A Case Study: Resolving Boundary Conditions in Economic Analysis of Distributed Solutions for Water Cycle Management

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Economic analysis of targets for sustainable buildings by the Queensland Competition Authority (QCA) and the Rainwater Harvesting Association of Australia (RHAA) is examined as a case study. The results of the analysis were defined by the costs and benefits that are inside or outside of the boundaries of legitimate and recognised consideration. This paper refers to those differences as boundary conditions and considers how those boundary conditions affect the outcome of analysis. Setting of boundary conditions (what is included, what is excluded and assumptions) in engineering and economic analysis dominates outcomes of decisions about government policy. The investigations outlined in this paper were combined to create an enhanced version of a systems analysis of a policy for setting targets for water savings on all new dwellings. It was established, using appropriate boundary conditions, that a 40% target for water savings is feasible for South East Queensland and provides a cost-benefit ratio of 2.1. These results indicate that a policy of mandating targets for sustainable buildings would provide substantial benefits to the state of Queensland, water utilities and citizens.

1. INTRODUCTION

This paper investigates the repeal of legislation for sustainable buildings in South East Queensland (SEQ) as a case study. The influence of assumptions and boundary conditions in engineering and economic analysis on decisions about government policy is examined using published reports and systems analysis of the SEQ region. Detailed discussion about engineering and economic models is not addressed in this paper. Publications by Coombes & Barry (2015), Coombes (2015) and Coombes (2013) provide additional detailed information about systems analysis of water cycle systems that support this investigation. The primary focus of this paper is investigation of the “hidden” assumptions and boundary conditions imposed on analysis that change government policy.

A Background to this investigation is provided in Section 2 and Section 3 discusses the Appropriate Boundary Conditions for Economic Analysis of water cycle systems that includes solutions at multiple scales. This includes considering urban water cycle (water supply, wastewater disposal, stormwater management and protection of the environment) as a linked system that operates at different scales and timeframes (Coombes & Barry, 2014). It is also crucial to count all costs and benefits in the analysis (Coombes, 2013). The second set of boundary conditions is defined in the economic assessment of managing distributed transactions, particularly the operational cost of water delivery, security of water supply, stormwater quality and flooding. These issues are addressed in case study in Section 4 Comparison of Costs and Benefits which deconstructs the analysis underpinning the repeal of the MP 4.2 legislation for sustainable buildings in Queensland. Finally, these insights are combined with the latest audited economic reports (National Performance Reports, Queensland Competition Authority assessments, Annual Reports of water utilities and town planning projections) in a detailed systems analysis of water resources and associated economics that is presented in Section 4 as a comparison between Business as Usual (BAU) and Sustainable Buildings (SB) options.

2. BACKGROUND

South East Queensland (SEQ) in Australia has a population of over 3.2 million people and is served by ten local government authorities (see Figure 1) and six water utilities (see Figure 2).

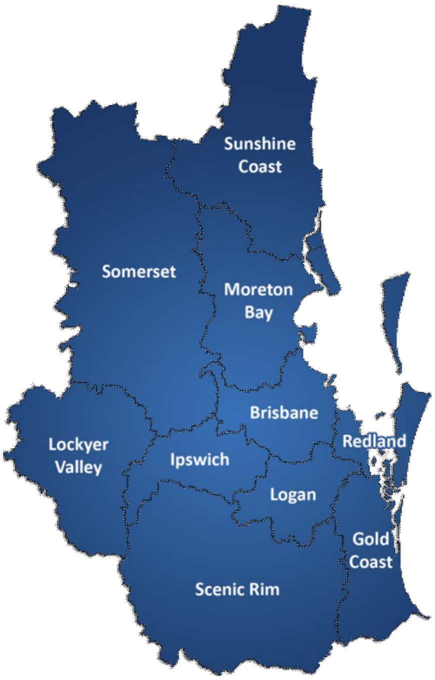

Figure 1: Local government in the South East Queensland region

Figure 2: Water utilities supplying South East Queensland

Figure 2 shows that SEQ is serviced by a bulk water authority Seqwater. Five distribution and retail water authorities provide water, recycled water and wastewater services, namely Queensland Urban Utilities (QUU), Unity Water (UW), City of Gold Coast (CGC), Logan City Council (LCC) and Redland City Council (RCC). Stormwater management is provided by local government authorities. The region experiences population growth of over 1.9% and is expected to accommodate 4.1 to 5.1 million people by 2031 (Queensland Treasury and Trade, 2012). More than 19,000 new dwellings are constructed in each year.

The main source of water for the region is from water stored in large dams supplied by river systems. Water is released from these regional storages to water treatment plants, treated to drinking water standard and pumped to holding reservoirs throughout urban areas. Drinking water is then distributed to dwellings and businesses under pressure via a network of water pipes. Management of this infrastructure, treatment facilities and distribution processes result in capital and operational costs to water utilities that are passed onto consumers as fixed and variable service fees. A majority of water use in dwellings is for drinking, bathing, toilet flushing, clothes washing, cleaning and for irrigation of gardens. Some water is removed from the system for drinking, kitchen and garden uses but most of the water supply demanded by dwellings is discharged as wastewater. Wastewater is discharged from dwellings and businesses via gravity to a network of sewage pipes that flow to pumping stations that transfer wastewater to treatment plants for treatment and release into receiving waters. There is substantial leakage of groundwater and stormwater runoff into the wastewater networks (wastewater networks are designed for wet weather factors of 2 to greater than 12). Consumers pay fixed fees to water utilities for wastewater services.

Stormwater is managed by local government in a process that is not usually integrated with the management of water and wastewater. Stormwater runoff from properties is collected and transported in drainage networks of stormwater pipes to local waterways. The quantity of stormwater runoff is managed in regional detention basins, whilst urban stormwater pollution is mitigated using bio-retention and constructed wetlands. Stormwater services are not purchased or consumed, but are provided by government to protect the community and the local environment. South East Queensland has a variable climate with significant variations in rainfall that has created drought and floods. Security of water supplies, flooding and the ecological health of waterways are significant management issues. The region also experiences spatial variation of average annual rainfall depths (Figure 3) and frequency (Figure 4) which impacts on the behaviour of water, sewage and stormwater systems.

