Quantifying mains water savings from residential tanks

Author

Beal, Cara, Chong, Meng Nan, Fyfe, Julian, Turner, Andrea, Gardner, Ted

Published

2015

Book Title

Rainwater Tank Systems for Urban Water Supply

Version

Published

DOI

https://doi.org/10.2166/9781780405360

Copyright Statement

Downloaded from

Griffith Research Online

Chapter 3

Quantifying mains water savings from residential rainwater tanks

---

Cara D. Beal, Meng Nan Chong, Julian Fyfe, Andrea Turner and Ted Gardner

ABSTRACT

The premise for mandating rainwater tanks, or implementing expensive financial incentive programs such as rebates for the installation of tanks, is that meaningful savings can be achieved from the potable water supply. Whilst there is a depth of literature on modelled and theoretical savings from rainwater tanks, there are scant studies that seek to quantify the savings from multiple household 'real life' examples. The primary objective of this chapter is to present three different methods for assessing the savings in mains water use from regions of Australia that have recently installed rainwater tanks. We believe all three methods are internationally applicable. Various 'before' and 'after' comparisons are presented of mains water demand resulting from either rebated or mandated rainwater tank installations. Case Study 1 is a desktop assessment that uses water utility water billing data, lot sizes and presence or absence of an internally plumbed rainwater tank (RWT) to make pair-wise statistical inferences on the range of savings from internally plumbed tanks at a scale of local authority areas. Building on Case Study 1, Case Study 2 applies known household socio-demographic data matched with their household billing data to determine a benchmark water savings. Case Study 3 focuses on the water savings derived from a city-wide rainwater tank rebate program by comparing water consumption of each individual rebated household with a statistically-matched non-rebated household. Conclusions from all the studies focus on the need for sufficiently large sample sizes, known household occupancy, and the penetration of water-efficient appliances in households. Comparison of savings estimates highlighted the variability of rain tank yields between regions associated with climate, tank sizes and functionality, and connected end uses and roof area. Outdoor consumption is a critical end-use that will maximise savings. Thus factors such as potable water restrictions, lot size and behavioural cues (willingness to water use) are also important in determining water savings.

Keywords: modelling; harvesting; demand management; rainwater yield; tank rebates.

3.1 INTRODUCTION

3.1.1 Why quantify mains water savings?

As described in earlier chapters, the challenges in providing adequate and reliable sources of water for the urban community across the globe have been elevated due to potential climate change impacts and population growth. Various water strategies have been proposed to offset the demand from traditional potable water supplies, and one of the approaches for urban communities is the use of rainwater tanks. Rainwater tanks have enjoyed a recent resurgence in popularity due to widespread drought conditions and resultant water demand management schemes across many parts of Australia. In some Australian jurisdictions, rainwater tanks are mandated through building codes, requiring them to be installed in new developments or new buildings. The premise for mandating rainwater tanks, particularly those that supply internal household end-uses such as washing machines and toilets as well as external end-uses such as garden irrigation, is that significant volumetric savings of potable water can be achieved. These tanks will be referred as ‘mandated rainwater tanks’ in this chapter. The driving objective of installing a rainwater tank is essentially to reduce mains water demand through the on-site harvesting (collection, storage and use) of rainwater. In general, the underlying assumption that rainwater yield will adequately supplement household demand has yet to be convincingly demonstrated across a variety of rainwater tank configurations and regional settings. Additionally, yield (kL/household/year) will vary both spatially and temporally across a given region. Thus, the actual harvesting behaviour of rainwater tanks – internally and/or externally connected – is critical in terms of setting realistic and achievable water demand management goals.

As well as mandated rainwater tanks, many states in Australia have introduced rebate programs whereby residents are offered a financial incentive to voluntarily install a rainwater tank for internal (washing machine and or toilets) and/or external garden supply. The amount of rebate is linked to the overall internal and external end-uses. These ‘rebated rainwater tanks’ as they will be referred to in this chapter, have been very popular across Australia. However the success of these rebate schemes, and the justification for future similar programs, needs to be examined objectively.

Accurate data on the actual *mains water savings* from rainwater tanks is critical for assessing the range of urban water management strategies, along with improving the accuracy of demand (and revenue) forecasting models for future infrastructure planning and optimisation. This chapter addresses many of these questions by presenting three case studies which explore various approaches in determining mains water savings from residential water tanks used for either internal and/or external end-uses.

3.1.2 Previous studies on mains water savings

There are numerous studies that report predicted yields and optimal design criteria (e.g., tank size, roof catchment) for rainwater tank systems, based on water balance simulations and probabilistic methods (Campisano & Modica, 2012). Ideally however, a combination of field and desktop methods using smart metering, historical water billing records, long-term climate data, household demographics, household water end-use surveys and rainwater tank system audits, would capture of all the variables that determine rainwater yield and potable water savings. Such a holistic study would also include the energy demand associated with rainwater tanks (Siems *et al.* 2013). This level of detailed data is rarely available, thus a mixed method approach is often adopted whereby both empirical and modelled data are used to determine potable water savings. Some examples include Chong *et al.* (2012), Fyfe *et al.* (2011) and Sydney Water (2008). Others have used statistical methods with ‘before and after’ retrofit comparisons to identify mains water savings (e.g., Beal *et al.* 2011a; McBeth, 2011; Ghisi *et al.* 2007a; Turner *et al.* 2005). A summary of selected studies is presented in Table 3.1.

Table 3.1 Summary of some previous studies on mains water savings from rainwater tanks.

Location	Approach	Reported savings (kL/ household /year)	Comments	Reference
Various capital cities across Australia	PURRS model (Probabilistic Urban Rainwater and wastewater Reuse Simulator model)	42–90 kL	Modelling assumed rainwater was used for hot water, toilet, laundry and outdoor end-uses.	Coombes and Kuczera (2003)
Various capital cities across Australia	Water balance model	42 kL (externally plumbed only) 71 kL (internal and external)	Supply scenarios modelled included all internal end-uses (excluding cold water to kitchen and bathroom) or external only.	Marsden Jacob Associates (2007)
Sydney, Australia	Comparison between BASIX (homes that have undergone a water efficiency retrofit program) and Non-BASIX homes.	Approx. 36 kL	Volumetric savings estimated. No 'before' dataset to compare with.	Sydney Water (2008); Sullivan and Wilson (2009).
Sydney, Newcastle, Wollongong, Australia	Estimated savings from end-uses connected to rain tanks. Continuous simulation water balance model.	21–57 kL depending on tank size and location.	The end-use rates (L/p/d) were based on Sydney Water's recommended demand rates, not measured datasets.	Eroksuz and Rahman (2010)
Northern NSW, Australia	Similar to BASIX approach. Statistical analysis.	27 kL	Rebated tanks were examined.	McBeth (2011)
Sydney, Australia	Simulation modelling.	45–58 kL (irrigation use) 27–34 kL (internal and outdoor)	Assumed water-efficient appliances and fixtures. Assumed a 5 kL tank size.	Hajani and Rahman (2013)
South east Brazil	Desktop assessment using demand data and population statistics.	16–175 kL	Volumetric savings estimated from % savings, water demand and average household occupancy.	Ghisi *et al.* (2007)

3.1.3 Chapter objectives and scope

The primary objective of this chapter is to present three different, internationally-applicable methods for assessing the savings in mains water use from rainwater tanks. The case studies selected describe both theoretical modelling approaches and empirical data from in-situ measurements. They examine both mandated tanks and rebated tanks. The methodologies presented in this chapter have been chosen based on their global relevance, and thus can be applied in any part of the world where rainwater tanks are used as part of integrated urban water management to reduce reliance on mains water supply.

The different circumstances under which residential rainwater tanks are typically installed are presented in Figure 3.1. Case Studies 1 and 2 are concerned with water savings from mandated tanks, whilst Case Study 3 examines savings from tanks installed voluntarily by the householder under government rebate schemes. The methodology for each case study is discussed in detail with only a summary of results and discussion as it is the approach used, rather than the specific quantum of savings from RWTs, that is the focus of this chapter. The extended data on mains water savings and rainwater tank yields for various locations around the world can be accessed in various publications (e.g., Adeyeye, 2014; Ghisi *et al.* 2007).

