographic zones are combined in this framework. This process compiles inputs from a wide range of commonly utilised analysis tools, including for local water demands and water balances and hydrology. Key inputs to this framework include:

- Demographic data from the Australia Bureau of Statistics and State Government departments;
- Climate data from the Bureau of Meteorology (BOM) and streamflow data from the Queensland government.
- Water and sewage flows sourced from water authorities and the Queensland government.
- Local and cluster scale inputs simulated in the PURRS model at 6 minute timesteps using long climate records sourced from the BOM.
- Urban areas and LGAs analysed using a range of models including PURRS. These smaller scale systems are also analysed in more detailed WATHNET models.
- The biophysical and scale transition model compiles inputs from PURRS into zones based on statistical local areas and calibrates to observed data from water and sewage catchments.

- The Wathnet model was used to collate and simulate all inputs across the entire region
- Financial data from WSAA and NWC reports, and from annual reports of Queensland water authorities

This framework incorporates the movement of water throughout the region and connectivity to the water supply headworks system. Similarly, this framework includes the movement of sewage and stormwater throughout the region and connectivity with discharge points or reuse systems. A genuine integrated systems analysis is the only method that can reveal the multiple scale benefits of alternative strategies and the actual costs of current strategies.

Household water consumption for the period 2005 to 2006 was selected in this study as representing base water consumption for the region during a period relatively free of water restrictions. These water demands were then modified by a range of processes including adoption of water efficient appliances in some houses, connection to wastewater reuse systems and changes in demographics. The economic analysis was based on the 2010/11 financial period.

Inputs to the whole of system economic analysis included financial data sourced from the National Water Commission (NWC)[17], the Queensland Water Commission (QWC)[18] and the report on the Ridges project by Bonacci Water.[19] Note that the Bonacci Water report summarised a range of publications to understand the most likely operational costs of stormwater management in Queensland. An overview of the operation, renewal and extension costs for water and stormwater infrastructure used in this investigation are provided in Table 5.1.

Table 5.1: Operating costs of water and stormwater infrastructure

Criteria	Operating	Renewals	Extensions
Water	$3,493/ML	$293/ML	$3,664/ML
Stormwater drainage	$20/hh/yr	$58/hh/yr	$4,025/hh/yr
Detention	$1.5/hh/yr	$4.36/hh/yr	$305/hh/yr
Water quality	$787/hh/yr	$46/hh/yr	$2,324/hh/yr

The information in Table 5.1 and the reported 236,000 households that utilised rainwater tanks in South East Queensland was used to determine the benefits that rainwater tanks currently provide the Queensland state government. These results are summarised in Table 5.2.

Table 5.2: Current economic savings from reduced costs for water supply and stormwater management

Rainwater use	Water savings (GL/annum	Economic savings ($m)		Economic savings ($/tank)
		Water	Stormwater	
Indoor + outdoor	21.2	158	853	4,285
Outdoor	11.3	84.1	454.4	2,282

[17] NWC (2012). National Performance Report 2010-11: urban water utilities.
[18] QWC (2012) South East Queensland water strategy annual report.
[19] Bonacci Water (2009). Review of the integrated water cycle management strategy for Ridges at Peregian Springs for Sunshine Coast Regional Council.

Table 5.2 demonstrates a range of benefits currently accruing to the Queensland government for households with rainwater supply. The upper range of the benefits are derived from households that use rainwater for indoor and outdoor uses (average savings of 89,790 Litres/household/annum from monitoring) and the lower range of benefits is for households with rainwater supply for outdoor uses (average savings of 47,820 Litres/household/annum from monitoring).

The benefits of $4,285/household to $2,282/household that currently accrue to the state of Queensland are indeed significant. Removal of these rainwater harvesting systems from housing will add these infrastructure costs to housing via impacts on water authorities and local government.

These benefits are derived from reduced requirement to source, treat and transport water across South East Queensland to households. Reduction in water demands delays or avoids requirement for extension or renewal for infrastructure whilst also reducing the operational cost of the infrastructure. For example, the operating costs are reduced at water treatment plants and the requirement to renew or extend (or augment) the capacity of the plant is also diminished by lower water demands.