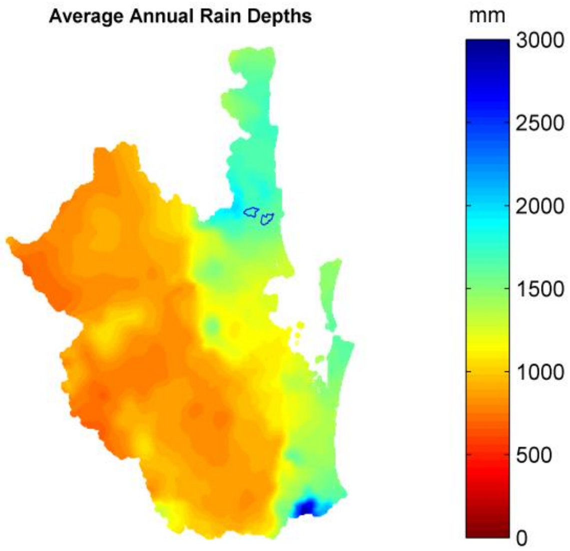

Figure 3: Average annual rainfall

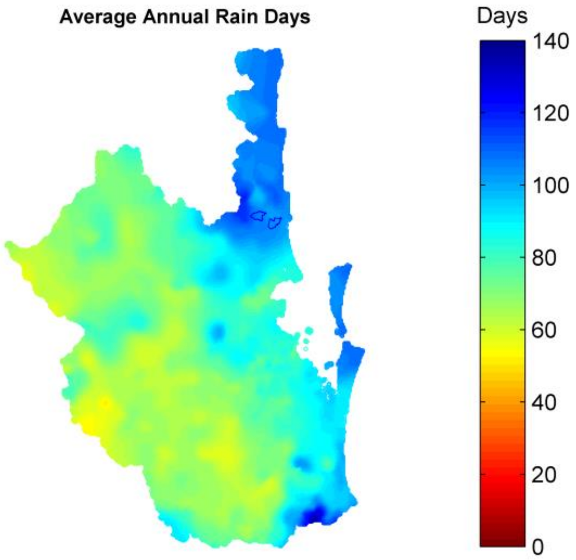

Figure 4: Average annual number of rainfall days

Figure 3 demonstrates that the region is subject to relatively high average annual rainfall depths (900 mm to 2,000 mm) and high average annual frequency of days with rainfall (50 days to 130 days). On average the region will generate substantial volumes of stormwater runoff, including rainfall runoff from roofs, which are managed by local government. Stormwater management is a challenge for the region due to high intensity rainfall events and increasing urbanised areas that drive flood risks. The need to manage urban stormwater pollution is also a substantial issue for protection of the amenity and environmental values provided local waterways. Morton Bay is the receiving environment for urban stormwater runoff and is recognised by RAMSAR as an internationally significant ecosystem.

The prices charged by the state owned water monopolies is regulated by the Queensland Competition Authority (QCA) who act to ensure monopoly businesses operating in Queensland do not abuse their market power through unfair pricing or restrictive access arrangements. Water pricing is the same rate for a geographic area of a water utility and is not varied by the cost of supply, transport or treatment to deliver the water or manage wastewater. However, the characteristics and behaviour of cities are subject to strong spatial and temporal variation that needs to be included in analysis of the economics of water and wastewater services (Coombes & Barry, 2014). Considerable spatial and temporal variation in climate, stormwater runoff, water use behaviours, and costs of water and wastewater services were observed throughout urban regions. During the recent drought water volumes in the region's major storage Lake Wivenhoe declined to 15% of capacity. This event prompted the establishment of the SEQ Water Grid which prompted connection of twelve dams in the region, construction of the Tugun desalination plant and the Western Corridor recycled water scheme. In addition, the Queensland Development Commission (QDC) created mandatory provisions for water savings targets (MP4.2; QDC, 2008) for residential buildings and for alternative water sources in commercial buildings (MP4.3; QDC, 2009). These provisions utilise rainwater harvesting, grey water schemes and water efficient appliances.

An independent audit and monitoring of water use behaviours throughout South East Queensland revealed that dwellings with water efficient appliances that utilised rainwater for indoor and outdoor uses exceeded the requirements of Queensland Development Code MP 4.2 (Coombes, 2012). Water efficient dwellings using rainwater for outdoor uses only provided average annual reductions in demand for mains water of 48 kL and dwellings using rainwater for indoor and outdoor uses provided average annual reductions in mains water demands of 90 kL. Relatively small rainwater tanks (2 m^3) and roof areas (50 m^2 to 100 m^2) generated the substantial reductions in mains water demands. Use of rainwater for indoor uses reduced peak daily and hourly mains water demands which diminishes impacts on and requirement for water distribution, pumping and treatment infrastructure. The observed change in frequency and magnitude of household water use events is demonstrated by the comparison between a households with water efficient appliances and rainwater harvesting (Figure 6) and households that do not include rainwater harvesting (Figure 5).

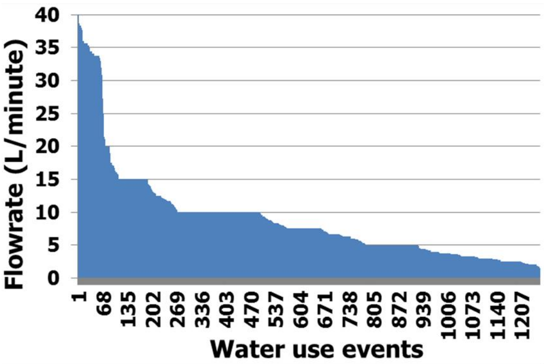

Figure 5: Frequency and magnitude of mains water demands in dwellings without rainwater harvesting and water efficient appliances

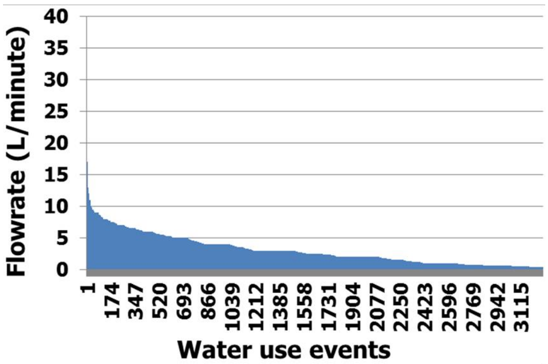

Figure 6: Frequency and magnitude of mains water demands in dwellings with rainwater harvesting and water efficient appliances

Figure 6 reveals that water efficient dwellings with rainwater harvesting provide large reductions in the frequency and magnitude of demands for mains water which will impact on the costs of providing and operating water infrastructure (Coombes, 2012). This observation is confirmed by Lucas et al. (2010) in their analysis of impact of demand management and rainwater harvesting on the design of local water distribution networks. The changes in household mains water use patterns directly impacts on network dynamics. Demand management and rainwater tanks impact upon the diurnal patterns of water flows in a water supply network and can significantly reduce peak mains water demands. This outcome provides reductions in water infrastructure costs by up 53% or $2,010 per dwelling. In addition, Coombes (2007) found that widespread installation of rainwater harvesting at residential dwellings generates net present value savings (from 2010 to 2050) in the provision and operation of large scale water infrastructure ranging from $57 to $6,371 for each dwelling with a rainwater harvesting system. Building scale solutions can provide substantial improvements in the security of urban water supplies that defer requirement for augmentation (Coombes et al., 2002; Coombes, 2005; Coombes & Barry, 2014).

The New South Wales government has determined that the BASIX legislation mandating 40% reductions in household water use will provide cumulative reductions in mains water use of over 300 GL and in greenhouse gas emissions of over 102 million tonnes at a net present value of $843 million to 1.2 billion from 2010 to 2050 (NERA, 2010). A majority of these benefits are provided by water efficient appliances and rainwater harvesting. Observations from National Performance Reports for Urban Water Utilities (NWC, 2012; BOM, 2015) were examined to determine the historical impact of sustainable buildings on the operating costs of water utilities. The water operating costs for utilities subject to BASIX performance targets for sustainable buildings (Sydney Water and Hunter Water) is compared to the water operating costs of utilities (City West Water, South East Water and Yarra Valley Water) that operate in jurisdictions without targets for sustainable buildings in Figure 7.

Figure 7 shows that growth in water operating costs of utilities in jurisdictions with BASIX legislation has significantly reduced in comparison to water operating costs of utilities in areas without mandates for sustainable buildings. A combination of water operating costs from Brisbane Water and then Queensland Urban Utilities in SEQ is an interesting contrast. The establishment of mandatory provisions for sustainable buildings in 2008 contributed to a decline in the growth in operating costs but the high costs of the operation of the water grid with desalination and the Western Corridor scheme ($3,512/ML) from 2009, as shown in Figure 8, resulted in an escalation in operating costs.