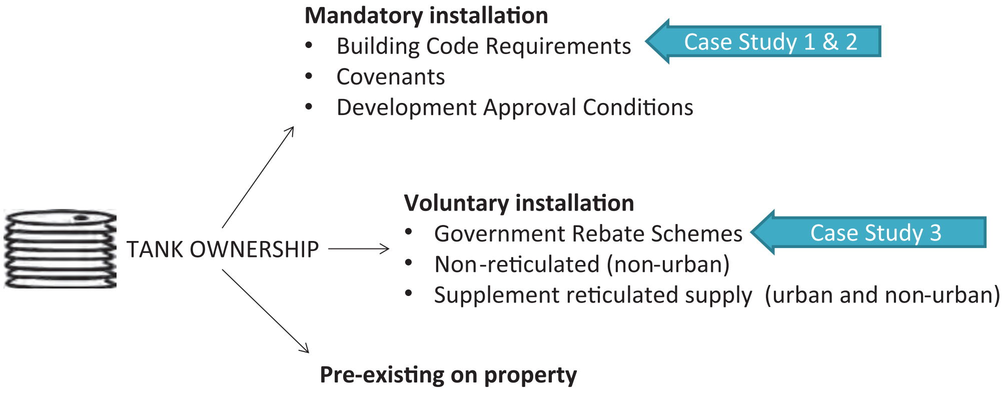


Figure 3.1 Categories of tank installation examined in the three case studies.

3.2 CASE STUDY 1 – DESKTOP ANALYSIS OF MAINS WATER SAVINGS

3.2.1 Background

In south-east Queensland (SEQ), Australia, the challenges in providing adequate and reliable sources of water for the urban community has prompted state water planning authorities to develop sustainable water planning strategies and management practices to address such important urban water issues. Different water strategies have been proposed, and one of the approaches for urban communities in SEQ is the installation of rainwater tanks. These have become an integral feature of the vast majority of detached dwellings in SEQ, either through the WaterWise Rebate Scheme commenced in 2006 (Walton & Homes, 2009) or mandated through the Queensland Development Code (QDC) MP 4.2 – *Water savings targets* (DIP, 2007). Although the requirement to achieve a mains water saving target of 70 kL per year (usually via a rainwater tank) has now been removed (as of 1st February 2013) from Queensland legislation following a change of government, there was considerable research effort directed at developing methods to assess the actual mains water savings from rainwater tanks. This knowledge provides methodologies that allow similar mandated programs on rainwater tank to be assessed by scientifically rigorous analysis of data in other regions of the world.

Mandated rainwater tanks (MRT) clearly played an important role in achieving the sustained reduction in demand, although quantifying this was not a simple task due to an absence in actual consumption data from newly constructed homes. In addition, there was difficulty in separating out the role that other water demand management strategies contributed to demand reduction. Case Study 1 presents the first of a staged methodological approach to investigate the mains water savings that can be achieved from mandated rainwater tanks. The second staged methodology to investigate mains water savings is discussed in Case Study 2.

3.2.1.1 Research objectives and hypothesis

The aim of the research was to conduct a desktop assessment using statistical analysis of the potential mains water reductions from internally plumbed rainwater tanks in new developments in the SEQ, Australia. A further objective of this desktop approach was to provide baseline data for further experimental work. The following hypotheses were used to frame the research methods:

- *Null hypothesis* (H_o)*:* Water consumption in houses with mandated rainwater tanks (MRT) is not significantly different from the water consumption for houses without rainwater tanks (No Tank).
- *Alternative hypothesis* (H_1)*:* Water consumption in houses with mandated rainwater tanks is significantly different from the water consumption for houses without rainwater tanks (No Tank).

3.2.2 Methods

3.2.2.1 Site locations and data collection

Three SEQ local government areas (LGAs) were included in this study: Pine Rivers City Council (now amalgamated into Moreton Bay Regional Council), Gold Coast City Council and Redland City Council (Figure 3.2). These local government areas were chosen as they represented a good cross-section of the socio-economic and climatic conditions in SEQ. At the last available Australia Bureau of Statistics (ABS) census in 2006, these regions collectively comprised almost 40% of the SEQ population (DIP, 2009). Further, they represented around a third of the areas marked for future greenfield development in the SEQ Regional Plan (DIP, 2009). From the council databases provided, approximately 8300 (Pine Rivers), 9100 (Gold Coast) and 1000 (Redland) new dwellings were selected, which had been approved (but not necessarily constructed) since January 1st 2007 when the QDC MP 4.2 requirements became active.

Potable water consumption data for 2008 was obtained from the water billing section of each council. Some councils had difficulties in providing complete datasets of water billings for post-2007 approved dwellings. Once the data was collected from the councils, the method described in 3.2.2.2 was applied to isolate post-2007 constructed properties with mandated rainwater tanks.

The rainfall data for Case Study 1 and 2 (both yearly and long-term) is presented in Table 3.2. For Case Study 1, the year 2008 is of interest for the regions of Pine Rivers, Gold Coast and Redlands.

*Note: Pine Rivers and Caboolture are part of the Moreton Bay Regional Council

Figure 3.2 Location of the local government areas in SEQ used for desktop study (http://en.wikipedia.org/wiki/South_East_Queensland).

Table 3.2 Rainfall data for the studies regions examined in Case Studies 1 and 2.

Region[1]	Annual rainfall in 2008 (mm)	Annual rainfall in 2009 (mm)	Annual rainfall in 2010 (mm)	Long-term annual rainfall (mm)
Pine Rivers	1201	1367	1996	1131
Gold Coast	1766	1548	2320	1372
Redland	1348	1213	1834	1192
Caboolture	1525	1971	2118	1219

[1] data taken from Bureau of Meteorology weather stations available from Climate Data Online (http://www.bom.gov.au/climate/data/).

3.2.2.2 Identification of sample cohorts

In Case Study 1, properties approved and constructed post-2007 were not able to be directly identified in the raw datasets provided. Therefore a methodology was developed to extract the relevant information from typically available household databases. The main steps and assumptions in the analysis are listed below.

(1) The raw data set was filtered for duplicate and ambiguous data (e.g., incomplete, repeated records) using MS Access™ and MS Excel™ software. This data set was then filtered for the Land Use Code representing a Class 1 building as per the Queensland Development Code mandate requirements.

Only single, detached dwellings were selected, which represent up to 60% of SEQ regional water consumption (MWH, 2007).

(2) No Tank and MRT properties were isolated by using property registration (i.e., cadastral data), meter installation and connection dates where available. In the case of Gold Coast Water, the data was supplied in predefined No Tank and MRT samples.

(3) All properties that were identified as having received a rainwater tank state government rebate were excluded. Some councils also had a field that indicated a local council rebated water tank (e.g., Gold Coast). Excluding rebated properties could only be performed where Lot and Plan data (a unique cadastral identifier for the house allotment) was supplied by council. By excluding rebated tank properties, the differences in water use between No Tank and MRT houses were likely to be maximised. Excluding rebated properties could only be performed for Pine Rivers (n = 12,342 rebated properties) and Redlands (n = 4994 rebated properties) where Lot and Plan data was supplied by council. MRT and No Tank data were divided into two lot size categories: ≤700 m^2 and >700 m^2 by filtering for lot size. The value of 700 m^2 represented the median (50th percentile) allotment size identified after developing a probability distribution curve for all councils. Water consumption between No Tank and MRT homes was analysed for the two lot size categories, where sample size allowed this. There was a trend for larger allotments to use more water, but as only limited statistically significant results occurred between regions, this data is neither presented nor discussed further in this chapter.

(4) No Tank and MRT properties were further grouped into suburbs within each lot size category. However, sample size was generally insufficient for a suburb grouping.

Only consumption data recorded in the 2008 calendar year was used for comparative analysis. This method reduced the likelihood of selecting new developments that were constructed after January 1st 2007 and were yet to be fully occupied, or developments that were approved *before* January 1 2007 but *constructed after* 2007. Billing data provided for all regions included information on the date of water meter installation and/or the date of house construction. This information was useful when differentiating between properties which were constructed pre- and post-2007. Unlike previous studies such as Turner *et al*. (2005) and the Sydney Water BASIX study (Sydney Water, 2008), a comparison of identified properties using known household occupancy data was not possible for this analysis. The final number of samples for the MRT and No Tank groups are shown in Table 3.3.

