Work Package 4: Rainwater

Prepared for: **Hunter Water Corporation**

Prepared by: **The Institute for Sustainable Futures**

FINAL REPORT
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The Institute for Sustainable Futures (ISF) was established by the University of Technology Sydney in 1996 to work with industry, government, and the community to develop sustainable futures through research and consultancy. Our mission is to create change toward sustainable futures that protect and enhance the environment, human wellbeing and social equity. We seek to adopt an inter-disciplinary approach to our work and engage our partner organisations in a collaborative process that emphasises strategic decision-making.

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Executive Summary

Hunter Water Corporation (HWC) requested the Institute for Sustainable Futures (University of Technology Sydney) to review recent publications and case studies on potable rainwater substitution through household rainwater harvesting. ISF previously under took a study HWC to investigate the reliable yield from rainwater tanks (RWT) in the Lower Hunter service area (Mukheibir et al 2013). The key knowledge gap emerging from that evaluation was the severe lack of reliable data to derive a factor by which to determine the functional number of tanks. This report aims to build on the previous study by presenting updated published knowledge that could guide the maximisation of potable water substitution through rainwater tank systems.

The findings are summarised as follows:

Rainwater yield – More recent onsite evaluations in Melbourne (Moglia et.al. 2015) have shown potable water substitution to be around 42 kL/yr, with more than 75% being used indoors. These observations reveal a lower substitution volume, and specifically a lower outdoor use than estimated for the Lower Hunter region in the ISF 2013 report – an average of 37% outdoor use. This is potentially due to different climatic conditions, tank volumes and garden sizes.

Functionality factor – The Moglia et.al. (2015) audit showed that in Melbourne the functionality of the surveyed sample was in the order of 73%, up from the 60% suggested in their study from 2012 based on survey responses. It is recommended therefore that Hunter Water adjust the assumption for functionality to range between 55-75% for future analyses.

Future State regulations (BASIX) – In 2013, an increase from 40-50% water savings against the baseline was proposed but has not yet been implemented. This would most likely be achieved through connecting the laundry and toilets to the rainwater system and possibly also increasing the storage volume and roof catchment area. However, as indicated in the discussion on energy efficiency, such additional connections would increase the energy intensity of the rainwater system.

Compliance with BASIX still proves to be an issue and serves to undermine the accuracy of the expected calculated savings.

Technology improvements – The "talking-tanks" program in Melbourne, has developed technologies that allow the rainwater tank to receive a signal based on the rainfall forecast to trigger a pre-emptive release of the stored water into the environment, so that storage space can be made available to receive the predicted rain, thereby reducing the impact on the stormwater infrastructure and avoiding downstream flooding. This has relevance for accounting for externalities when developing business cases.

Energy efficiency – It has been demonstrated that systems that use cheaper fixed-speed pressure pumps to provide water to toilets and washing machines have a much higher energy intensity than those systems that supply to high flow end-uses.

The following recommendations are suggested in this regard:

- Matching the correct pump type and size for the associated end-use
- Fitting a header tank or pressure vessel to provide a constant pressure and allow the pump to operate at the design / optimised rate.
- Avoid using rainwater for toilet flushing and washing machine use.

Financial considerations – When considering the capex and opex, the economic cost has been shown to be much higher than centralised supply options, and the burden is not equally distributed across the whole customer base. Further, the NPC cost to install individual household rainwater tanks is considerably higher than for communal or regional systems.

Externalities – Stormwater abatement is the key externality that has been cited, but the published materials have not quantified this benefit in dollar terms, or demonstrated how this was accounted for in business cases.

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1 Introduction and approach

The Institute for Sustainable Futures (ISF) previously under took a study for Hunter Water Corporation (HWC) to investigate the reliable yield from rainwater tanks (RWT) in the Lower Hunter service area (Mukheibir et al 2013), where assumptions relating to the functionality of the RWT were presented and used to determine the likely potable water substitution. The key knowledge gap emerging from that evaluation was the severe lack of reliable data to derive a factor by which to determine the functional number of tanks.

The findings presented in this report aim to build on the previous study by presenting updated published knowledge that could guide the maximisation of potable water substitution through rainwater tank systems. ISF conducted a desk top review of recently published studies (since 2012), as well as other relevant older publications (see Appendix A), to ascertain if the assumptions used in the 2013 report can be updated and/or made more robust. Searches for literature were undertaken using academic databases for publications from 2012 or later in addition to internet searches for reports and case studies.

Specifically, through the review of recent case studies and publications, the report presents:

- A desk-top literature review of monitored and modelled rainwater yield, together with reported audits of rainwater tank functionality and end-use connections.
- An assessment of the future role of regulations in NSW (BASIX), and insights into the viability of future opportunities to expand the rainwater tank stock and yield in the Hunter Water servicing catchment.
- An analysis of available industry-focused literature on technology improvements and the influence that innovation may have on the rainwater tanks systems.
- Reported costs of rainwater tank systems, and the role of externalities in supporting a decision to implement a rainwater tank program.

No examples of where utilities had delivered programs to improve the functionality of rainwater tank systems were reported in the published literature.

Table 1: – Summary of new case studies examined for this literature review (more quantitative detail from case studies is provided in Appendix A)

Location	Case / sample	Nature of data	Reference
Southeast Queensland (SEQ)	Smart metering of 19 households	Rainwater yield, energy intensity	(Siems and Sahin, 2016)
Gold Coast, QLD	Smart metering of 19 households	Rainwater yield, energy intensity	(Talebpour et al., 2014)
Melbourne	Dobson's Creek catchment & Talking tanks	Stormwater values, new technology	(Melbourne Water, n.d.; South East Water, 2014)
Melbourne	417 households	Tank condition, rainwater yield	(Moglia et al., 2015)
SEQ	20 properties monitored over 12 months	Rainwater yield, energy intensity	(Umapathi et al., 2013)
Sydney	52,000 households with tank rebates	Rainwater yield	(Sountharajah et al., 2017)

Location	Case / sample	Nature of data	Reference
SEQ	Stochastic simulation of 10,000 systems	Rainwater yield	(Maheepala et al., 2013)
Wollongong	21 interviews, 1425 surveys	Householder perceptions of rainwater	(Delaney and Fam, 2015)
SEQ	Online survey of 533 rainwater tank owners	Community perceptions of tank maintenance and governance	(Walton and Gardner, 2012)
Melbourne	Aquarevo – planned housing development	New technology	(CRCWSC, 2017)
Theoretical	Hypothetical community scale rainwater system	Costing of individual tanks and networked tank systems	(Gurung et al., 2012)
SEQ	Calculated, theoretical	Costs	(Hall, 2013)
Perth, WA	77,000 properties sold 2008-2012	Costs/benefits (hedonic pricing)	(Zhang et al., 2015)
Sydney	Modelled for 10 hypothetical locations around Sydney	Costs	(Hajani and Rahman, 2014)
Western Sydney	Monitored 2 households, modelled stormwater	Stormwater impact	(van der Sterren et al., 2014)
Warrnambool, VIC	Modelled regional roof water harvesting scheme	Water savings, costing	(Barnes, 2016; Wilson, 2011)
Spain	Simulation for 3 households	Environmental benefits of replacing hard water with soft rainwater	(Morales-Pinzón et al., 2014)
Australian cities & Kenya	Metering and modelling in urban and peri-urban areas	Cost benefits of using soft water	(Amos et al., 2018)
Melbourne	Monitoring of 12 households	Water savings	(Burns et al., 2015)
Melbourne	Fisherman's Bend development	New technology, benefits	(South East Water, n.d.)

2 Review of rainwater system performance

Determinations of rainwater tank yields vary from metering to statistical analyses and theoretical models. Just a handful of studies have used on-site monitoring, and the vast majority of evaluations have been conducted in Southeast Queensland (SEQ).