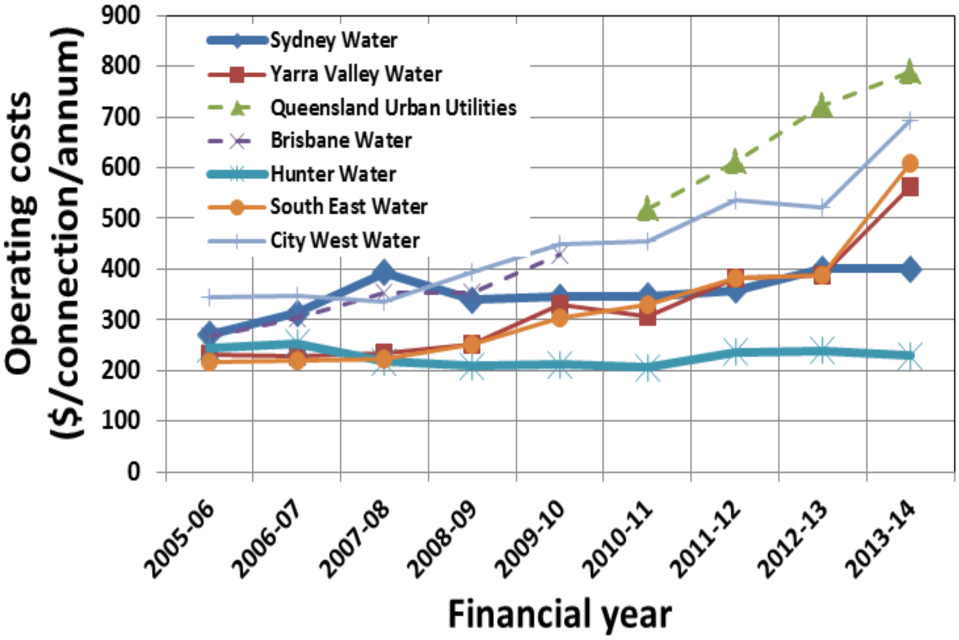

Figure 7: Water operating costs for utilities operating with mandates for sustainable buildings versus costs of utilities without mandates for sustainable buildings (NWC, 2012; BOM, 2015).

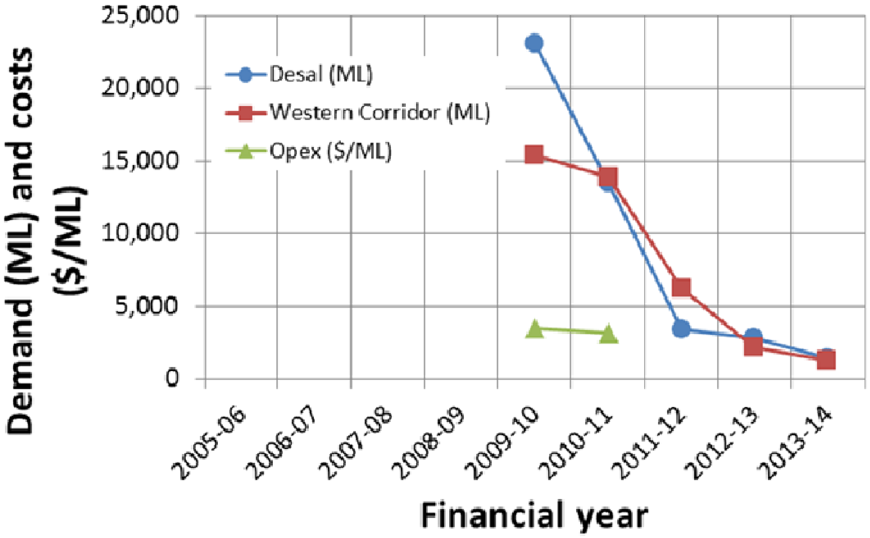

Figure 8: Operation of desalination and Western Corridor scheme with costs (NWC, 2011)

Figure 8 highlights that the maximum utilisation of desalination and the Western Corridor scheme was during the period 2009 to 2011 which declined to minimal use in 2013. The growth in water operating costs for SEQ was impacted by mandates for water savings in buildings (2008 to 2012), the operation of the water grid (from 2009) and the repeal of the mandates for water savings in buildings (from 2012).These competing processes have the effect of obscuring the reduced operating costs generated by the mandatory provisions for sustainable buildings and only 32% of sustainable buildings utilised rainwater for indoor uses (ABS, 2013). It is proposed the mandatory provisions impeded more rapid growth in operating costs. Implementation of a planning policy for sustainable buildings with similar governance to BASIX is likely to achieve greater benefits.

In 2012, the Queensland government formed a view that the costs of the mandatory provisions for sustainable buildings (MP 4.2 and MP 4.3) were greater than the benefits and requested that the economic regulator QCA conduct a review. The assessment by the QCA considered submissions from other government departments but was almost solely reliant on analysis by a consultant (MJA,

2012) ï hereafter referred to as the QCA analysis - and did not substantially consider other submissions in agreeing to the repeal of the mandatory provisions for sustainable buildings. In part, the philosophy of the economic assessment was that regulation or performance targets impedes the operation of the ñfree marketò and legislated performance targets need to be dismissed as ñred tapeò. However, perfect markets with adequate access, knowledge and competition may only exist in text books, elsewhere regulations need to be applied to force imperfect markets to generate acceptable economic behaviours from perspective of whole of society.

Free market forces and competition do not apply to water and wastewater services that are managed by the bureaucracy as government owned monopolies (ACCC, 2015)[1]. Stormwater services are managed by local government and are also not provided via market mechanisms. The implication is that the market forces, which are expected to drive efficiency and productivity, are not operating. In addition, markets are strongly dependent on local and distributed transactions that may not be captured in a centralised average analysis of water options. Water services are essentially a transport business with cumulative impacts and costs (Coombes, 2013; Coombes & Barry, 2014). A highly treated, monitored and heavy commodity is provided on demand direct to the user through large, single purpose infrastructure over a considerable distance from source to local demand. This process is repeated in reverse for wastewater. A third set of infrastructure is required for stormwater management. Such a business is expensive to operate and reductions in the volume of water that needs to be centrally managed and transferred to users results in significant savings that were not considered by the QCA. Similarly, planning for water security in SEQ is almost entirely reliant on desalination and large scale recycling services to meet future water demand. Full use of the water grid is implied when demand reaches 545 ML/day and supply augmentation is not expected until after water demands reach 585 ML/day (QWC, 2010) but the high capital and operating costs of these additional supplies should be included.

3. APPROPRIATE BOUNDARY CONDITIONS FOR ECONOMIC ANALYSIS

Distributed local solutions, such as sustainable buildings, are installed and operate throughout existing centralised water cycle systems to modify the cumulative demand for traditional services and improve the behaviour of a more diverse water system. Analysis of the impact of distributed solutions on centralised systems requires adequate detail to capture the variable changes in behaviour that are driven by spatial and temporal variations in climate, demographic, socio-economic, topographic, ecological and infrastructure considerations. The behaviour of an alternative (such as Sustainable Buildings) option must be compared to a credible definition of the business as usual (BAU) option that includes sufficient detail to allow comparison to the proposed alternative option. Importantly, the analysis must include the alternative solution, strategy or policy as part of the existing system rather than isolated or separate assessment of alternative options. Comparison of a sustainable buildings option that includes rainwater harvesting and water efficient appliances requires definition of the BAU option for the region with a high level of spatial and temporal detail. In addition, it is essential to understand that the BAU option will include some elements of the alternative option. It is often the case that the relative systems response is driven by a change in the rate of adoption of the alternative options within the BAU system over time.

A systems analysis examines the movement and storage of water from sources (extraction from waterways) to sinks (disposal to waterways). The transactions throughout the system include the costs of operation, replacement and provision of infrastructure that are dependent on demand for a service, which can be defined as volumes of water or magnitude of energy. Mandating sustainable buildings will generate an additional cost to the homeowner of installing, operating and replacing rainwater harvesting systems and water or energy efficient appliances. This includes installation of rainwater storages, leaf diverters, first flush diverters, pumps, filters, more efficient appliances and plumbing connections. The operation of this system will require periodic replacement of components in accordance with expected design lives (for example; water efficient washing machines and

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[1] ñAustralians rely on the market economy to provide positive outcomes for their prosperity and welfare. However, the market economy is not perfect. Consumer welfare can be undermined, especially in some areas of infrastructure provision where there are or have been monopoly suppliers. When this occurs, our role is to provide effective regulation that will protect, strengthen and supplement competitive market processes to improve the efficiency of the economy and increase the welfare of Australians.ò

rainwater pumps have a design life of about ten years and a rainwater storage has a design life of about thirty years).