Table 3.3 Number of MRT and No Tank properties for each region of interest for pairing.

Region	**MRT homes**	**No Tank homes**
	(number of samples)	
Pine Rivers	648	32,718
Gold Coast	422	2993
Redland	112	33,117
Total	**1182**	**68,828**

3.2.2.3 Statistical analysis

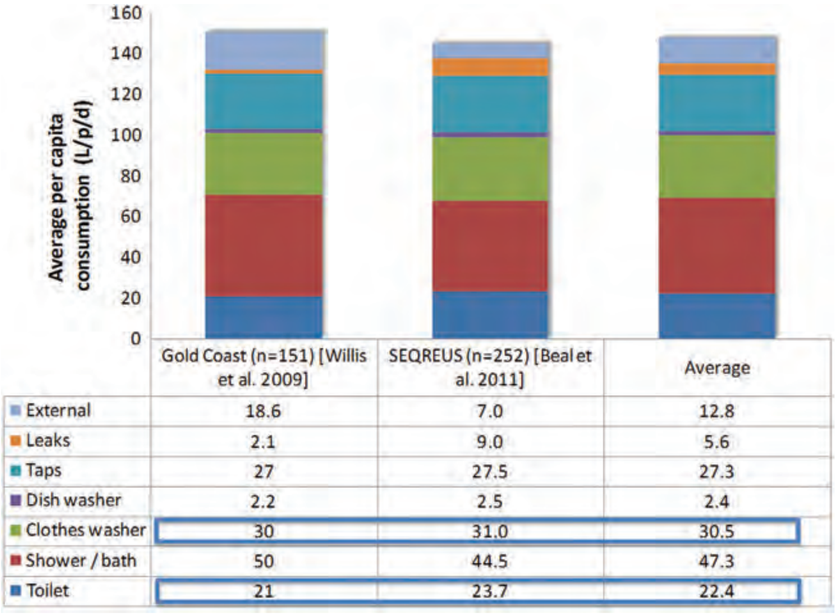
Mean values were used to statistically compare water consumption for this desktop study using a two-tailed, independent Student's t Tests in MS Excel™ and SPSS© software packages. Although the distribution curves were skewed slightly to the right, the t-Test is more robust than other tests (e.g., z Test) to deviations from normality (Johnson, 1978). With the exception of comparing combined totals for water use, the *t*-Test was based on equal variance and equal samples between the No Tank and MRT properties. Further statistical descriptions can be found in Beal *et al.* (2011a).

3.2.2.4 Overcoming limitations with data availability

3.2.2.4.1 Bottom-up end use calculations

The examination of savings from mandated rainwater tanks is not an easy task, particularly given the paucity (or inaccessibility) of specific council data required for a pairwise analysis. Therefore, two other approaches have also been used to assist in evaluating and providing a 'ball park' reality check on the results of the desktop analysis. These 'cross-checks' help to set the bounds of likely potable water savings for the different end use assumptions (e.g., with and without garden irrigation).

An estimation of expected mains reductions from internally plumbed rainwater tanks was made based on internal water use data from the Gold Coast end use study in the Pimpama-Coomera region (Willis *et al.* 2010) and from a recent SEQ end use study (Beal & Stewart, 2011). These studies reported a range of consumption data for various internal fixtures including the washing machine (cold water tap) and toilet. The combined water demand from these internally connected end uses provide a baseline estimation of indoor mains water savings from a MRT (Figure 3.3). Note that whilst the statistical analysis assumes a contribution from outdoor water use, the two cross-checking approaches only consider indoor end uses. Predicting outdoor end uses with any degree of accuracy is extremely difficult due to the number of factors influencing its use (e.g., climate, lot size, garden area, turf area, soil type, personal behaviour and council water restrictions). Indoor water consumption is considered a far more homogenous dataset that has less variability and is therefore easier to predict (Makki *et al.* 2011; Fox *et al.* 2009). End use studies by Willis *et al.* (2011) and Beal and Stewart (2011) suggest external water use was atypically low during the period of our tank studies (2008–9).



	Gold Coast (n=151) [Willis et al. 2009]	SEQREUS (n=252) [Beal et al. 2011]	Average
■ External	18.6	7.0	12.8
🟧 Leaks	2.1	9.0	5.6
🟦 Taps	27	27.5	27.3
🟪 Dish washer	2.2	2.5	2.4
🟩 Clothes washer	30	31.0	30.5
🟥 Shower / bath	50	44.5	47.3
🟦 Toilet	21	23.7	22.4

Figure 3.3 Summary of measured internal water end uses from a number of recent SEQ end use studies.

3.2.2.4.2 Rainwater tank modelling

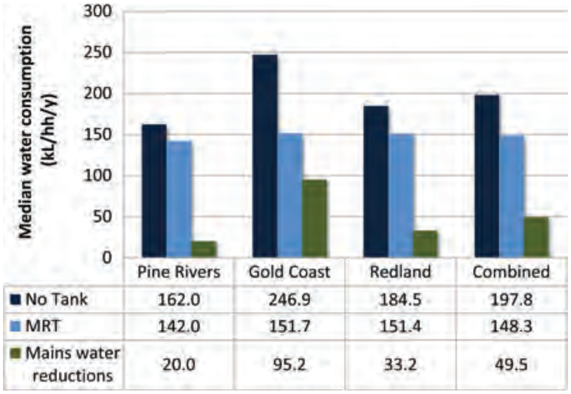
The Rainwater TANK model is an Excel-based spreadsheet model linked to a FORTRAN executable file (Vieritz *et al.* 2007). Rainwater TANK simulates the capture of rain by an urban roof. The primary aim of the model is to assess the ability of the rainwater tank to meet the water demand of connected end uses. For the purposes of this study, TANK provided a first approximation of the supply performance of rainwater tanks for comparison with the statistical desktop results. Rainfall years that were used in the modelling are provided in Table 3.4.

Table 3.4 Rainfall input data used for rainwater TANK modelling.

Region	Rainfall scenario	Yearly Rain (mm)
Pine Rivers	Dry (2006–7)	850
	Av (28 yrs)	1131
	Wet (2008)	1201
Gold Coast	Dry (2006–7)	1193
	Av (28 yrs)	1372
	Wet (2008)	1766
Redland	Dry (2006–7)	956
	Av (28 yrs)	1192
	Wet (2008)	1348

3.2.3 Results

There was a significant reduction ($p < 0.05$) in mains water consumption for MRT properties in all regions (Figure 3.4). Mains water consumption for No Tank homes averaged 197.8 kL/household/year compared with an average of 148.3 kL/household/year for MRT homes. Within regions, this trend continued with Gold Coast and Redland No Tank homes consuming the most mains water at an average of 246.9 and 184.5 kL/household/year, respectively. These two council areas were operating under relaxed outdoor watering restrictions in 2008. Mains water savings varied markedly across regions, with values ranging from 20 to 95 kL/household/year, with an average of 50 kL/household/year (Figure 3.4).



	Pine Rivers	Gold Coast	Redland	Combined
■ No Tank	162.0	246.9	184.5	197.8
■ MRT	142.0	151.7	151.4	148.3
■ Mains water reductions	20.0	95.2	33.2	49.5

Figure 3.4 Results from pairwise statistical analysis of water consumption from MRT and No Tank properties.

The result of the two approaches used to cross-check the statistical analyses are presented in Table 3.5. Both of these approaches only consider indoor water consumption. Assuming an average household occupancy of three people (Australian Bureau of Statistics, 2006) in new developments, tanks supplying water efficient toilets and washing machines should reduce mains water use in the range of 43 to 46 kL/household/year, regardless of outdoor uses of rainwater. Notwithstanding the high estimated savings from the Gold Coast, where there were no restrictions on external water use in 2008, the other two council areas had lower than expected mains reductions when cross-checking them with results from predicted indoor reductions, as shown in Table 3.5.

Table 3.5 Summary of mains water use reductions for 2008 compared with two independent estimates of the water savings.

Region	Desktop Analysis of water meter records: Mean values	Desktop analysis of water meter records: median values	Water consumption based on regional end use studies (internal only)	TANK model predictions (internal only)
		(kL/household/year)		
Pine Rivers	20	28		49
Gold Coast	95	52	43 to 46	54
Redland	33	41		46
Average reduction	**50**	**40**	**44.5**	**50**

A non parametric rank test was used to statistically analyse the mains water reductions between properties that were under high water restrictions compared to those under low or no water restrictions. The results show that water consumption in No Tank homes located in low or no restrictions (Gold Coast and Redland) was statistically higher ($p < 0.05$) than for No Tank homes in high water restriction areas (Pine Rivers) (Figure 3.5). This will be discussed in more detail in the section below.