Similarly, reductions in stormwater runoff volumes produces a range of benefits including diminished nuisance flooding that requires stormwater drainage infrastructure and reduced requirement for stormwater treatment infrastructure including constructed wetlands. This reduces that operation, renewal and extension costs of stormwater infrastructure. For example, reductions in stormwater runoff volumes diminish the pollutant loads discharging to constructed wetlands and reduces requirement for the constructed wetlands. Given that high cost of managing and providing constructed wetlands a reduction in stormwater runoff and associated pollutant loads from urban areas provide very substantial benefits.

The economic benefits from installation of rainwater tanks at all new houses until 2056 is presented in Table 5.3. This analysis has utilised the population growth projections published by the QWC[20] and a discount rate of 9%.

Table 5.3: Current economic savings from reduced costs for water supply and stormwater management

Rainwater use	Water savings in 2056 (GL/annum)	Economic savings (NPV: $B)		Economic savings (NPV: $/tank)
		Water	Stormwater	
Indoor + outdoor	106.7	1.959	3.462	4,554
Outdoor	56.9	1.044	2.019	2,573
Hot water, laundry, toilet and outdoor	135.9	2.304	4.814	5,979

Table 5.3 shows that the net present value of the benefits of installing rainwater tanks to all new dwellings ranges from $4,554/household for the current policy (rainwater supply for laundry, toilet and outdoor uses) and this benefit increases to $5,979/household when rainwater supply is extended to hot water services. Households that include rainwater supply for only outdoor use

[20] QWC (2010). South East Queensland water strategy. Report by the Queensland Water Commission.

provide a significant albeit reduced benefit to reducing the costs of operating regional infrastructure. Note that these benefits do not include deferment of regional water security infrastructure or household savings.

The impacts of installing rainwater tanks for all new houses to supply outdoor uses RWT_O; laundry, toilet and outdoor uses RWT_LTO and Hot water, laundry, toilet and outdoor uses RWT_HLTO on regional water demands in the South East Queensland region are shown in Figure 5.1.

In addition, the impact of also installing rainwater tanks for all renovated housing (assumed to be 1% of existing dwellings) for these scenarios is presented as RWT_R1_O, RWT_R1_LTO and RWT_R1_HLTO. Note that the business as usual (BAU) scenario is based on the South East Queensland water strategy published by the QWC.[21]