There will be reductions in average and peak water demands from the centralised system that results from more efficient water uses and substitution of mains water demand by use of rainwater. Reductions in mains water demands in buildings will decrease revenue from provision of water and wastewater services, and provide offsetting reductions in operating and capital expenses to water utilities. The extent of the diminished revenue for water and sewage services is dependent on the regulated tariff structure ï for example the proportion of fixed charges determines the relative magnitude of any reduced revenue. Similarly, the magnitude of reduced operating costs is driven by cumulative impacts throughout a region. It is also necessary to consider the longer term impacts of strategies. For example, an overview of the integration of local rainwater harvesting on the urban stormwater system is shown in Figure 9.

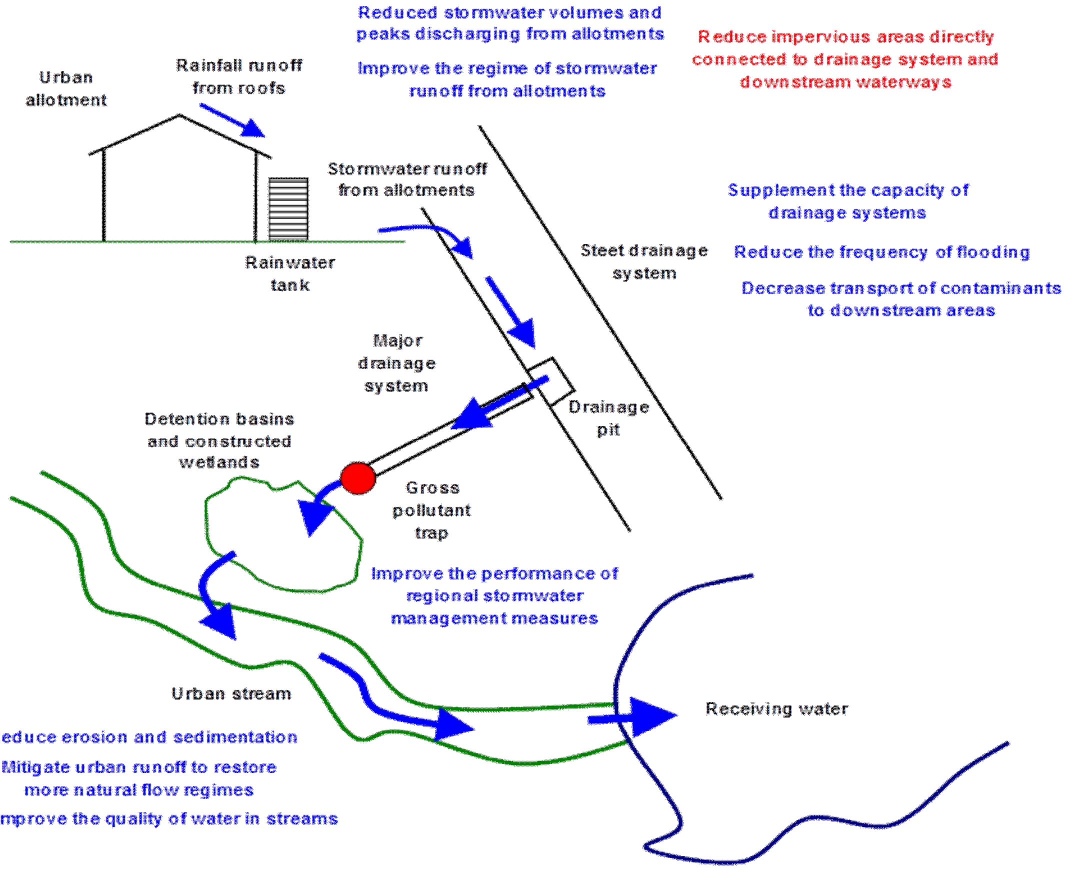

Figure 9: An overview of the integration of rainwater harvesting on urban stormwater systems.

The volumes of stormwater runoff are reduced and quality of urban stormwater is improved by retention of roof runoff in rainwater harvesting systems. The operational and capital costs of managing stormwater quality onsite, in downstream constructed wetlands and treatment systems are reduced and deferred. This improves the health and amenity of local waterways and receiving waters. Reductions in stormwater runoff volumes decrease the risks of local flooding in drainage networks, flood management facilities and waterways. This can lead to reduction in the volume of infrastructure required for flood management. The operational and capital costs of flood reduction infrastructure can be reduced and deferred.

Reduction in demands for mains water also has longer term impacts. In the medium term the operational and replacement costs of water treatment plants, pumps and pipelines decrease. Reductions in peak demands reduce the maximum capacity requirements of the water network to supply services. These reductions in costs are cumulative throughout water cycle networks and increase over time. In the longer term the capital costs of building new pressure reservoirs, higher capacity networks and larger treatment plants are deferred or avoided by reducing the cumulative volume of demands. This has a secondary impact of avoiding the higher operational costs of larger infrastructure such as desalination plants and regional recycled water schemes. It is essential to include all connected elements of the water and energy cycle in analysis. An overview of the interaction of local rainwater harvesting on the urban water supply systems is shown in Figure 10.

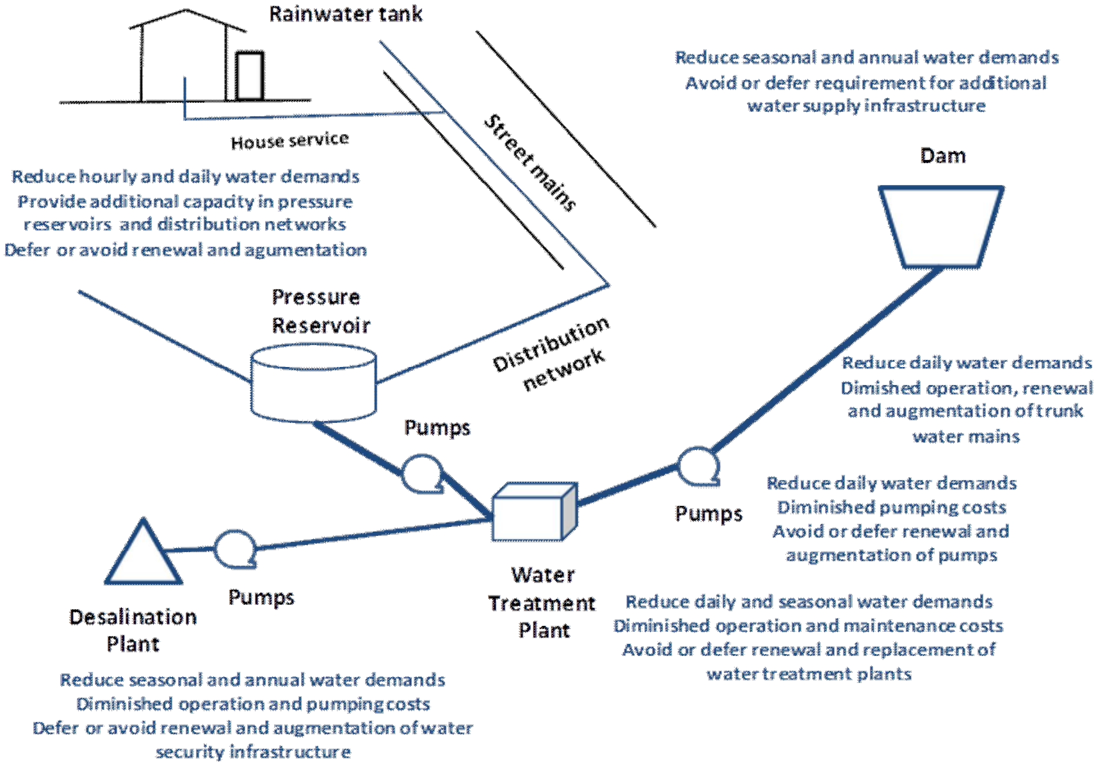

Figure 10: Interaction of distributed sustainable buildings on regional water supply systems