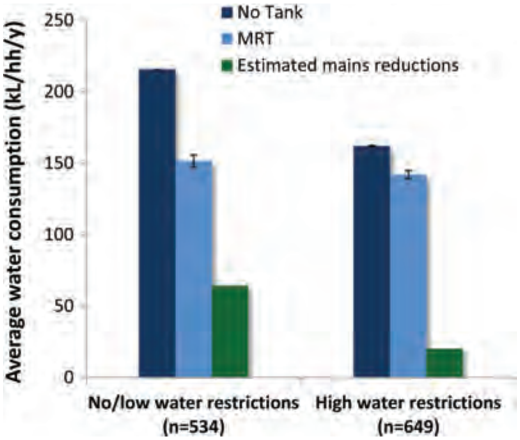


Figure 3.5 Comparison between water consumption and estimated mains reductions for regions with high and low/no water restrictions.

3.2.4 Discussion and implications

Comparative analysis of mains water consumption between No Tank and MRT properties overall clearly showed that consumption was greater for homes without MRT. There are two main factors that are likely to be influencing the lower estimated reductions calculated from the statistical analyses: the influence of water restrictions during the period of analysis (discussed below) and the limitations of the council billing data used to determine MRT from No Tank homes (Section 3.2.5).

3.2.4.1 Influence of water restrictions

The influence of water restrictions is illustrated in Figure 3.5, which showed smaller differences in water consumption between MRT and No Tank properties in those regions with high-level water restrictions (i.e., no or low outdoor watering). Conversely, the differences in mains water use (i.e., the savings) is greater for those homes located in low or no water restriction areas where rainwater had the opportunity to substitute for garden water use otherwise supplied by mains water (Figure 3.5). The strictest water restrictions in 2008 occurred in the Moreton Bay Regional Council area, which encompasses Pine Rivers. Outdoor watering using mains water was limited to hand held bucket or watering cans. This included newly established gardens or lawns. In contrast, Gold Coast City Council had no restrictions between February and November 2008 due to high rainfall events overtopping their main water supply dam (Hinze Dam). Consequently, there was no limitation to outdoor watering with mains water. Properties in Redland Shire Council were on Level 2 restrictions which allowed outdoor watering using mains water to occur with a hand held hose both for established and new gardens. Daily per capita water use for No Tank properties all exceeded the 2008 average value for areas in SEQ under water restrictions (data not shown). Conversely, average per capita water use from households with MRT was ~20% less, and was similar to the average water use for restricted SEQ regions at that time which was 128 L/p/day (equivalent to about 131 kL/household/year). When compared to homes with a MRT, high water usage from No Tank homes would maximise the main water savings able to be achieved from rainwater tanks. However, if people are frugal in their water use due to water restrictions and demand management strategies (as was the case during our 2008 study) this will compress the differences in mains water use between tank/no tank homes, and hence minimise the potential for mains water savings from rainwater substitution.

3.2.5 Limitations of Case Study 1

Although all local government regions could be confidently divided into the two groups of No Tank and MRT, and then subsequently paired for statistical testing, there still remained some important information that could not be extracted from the data provided. This absence of information for some or all of the regions created the following limitations:

- Separating the billing data into MRT and No Tank subsamples could only be done using assumptions and proxy data, as detailed in the methods section;
- Separating out the influence of MRT from other water restriction influences was not possible;
- Details on critical factors that influence residential water consumption (garden size, water efficient fixtures etc.) could not be fully taken into account; and
- Details on socio-demographic factors such as household occupancy, family makeup and income could not be controlled for in the analysis.

These limitations are likely to have had some influence on the outcomes from the analysis. Without specific knowledge of household occupancy, household water demand cannot be properly controlled for.

For example, a single person No Tank household with low total water use volumes may be matched with a six person MRT family using very high volumes of water, thereby reducing the estimated contribution from rainwater tanks. The same argument follows for controlling for outdoor water demand if garden sizes (as opposed to allotment sizes) were known. Although MRT and No Tank homes were paired based on two lot size categories, there were no strong trends in the differences in water consumption and savings between lot size categories. However, a large allotment does not necessarily translate into a large, irrigated garden area. With this knowledge, external water demand can be controlled for to some extent, although external water uses are notoriously difficult to quantify (Beal & Stewart, 2011; Wang, 2011).

Finally, the role of water-efficient household stock such as low water use (5 star rated) washing machines, low-flow shower roses and tap flow controllers have not been able to be quantified in this Case Study. Research shows that these efficient features and fixtures can be very effective in reducing domestic water consumption (Willis *et al.* 2010; Beal *et al.* 2011b). It is likely that had such data been available for the MRT properties, one would have seen a greater difference in water consumption from MRT (more savings) and No Tank properties.

3.2.6 Concluding remarks

Whilst it is clear that internally plumbed rainwater tanks will offset mains water demand, the annual volume of that offset is highly variable, and influenced by a range of factors including demand for rainwater (e.g., from external and internal water uses), rainfall, demographic factors (e.g., household size and waterwise awareness) and water efficient household appliances/fixtures. Additionally, the timing of the analysis with a drought-focussed community, where external water use was conservative due to water restrictions, made the differences due to tank supply options harder to detect. Any water saving features in new homes that are not present in pre-2007 homes will reduce mains water use and hence increase apparent rainwater contributions. Similarly, any systemic population difference between post- and pre-2007 homes will affect mains water use and hence bias the calculated tank water contributions.

Despite these acknowledged limitations, the desktop methodology presented in this Case Study has the advantages of providing a base range of savings for relatively low cost experimental inputs (e.g., no field trial costs or modelling work required). It exploits available datasets and uses a basic statistic pairwise approach to estimate the likely range of savings. At the least, it provides a 'first pass test' to estimate the range of achievable savings expected from mandating rainwater tanks in any given area. This may moderate the expectations of potable water saving from mandating rainwater tanks in other regions.

3.3 CASE STUDY 2 – BENCHMARK ANALYSIS OF MAINS WATER SAVINGS

3.3.1 Background

To improve the validity of the Case Study 1 approach, there were a number of recommended additional steps to take for a second stage assessment of mains water savings. These were focussed around improving the lack of specific knowledge on MRT and No Tank homes, socio-demographic data, knowledge of rebated tank installations and household water stock (e.g., presence or absence of water-efficient stock). This work is now presented in the following section.

3.3.2 Research aims

The aim of Case Study 2 is to provide a sound and methodical approach to validating the MRT savings target of 70 kL/hh/yr under the QDC MP 4.2 for SEQ. It will provide some contextual understanding for results discussed in Case Study 1 in achieving the mains water savings through MRT. A further aim of Case Study 2 is to document a methodological approach that can be applied globally to estimate, and subsequently justify, water supply from rainwater tanks as an alternative water supply source.

3.3.3 Methods

3.3.3.1 Data collection and participant details

The study area comprised four LGAs in the SEQ region, three of which were examined in Case Study 1: Caboolture, Pine Rivers, Redland and Gold Coast (Figure 3.2). The 2006 Australian Census described these four LGAs as containing over 40% of SEQ urban population (DIP, 2009). These regions were selected due to the availability of necessary data for this benchmark analysis. Only properties built after 2007 were included in the study to ensure only households with MRT were analysed.

A phone survey was conducted between July and August 2010 to understand the potential contribution of biophysical and social factors in achieving water saving targets as identified in Case Study 1. The results of the phone survey research are described in Chong *et al.* (2011). The participants groups, who were recruited during the phone survey study, provided their consent to access their mains water billing records from their water supply provider. Of the 15,615 targeted households, 1134 householders from the four LGAs responded to the survey satisfying the screening criterion that the household had an MRT. The water consumption data for the consenting households were obtained from the Queensland Water Commission (QWC) database. Some households were subsequently excluded from the analysis due to inconsistent or incomplete water billing data. A total of 691 households across the four council areas were ultimately found to be suitable for inclusion in the Case Study 2 analysis. Rainfall data for each of the regions is presented in Table 3.2.