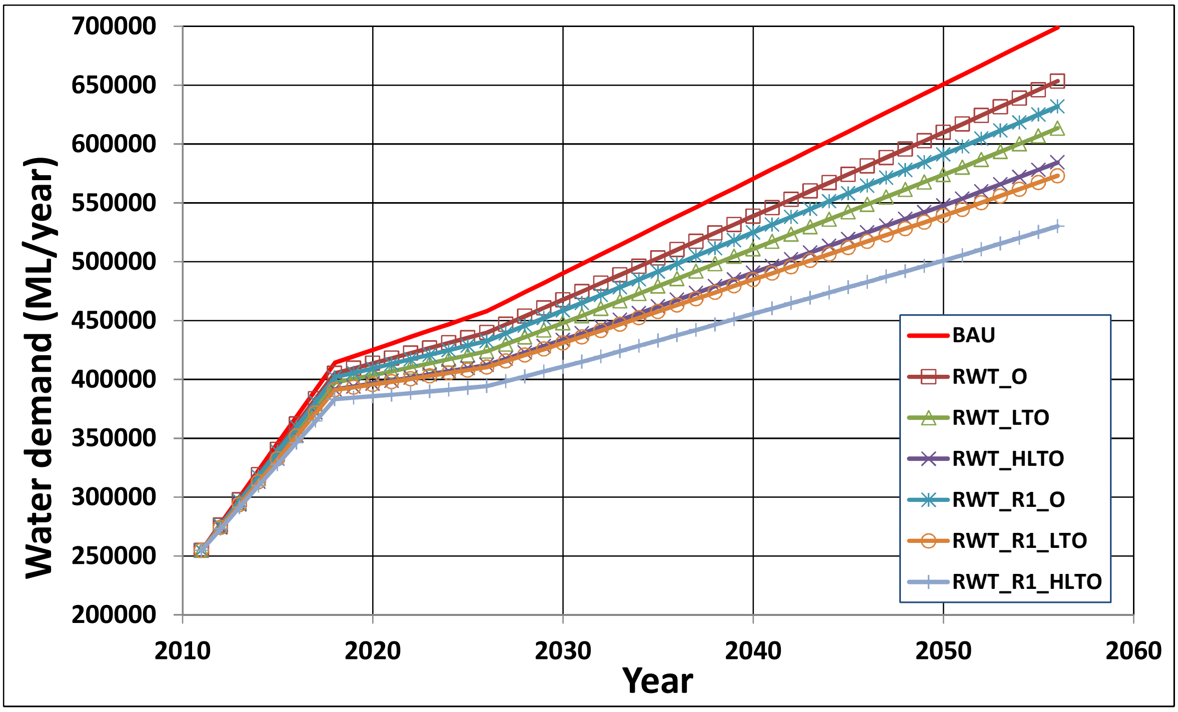

Figure 5.1: Water demands for the South East Queensland region

Figure 5.1 reveals that installation of rainwater tanks to all new houses or all new and renovated houses generates substantial reductions in regional water demands during the planning horizon to 2056.

The reductions in regional water demands will delay the requirement to augment regional water security infrastructure with new desalination plants and dams. These results were combined with the QWC's assessment that augmentation of the system may be required in a climate change scenario when regional water demands exceed 503 GL/annum in Table 5.4.

[21] QWC (2010). South East Queensland water strategy. Report by the Queensland Water Commission.

Table 5.4: Impacts of the different rainwater policies on water demands and regional augmentation

Indentity	Rainwater use	Scenario	Water savings (GL)	Augment (year)	Size of Augmentation (GL)
BAU	None			2031	196
RWT_O	Outdoor	New dwellings	57	2035	150
RWT_LTO	laundry, toilet and outdoor	New dwellings	107	2039	110
RWT_HLTO	hot water, laundry, toilet and outdoor	New dwellings	136	2043	81
RWT_R1_O	Outdoor	New and renovated dwellings	79	2037	129
RWT_R1_LTO	laundry, toilet and outdoor	New and renovated dwellings	147	2044	70
RWT_R1_HLTO	hot water, laundry, toilet and outdoor	New and renovated dwellings	190	2051	27

The timing and cost of augmentation from Table 5.4 were used in the economic model for South East Queensland. Augmentation costs for desalination plants or new dams were estimated to be $1 billion for each 50 GL of annual capacity. Note that this estimate is consistent with the actual cost of the Wonthaggi desalination plant. The average costs to supply and install 5 kL rainwater tanks to new homes were sourced from actual sales data from 27 suppliers as presented in Table 5.5.

Table 5.5: Industry costs for installation of 5 kL rainwater tanks

Item	**Installation costs ($)**				
	Round (Poly)	**Round (Steel)**	**Slimline (Poly)**	**Slimline (Steel)**	**Underground (Poly)**
Rainwater tank	800	900	1,450	1,200	2,896
Pump + auto changer	550	550	750	750	750
Pipework	43	43	54	54	$94
Base + backfill	164	164	200	200	290
Leaf filter	38	38	65	65	65
Diverter	40	40	60	60	60
Labour	220	220	450	450	250
Total	**1,755**	**1,955**	**2,779**	**3,029**	**4,505**

Table 5.5 highlights that the actual costs to install 5 kL above ground rainwater tanks to new dwellings range from $1,755 to $3,029. Installation of rainwater tanks to dwellings subject to renovation is subject to an average increase in costs of $450 to account for additional plumbing.

We note that these actual installation costs are mostly lower than the costs claimed by the Master Builders Association (MBA) that range from $2,400 to $6,850.[22] It is assumed that the MBA are claiming the entire cost of plumbing for laundries and toilets rather than the additional cost of plumbing from a rainwater tank to the dwelling via the pump.

The costs in Table 5.5 also account for the additional concrete and associated works for construction of the tank base. However the tank base is usually installed at the same time as the foundations for the new dwelling. Thus the plumbing and installation costs should actually be classified as marginal costs. It is understood that builders may have included the cost of separate delivery and a substantial profit.

Sales data from the entire industry highlights that the most popular rainwater harvesting systems included a round rainwater tank and slimline tanks were a small proportion of overall installations. Similarly, installation of underground rainwater tanks also proved to be a small proportion of overall installations. Thus the majority of rainwater harvesting systems include above ground round tanks. This actual community choose is also consistent with the small area of 3 m^2 required for this type of rainwater tank.