4. COMPARISON OF KEY ASSUMPTIONS FROM A CASE STUDY

During 2012, the Queensland government repealed legislation (QDC MP 4.2 and QDC MP 4.3) that mandated sustainable buildings. This decision resulted from analysis by the QCA (2012) with inputs from consultants (MJA, 2012) that found the costs of the legislation were greater than the benefits. The QCA analysis is compared to the systems analysis by RHAA (Coombes, 2012a) to prompt discussion about appropriate boundary conditions and economic processes for assessment of benefits of distributed solutions. A review of the QCA and RHAA reports revealed that different information was provided about economic analysis and assumptions which created difficulty in the comparison. Additional information was requested from the consultants and from the Queensland government to clarify the QCA analysis. In the absence of the requested additional information, the authors were able to reconstruct the QCA analysis using only the information provided in the various reports (MJA, 2012; QCA, 2012) as shown in Tables 1 and 2.

The QCA and the RHAA utilized different discount rates planning horizons. The key assumptions in both reports are summarised in Table 1 for the costs of rainwater harvesting and in Table 2 for the benefits of rainwater harvesting. These assumptions listed in Tables 1 and 2 were combined with the results of each report to create a comparable economic analysis.

Different modelling philosophies were also employed with the QCA focused on a Cost Benefit Analysis and the RHAA utilised a regional water balance methodology that also incorporated an economic analysis. Nevertheless, this discussion is concerned with the impacts of input assumptions and processes on the outputs of analysis and does not focus on the detail of water resources modelling. However, there were some similarities in the structure of the analysis ï both the QCA and RHAA analysed the SEQ region as a single node using inputs from other studies (QCA) or a regional water balance model (RHAA) to define inputs about distributed rainwater harvesting.

Table 1: Summary of key assumptions about costs of rainwater harvesting

Item	**QCA**	**RHAA**
Installation of rainwater harvesting systems (RWHS)	17,968 houses and 2,849 apartments (MJA, 2012: Table 19, pp. 45), and 1,653 non-residential (inferred using Table 6, pp.24) per annum.	All new dwellings: Option RWT_LTO (Coombes, 2012a: pp. 30) based on QWC (2010) population projections.
Existing rainwater harvesting systems	100,000 since 2007 (MJA, 2012: Table 18, pp. 45)	236,000 since 2007 (Coombes, 2012a: pp. 28)
Rainwater yields	50 kL/dwelling/yr, 84 kL/building/yr (MJA, 2012: Table 19, pp. 46)	90 kL/dwelling/yr (Coombes, 2012a: pp. 29) includes water efficient appliances
Install costs	Residential Tanks: $3,500, Non-residential tanks: $4,400, Pumps: $600 (MJA, 2012: Table 19, pp. 46)	New: $2,350, Retrofit: $2,900 (Coombes, 2012a: pp. 32)
Operation costs	$40/tank/yr (MJA, 2012: Table 19, pp. 46)	$265/ML (Coombes, 2012a: pp. 29)
Pump replacement	Every 10 years **but no pumps replaced** (MJA, 2012: Table 19, pp. 46)	Every 15 years at a cost of $550 (Coombes, 2012a: pp.32)
Tank replacement	Every 20 years **but no tanks replaced** (MJA, 2012: Table 19, pp. 46)	Every 25 years at a cost of $2,350 (Coombes, 2012a: pp.32)
Abatement costs	$4/yr in nutrient costs for each RWHS not operating (MJA, 2012: Table 20, pp. 47)	Not required

Table 2: Summary of key assumptions about the benefits of rainwater harvesting

Item	QCA	RHAA
Discount Rate	4.4%	9%
Length of Analysis	40 years	46 years
Base water demands	Houses: 238 kL/yr, Units 128 kL/yr and Non-residential 721 kL/yr (MJA, 2012: Table 18, pp.45)	Demand projections for SEQ by QWC (2010) (Coombes, 2012a: pp.29)
Stormwater benefits	Avoided Capex $819/house, Renewal $410/house and Opex $14/house/yr. (MJA, 2012: Table 20, pp.47)	Avoided Capex $16,229/ML, Renewal $263/ML and Opex 279.5/ML (Coombes, 2012a: inferred from Table 5.1, pp. 28)
Water supply benefits	Avoided Fixed Opex $157.8/ML and variable Opex $495/ML (MJA, 2012: inferred from Table 6: pp. 24)	Avoided Capex $3,664/ML, Renewal $293/ML and Opex $3,493/ML (Coombes, 2012a: Table 5.1, pp. 28)
Augmentation	Cost: $1,032 m and deferral from 2034 to 2037 (MJA, 2012: Table 21, pp. 47)	Deferral from 2031 to 2039, Cost in 2031: $3,290 m and cost in 2039: $2,200. Size of desalination plant determined by future demands to 2056. Cost of desalination: $1,000 m/50 GL annual demand. (Coombes, 2012a: Table 5.4, pp. 31)

Tables 1 and 2 reveal that sufficient information was available to allow reconstruction of both analyses into timelines of rainwater savings, costs and benefits that are discussed in detail in the following Sections. The RHAA analysis was altered to incorporate a 4.4% discount rate and a 40 year planning horizon to provide comparable outputs in the same categories as the QCA analysis. A comparison between the cumulative savings from the QCA and the RHAA are presented in Figure 11.

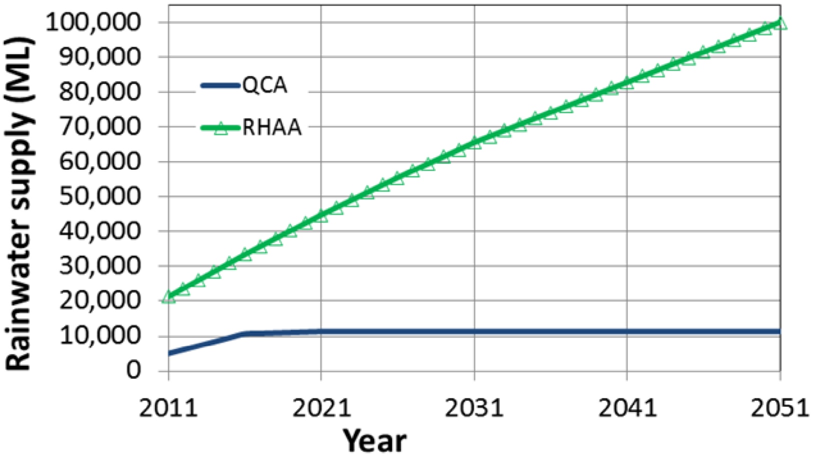

Figure 11: Comparison of total rainwater supply from the QCA and RHAA analysis

Figure 11 demonstrates a substantial difference between water savings used in the QCA and RHAA reports. The assumption by the QCA that pumps and rainwater tanks are not replaced at the end of their useful life creates a flat water saving regime after 2017 and dominates the difference in water savings. Cumulative water savings are also impacted by assumptions about the number of rainwater harvesting systems installed prior to 2011 and by a focus by RHAA on sustainable buildings which also include water efficient appliances. The timelines of costs and benefits resulting from the different reports are provided in Figures 12 and 13, respectively.