3.3.3.2 Assessment procedure

A benchmark analysis approach similar to Sydney Water's BASIX approach (Sydney Water, 2008) was applied for assessing mains water savings. Figure 3.6 shows schematically the benchmark analysis approach to estimate the potential mains water savings from dwellings with mandated rainwater tanks (MRT).

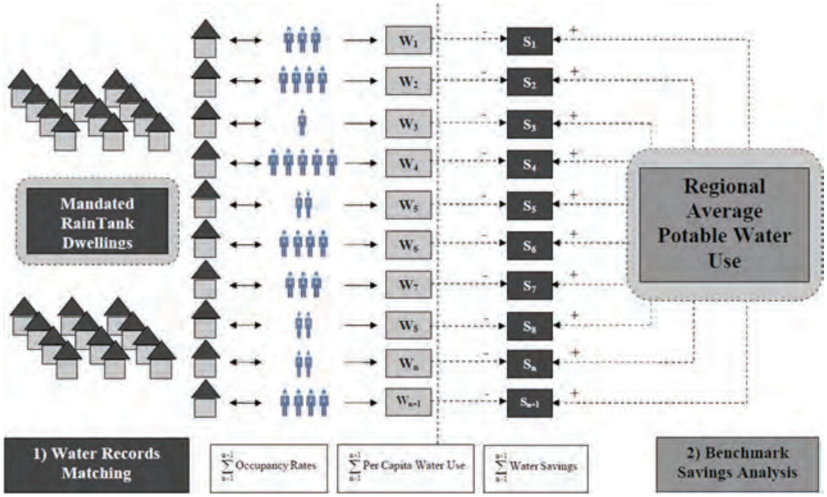


Figure 3.6 Schematic diagram for the benchmark analysis in estimating the potential mains water savings.

Mains water consumption records for each MRT dwelling were matched to their individual household occupancy number obtained from the phone survey. This was followed by the normalisation of mains water consumption to provide the per capita mains water usage (W_X) of each matched dwelling. The water usage data set (W_X) was then individually subtracted from the *average* mains water use for the respective LGA to generate the individual mains water savings (S_X). A positive sign notation (+) indicates a mains water savings from MRT dwellings. Negative values (–) indicate the mains water consumption at the particular MRT dwelling was actually higher than the regional average value. Subsequently, the average annual mains water savings from the MRT dwellings was estimated from the summation of each of the individual mains water savings (S_X) values.

3.3.4 Results and discussion

3.3.4.1 Water consumption data for MRT dwellings

The resultant mains water savings was expressed in litres/person/day (L/p/d). In order to convert the savings into kL/hh/yr, the mean occupancy rate was estimated via telephone interviews and used to provide more accurate results in determining the water consumption in these LGAs (Table 3.6). Interestingly, the known average occupancy was found to be higher than that assumed in the Case Study 1 (3 people per dwelling).

Table 3.6 Mean water consumption (L/p/d) in MRT households and average persons per household.

Region with mandated rainwater tanks	Sample size	Mean water usage 2009 (L/p/d)	Mean water usage 2010 (L/p/d)	Average person number per household assumed by Beal *et al.* (2011)	Average person number per household in this study
Pine Rivers (Moreton Bay Regional Council)	197	119.4	109.4	3.00	3.21
Caboolture (Moreton Bay Regional Council)	158	108.5	108.2	–	3.20
Gold Coast City Council	172	138.8	125.7	3.20	3.34
Redland City Council	164	129.1	121.9	2.90	3.18

3.3.4.2 Benchmark analysis of mains water savings for MRT households

The average mains water usage for the MRT cohort was compared with the SEQ average mains water consumption data for each LGA. The differences between the two data sets provide an estimate of the mains water saving for MRT households in 2009 (Table 3.7) and 2010 (Table 3.8).

The estimated per capita mean values for mains water saving from MRT dwellings were considered to be more accurate than the earlier analysis of Beal *et al.* (2011) in Case Study 1, as they are now normalised to the specific occupancy rate for every matched household. Although both the mean and median values were estimated, mean values are reported to maintain consistency with the units used in the State Government published data for the SEQ region. Since the ultimate aim of this study is to validate the 70 kL per year mains water savings target under QDC MP 4.2, the calculated annual mains water savings in L/p/d in Tables 3.7 and 3.8 were converted to kL/hh/y based on the average occupancy rates per household obtained from the phone survey (Table 3.6). Further, there is some doubt as to the relevance of savings predicted from prior Probabilistic Urban Rainwater and Wastewater Reuse Simulator (PURRS) modelling because of high water use assumed at that time, that is, 300 L/person/day (WBM Oceanics, 2006). This PURRS modelling was used to set the 70 kL/hh/year MP4.2 savings target, and was based on high external water use (around 50 L/p/d) estimated at the time (2005) in SEQ. However, this amount of outdoor use simply did not occur during and after the drought in SEQ (2007 onwards) as evidenced in Figure 3.3.

Table 3.7 Average annual water savings in MRT households in 2009 for four local government areas in SEQ (sample size in brackets).

Description	**Pine rivers (197)**	**Caboolture (158)**	**Gold coast (172)**	**Redland (164)**
Average persons per household	3.21	3.20	3.34	3.18
Average mains water consumption for all households in the LGA (L/p/d)[1]	140.4	140.4	211.4	201.5
Average water consumption in MRT households (L/p/d)	119.4	108.5	138.8	129.1
Average water savings in MRT households (L/p/d)	20.9	31.9	72.6	72.4
Average annual savings in MRT households (kL/hh/yr)	24.5	37.3	88.5	84.0
Average mains water use savings (%)	15	23	35	36
Average savings over all samples (691)		**58.8 kL/hh/yr**		

[1] *Source*: QWC data.

Table 3.8 Average annual water savings in MRT household in 2010 in four local government areas in SEQ (sample size in brackets).

Description	**Pine rivers (197)**	**Caboolture (158)**	**Gold coast (172)**	**Redland (164)**
Average persons per household	3.21	3.20	3.34	3.18
Average mains water consumption for all households in the LCA[1] (L/p/d)	143.3	143.3	192.0	183.1
Average water consumption in MRT households (L/p/d)	109.4	108.2	125.7	121.9
Average water savings in MRT households (L/p/d)	33.6	34.8	66.3	61.2
Average annual savings in MRT households (kL/hh/yr)	39.7	40.9	81.0	71.0
Average water use savings (%)	24	25	35	33
Average savings over all samples (691)		**58.2 kL/hh/yr**		

[1] *Source*: QWC data.

Results from 2009 modelling (Table 3.7) demonstrate that households with MRT substantially reduced mains water use in all the studied LGAs. Variation between LGAs could be driven by factors such as rainwater tank yield including factors related to rainfall, socio-demographic factors (water wise awareness and household water conservation behaviour) and water efficient household appliances and fixtures. The average mains water savings for Pine Rivers and Caboolture in 2009 were 20.9 L/p/d and 31.9 L/p/d respectively, which were significantly lower than the water savings for Gold Coast and Redland (72.6 and 72.4 L/p/d respectively). These data reflect the continued low water consumption in Pine Rivers and Caboolture in 2009 in the aftermath of the severe water restrictions placed on those regions in 2008.

Table 3.8 presents the average mains water consumption for IPT dwellings in 2010. The average annual mains water savings per household per year across the four council areas were found to range from 39.7 kL/hh/yr (Pine Rivers) to 81.0 kL/hh/yr (Gold Coast). Per capita reduction in mains water consumption per day ranged from approximately 24 to 35% (Table 3.8). The overall average water savings across the four regions in 2010 (for 691 households) were 58.2 kL/hh/yr. Interestingly, it was found that the mains water use pattern for the quarters in 2010 are quite different from quarters in 2009 where the inverse of higher water consumption rate towards late 2010 was observed. As discussed for Case Study 1, higher potable water savings for Gold Coast and Redland, which approximate the PURRS predictions, are probably due to much higher external water use, as these areas had minimal water restrictions compared with the other 2 LGAs.

3.3.5 Challenges and limitations

Although some challenges faced in Case Study 1 have been addressed in this analysis, there remained difficulties in obtaining complete data sets for some households. This limitation is likely to be a globally common problem. Typical difficulties associated with data gathering include:

(1) Many local authorities often had partially complete or missing billing information for households;
(2) Some datasets had been merged or removed for various reasons;
(3) The period of time for which water consumption was billed was not consistent, for example, quarterly versus six monthly; and
(4) Privacy issues can severely delay or prevent obtaining identified data.