In the 2013 report (Mukheibir et al 2013), ISF estimated that the average weighted potable water substitution for a 4kL tank under various combinations of end-use configurations, normal and dry climate conditions and for inland and coastal locations. The substitution varied from 29 kL/household/year to as much as 67 kL/household/year, depending on the location, end-uses and the climatic conditions. These estimates have not been verified with on-site surveys.

Table 2: Estimated average weighted potable water substitution per household (kL/a)

	Pre-2004 Tanks		Rebate Tanks		BASIX Tanks	
Climate	**Normal**	**Dry**	**Normal**	**Dry**	**Normal**	**Dry**
Inland locations	31	29	38 - 40	31 - 32	60 - 64	46 - 49
Coastal locations	29	33	37 - 46	36 - 39	67	62 - 63

The 2013 report further referred to the effectiveness of a RWT system substituting rainwater for mains water was as the *functionality* of the RWT system, and is directly linked to how well the rainwater capture and end-use connection system is operating (Mukheibir et al 2013). It was stated that "quantitative data on the condition of existing tank stock is typically unavailable for most regions (Magnus Moglia, G. Tjandraatmadja, et al. 2011), including the Hunter Water supply area". This statement is still largely true, however, Moglia et al (2015) have undertaken a major survey and inspection of 417 household rainwater systems in Melbourne which has provided some useful new figures to estimate failure rates due to various types of malfunctions.

In this section, we discuss the key findings from the literature in relation to these issues since 2012.

2.1 Monitored and modelled rainwater yield

In a monitoring study of 20 household rainwater systems conducted over 12 months in SEQ, households were found to have a rainwater yield of 40 kL/year, which translated to 31% of the total average household demand, where the overall average per capita water use was 144 L/p/d (Umapathi et al., 2013). This data was drawn from three separate areas within Southeast Queensland (SEQ). This is similar to a stochastic modelling study by Maheepala et al., (2013) that found an average rainwater yield of 42 kL/year in SEQ. A high-resolution monitoring study also conducted in SEQ found that rainwater yield associated with a 2.8 person household in SEQ would be 58 kL/year (Siems and Sahin, 2016). However, in the latter study, metering was only carried out for a 6-month period from November to April, which is the highest rainfall period of the year, and this may account for the difference.

Several studies have confirmed that the largest rainwater substitution can be achieved with households that are connected to multiple indoor end-uses (Burns et al., 2015). Monitoring of 20 households in Melbourne found that households using rainwater had a **combined indoor and outdoor average of 42 kL/year** (Moglia et al., 2015):

- External only sites (6 sites) had an average rainwater use of 11 kL per annum. However, when the one extreme outlier was removed, this average dropped to 3.7 kL/year.
- The 4 indoor only sites had an average rainwater use of 31 kL.
- The 10 sites where rainwater was used both for indoor and outdoor purposes had an average rainwater use of 42 kL.

The figures above were compensated for malfunctions, most notably switch malfunctions – the impact of which is considerable. If they are included, the overall indoor/outdoor yield reduces to 33 kL/year

(Moglia et al., 2015). It is also notable that the outdoor component of rainwater use is somewhat dependent on summer rainfalls – but this component is relatively small compared to what is feasible for indoor potable substitution. While the outdoor portion in the Melbourne example amounts to around 25% of the potable substitution, the estimate in the ISF 2013 report suggested that the outdoor portion was more in the region of 37%. This could be attributed to different climate conditions, tank volumes and tank sizes.

A major Sydney Water study monitored the water and energy consumption of rainwater systems in 52 households. That study found **average water savings of 38 kL per household per year or 21% of household demand** (Ferguson, 2012). In contrast, a newly published study evaluating water savings from billing data in Sydney found an average water saving of 9% across 44 local government areas for households which had a tank registered with Sydney Water, after receiving a rebate. Water savings were as high as 15% in some areas. The average equated to 24 kL of water savings per household per year (Sountharajah et al., 2017). This calculation reflects the savings through rainwater tanks alone, as other demand management activities (efficient appliances, education and awareness campaigns, and restrictions) achieved water savings in addition. The differing result between these two studies may be partially due to tank functionality issues. While the Ferguson 2012 study monitored 52 households, the Sountharajah 2017 study examined 52,000 houses through billing data, which is more likely to include households whose systems are failing.

These studies suggest water savings in Sydney may be slightly lower than for Melbourne and Brisbane. However, the Sountharajah et al (2017) study examined billing data from 2002-2009, where overall water consumption also decreased significantly due to voluntary water restrictions, so that average household consumption in Sydney went from 280 to 200 kL/hh/day (Sountharajah et al., 2017). This reduction in overall demand diminishes the volume of water savings that are possible from a rainwater system. Local government areas situated in the inner city of Sydney tended to achieve more water savings, and this was attributed to the smaller lot sizes (Sountharajah et al., 2017). Changing demand profiles due to voluntary restrictions have affected rainwater tank yield calculations over the years. For example, based on demand profiles available in 2005, Beal and Gardner (2011) calculated an expected rainwater yield of 70 kL/hh/ year in SEQ. By 2008, household water consumption had nearly halved and this reduced rainwater yield expectations (Hall, 2013). From these results, it is clear that variations in demand play an important role in determining water savings due to rainwater use.

A social study of household rainwater tank use in the Illawarra region of NSW highlighted the importance of behaviour with regards to the rainwater yields. The authors recommended the connection of indoor end uses to rainwater systems to limit the influence of behavioural factors and to ensure greater water savings (Delaney and Fam, 2015).

Several studies have used sophisticated methods to model rainwater yields. Maheepala et al (2013) used a stochastic simulation with factors that are known to affect yield, including tank size, effective roof area, roof losses and household demand. Their study drew upon household demand data collected by Beal and Stewart (2011). The modelling exercise found that household rainwater systems in SEQ were likely to have an average yield of 43 kL/hh/year and a volumetric reliability of 72%, with rainwater applied to toilet flushing, clothes washing and garden use (Maheepala et al., 2013). The study determined that the spatial variability of demand was the biggest factor contributing to modelling discrepancies. For example, in Brisbane household water consumption was 130 L/p/d, in the sunshine coast it was 157 L/p/d and in Ipswich 109 L/p/d. The authors suggested that improving the model would require probability distributions for each of the input variables (Maheepala et al., 2013).

In another modelling effort in SEQ, rainwater yield was calculated using two methods, one using average values for key inputs, and another using a distribution of values for roof area, demand profiles and tank size. The averages method calculated a rainwater yield of 50.13 kL/yr, while the distribution approach found a lower yield of 43.37 kL/yr across SEQ (Hall, 2013). The study actually calculated differing yields for five different geographical areas of SEQ, with averages ranging from 34 to 48 kL/yr (Hall, 2013). In addition to the study by Maheepala et al (2013), this study highlighted the importance of geographical variability.

The estimates of the yield calculation in the 2013 ISF report (see Table 2 above) are slightly higher than those from other jurisdictions. Based on this review of yield calculations, it appears that key issues affecting the accuracy of yield modelling include: geographical variations in demand; and variations in demand over time due to drought and restrictions – and **it is therefore difficult to make direct comparisons with the Hunter context**. Undertaking a local audit will lead to an improved understanding the distribution of these variations and may assist with developing more realistic (and lower) yield estimates.

2.2 Functionality and tank condition

Studies during 2013-2014 highlighted the lack of understanding regarding the reduced yield of rainwater systems due to functionality issues (Mukheibir et al., 2014). The issue is that rainwater tank models typically overestimate yield when compared to actual values, and the difference may be due to unaccounted for failures. The authors suggest there may be three types of system failures affected rainwater yield:

- Quality of the installation (e.g. incorrect tank installation, end-use plumbing issues, incorrect placement of downpipes, etc.) and noncompliance with BASIX requirements
- Operational failure mechanisms (e.g. pumps or switching devices)
- Behavioural factors.