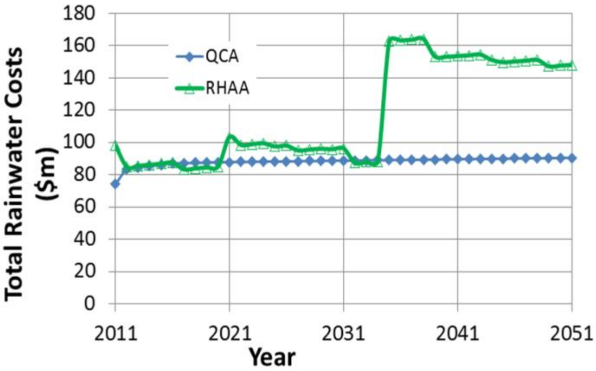

Figure 12: Comparison of rainwater costs

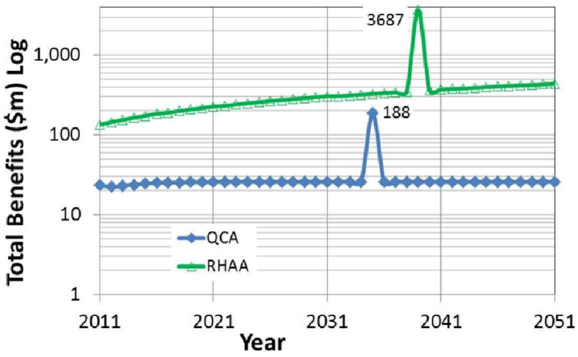

Figure 13: Comparison of rainwater benefits

Figure 12 shows that the timelines of total rainwater costs in the QCA analysis are lower than the RHAA timeline of costs. These differences are driven by the QCA assumption that pumps and rainwater tanks are not replaced at the end of their asset life, use of higher installation costs and fixed annual installation numbers. In contrast, the variability of the RHAA timeline of total costs is driven by population projections, assumed periodic replacement of all pumps and rainwater tanks, and historical installation rates of sustainable dwellings prior to 2011. Another key difference is that the QCA assume no rainwater harvesting systems prior to 2007 and the RHAA assume 108,400 sustainable dwellings in 2007.

Figure 13 reveals considerable differences in the timelines of benefits derived from the QCA and RHAA analysis. The QCA assumption that all rainwater harvesting systems cease working after ten years (pumps and rainwater tanks are not replaced), lower values for deferred operational costs of supplying water and smaller values for deferred augmentation has resulted in a constant and smaller annual benefit from rainwater harvesting. Note that the spikes in the benefit timelines represent the actual future value of deferred augmentation that was deconstructed from the net present values in the reports. A comparison of the benefits and costs of the different analysis is presented in Tables 3 and 4 respectively.

Table 3: Comparison of present value of benefits from QCA and RHAA analysis

Benefits	QCA ($M)	RHAA ($M)
Avoided water operation costs	129.3	3,436
Deferred augmentation	46.5	956
Avoided water capital costs	0	158
Avoided stormwater operating costs	36.7	275
Avoided stormwater capital costs	305.6	898
Total benefits	**518**	**5,723**

Table 4: Comparison of present value of costs from QCA and RHAA analysis

Costs	QCA ($M)	RHAA ($M)
Rainwater harvesting installation	1,492	1,831
Pump replacement	-	214
Rainwater tank replacement	-	322
Rainwater harvesting Operation	140	261
Abatement cost of pumps not replaced	13	-
Total costs	**1,645**	**2,628**
Cost benefit ratio	**0.31**	**2.1**

The results in Tables 3 and 4 reveal substantial differences between the QCA and RHAA analysis that would justify vastly different policy decisions. A cost benefit ratio of 0.31 from the QCA would drive rejection of a policy and the ratio of 2.1 from RHAA would prompt acceptance based on economic criteria. It is noted that both the costs and benefits of the RHAA analysis are substantially higher than the QCA analysis. These differences in the comparison warranted further discussion as outlined below.

4.1. Sustainable buildings and installation costs

The RHAA analysis is based on population projections provided by SEQ Water Strategy (QWC, 2010), analysis using a regional water balance and performance of sustainable buildings (water efficient appliances and rainwater harvesting) in accordance with the MP 4.2 legislation. Annual water savings of 90 kL (average savings: rainwater 59 kL; water efficient appliances: 31 kL) were assigned to each Sustainable Building in accordance with monitoring results for SEQ from Coombes (2012). This analysis assumed that all new dwellings will be Sustainable Buildings. A total of 875,962 Sustainable Buildings were established between 2011 and 2051 that generated annual water savings of 78,837 ML in 2051 at a net present cost of $1,831 m.

In contrast, QCA focused on rainwater harvesting systems installed in new dwellings or buildings in response to the MP 4.2 and MP 4.3 legislation, utilized a fixed average number of new rainwater harvesting systems in each year and assumed an annual rainwater supply of 50 kL to each system. This analysis was completed as an accounting process that was not linked to the SEQ water balance or planning projections for the region. Table 6 in the QCA report (MJA, 2012) presents net present capital costs of rainwater harvesting systems of $1,645 million and a net present cost of $4,861 per rainwater harvesting system. These results imply that 338,500 rainwater harvesting systems were installed over a 40 year period but 875,962 new homes were projected. The total water savings generated by rainwater harvesting was not reported.

The reporting associated with QCA analysis appeared to incorporate 537,462 fewer rainwater harvesting systems than the RHAA investigation at a higher cost. Nevertheless, the Queensland

Treasury and Trade (2012) estimate that over 18,000 new dwellings in each year are constructed in SEQ and ABS (2013) found that 55,128 to 32,204 rainwater harvesting systems were installed in each year during the operation of the MP 4.2 legislation. It would appear that the QCA has assumed low installation rates. However, our reconstruction of the analysis using details provided in the above Table 1 indicates that 878,960 rainwater harvesting systems were included in the QCA investigation. These results indicated that the actual net present capital cost of a rainwater harvesting system should have been reported as $1,524 by the QCA rather than the $4,861 reported.

4.2. Avoided water operating costs

There are substantial differences in the magnitude of avoided water operating costs between the RHAA (NPV of $3,436 m) and QCA (NPV of $129.3 m), which indicate substantial differences in assumptions and boundary conditions employed in the analysis. The RHAA used the water operating cost of $3,493/ML that was derived from the National Performance Reports (NWC, 2012) for Queensland Urban Utilities. The RHAA analysis commences with 236,000 sustainable buildings with annual reductions in mains water demand of 21,240 ML in 2011 and finishes with annual reductions in mains water demand of 107,142 ML in 2051. It was also assumed that all rainwater pumps were replaced after 15 years (this includes a warrantee period of 5 years for pumps) and all rainwater tanks were replaced after 25 years operation.

The RHAA use of water operating costs reported in the National Performance Reports will need clarification against water authority annual reports and regulatory reviews by the QCA to derive variable proportion of water operating costs. Similarly, these variable costs will be different for each authority across SEQ and with the length of analysis. These considerations may reduce the magnitude of the avoided operating costs that were reported by RHAA. Nevertheless, we are mindful that the Queensland Auditor General has found that the Tugun desalination plant and the Western Corridor Scheme (WCS) has actual additional operating costs of up to $4,419/ML (QAO, 2012) and Water Secure reported an operating cost of $3,512/ML (NWC, 2011). These figures are not consistent with the inferred operating cost of $495/ML used by the QCA to estimate the benefits of avoided operating costs (Table 2). Importantly, the SEQ water system includes a cumulative network of solutions and providers that links security infrastructure (desalination and WCS), the water grid, bulk water providers, water and sewage retailors, and local government. The average operating costs reported by Water and Sewage retailors may represent these accumulative operating costs, but it is more likely that full operation of security infrastructure is additional to these costs. The RHAA analysis did not consider the increased operating costs that are triggered by the additional use of the water security infrastructure in the water grid. This may increase avoided water operating costs.