As for Case Study 1, some inconsistencies in datasets made matching of data pairs more challenging and resulted in a reduced sample size.

3.3.6 Concluding remarks

Case Study 2 demonstrated that MRT households could reduce their reliance on mains water supplies in all the studied LGAs, albeit with substantial variation among LGAs. Case Study 2 (benchmark with empirical data) was designed to build on the results from Case Study 1 (desktop study with billing data), and to identify the advantages of this approach in more accurately quantifying mains water savings from rainwater tanks. The key difference between the two approaches is that known household occupancy rates (from the phone survey) were matched to the individual water billing records in Case Study 2. Conversely, Case Study 1 did not have access to this data, thus relied on using the average household occupancy rate from the 2006 Australian Bureau of Statistics (ABS) Census District Data for cross-checking the pairwise statistical analyses. It is anticipated that the Case Study 2 methodology can be used for most urban areas of the world, although the exact uses of the rainwater should be known. For example, if there is only internal uses (toilet and clothes washing) and little or no outdoor use, the savings from mains supply will be reduced. End uses studies reported by Beal *et al.* (2011b, 2013) are very valuable in understanding the quantum of potable water savings expected from rainwater tanks. Additionally, consumption and end-use also should be matched with socio-demographics and socio-economic status as this strongly influences water use per person per day (wealthy people typically use more water!).

3.4 CASE STUDY 3 – WATER SAVINGS FROM REBATED RAINWATER TANKS

3.4.1 Background

This case study presents the estimated mains water savings from installation of rebated rainwater tanks in Canberra and the broader Australian Capital Territory (ACT) based on analysis of water billing data. As part of its *Think Water, Act Water* strategy, the ACT Government subsidised the cost of purchasing and installing tanks. Initially run by the local water utility, the rebate program commenced in 1997, offering subsidies for installing medium to large tanks (>4 kL), but with no requirement for plumbing tanks to indoor connections (Fyfe *et al.* 2011). In 2004, the ACT Government took over administration of the program, adding rebates for indoor connections to new and existing tanks, and reducing eligible tank size threshold to 2–4 kL. Rebate incentives were adjusted four times between 2004 and 2007, and from July 2006 indoor connections were made a requirement for all rebates.

Throughout the majority of the program, the ACT experienced drought conditions and residents were subject to mandatory water restrictions. From 2005 to 2007, when restrictions were at their tightest, peak summer demand in the ACT dropped from 250–300 ML/d (unrestricted) to 150–170 ML/d (Fyfe *et al.* 2011). This demand reduction was in part due to customer response to water restrictions and associated public campaigns. Additional factors were the national Water Efficiency Labelling Scheme (WELS) (Australian Government, 2014), local water sensitive urban design projects, and a number of efficiency programs such as home retrofits of water-efficient devices under the *Think Water, Act Water* strategy (ACT Government, 2004).

3.4.1.1 Research aims

The central aim of the evaluation study conducted for the ACT Government (Fyfe *et al.* 2011) was to produce robust estimates of water and energy savings, and associated reductions in greenhouse gas emissions from the various efficiency programs under the *Think Water, Act Water* strategy. A key component of the research was to validate the methodologies used to generate the estimates. The research presented in this section focuses on the water savings derived from the rainwater tank rebate program.

3.4.2 Methods

3.4.2.1 Data sources and pre-processing

Data identifying rebate participants (all voluntary), their address, rebated tank size and connection details were provided by the ACT Government. The data were filtered to remove duplicates, incomplete records and participants that had participated in *other Think Water, Act Water* efficiency programs. The data for the remaining participant households were linked to quarterly water billing (metered consumption) data provided by the ACT water (and electricity) utility using lot, block, section and suburb identifiers. Only individually metered dwellings were analysed, causing most multi-residential dwellings to be excluded. The utility also supplied dates of changes to dwelling occupants (identified by changes to electricity account holders[1]), allowing the analysis to focus on households that occupied

---

[1] In Australia, electricity is typically billed to actual household occupants whilst water is billed to property owners who can choose to pass on the charges to their tenants.

a property both before and after receiving a rebate. The connected roof area was not known for the households examined, but as the ACT study examined retro-fitted tanks, it was assumed to be lower than for the MRT homes in SEQ. Water billing data for all non-participant households in the ACT was also supplied by the utility to provide a pool of 'controls' information. All billing data were screened for negatives, missing records and statistical outliers before being converted into monthly values using the 'binning' algorithm explained in Fyfe *et al.* (2010). Binning is used to overcome the problem of households having differing billing cycles where for example group X's household quarterly bills might end on 5th April, whilst group Y's household bills ends on 20th May. The process regularises the consumption data on a pro-rata basis so that it conforms to calendar months, allowing direct time-based comparisons between households.

3.4.2.2 Analysis procedure

The methodology used to estimate savings is based on a pair-matching approach similar to that used in Case Study 1 (Section 3.2), except matching was performed using historical consumption patterns rather than lot size and location. The matched pairs means comparison (MPMC) method compares the consumption of *each rebated household* with *every non-rebated household* in the entire utility based on data generated within the period between 3 and 14 months *prior to tank installation*.[2] The strongest match is determined by the lowest root square error (RSE) result calculated as:

$$\sqrt{(N_{-14} - R_{-14})^2 + (N_{-13} - R_{-13})^2 + \ldots + (N_{-3} - R_{-3})^2} \quad (3.1)$$

where R = monthly average day consumption of the (future) rebated household (kL/d), N = monthly average day consumption of corresponding non-rebated household (kL/d) and subscripts indicate the month relative to the participant's rebated tank installation. A perfect match will produce an RSE of zero.

The matched non-rebated household is assumed to have similar characteristics and responses to external demand drivers as the rebated household, and is adopted as a control. Matching is performed for each participant household in a random sequence until every rebated participant has its own control household. Matches are then subjected to several statistical tests to check the veracity of the match, which are described in detail in Fyfe *et al.* (2010).

Savings in month m of year y were then calculated as:

$$(N_i - R_i)_{m,y} - (N_i - R_i)_{m,Y} \quad (3.2)$$

where R_i is consumption of rebated household i in month m of post-installation year y or the pre-installation year Y, and N_i is consumption of the matched non-rebated control in the same month.

Repeated measures *t*-Tests were applied to the paired household differences for each month to test against the null hypothesis that the population of monthly savings had a mean of zero (i.e., no discernable water savings). Household savings typically showed a non-normal distribution, thus, Wilcoxon signed rank tests were also applied as a non-parametric (non-normally distributed) alternative.

---

[2] Since ACT water bills span three months, monthly consumption data produced by the binning process is influenced by consumption that occurred up to two months before or after any given month. Thus a distinct intervention month could not be isolated in the consumption data and the two months data before and after installation had to be excluded from the analysis.

3.4.3 Mains water savings results

Over the life of the program, 2744 rainwater tank rebates were paid to residents. Linking and pre-processing the data reduced the sample to 1913 households, and filtering through the MPMC method further reduced the sample size to 1410 households, with consumption data that ranged from October 2001 through to March 2011. The global mean savings estimate for rebated tanks between April 2003 and March 2011 (inclusive) was 40 ± 25 L/household/day, equivalent to 15 ± 6 kL/household/year. This is equivalent to 5% of average participant household water consumption in the pre installation period. Savings estimates for particular tank configurations based on analyses of subsets of the full data set are given in Table 3.9.

Table 3.9 Sample sizes, median tank sizes and savings estimates for different configurations of rebated rainwater tanks (April 2003–March 2011).