There has been major concern in the water industry that household tanks are not in fact being maintained, therefore Moglia et al (2015) conducted inspections of 417 household rainwater systems in Melbourne to understand their condition, with 20 households being monitored in more detail. Their study found the following rainwater system faults:

- 13% were leaning on one side due to uneven foundations
- 5% had pumps that weren't working
- 39% of roofs had lead flashing
- 25% of tanks were not fitted with mesh to prevent mosquitos from entering
- 9% had faulty automatic switches, which meant that rainwater was not being used.

This suggests that 14% of household rainwater systems were not using any rainwater at all due to faulty pumps or switches. As an input for future modelling efforts, it could be assumed that 14% of tanks are non-functional. However, considering the structural issues, there is potential for a further 13% to become non-functional, or not fully functional, in the future if systems are not maintained. Mukheibir et al. (2014) suggested an interim functionality factor of 50-70%, drawing on the Moglia 2011 study (based on a comprehensive survey of plumbers and professionals[1]) which found a 40% failure rate after 2 years i.e. that an average of 60% could be considered fully functional. The Moglia et al. (2015) study updates this estimate with clear evidence for an initial 14% failure rate. This figure could increase to 27% for leaning tanks that may be unmaintained and unused over a period of time. This would suggest then that **an average of 73% could be considered fully functional**. The Moglia et al. (2015) study did not report on end-uses that had been disconnected over time i.e. how the potable water substitution may have been altered over time.

The Moglia et al. (2015) study suggested a number of approaches for improving system functionality including improving installation practices, encouraging maintenance or the use of simple alarms to alert householders when systems need attention (Moglia et al., 2015). The authors estimated that 27% of all rainwater tanks have automatic switches for controlling the top-up from mains water, and that 35% of them are non-operational (this translated to 9% of the total). However, 98% of tanks were in a fair to good condition, and 90% of pumps were operating (Moglia et al., 2015). In the Moglia et al (Melbourne) study, only 37% of the tanks received rebates, so the majority were independently motivated. The variability in rainwater yield found in this study suggests that better system configuration and management could significantly improve yield in the future (Moglia et al., 2015).

With regard to water quality, the Moglia et al. (2015) study found that 57% of rainwater tanks contained discoloured water, 19% had a malodour and 6% had a high concentration of sediment, which suggests that contamination of rainwater is quite common. A water quality study of rainwater tanks in Western Sydney found that water quality varied significantly depending on the roof and tank materials. Households with pre-painted galvanised iron or steel tanks had higher levels of aluminium, copper and zinc. Incidences of contamination with lead and E.coli occurred in all of the four sites where tanks were

[1] n = 235, with 175 responses from Queensland. A breakdown of respondents identified as professionals: work for council (13.4%), state government (17.5%), service enterprises (46.3%), other (6.1%). Fifty-seven per cent of respondents were tank owners.

monitored (van der Sterren et al., 2013). These studies highlight that untreated rainwater is most reliably used for non-potable end-uses.

There are no studies evaluating the functionality of rainwater systems in the Hunter Region, however, a housing development in the Hunter called Figtree Place was a very early example of rainwater collection for household use, built in 1998. An evaluation of that system found numerous faults that occurred in implementation, including the omission of first flush devices that were included in the design, frequent failure of solenoid switching devices, inadequate guttering, and pump problems which lead to variable water pressures in households (Coombes, 2013). This example highlights the wide variety of implementation issues that can affect tank functionality and water quality.

An SEQ study examining community perceptions of household rainwater governance through focus groups found that householders had a low level of awareness of the need to undertake tank maintenance, but were highly motivated once they were made aware, as people liked “to keep things maintained” in their homes (Walton and Gardner, 2012). However, people who used rainwater outdoors were less motivated than those who used rainwater indoors (Walton and Gardner, 2012). The report suggested policy approaches that increase awareness, foster positive attitudes towards maintenance, and help to improve people’s capabilities in this regard (Walton and Gardner, 2012). Participants in their study thought that regulations/penalties or monitoring of household tanks would be unfair, and indicated that they would prefer incentives to disincentives (Walton and Gardner, 2012). A separate study in SEQ investigating the management of rainwater tanks (Moglia et al., 2012), found that householders believe that the operation and maintenance of tank systems should be undertaken by the householder.

The suggested functionality factor of 60% in the ISF 2013 report, was based on the Moglia (2012) study, where the majority of the respondents were located in Queensland. The more recent study by Moglia (2015) is based on audits of Melbourne based systems, and would suggest a much higher functionality factor of 73% (although this does not included changes to end-use connection to rainwater). Given that these are the only two published studies of RWT system functionality, **Hunter Water could consider a revised functionality assumption of the average of the two i.e. 66% - two thirds being considered functional, or within a higher envelope range of 55-75%.**

Hunter Water experience has shown that installed rainwater tanks may be bypassed due to failures, or where owners lack knowledge about their systems. In order to gain greater insights on the likely failure rate, an audit of a random sample of RWT systems within the Lower Hunter region would provide additional and localised insights into the connection of end-uses and the functionality of the RWT systems. As suggested by the SEQ studies, householders are likely to need education or capacity building to ensure that tank maintenance is undertaken.

3 Impact of State regulations

In NSW, development is regulated by a number of policies and environmental planning instruments (EPIs). Planning and development is primarily carried out under the *Environmental Planning and Assessment Act 1979* (the EP&A Act) and the Environmental Planning and Assessment Regulation 2000. This legislation provides the framework for the development of planning instruments including State Environmental Planning Policies (SEPPs).

There are currently two SEPPs in place that directly concern RWTs:

- SEPP (Building Sustainability Index: BASIX) 2004; and
- SEPP (Exempt and Complying Development Codes) 2008.

The first was designed to improve energy and water efficiency within new residential developments and in renovations valued at over $50,000. It operates in conjunction with the Environmental Planning and Assessment Amendment (Building Sustainability Index: BASIX) Regulation 2004. SEPP 2008 lays out the compliance requirements for an RWT installation for it to be considered as exempt development. The installation of all RWTs, whether they are for new or retrofitted developments, must comply with SEPP 2008.

3.1 BASIX regulation

BASIX legislation is now the principal regulatory lever for influencing the uptake of residential RWTs in NSW. Under the current BASIX regulation, new dwellings in the Lower Hunter region are required to achieve a 40% reduction in water and greenhouse gas emissions relative to 'pre-BASIX' home benchmarks (90,340 litres per person per year for the water benchmark or 247 litres/person/day), whilst alterations and additions valued at more than $50 000 are required to meet minimum efficiency standards for appliances, fittings and fixtures (NSW P&I, 2004).

As can be noted from the graphs below (NSW Government, 2016), there has been a gradual shift away from the large rainwater tanks to the smaller ones, and steady increase in the number of tanks connected to indoor appliances (which follows the annual increase in the number of RWTs installed). The shift to smaller tanks over the 10 year period can be attributed to the cost of the tanks, and the possible compliance nature of the installation i.e. developers/owners going for the smallest possible option just to meet the BASIX requirement. However, since the previous ISF 2013 study, the size of the installed tanks each year have remained relatively steady.