The QCA did not publish the water operating costs used in their analysis, but as inferred above in Table 2, their assumed operating costs were significantly lower than the costs used by the RHAA. In addition, the analysis was limited to rainwater harvesting systems with lower water savings (50 kL for rainwater harvesting versus 90 kL for sustainable buildings). Whilst these issues would reduce the water savings and associated operating costs in the analysis, the dominant driver of the differences in water savings and associated water operating costs is the QCA assumption that rainwater pumps and tanks would not be replaced at the end of assumed 10 year and 20 year design lives. This assumption has the effect of limiting the working life all rainwater harvesting systems to 10 years and ensuring that the cumulative water savings from rainwater harvesting systems cannot exceed 11,380 ML in any year.

These assumptions by QWC have dramatically reduced the water savings from rainwater harvesting systems (by a factor of 8), but also produce a significant reduction in benefits and increase the volumetric costs of installation. Whilst the assumption by the QCA that all pumps and tanks were not replaced was reported to be compliant with the wishes of the QWC, it was inconsistent with available evidence. Surveys by CSIRO (2014) found that 93% of respondents were satisfied with their rainwater harvesting system, and the level of satisfaction was higher for mandated installations. Similarly, ABS (2013) found 60% of rainwater tank owners in Queensland had carried out maintenance in the last 12 months and 49% of these checked pipe work and connections. This evidence is also inconsistent with the QCA assumption that all mandated tank owners will not invest in maintenance and repairs.

4.3. Deferred augmentation of water security infrastructure

There are significant differences in the value of deferred augmentation of water security infrastructure between the QCA (NPV of $46.5 m) and the RHAA (NPV of $956 m) in Table 3. Some of these differences are explained by the low numbers of operating rainwater harvesting systems that limits water savings in the QCA analysis as discussed in the previous Section addressing avoided water operating costs. However, the magnitude of this benefit is further impacted by QCA assumption that augmentation would occur in 2032 using either a desalination plant (construction cost: $1.56 billion; operation: $34.3 million/year) or a local water source (construction cost: $500 million; operation: $10 million/year) and that rainwater harvesting systems would only defer augmentation by 3 years. Reconstruction of the QCA analysis using the values in Tables 1 and 2 that were derived from additional investigation of reports revealed that a medium value of 1,032 million was assumed for augmentation and operating costs of a new desalination plant were not counted.

The RHAA water balance for the SEQ region indicates that augmentation may be required in 2031 using a desalination plant with a capacity of 535 ML/day at a cost of $3.92 billion. Sustainable buildings will defer augmentation or water security infrastructure to beyond 2039 (by at least 8 years) and reduce the size and cost of the desalination plant to 300 ML/day and $2.2 billion, respectively. Sizing of these desalination plants was based on the expected water demands to 2056 for scenarios with and without sustainable buildings. The RHAA did not include the additional operating costs of desalination and the analysis could be improved by inclusion of the current water security options included in the water grid. Nevertheless, combining sustainable buildings and regional water resources in a water balance has facilitated a more robust assessment of the impact of distributed solutions on regional water storages which define water security.

4.4. Avoided expenditure for water and stormwater infrastructure

The QCA analysis limited assessment of avoided capital expenditure on water and stormwater infrastructure to assumptions about the size of bio-retention required for each dwelling. The impact of reduced stormwater runoff on drainage, detention and water quality infrastructure was dismissed based on an opinion from "drainage engineers" that rainwater tanks would be full prior to storm events and did not reduce peak flows. However, Coombes & Barry (2008) found that 5 kL rainwater tanks connected to 100 m^2 roof areas to supply toilet, laundry and outdoor uses in Brisbane will have retention storage of over 4 m^3 available prior to storm events greater than a ten year average recurrence interval (ARI). Rainwater tanks used to supply indoor uses will be almost empty prior to the storm events used to design stormwater drainage infrastructure. This result is due to the seasonality of rainfall and an alignment between higher likelihood of storm events and water use in Brisbane. However, impacts on stormwater infrastructure is not limited to peak flows and reduced volumes of stormwater runoff across larger scales also diminish requirements for storage capacity in trunk infrastructure (Coombes & Barry, 2014).

Similarly, the benefits of rainwater harvesting on water distribution networks, transfer pumps, pressure reservoirs and water treatment plants was dismissed based on an assumption that installation and renewal of smallest street scale infrastructure would be dominated by fire-fighting requirements. In addition, it was assumed that regional infrastructure was already constructed and there were no benefits in deferring augmentation of water treatment plants or stormwater detention facilities (for example). As such the QCA has set a narrow boundary condition on the analysis to a single scale by excluding a wide range of infrastructure considerations and have not considered evidence such as by Lucas et al., (2010), Coombes (2012) and many others about impacts of local solutions on regional infrastructure.

In contrast, the RHAA has considered the impacts of sustainable buildings on water and stormwater infrastructure across local to regional scales. The impact of reduced stormwater runoff and water demands on the operation, renewal and augmentation of infrastructure was incorporated as a function of the likely impacts derived from multiple publications and projects. For example, monitoring by Coombes (2012) throughout SEQ found that sustainable buildings reduced peak instantaneous and daily water demands by 35% and 53%, respectively. This result implies that sustainable buildings will reduce impacts on local and regional transfer infrastructure. However, the diminished volumes of demands also reduce impacts on pressure reservoirs, water treatment plants and dams. As discussed in the introduction, a combination of distributed solutions and regional infrastructure networks can change the dynamics of regional infrastructure systems resulting in significant benefits. The use of a regional water balance methodology by RHAA has allowed understanding of the changes in the dynamics of linked regional infrastructure created by widespread implementation of sustainable buildings. However, as presented in Figures 3 and 4, the SEQ region is subject to a high level of spatial variability that required greater spatial detail in the water balance methodology applied by RHAA.

5. SYSTEMS ANALYSIS OF SEQ WATER RESOURCES AND ECONOMICS.

The RHAA systems analysis of water balances in SEQ region was enhanced to incorporate the issues discussed in Sections 3 and 4 of this paper, and to include the latest water resources, population and financial data. This enhanced capability was then utilized to understand the costs and benefits of incorporating targets for sustainable buildings throughout the SEQ buildings region. Greater spatial detail was included to capture water balance and financial behaviours in the jurisdictions of each water retailer in the region (see Figure 2); Queensland Urban Utilities, Unity Water, Gold Coast Council, Logan Council and Redlands Council.

A comparative analysis of BAU versus sustainable buildings (SB) options was the undertaken using the latest population projections from Queensland Treasury and Trade (2012) for each area. Dwellings with outdoor rainwater supply only used rainwater for outdoor uses. Sustainable dwellings with indoor rainwater supply were defined as harvesting rainwater from 100 m^2 roofs for collection in 5 kL storages to supply laundry, toilet and outdoor water uses. These dwellings also included the best available water efficient toilets, washing machines, showers and tapware. The sustainable dwelling with indoor rainwater supply was used to define the potential to reduce mains water demand and define targets for SEQ. The performance of the sustainable buildings was defined for each jurisdiction using local climate and water use data in a local water balance model PURRS (Coombes, 2006) that operated at 6 minute time steps. Water demands, sewage discharges and stormwater runoff from each dwelling with and without sustainable elements was used in the analysis. The local water balance model was calibrated using the latest residential water use information from BOM (2015).

Data from ABS (2013) indicated that 26% of properties were connected to mains water supplies included a rainwater harvesting system in 2013 and rainwater was used for indoor uses in 32% of these properties and for outdoor uses in 68% of properties. This information was used to define the characteristics of sustainable buildings prior to 2015 in each option and throughout the planning horizon in the BAU option. The BAU option included sustainable buildings for 10% of new dwellings in each year in accordance with the observations from ABS (2013) for the period after repeal of the MP 4.2 mandate and the SB option incorporated sustainable dwellings with indoor rainwater supply in 90% of new dwellings. At the commencement of the analysis in 2011, both the BAU and SB options included 291,460 properties with rainwater harvesting systems which provided 17,280 ML in mains water savings. In 2056, the BAU option included 448,200 sustainable buildings that produced 29,800 ML in mains water savings whilst the SB option included 1,918,810 sustainable buildings that provided 160,634 ML in mains water savings.