Rebated tank configuration	Sample size		Median tank size	Mean annual savings		Saving as a % of average participant consumption before installation	
	Households	Monthly consumption data points	kL	(kL/hh/year)			
All tanks	1410	66,116	5	15	±6	5	±2
Indoor plumbed	176	4837	5.3	9	±15*	3	±5*
Outdoor plumbed	845	45,176	5	10	±7	3	±2
Indoor and outdoor plumbed	182	4516	5.6	21	±16	7	±5
Tanks <4kL capacity	242	10,998	2.25	7	±11*	2	±3*
Tanks ≥4kL and <9kL capacity	660	30,794	5	13	±8	4	±3
Tanks ≥9kL capacity	478	23,016	10	20	±11	6	±3

**Notes*: Error bounds are 95% confidence intervals; not statistically significant at the 5% level.

The plot of savings for all tanks in Figure 3.7 shows that there is no clear long-term decay or growth, or seasonal pattern. Note that Figure 3.7 does not include data for the year 2003 as savings estimates were grossly exaggerated by outliers in small samples and were not statistically significant. The same absence of seasonality is evident in savings from tanks with exclusively outdoor connections (data not shown). Savings were not consistently statistically significant ($p > 0.05$), exhibiting a large dip from October 2006 to January 2007 (summer) following an extended period of low rainfall that also led to the introduction of stricter stage 3 water restrictions (after a year of relaxed restrictions) and low overall water consumption.

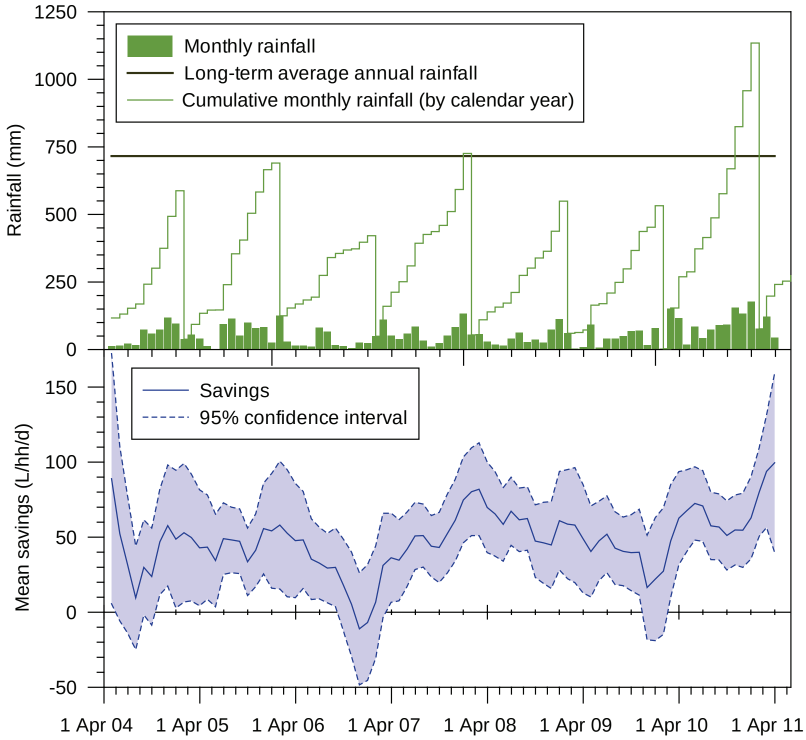


Figure 3.7 Mean monthly savings for all rebated rainwater tanks (bottom) and observed and long-term average monthly rainfall (top) over time.

3.4.4 Interpretation and implications

Savings were generally lower than anticipated and were not statistically significant for tanks with only an indoor connection, and for tanks of <4 kL capacity. Combined indoor and outdoor connections produced the greatest potable water savings (21 kL/hh/yr), and despite the small sample, the savings estimate was statistically significant ($p < 0.05$) and close to the sum of the separate indoor and outdoor connection savings. The climate of the ACT region may be characterised as Mediterranean, with relatively low rainfall throughout the year and hot, dry summers. Accordingly, rainwater tank yields cannot be expected to be as high as in the sub-tropical region of SEQ (Case Studies 1 and 2). However, savings for outdoor connected tanks (10 kL/hh/yr) were notably lower than the theoretical yield of 19 kL/year for a median-sized (5 kL) tank in the ACT region assuming a small roof catchment (50 m^2) and a relatively small 100 m^2 irrigated garden/lawn.[3] As shown in the upper plot of Figure 3.7, annual rainfall was below average (716 mm) in 5 of the 7 years s, which would have reduced yield from all tank installations. With water restrictions in force, access to mains water for irrigation was heavily constrained, thereby reducing apparent mains water savings. That is, the substitution of potable water with rainwater for outdoor end uses would not have been reflected in mains water savings for tank-owning houses.

---

[3] Derived using the water balance model described by McKibbin and Fane (2011).

Savings associated with indoor connections (9 kL/hh/yr) were also considerably lower than theoretical yield for connections to toilets and/or laundry (between 15–31 kL/year for 5 kL tanks connected to a 50 m^2 roof catchment). This supports the findings of Mukheibir *et al.* (2013), who recommend applying a 'functionality factor' of between 0.5 and 0.7 to theoretical rainwater tank yields to account for reduced catch efficiency associated with compromised installation quality, operational failures and behavioural issues. The scale of the yield impairment would appear high in this case, particularly when contrasted with the good agreement between measured and predicted savings in the SEQ case studies. However, this could in part be due to the fact that the tanks were retro-fitted to existing dwellings such that many would have had sub-optimal roof catchments, guttering and plumbing. In contrast, the SEQ houses with MRT as per the 2007 building code, were likely to have greater area of connected roof to the tanks, thus further contributing to the higher mains water savings observed in Case Study 1 and 2.

3.4.5 Challenges and limitations

By using prior consumption patterns to match tank participants to controls, the MPMC method circumvents the need for collecting data on household characteristics such as number of occupants, lot size, income and plumbing fixtures and appliances. It also implicitly controls for external factors such as restrictions and price changes. However, it cannot be applied to new homes with no water use history. Also it is not immune to the vagaries of internal household dynamics such as changes in appliances, new or departing occupants and voluntary behaviour change. Thus, it relies on a sample size of several hundred or more households to obtain robust savings estimates. Four of the six tank configuration subsets reported in Table 3.9 comprised less than 500 households, which meant that monthly average savings estimates (within the time series) were at times not statistically significant (see Figure 3.7). The extensive longitudinal component of the data set helped those sub-samples produce statistically significant global savings estimates, but these have large confidence bounds, making inferences more indicative than definitive. The analysis did benefit, however, from having household occupancy details verified using electricity accounts, thereby ensuring savings estimates were not biased by changes in ownership or tenancy.

3.4.6 Concluding remarks

The analysis of household billing data confirms that the installation of rebated rainwater tanks in existing homes of the ACT has achieved measurable potable water savings, but that those savings are significantly less than theoretical yield estimates. Recent research undertaken by Mukheibir *et al.* (2013) found that rainwater tank installation, maintenance and usage is often sub-optimal, resulting in impaired yields. In the case of rebate programs such as this one, poor tank functionality would be exacerbated by the difficulties associated with retrofitting tanks to existing dwellings such as limited accessible roof catchments and deteriorating guttering. Small yields caused by low rainfall and substandard functionality would produce low apparent mains water savings, which would have also been suppressed by reduced water usage amongst the broader community stemming from water restrictions and acute awareness of water scarcity. Functionality issues and low rainfall are also likely to be behind the notable differences between savings observed in this case study and those reported in Case Studies 1 and 2.

Nonetheless, the MPMC method is a robust method, and can be considered the 'Gold Standard' of treatment comparisons in estimating actual savings achieved by implemented programs, including rainwater tank rebate programs, provided prior water use behaviour of the house cohorts is available. It has been used on a variety of efficiency programs across Australia (Turner *et al.* 2013). It is recommended that a minimum 28-month billing dataset comprising 14 months either side of implementation is available before a robust analysis can be conducted using a 3-month billing cycle. Longer billing cycles require proportionally larger datasets. Based on the observed magnitude (~5%) and variation of the savings signal, the analysis precision will benefit from a sample size of more than 500 households, particularly when yield is likely to be lower due to small tank sizes or singular (indoor or outdoor) plumbing connections.

3.5 KEY CONSIDERATIONS IN QUANTIFYING MAINS SAVINGS

Having presented and critiqued three approaches to quantifying mains water savings from installing both internally and externally supplied rainwater tanks, there are a number of key points to consider when designing an approach to quantifying mains water savings. Ultimately, the goal is to have a large sample size based on desktop and field data of high quality. This is not always possible due to resource and time constraints. A method evaluation chart is presented in Figure 3.8 which assess costs against sample size, method approach and data quality. The larger the circle, the greater the costs, but usually, the higher the accuracy of outcomes. Figure 3.8 suggests that if only one approach is used for determining mains water savings, then the accuracy can be improved with a dataset of large sample size and high quality. Similarly, if the quality of the data is not detailed, but two or more approaches are being used based on a large sample size, a reasonably accurate outcome can be achieved.