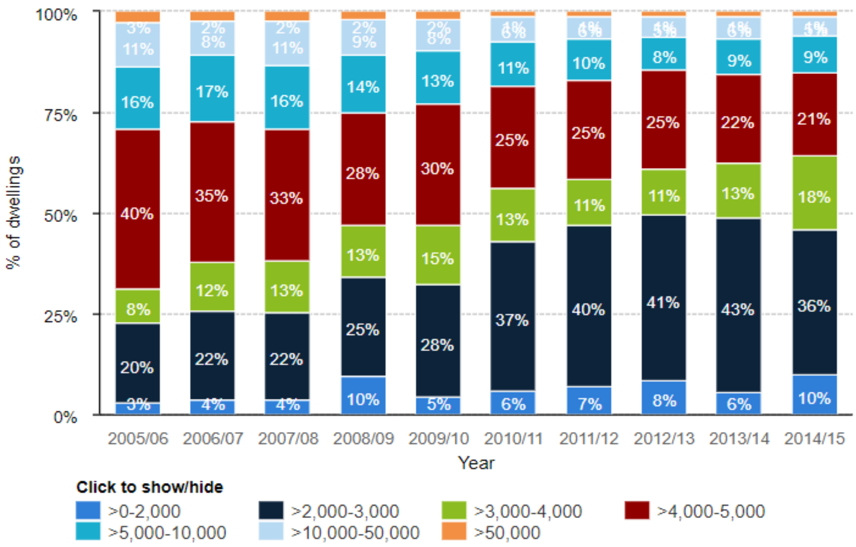


Figure 1: Percentage of dwellings in each grouping of tank volumes (litres)

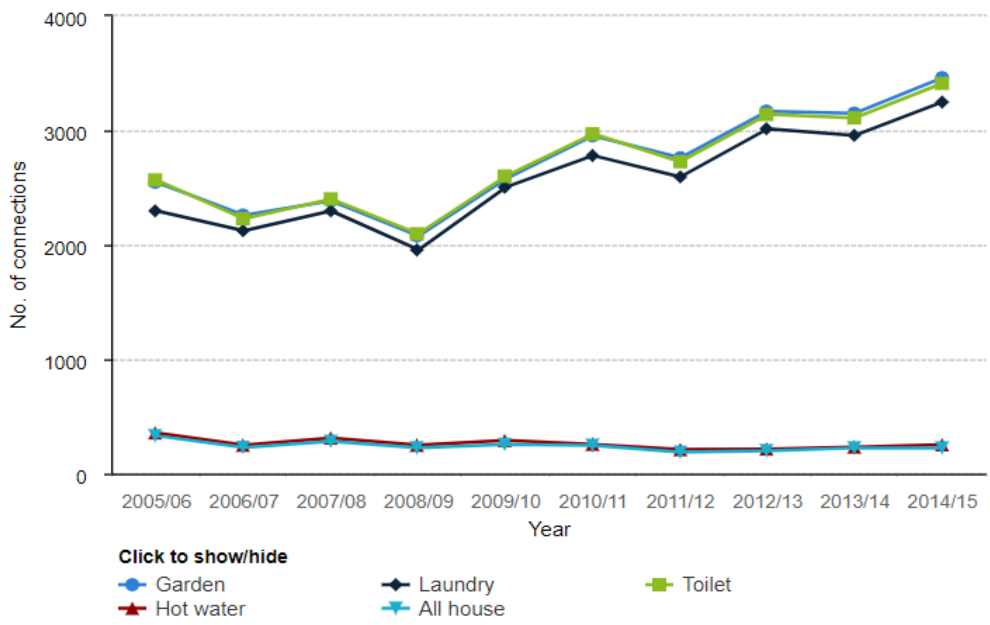


Figure 2: Number of rainwater tank connections for particular end uses

Water Target

The BASIX water target has not increased since BASIX was applied to the Hunter Water area in 2005. In December 2013 proposed increases to the BASIX water, thermal comfort and energy targets were put on exhibition (NSW Department of Planning and Infrastructure, 2013), however only the thermal comfort and energy target increases were implemented (in July 2017).

The proposed increases to the water target were a 10% increase for houses (from 40% to 50% in the water target zone covering Hunter Water) and a 5% increase in the water target for mid-rise developments (from 40% to 45%). A cost benefit analysis (The Allen Consulting Group, 2013) found that for the combined increase in water, thermal comfort and energy targets, every $1 spent on complying with the increased targets would benefit the NSW economy by $1.64 (because the reduction in utility bills more than made up for the additional capital cost). The cost benefit analysis for the water target increase alone was not given. However, water savings were broken down by index in Table 4, and water savings made up 36% ($464.8 of the total $1305.5 million) and the cost data (MBMPL, 2013) (based on totals from Annexure 1) indicates that water costs were around the same fraction of the total costs. Overall it is likely that the benefits would outweigh the costs for a water target increase on its own, and so if water savings became a priority again, a water target increase could be expected.

According to the Allen Consulting Group (2013) (Table B1), meeting the increased BASIX water target would typically involve connecting the laundry and toilet[2] to the rainwater tank (as well as using rainwater for landscape irrigation) and sometimes higher efficiency taps and toilets would also be required (5 star taps, 4 star toilets). However, BASIX data (NSW Department of Planning and Environment, 2015) indicates that in the Hunter region 97% of tanks are used for landscape irrigation, 97% are used for toilets and 92% are used for laundry. This is higher than the NSW average of 94% for landscape, 88% for toilets and 78% for laundry, but these higher than average rainwater connections are not contributing to higher than average over-compliance (in NSW 20% of single dwellings score 8+ points above the water target but in the Hunter region only 13% do) and so a higher water target in the Hunger region may also require a larger tank and/or larger roof area connected.

[2] However, as discussed in the 4.3 Energy efficiency, connecting toilets and laundry appliances often results in higher energy intensity of the overall system, since the pressure pumps do not operate at optimal efficiency when pumping low flows.

BASIX Alterations and Additions

The BASIX alterations and Additions tool applies when the building work is valued at least $50,000 or a pool is being installed with a volume of 40kL or more (including spa volume). Any new water fixtures must be at least 3 stars and if a 40kL+ pool is being installed, a rainwater tank must be installed that is large enough to offset pool water use (with the rainwater being available for filling the pool).

Given the increase in the thermal comfort and energy targets for new dwellings in 2017, it is likely that the BASIX Alterations and Additions tool will require an upgrade to match the BASIX New Dwellings stringency change.

Even if a tank has to be installed to compensate for a new pool, BASIX Alterations and Additions does not require that it be connected to any internal uses. Because BASIX is applied to building approvals, and because alterations and additions do not cover the entire house, it is not likely that BASIX Alterations and Additions could ever require that existing laundry taps or toilets be connected to a new rainwater tank. However, the tool could possibly be expanded to look at rainwater connections to new toilets and laundries. The impact this would have would depend on the water reduction target selected, and target selection would have to take into account the cost of retrofitting.

Compliance

There is an awareness that building compliance could be improved, which would include BASIX compliance, and rainwater tank compliance. The BASIX water compliance of a sample of 465 houses with BASIX certificates generated between 2004 and 2008 was checked by Sydney Water (Schlunke, 2011) and it was found that 6 (1.3%) were missing a rainwater tank, 34% had a smaller roof area connected than required, 20% of tanks were smaller than required, 5% were missing a tap for irrigation, 15% were missing a toilet connection and 22% were missing a laundry connection (Significant over-compliance in some properties was also discovered - having tanks larger than required, roof area larger than required or extra connections, and this helped to offset the savings lost through non-compliance). If the Lower Hunter region has a similar problem with rainwater compliance then the impact of improved compliance would mean larger potable water savings due to rainwater use.

Impact of recycled water

When reticulated recycled water is available, it is possible to pass BASIX without installing a rainwater tank. If new reticulated recycled water schemes are built within the Lower Hunter region (like the Hunter Water reticulated recycled water scheme in Maitland), then demand for rainwater tanks for new dwellings would reduce, but demand for potable water would also reduce, probably by the same amount as if rainwater tanks were installed (unless compliance or behaviour was different, or unless aspects of the BASIX model, like expected rainfall, don’t match reality).

The Hunter Regional Plan 2036 (NSW Department of Planning and Environment, 2016) mentions population growth, more compact settlements and small-lot housing. Smaller household sizes are expected, so dwellings will be built to match (studio, 1 or 2 beds instead of 3 or 4 beds). Smaller lots will probably mean smaller landscaped areas, but also smaller roof areas, which limits the amount of rainwater collected. Higher ratios of floor area to lot size mean smaller roof area per occupant, limiting the amount of rainwater that can be harvested for each person, and making it more likely that recycled water will be considered.