The actual financial data for installing rainwater tanks and the preferences of the community were considered in the selection of the costs included in the economic model. A realistic profit margin of 20% was also assigned to the installer to derive an average cost for installation at new homes of $2,350 and for renovated homes of $2,900.

This information was combined with the reduced augmentation and operation costs for the regional water authorities and replacement of rainwater pumps every 15 years at a cost of $550. The results of the economic analysis are presented in Table 5.6.

Table 5.6: Whole of society economic impacts of rainwater tanks for South East Queensland

Scenario	NPV ($m)	NPV ($/tank)	NPV ($/kL)
RTW_O	1,877	1,577	1.13
RWT_LTO	4,811	4,041	1.54
RWT_HLTO	6,720	5,645	1.75
RWT_R1_O	1,846	1,551	0.89
RWT_R1_LTO	5,051	4,243	1.25
RWT_R1_HLTO	6,933	5,824	1.40

Table 5.6 reveals that installation of rainwater tanks to all new houses or to all new and renovated houses until 2056 generated economic benefits ranging from $1,846 million to 6,933 million. These benefits that include the costs to install and operate the rainwater tanks are derived from reducing

[22] Mainstream (2012). Domestic rainwater tanks in Queensland - cost effectiveness and impacts on housing costs. Report for the Master Builder Association.

the costs to operate state owned water authorities. These benefits range from $1,551 to $5,824 for each household with a rainwater tank or from $0.89/kL to $1.75/kL of rainwater supply. It is noteworthy that continuing the Queensland Development Code MP 4.2 will provide economic benefits to the state of Queensland ranging from $1,877 million to $4,811 million.

Key Findings

The Queensland development Code MP 4.2 has:

Provided annual water savings of 21.2 to 11.3 GL
Generated economic benefits to the State of Queensland of $2,282 to $4,285 for dwellings with rainwater supply

Continuing the Queensland Develop Code MP 4.2 will:

Provide annual water savings of 57 GL to 107 GL by 2056
Defer regional augmentation by 4 years to 8 years
Generate economic benefits to the state of Queensland of $1,557 to $4,041 for dwellings with rainwater supply

Including rainwater supply to hot water services in Queensland Development Code MP 4.2 will:

Provide annual water savings of 136 GL by 2056
Defer regional augmentation by 12 years
Generate economic benefits to the state of Queensland of $6,720 for dwellings with rainwater supply

Inclusion of renovated dwellings in the Queensland Development Code MP 4.2 will:

Provide annual water savings of 79 GL to 190 GL by 2056
Defer regional augmentation by 6 years to 20 years
Generate economic benefits to the state of Queensland of $1,846 to $6,933 for dwellings with rainwater supply

6. Conclusions and recommendations

Households with rainwater tanks to supply indoor and outdoor water uses have exceeded the requirements of the Queensland development Code MP 4.2. These households have provided annual water savings of 21.2 GL to 11.3 GL in the South East Queensland region at an economic benefit to the Queensland government of $2,282 to $4,285 for each household with a rainwater tank.

Continuing with the Queensland Development Code MP 4.2 will provide substantial economic benefits of $1,557 to $4,041 for each household with rainwater tanks and annual water savings of 57 GL to 107 GL by 2056.

Extending the MP 4.2 strategy to include use of rainwater in hot water services and installation of rainwater tanks for renovated housing with provide considerable economic benefits to the Queensland government of $1,846 to $6,933 for each household with rainwater tanks and annual water savings of 130 GL to 190 GL.

The whole of water cycle and society benefits of alternative strategies that are an essential part of an integrated and robust water strategy cannot be understood unless an integrated systems analysis perspective is adopted. Similarly, the economic benefits of alternative strategies cannot be understood using partial analysis that excludes most of the benefits to Queenslanders.

It is recommended that the Queensland government utilised independent systems analysis of the entire water and investment economic cycles to fully understand the value of diverse and integrated strategies.

The benefits and opportunities of alternative and integrated strategies can only be realised if analysis methods, design codes, government policy and regulators understand and allow implementation of these strategies.

Failure to continue with the Queensland Development Code MP 4.2 may generate indirect costs to Queenslanders of up to $6,933 per new home that will manifest as increased prices of housing that will be driven by greater costs of providing infrastructure, and substantially higher water bills and council rates.