The regional water balance model for SEQ was altered to include water demands from non-residential users, irrigators, power stations and country towns that are reliant on the regional water supply (see Coombes & Barry, 2015 for a description of the Systems Framework). Information from the National Performance Reports (BOM, 2015), water utility annual reports and the economic regulator QCA (2014) was employed to determine the variable and fixed costs for water supply and wastewater disposal. These results were used to upgrade the costs used for operation, renewal and provision of water and sewage infrastructure. Operation and renewal costs are multiplied by the total volumes of mains water demands, sewage discharge or stormwater runoff for a given location in each year of the analysis. Capital costs are multiplied by the volume of changed water demand, sewage discharge or stormwater runoff in any year to capture the requirement for new regional infrastructure. The costs of street scale water and sewage infrastructure was not included in the analysis as it was assumed that this infrastructure would be relatively unchanged. The costs to install or replace rainwater tanks, pumps and water efficient appliances were assumed to be $2,900, $550 and $500, respectively. The regional analysis assumed that rainwater pumps and water efficient appliances are replaced every ten years and rainwater tanks are replaced every 30 years. A majority of the cumulative costs of water and sewage services in SEQ were considered to be represented by the costs incurred by the water retailers with the exception of the costs of operating the security measures in the water grid and for augmentation of water security. Similarly, most of the revenue is generated by the fixed and usage tariffs paid by consumers as defined by QCA (2013) that are included in the analysis. The results of the analysis are summarized in Table 5.

Table 5: Comparison of benefits from BAU and Sustainable Building (SB) Options

Criteria	**NPV ($m) to 2056 at 4.4% discount rate**		**Change (%)**	**Benefits ($m)**
	BAU	**SB**		
Water revenue	33,943	31,376	-7.6	-2,577
Sewage revenue	28,881	28,881	0	0
Water costs	34,564	30,907	-10.6	3,657
Sewage costs	22,265	21,208	-4.7	1,057
Stormwater costs	15,309	14,879	-2.8	430
Sustainable Building costs	656	3,970	506	-3,315
Additional water grid cost	1,004	293	-71	711
Augmentation costs	1,232	230	-81.3	1,001
Water utility profit	**3,760**	**7,609**	**102**	**3,849**
Whole of society costs	**75,050**	**71,488**	**-4.7**	**3,541**

Table 5 demonstrates that a policy to mandate targets for sustainable buildings would generate $3,849 million (102%) financial improvement accruing to water utilities where reduced costs outweigh decreases in revenue as a result of water savings from sustainable buildings. The whole of society costs of water cycle services was reduced by $3,541 million (4.7%). These results produce at cost-benefit ratio of 2.1. These results indicate that a policy of mandating targets for sustainable buildings would provide substantial benefits to the state of Queensland, water utilities and citizens.

A large proportion of the benefits from sustainable buildings resulted from reductions in mains water demands that diminished the costs of operating, renewing and providing water infrastructure. Significant benefits were also generated by use of water efficient appliances that reduced sewage discharges and associated costs. The analysis established that 27% of the costs of operating water utilities were attributed to fixed and corporate costs that were relatively unchanged by the SB option, and were $20,293 million and $19,401 million for the BAU and SB options, respectively. The smallest proportion of the economic benefits was provided by reductions in stormwater runoff generated by rainwater harvesting elements of the sustainable buildings option. Deferral of the requirement to utilise the existing water security measures in the water grid and to augment the water supply were also significant benefits. A requirement to utilise the security measures (Tugun desalination and the Western Corridor Scheme) in the water grid incurs an additional operating cost of $1,250/ML and is triggered when annual water demands for the SEQ region exceed 545,000 ML. The SB option delayed the requirement to utilise the security measures in water grid by 8 years. The need to augment the SEQ water supplies with a desalination plant was triggered when regional water demands exceeded 585,000 ML/annum. Augmentation was delayed by the SB option by 10 years.

Analysis of the local water balances of sustainable buildings in each of the water distribution jurisdictions revealed water savings ranging from 42% (Logan) to 52% (Sunshine Coast). A target for water savings of 40% from a baseline of observed water use in houses without water saving measures in the 2013-14 financial year for all new buildings for each jurisdiction is feasible. The economic analysis has determined that a policy to mandate sustainable buildings is also economically viable from the perspective of whole of society, water utilities and the Queensland government. However, we are mindful that we have not counted a wide range of additional benefits that would be created by a mandate for water savings targets in buildings, including reduced greenhouse gas emissions, improved health of waterways, increases liveability and generation of much needed local employment. For example, it is estimated that mandated water targets may generate over 800 additional jobs.

This investigation has revealed the ñhiddenò boundary conditions that dramatically impact on engineering and economic analysis, and decisions about government policy. Our analysis should also consider variations in the timing and numbers of households that replace rainwater pumps at the end of design life. Whilst it is unreasonable to assume that 100% of rainwater assets fail and are not replaced during an estimated design life, it is also necessary to incorporate results from independent ABS surveys (for example) to test the impacts of evidence based behaviour bounds. Similarly, it is important to investigate potential variations in the cumulative operational costs throughout a city on the benefits of alternatives and explore different rates of installation of sustainability measures. The authors are now addressing these considerations and use of energy targets using our established Systems Framework for the SEQ region.

6. CONCLUSIONS

In 2012, the Queensland government repealed the Queensland Development Code (QDC) Mandatory Part (MP) regulations 4.2 and 4.3 that required new buildings to install rainwater systems or grey water systems to provide water savings. The recommendation for repeal was made by the Queensland Competition Authority (QCA) based on a cost-benefit analysis that concluded that the costs of retaining compulsory installation of rainwater harvesting for new dwellings exceeded the benefits. The QCA found that the cost-benefit ratio for continuing the MP 4.2 legislation was between 0.13 - 0.66. Analysing the QCA reports was challenging as calculations and many assumptions were not provided. Some of the critical assumptions were inconsistent with readily available evidence, and important costs and benefits were not included in the analysis. The partial analysis was conducted in isolation to existing and BAU infrastructure. However, the authors were able to reconstruct the QCA investigations to understand the key assumptions or boundary conditions that defined the results.

In contrast, the whole of water cycle analysis of the South East Queensland (SEQ) region by the RHAA found a cost-benefit ratio for continuing the MP 4.2 policy was 2.1, which indicated that retention of the legislation was the best outcome. This historical process revealed that the setting of boundary conditions (what was included, what was excluded and assumptions) dominates the outcomes of decisions about government policy. Indeed, the major benefits in the RHAA analysis were derived from reduced water operating costs and deferred augmentation of the regional water supply. The boundary conditions set by the QCA analysis did not allow realisation of these benefits. This investigation revealed that economic analysis of distributed solutions must include sufficient spatial and temporal detail to account for the distributed operation of alternative options within existing or business as usual (BAU) water cycle infrastructure. The assumptions used to compare the performance of an alternative option to BAU must include equivalent base assumptions and account for the behavioural links between options. Analysis of alternative policies, strategies and solutions in isolation to existing systems is may not produce reliable policy decisions. The investigations outlined in this paper were combined to create an enhanced version of the RHAA analysis of a policy for setting targets for water savings on all new dwellings. It was established that a 40% target for water savings is feasible and provides a cost-benefit ratio of 2.1. These results indicate that a policy of mandating targets for sustainable buildings would provide substantial benefits to the state of Queensland, water utilities and citizens.

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