The effect of reduced rainfall predictions

If BASIX were to revise the rainfall data used, especially if predictions of reduced rainfall were taken into account, then the predicted potable water savings due to rainwater tanks would decrease. This would mean that in order to pass BASIX, dwellings would have to improve their rainwater tank commitments (larger tanks and/or more roof area connected and/or more connections).

3.2 Ratings at point of sale or lease

Most dwellings in NSW have not had to meet any BASIX requirements, because they were built before BASIX began and have not had significant enough renovations. If a requirement were introduced that homes for sale or lease met the BASIX water target (or even a slightly lower target) then it would have a large impact on the number of rainwater tanks installed in NSW. According to BASIX data (NSW Department of Planning and Environment, 2015) currently 97% of new houses in the Hunter region install a rainwater tank (which is higher than the NSW average of 90%, but most of the new dwellings that don't have a tank have access to a reticulated recycled water scheme).

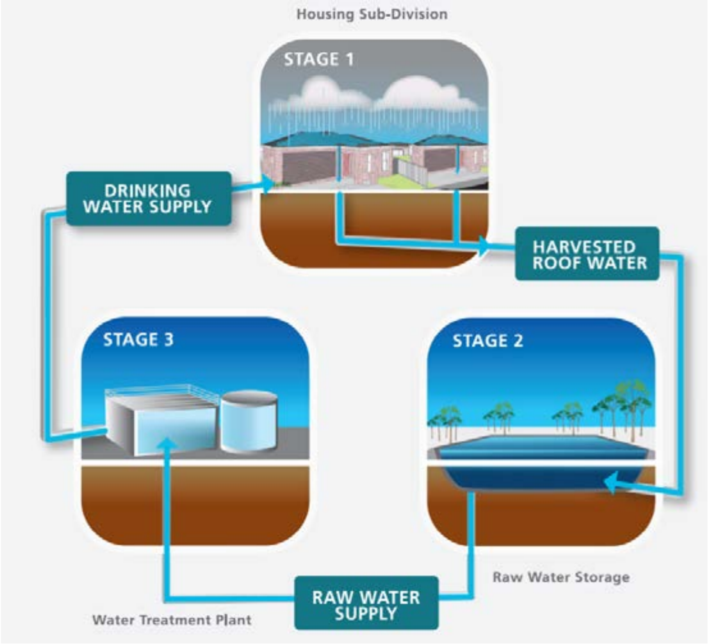
There are some schemes that require a dwelling for sale or lease be rated, or meet minimum requirements, but none come close to the BASIX requirements:

- In NSW one of the criteria for passing on water use charges to tenants is that the property must meet the required water efficiency standards. The maximum allowed flow rate of showers, kitchen taps and basin taps is 9 litres per minute, and there must not be any leaking taps (NSW Department of Fair Trading, 2014).
- In NSW a NABERs energy rating is required for commercial tenancies if the floor space is 1000 square metres or more (Australian Government, 2018), but there is no minimum required rating for water.
- In the ACT energy efficiency ratings are required when houses are sold (ACT Government, 2017) but there is no minimum required rating for water.

For BASIX requirements to be implemented at the point of sale or lease there would have to first be a much higher priority given to urgent improvements in the water and energy efficiency of buildings.

3.3 Regulated roof water harvesting

Wannon Water in Victoria have worked together with the Warrnambool City Council to make the installation of roof water harvesting a requirement of all developers in specified catchments where the geography and water system make it possible for freshwater augmentation (Wilson 2011). Legislative responsibility for stormwater in Victoria vests with municipal councils. With the support of the Warrnambool Council, all roof water (either directly from the roof or from the overflow of a rainwater tank) is required to be connected to the "roof water harvesting connection point". This initiative is supported by Section 56.07 of the Victorian Planning Schemes – Integrated Water Management (Wilson 2011).



4 Technology improvements

Technological advances in rainwater systems since 2013 have been concentrated in housing developments around Melbourne and focus upon improved monitoring and tank operation. Two specific monitoring systems that have been developed are called “Talking Tanks” and “Onebox” and both have been driven by Southeast Water, the Melbourne based water utility. The application of these technologies is described below. Following this, we have reviewed the latest research with regards to the energy implications of rainwater systems, and discuss the management options for energy efficiency.

4.1 “Talking Tanks”

Southeast Water in Melbourne have invested in new technologies through their commercial arm called “iota”. Iota has developed a monitoring system for rainwater tanks to enable them to provide water storage during storm events. The “Talking Tanks” monitoring system receives weather predictions from the Bureau of Meteorology and detects water levels in household tanks, so that if rain is forecast, the tank can release water from the tank at a controlled rate to optimise storage availability while maintaining some rainwater for household uses (South East Water, 2014). Householders can participate in this system by setting minimum tank levels, and controlling settings remotely via a smartphone (South East Water, 2014). This technology has been implemented in a peri-urban area near Melbourne, which sits within the catchment of Dobson’s Creek, which has important ecological values. The concept of *Talking Tanks* is therefore to help reduce peak stormwater flows from household roofs into the creek and the pollutants that the stormwater carries (South East Water, 2014). The *Talking Tanks* system has a microprocessor which modifies the amount of water released based on the volume of the forecast rain event. The volume of collected rainwater is subsequently calculated by the tank after each rainfall event, so that the system can learn to better predict rainfall capture volumes over time. The *Talking tanks* monitors can be accessed remotely by the water utility using their SCADA system (South East Water, 2014). Initial observations have found they are operating as designed, however, detailed hydrological evaluations do not appear to have been undertaken yet. The efficacy of the system is likely to depend on the accuracy of weather predictions and the accuracy and timing of rainwater discharge. This will consequently affect rainwater yield, such that the system’s ability to learn will be critical in striking the right balance between water provision and runoff attenuation.

The Fisherman’s Bend development in Melbourne is planned to use a range of innovative water infrastructure, including rainwater capture and smart tanks for non-potable use, pressure sewers, centralised sewer mining and stormwater storage to reduce flooding. The water infrastructure is expected to reduce the developments’ water footprint by 45% (South East Water, n.d.).

4.2 Aquarevo – “Onebox”

Aquarevo is a decentralised water provision system developed by Southeast Water for a housing development outside Melbourne, which incorporates the use of a monitoring system called “Onebox” in addition to *Talking Tanks*. In this development, household rainwater systems have been installed on each house, and the rainwater is treated and used for hot water supplies, including hot water taps for showering, bathing, laundry and clothes washing, through a secondary plumbing system (CRCWSC, 2017). This may be the first application of rainwater for hot water use in a modern housing development in Australia. The treatment system includes screening, filtration, UV light and heating to 60 degrees celsius. The *Onebox* monitoring system remotely monitors household water and energy use. The *Talking Tanks* monitoring system has also been incorporated at the development to help reduce peak stormwater flows.

The combination of rainwater for hot water end uses and Class A recycled water for other (non-potable) end uses, is expected to achieve a 70% reduction in potable water consumption, with 35% of that expected to come from rainwater use for hot water (CRCWSC, 2017). This approach follows the principle of using water “fit for purpose”, with the higher quality source waters being used for higher quality purposes, such as potable water for cooking, rainwater for showering, and then recycled water for toilet flushing. The monitoring systems (*Talking Tanks and Onebox*) allow both the householder and the water utility to monitor water use. The business case for this new system was unique in that Southeast Water owned the land and bore the cost of the water management innovations. These costs were justified financially as a demonstration site for new technology (CRCWSC, 2017).

4.3 Energy efficiency

A number of studies investigating the energy implications of household rainwater systems had been undertaken prior to 2013; for example, Retamal et al., (2009), and Ferguson et al., (2012). These studies found average energy intensities for rainwater tanks in Sydney of 1.5 kWh/kL and 1.48 kWh/kL respectively, however with considerable variability around those averages. More recent studies have confirmed similar average energy intensities with 1.52 kWh/kL in SEQ (Umapathi et al., 2013), and 1.8 kWh/kL in Melbourne (Moglia et al., 2015). Other studies have confirmed that rainwater systems are nearly always more energy intensive than centralised water supplies, unless their systems have been optimised (Vieira et al., 2014). These studies suggest that the energy and greenhouse impacts of rainwater systems can be estimated based on an average 1.5 kilowatt-hours of electricity per kilolitre of rainwater yield.

Earlier studies compared the energy consumption associated with different rainwater system configurations, such as the use of different pump types and pressure vessels to understand how energy efficiency might be improved. To add to this research regarding the energy implications of system configurations, Umapathi et al. (2013) monitored 20 household rainwater systems in Southeast Queensland (SEQ), and found that energy consumption for systems with an automatic switching device had much lower overall energy use at 70 kWh/year, compared to an average of 115 kWh/yr for those with trickle top-up systems. This is an interesting finding when we consider the high failure rate of automatic switches, highlighting the need for that particular technology to be improved to ensure rainwater delivery at a lower energy intensity.

Beyond these studies examining rainwater system configurations, further research has been conducted into the water end-uses that contribute to high energy intensities, as it has been identified that much of the variability of energy consumption is due to the different flow rates of household end-uses, as well as pump characteristics (Tjandraatmadja et al., 2012). The fixed-speed pumps that are typically connected to household rainwater systems operate most efficiently at high flow rates, often greater than 20 L/min. Considering that most indoor water uses require low flow rates, such as a toilet (4-6 L/min) or washing machine (9-14 L/min), there is a mismatch between pumping capacity and pumping needs, and pumps then operate inefficiently (Tjandraatmadja et al., 2012).

To better understand the impact of different end-uses on energy consumption, one study monitored 19 homes in the Gold Coast with pumped rainwater systems (Talebpour et al., 2014). The study found that rainwater use in half-flush toilet cisterns had the highest and most variable energy intensity, whereas irrigation had the lowest average energy intensity. Specifically, the energy intensity of various rainwater uses were found to be:

- Dual flush toilets: 1.05-3.32 Wh/L
- Full flush toilets: 1.02-2.30 Wh/L
- Clothes washing machines: 1.28 Wh/L
- Irrigation: 1.12 Wh/L.

In considering the different end uses, another study in SEQ found that when rainwater for toilet flushing was removed from their monitoring, that rainwater yield fell by 19%, while associated energy usage fell by 43% (Siems and Sahin, 2016), which corroborates the finding that toilet end-uses are disproportionally responsible for more energy consumption. In particular, they found that half of the twenty monitored homes were consuming more rainwater and energy due to toilet cistern leaks, which led to pumps operating frequently to re-pressurise the pipe system. This situation with household leaks considerably increases the lifecycle impact of household rainwater systems (Siems and Sahin, 2016).

4.4 Key opportunities for innovation

The monitoring technologies developed in conjunction with Southeast Water in Melbourne – namely *Talking Tanks* and *Onebox* have the potential for more sophisticated rainwater system operations that can yield wider benefits, such as reductions to peak stormwater flows or real-time monitoring of water and energy use by both the householder and the water utility. However, at this stage these new technologies are yet to be evaluated, so it is difficult to verify the potential hydrological or stormwater quality benefits and/or behavioural changes that may be possible.

With regards to energy efficiency, rainwater system components need to be considered as an entire system, as energy efficiency can be achieved by different methods. Suggestions for ways to reduce the energy consumption associated with household rainwater systems include:

- **Changing pump types** - matching pump type and size to the uses of rainwater within the house; such as a low-power pump for primarily indoor uses (Siems and Sahin, 2016; Talebpour et al., 2014); or installing a variable speed pump to adapt to the various flow rates needed for household end uses (Siems and Sahin, 2016). However, noting the higher cost associated with variable speed pumps (Retamal et al., 2009).
- **Fitting a header tank** - for certain uses such as toilet-flushing (Talebpour et al., 2014). However, noting that header tanks may only be useful if inlet valves on appliances such as toilet cisterns can be changed; as header tanks would not provide sufficient pressure with existing fittings (Tjandraatmadja et al., 2012). Another alternative could be to develop high flow toilet cisterns that enable rainwater pumps to operate at full efficiency.
- **Installing a pressure vessel** - Pressure vessels can reduce pump energy consumption by maintaining a pressurized volume of water and reducing the frequency of pump activation for low-flow end-uses (Retamal et al., 2009; Tjandraatmadja et al., 2012). The larger the pressure vessel, the more effectively the pump can operate, however larger pressure vessels increase capital costs (Tjandraatmadja et al., 2012).
- **Avoiding using rainwater for toilet flushing** – due to the disproportionately high energy use associated with this end use, and the likelihood of leaks (Siems and Sahin, 2016).

Note that these options are not additive, so that for example, installing a pressure vessel would mean that header tanks or changing pumps or end uses would not be necessary.

5 Costing of rainwater systems

In the 2013 ISF report, the estimated costs for an average 4 kL tank retro-fitted under different conditions and end-use connections ranged from $2,035 to $5,275 (excluding GST), while for a new build under BASIX, the range was estimated to be $ 2,730 to $ 4,975 (excluding GST). Installation for garden usage is the cheapest option, since it does not require plumbing retrofits, switch over to mains supply mechanism or backflow control devices. The operating costs for a retrofitted pump system was estimated to be in the order of $25 per annum. This is based on the electricity cost for pumping, assuming an intensity of 1.5 kWh/kL (Ferguson 2011) and an annual volume of 67 kL for an average Newcastle house. However, noting that this does not include other maintenance and replacement costs.

More recent cost estimates and calculations for individual household rainwater systems vary considerably, from $1500 installed in Melbourne (Moglia et al., 2015), to a theoretical NPV of $8600, including capital costs, maintenance and replacement (Gurung et al., 2012). The Melbourne based study did not consider externalities, but estimated that with a co-contribution from householders, retrofitting a system could cost $1.60 /kL for a water utility (Moglia et al., 2015). The NPV cost of $8600 per individual household was calculated over a 50-year analysis period for a 5 kL system. The final cost consisted of: 53% capital costs, 29% maintenance costs, 16% replacement costs, 2% operation costs (Gurung et al., 2012). This breakdown highlights the significant additional costs for maintenance and replacement, at 45% of the lifetime cost, around NPV $3870 per household.

A cost-effectiveness analysis has also been undertaken for household rainwater systems in Southeast Queensland (SEQ), which determined a levelised cost of rainwater tanks in SEQ per kilolitre as $9.22 (Hall, 2013). This study found the largest factors affecting the cost of rainwater systems included differing rainwater yields, the lifetime of tanks and pumps and maintenance requirements (Hall, 2013). For example, in the Sunshine coast, where rainfall is higher, rainwater tanks were found to be the most cost-effective at $7.62 /kL, whereas in Ipswich, rainwater tanks were much less cost-effective at $11.62/kL (Hall, 2013). This calculation used a 50-year timeframe, and a 3% discount rate.

In an alternative scenario, Hall (2013) calculated cost effectiveness from the perspective of a water utility using a discount rate of 6% and a 25 year timeframe, and a maintenance regime in accordance to recommended practices. This led to a much higher levelised cost of $14.11/kL (Hall, 2013). This study did not consider any externalities such as GHG or stormwater benefits, and noted that stormwater benefits are highly localised (Hall, 2013).

5.1 Costs at scale

A theoretical study was carried out by Gurung et al. (2012) to determine the optimal scale for communal rainwater harvesting systems. With modelling based on a flat topography, and a housing density of 20 dwellings per hectare, the study determined that the net present value (NPV) of communal systems would be approximately $10,150 per household. This is considerably higher than for equivalent individual systems, which were estimated to cost $8568 per household. However, the cost estimates change considerably if there is at least a 0.5% slope, then the communal systems are almost equal in cost to individual systems ($8770) (Gurung et al., 2012). For the communal rainwater systems, capital costs were higher due to laying of connecting pipework, which needed to be deeper in a non-sloping landscape. Pipe lengths were also progressively longer for larger networks. Otherwise, many of the other capital costs could be reduced in the networked system. Collection and recirculation pipes were assumed to be laid in parallel. The communal systems were also more expensive due to the need for rainwater treatment, which in this case included a sand filter, carbon filter, UV and chlorination (Gurung et al., 2012).

In addition to establishing the equivalent costs, the study tested housing layouts from 4-576 homes to test the economies of scale. Gurung et al. (2012) found an optimal size of 192-288 connected households, as larger networks were dominated by high costs for pipes, and smaller networks were more affected by the cost of treatment units. Unfortunately, this study did not compare the relative difference in rainwater supply reliability, however it did note that the communal systems would provide a higher reliability.

In the options analysis for supply augmentation in Warrnambool (Victoria)[3], Wilson (2011) showed that while the capital costs for household rainwater tanks ($2600) was lower than the regional roof water harvesting scheme, the NPC (over a 34 year period) of the regional scheme was much lower than the individual tanks systems on $/ML basis. This demonstrated that the economic cost of the ongoing maintenance of the household rainwater tank systems was much higher than for a centralised system.

Table 3: Warrnambool water resource option comparison (Wilson, 2011)

Option	Capital cost	NPC ($/ML)	Ultimate yield per annum
Groundwater resource development	$ 7.81m	$1 958	1500 ML
Regional roof water harvesting	$11.03m	$1 856	450 ML
Individual 5kL tanks	$ 8.53m	$5 482	210 ML

5.2 Role of externalities for supporting business cases

Current costing studies suggest that the life cycle costs of household rainwater systems cannot be paid back simply with the value of mains water supplied (Amos et al., 2018). This is confirmed by a study in Perth, which found that the cost of rainwater is higher than mains water, and particularly in cities with more seasonal rainfall variation (Zhang et al., 2015). Hajani and Rahman (2014) expect that increasing the cost of water may help to make rainwater systems more viable. The financial viability of rainwater systems also improves with an increase in household occupancy (Amos et al 2016).

Economic costing studies for rainwater systems that incorporate externalities or non-market benefits are very rare. In several projects in Melbourne, program operators have sought stormwater benefits from rainwater tanks. The *Stringy Bark Creek* project set out to significantly reduce the area of directly connected impervious surfaces to attenuate peak stormwater flows. The project also installed 230 rainwater tanks uses their storage capacity along with other stormwater infrastructure to mitigate peak flows (Melbourne Water, n.d.). As part of this project they developed an index for estimating environmental benefits for stormwater initiatives – the EBI (Environmental Benefit Index). Disconnecting 100m^2 of impervious area (including roofs) received an EB score of 1, and increases in those increments (Melbourne Water, n.d.). Another example of a stormwater-benefit approach is at Dobsons Creek in Melbourne, where households have been offered a unique “bidding” approach to have rainwater tanks installed and co-paid by the water utility. In the first stage, 95 tanks were installed. These are designed as “leaky” tanks that release a portion of their water slowly.

In Perth, one study examined the value of a rainwater tank through the hedonic pricing method, by examining house prices between 2008-2012. The study found that houses with a rainwater tank were worth about $18,000 more than those without (Zhang et al., 2015).

Schemes like the regional roof water harvesting approach in Warrnambool (Wilson, 2011), are effective at collecting all the water that falls onto the roofs, and is not limited by rainwater tank volumes. This approach substantially reduced the works required for stormwater management by the Council and developers.

Hydrological evaluations of these studies are currently lacking, however, some other studies have investigated the potential benefits of this approach. Van der Sterren et al. (2014) found that lot scale rainwater tanks can significantly reduce stormwater runoff, and a study from Spain found that the environmental benefits of implementing a rainwater harvesting system outweigh the environmental costs by as many as 26 times (Morales-Pinzón et al., 2014).

For the Fisherman’s Bend development in Melbourne, one study considers the non-market benefits of the suite of innovative water servicing infrastructure, which includes: healthier waterways by reducing stormwater runoff; creation of a microclimate and cooler temperatures due to a shady irrigated

[3] The scheme in Warrnambool sees all the roof water of the connected houses being directed to a freshwater storage reservoir before being treated and distributed via the centralised mains water supply (Wilson 2011).

environment; visual amenity for users; the ability to avoid water restrictions (CRCWSC, 2015). The study provides monetised values for particular benefits, based on previous willingness to pay studies (noting that such studies vary between communities):

- Avoiding water restrictions - $10.74 / person / year
- Cooler temperatures (for a 2 degree reduction) - $3.04 payment/ person / year
- Improved amenity - $0.49 / person / year (CRCWSC, 2015).

On the negative side, the increase in GHG emissions due to the higher energy demand per kL due to lift pumping for indoor use introduces a negative externality costs to the RWT system, and would need to be outweighed by the other externality benefits of the scheme when determining the economic cost.

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Appendix A: Case study findings for water, energy and costs

Authors/Year	Location	Approach	Characteristics	Case Study	Water Savings	Energy Intensity	Estimated Cost/s	Comments
Umapathi et al 2013	Southeast Queensland	Meter, model	Realtime monitoring study; no non-tank controls used.	12 months, 20 properties	Not quantified, but rainwater contributed 31% of household demand. Average household per capita water use was 144 l/pp/day (lower than reported averages (158 l/pp/day)).	1.52kWh/kl (trickle top-up 1.59kWh/kl). With automatic switching devices: 70kWh/kl.	N/A	Mean energy consumption in 9 homes with trickle top up devices was found to be 86.3 kWh as opposed to the 11 homes with switching devices that consumed only 64 kWh.
Vieira et al 2014	N/A	Meter, model	Review of energy intensity of rainwater harvesting systems (RWHS)	N/A	N/A	RWHS tend to be 3x more energy intensive than town water, unless optimised	N/A	Found that theoretical assessment of energy intensity may not sufficiently consider energy used for pump start-ups and standby mode, nor true motor and pump energy efficiency. Local characteristics (building type, rainwater demand, RWHS subsystem design, potable water plumbing design, town water energy intensity) will determine environmental/economic performance of RWHS.
Amos et al 2016	Australia, Kenya (location references include Sydney,	Meter, model	Investigates economic aspects of domestic RWHS in urban	N/A	Larger tanks of 3-5m^2 more economically viable.	Soft rainwater requires a lower washing temperature than hard tap	N/A	Found the economic viability of RWHS improves with number of occupants. Life cycle costs of a fully reticulated RWH system with pumps cannot be paid back in

Authors/Year	Location	Approach	Characteristics	Case Study	Water Savings	Energy Intensity	Estimated Cost/s	Comments
	Brisbane, Perth and Melbourne)		and peri-urban environments			water resulting in up to 0.84 kWh/cycle of power savings (at 0.22 AU$/kWh).		the lifetime of a RWH system purely by the value of mains water they can save. These results are in line with the majority of research (Campisano et al., 2017; Christian Amos et al., 2016; Ishida et al., 2011; Kumar 2004; Mitchell and Rahman, 2006; Rahman et al., 2007; Roebuck et al., 2011, 2012; Stec et al., 2017). Reducing installation costs (and especially pumps and plumbing) and maintenance costs, rather than increasing the price of water, seems to be the way forward for making RWH systems more economically viable in a wider range of circumstances.
Zhang et al 2015	Perth	Market data	Investigates if sale price is influenced by presence of a rainwater tank, and whether the premium is larger than the water savings, using the hedonic price method	The sample includes 77,234 properties sold over the period 2008–2012 in the Perth metropolitan area.	N/A	N/A	Estimates a $18,000 premium for home values where tanks are installed; estimate of the value of water savings from a 2 kL installation collecting water from half the roof (discounted at 5 per cent real over the expected 15 year life of a	A number of studies (Tam et al., 2010; Rahman et al., 2012; Coombes et al., 2002; Grafton and Ward, 2008) find that the average cost of water collected from rainwater tanks is higher than mains water, especially in cities with large seasonal rainfall variations. This study confirms this in an investment analysis for Perth. Given the premium versus the value of water savings, the authors conclude the majority of the price premium is attributable to factors other than the financial value of water savings.

Authors/Year	Location	Approach	Characteristics	Case Study	Water Savings	Energy Intensity	Estimated Cost/s	Comments
							tank) is AU$665.	In Perth, where permanent water use restrictions have been in place, people are particularly sensitised to water conservation issues and may also assume that the price of water is greater than it actually is (the value of 2 kL of mains supplied water (enough to fill a typical rainwater tank) is between AU$2.76 and AU$5.22.)
Hajani & Rahman 2014	Sydney	Model (FORTRAN) to simulate a RWHS; BOM data for greater Sydney; water demand data from Sydney Water	Life cycle cost analysis using 3 different combinations of water use (toilet and laundry; irrigation; combined), 8 different tank sizes and hypothesised 'new' developments at 10 study locations with 4 occupants and 250m^2	Uses historical BOM data and land size data for 10 hypothesised locations in greater Sydney (peri urban)	Average annual savings for 5kL tanks: Toilet and laundry: 33 kL. Irrigation Use: 51 kL. Combined use: 61 kL.	N/A	Life cycle cost analysis found that a 5kL tank had the highest benefit-cost ratio (0.86-0.97) among 8 tank sizes.	Results show a RWHS in these study areas not financially viable under the current water price in Sydney and the recommendation is that the water authorities provide a subsidy to home owners for installation. For a 5 kL tank, with a combined use the current water price in Sydney needs to be increased by 3% to achieve a benefit-cost ratio exceeding one. Reliability for combined use does not reach 99% for any of the ten locations, not even for a 20 kL tank.
Talebpour et al 2014	Gold Coast	Meter (smart meters)	Water/energy use: A total of 20 end use events were analysed for each category in each of the sampled homes. A total	Data for 6 months from October 2012 to March 2013 was analysed from 19 households	N/A	End use categories: Half-flush toilets: mean 1.88Wh/L Full-flush toilets: mean 1.61 Wh/L	N/A	Confirmed toilet cistern refills are more energy intense than clothes washing and irrigation and consume the largest total annual pump electricity. Low flow rate water efficient appliances adversely impact pump energy. Concludes that popular fixed speed pump

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			of 1210 end use samples were analysed.	with internally plumbed rainwater tanks (IPRWTs).		Irrigation: mean 1.12 Wh/L Clothes washer: 0.87 Wh/L to 2.98 Wh/L		models are inefficient at supplying indoor end uses – this should be addressed prior to installation. Fixed speed pumps produce unnecessarily high energy intensity values for the internal end uses they predominately supply (i.e. toilet and clothes washer). Pumps should therefore be matched to water-efficient appliances (such as variable speed pumps).
Siems & Sahin 2016	Gold Coast	Meter (smart meter), modelling	Empirical study that analyses energy intensity of IPRWTs and provides breakdown of energy consumed versus water supplied for each end use.	Smart metering data collected for six-month period from November 2012–April 2013, for 19 households at the Gold Coast.	See Table 5 in original publication.	End use categories (reported in Energy Intensity kWh/m^3): Half-flush toilets: 1.80 Full-flush toilets: 1.55 Clothes washing: 1.25 Irrigation: 1.02	Cost of installing an IPRWTS in SEQ is reported to be $1400 (Binney and Macintyre, 2012). See Table 6 in original publication for additional and ongoing costs/savings.	For the vast majority of households with standard water demand, it is preferable to plumb in all 3 end-uses. Consumers and installers should consider that high flow rate appliances will lead to lower electricity costs for typically installed fixed speed pumps. Lower power output and/or variable speed pumps should also be considered by home owners instead of always selecting the typical lower cost fixed speed pumps offered by builders.
Burns et al 2014	Melbourne	Meter	Empirical study to assess reduction in potable mains water usage and to retain run off from rainfall events. (Compared mean daily tank	Assessed 12 IPRWT households during April 2010 – March 2012.	Reductions between 10-100%	N/A	N/A	Largest reductions in mains water usage recorded for households with tanks connected to multiple indoor demands (clothes washing, toilet flushing and hot water). Results confirm the observation of Collins (2008) that large, regular demands are required to

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			usage with mean daily potable mains water usage for each household.)					achieve potable water substitution and improve run-off retention.
Morales-Pinzon et al 2014	Spain	Model (data inputs are locally derived)	Analyses the potential effect of collected rainwater hardness on domestic water uses, such as washing clothes, and any savings made. Uses different scenarios, including tank construction materials, capacity, weather conditions.	Simulation that considered three dwelling types in the Spanish context.	N/A	Low density housing systems possessed the highest potential energy savings, with single houses saving up to 42 kWh/ dwelling/ year on average. Apartment systems showed energy savings of approximately 17 and 19 kWh/ dwelling /year on average for the groups of apartment buildings and the one apartment building macro-systems, respectively.	Up to 0.84 kWh/cycle of power savings (at 0.22 AU$/kWh Potential for savings in detergent use (unquantified).	One aspect of the modelling shows that the environmental benefits of implementing a rainwater harvesting system outweigh the environmental costs by as many as 26 times. When ‘very hard’ tap water is replaced with rainwater, the estimated annual energy (and carbon) savings are increased by 3.9 times for low density housing systems (i.e. groups of houses, eight single houses and two single houses) and this reduces to 3.5 when considering high density apartment buildings

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Wilson 2011	Warrnambool	Model	Regional roof water harvesting scheme that captures all roof rain and directs this to a clear water storage reservoir for treatment and distribution through the potable water network.		450ML per year	Reduces pumping 80km from freshwater source. Not pumps at individual households	$1 856 /ML	
Hall 2013	Southeast Queensland	Model			N/A	N/A	Average levelised cost of $9.22/kL with lower and upper limits of a 95% confidence of $6.73 and $12.77/kL.	The variation in yield, pump and tank life and maintenance had the largest effect on the variation in the cost-effectiveness within a LGA.
Gurung et al., 2012	N/A	Model	Calculates costs for individual rainwater tanks and for networked communal systems	Hypothetical, tested potential for 4-5xx households connected	N/A	N/A	NPV cost for individual tank system $8,568. Communal systems on flat land $10,150. Communal system on land with at least a 0.5% slope $8,770.	Optimal housing scale for a communal rainwater system of between 192 and 288 households
Sountharajah et al., 2017	Sydney	Billing data	Examines the water savings due to installation of	52,000 registered households	9-15% mains water savings, approx. 24 kL/year	N/A	N/A	

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			rebated rainwater tanks					
Moglia et al., 2015	Melbourne	Meter	Qualitatively assessed 417 properties, detailed monitoring for 21 properties	417 households	Average rainwater consumption of 31 kL for indoor use only, 11 kL for outdoor use only and 42 kL for combined indoor and outdoor use	Pumps used 1.8 kWh/kL	Approximately $1500 per household	
Maheepala et al., 2013	Southeast Queensland	Model – stochastic simulation	Quantified the tank yield and tank overflow for five local government areas in the SEQ region	10,000 tank yield values	Average tank yield found from our study was 42 kL/hh/yr (i.e. the average of the five LGAs).	N/A	N/A	Total household water consumption (without leaks) were: 130 L/p/d in Brisbane, 157 L/p/d in Sunshine Coast, 150 L/p/d in Gold Coast and 109 L/p/d in Ipswich.