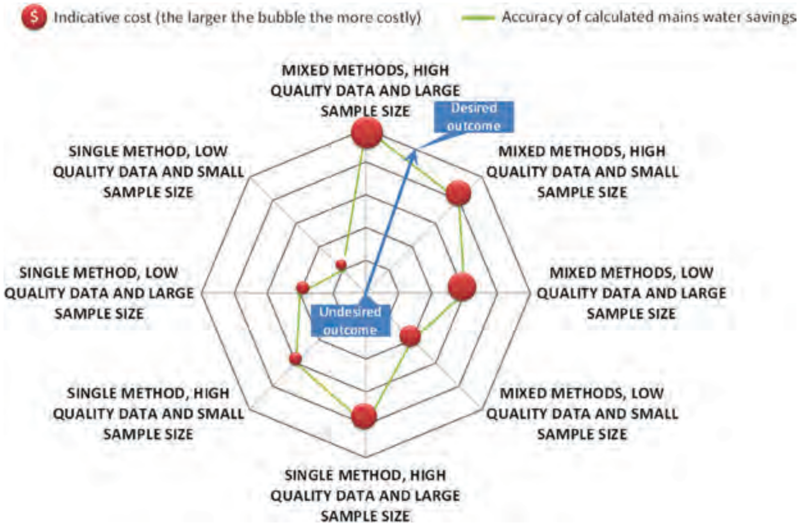


Figure 3.8 Method evaluation chart to assist in study design.

Each of the three main variables considered in Figure 3.8, data quality, methodological approach and sample size, are described below.

3.5.1 Quality of the datasets

3.5.1.1 Desktop approach only

Having access to quality data is obviously paramount in any field of research. A desktop approach using modelling and statistical analysis can certainly be valid, and even more so if it is coupled with at least one other method that allows for some empirical data to underpin the analysis (i.e., measured water consumption data). However, in the (often likely) absence of this possibility, a desktop approach alone may provide a reasonably accurate range of mains water savings, provided that it uses good quality data that can be applied with confidence to subsequent analysis. ‘Good quality’ data for estimating mains savings can be defined as having at least some or most of the following:

- *High resolution information on residential property* for example: dwelling configuration (detached, multi-unit, townhouse), people per dwelling, lot size, size of rainwater tank, rainwater end uses (internally or external only), date of tank installation, other water supply options on the property (dual reticulation/greywater system), connected roof area and degree of water-efficient appliances and fixtures.
- *Estimating external water use* is an important component as this end use has a high impact on the volume of rainwater used per year. As a first estimate, it is the difference between meter billing data and estimated internal water use for non-tank homes (as described in Case Study 1).
- *Large sample size* ($n = \geq 500$) of homes with *and* without rainwater tanks (and the configurations of the tanks).
- *A complete dataset of billing information* of water consumption (ideally at a three-month interval or less).
- *A spatially variable* dataset containing all of the above to allow some control for climate and biogeographical factors during analysis.
- *A longitudinal dataset* to also consider different seasons, water restriction regimes and water use activities (e.g., irrigation, school holidays, Christmas). Long-term data (≥3 years) for homes with and without rainwater tanks is critical to ensure representative water consumption patterns that encompasses both water restriction and non-water restriction regimes for example.

3.5.1.2 Field measurement approach

Where it is feasible to design a field measurement methodology, it is desirable that as many relevant parameters are measured for subsequent modelling and/or statistical analysis, particularly if an objective is to validate a desktop/modelling study. Chapter 4 presents a detailed section on the instrumentation for actual measurement for validation of the water savings. Below are some suggested ways to improve the quality of the data and accuracy of the method used for assessing mains potable savings from MRT (as per Figure 3.7):

- *Water consumption* – ideally both total and end-uses from the mains supply. End-use data will confirm the proportion of demand that can potentially be offset by rainwater. Smart metering equipment on both the mains meter and rainwater offtake should allow, at minimum, the total volumes of water supplied from each source. External water use, as emphasised throughout, is critical to estimate or measure as accurately as possible.
- *Socio-demographic data* – household occupancy has been emphasised as a very important parameter throughout this chapter. If there is no prior water consumption data, it is recommended to identify, as accurately as possible, the actual number of people in a household.
- *Household water-efficient stock* – if possible, the key water-related fixtures and appliances in the sample households should be identified as best as possible, and can be done simultaneously with smart meter installation if this is a feasible design option.
- *Water use behaviour* – the field methodology could also include a short survey on some water use behaviours around irrigation and outdoor use in general. For example, water behaviour information such as how often irrigation occurs and method of application (e.g., hand hose vs dripper system) will provide further opportunity to correctly match ‘like with like’.

3.5.2 Mixed method and analyses

The types of data-gathering methods such as desktop (accessing council data on water consumption and other relevant information), modelling (using known or assumed input parameters), field instrumentation (direct measurement of water consumption) and stock audit and survey (water-efficient fixtures and outdoor irrigation) will strongly influence the accuracy and representativeness of the results. Ideally, it is recommended a mixed method approach be adopted, whereby a desktop/modelling exercise (based on council billing data), is followed by a field study validation (instrumentation and survey).

In terms of statistical data analysis, a pair-matching approach can facilitate before-after control-intervention analysis design, which supports robust savings estimation. Ideally, well controlled, household pair-matching for both pre-intervention (No Tank dwellings) and post-intervention (MRT dwellings) is the ideal scenario for statistical comparisons of likely water use savings. Naturally, the higher the resolution of pair-matching the more informative the outcomes can be.

3.5.3 Sample size v quality of datasets

As shown in all three case studies, determining mains water savings often relies on a third party dataset (e.g., water utility billing data) of potentially doubtful quality for pair matching. Therefore, larger sample sizes are desirable as there can be considerable noise in both billing data and rainwater consumption rates from this third party dataset. For example in Case Study 1, a starting sample of council billing data for nearly 29,000 homes was reduced to 2800 possible matched pairs for MRT and No Tank, and down further to <790 if lot size category was being matched.

If there is a field study component, where good quality metering data is available for each home, and end-uses of rainwater and household occupancy is available, then a lower sample size is likely to be sufficient. However, this may be at a higher project cost. This is also true for modelling the savings from rainwater tanks, where high quality input parameters can improve the accuracy and reliability of the model outputs.

3.6 SUMMARY AND CONCLUSIONS

The primary objective of this chapter is to present and critique alternative statistical methods that can be widely used for assessing the savings in mains water use from rainwater tanks. Three case studies were selected which incorporated both theoretical modelling approaches and empirical field data for both mandated rainwater tanks and rebated voluntary rainwater tanks. Some key conclusions from this chapter are:

- Outdoor consumption is the critical end-use that will maximise savings. Thus, factors such as water use restrictions, lot size and behavioural cues (willingness to use water outdoors) are very important in determining savings.
- The methods employed to assess savings will depend on desired outcomes, availability of good quality data and resources. A large sample size ($n > 500$) can be partially substituted for by good quality data where household occupancy, type of RWT end uses, potable water use restrictions and lot size are known.
- A desktop approach using statistical analysis should be coupled with at least one other independent approach to underpin the confidence of the empirical data analysis.
- All three case studies focussed on the need for large sample sizes, known household occupancy and the level of water-efficient stock in households.

- Actual rainwater yields can vary significantly between regions due not only to climatic factors, but also tank sizes, connected end uses, connected roof area, and the level of functionality (related to the quality of the installation). The functionality component is an important factor to be considered in *ex-ante* assessments of yield from rebate programs. For example, internal mains water savings in Case Study 3 were significantly lower than theoretical yields, indicating compromised tank system functionality.
- Models can provide a valid range of potential savings data provided they use realistic end use consumption figures and household population estimates. Nonetheless, validation by some level of field work (e.g., phone survey, instrumentation) is ideal.
- The pre-intervention pair-matching approach is the most statistically robust method to estimate savings as the same households are used in the post-intervention analysis.
- Statistical analysis will benefit from a sample size of more than 500 households (matched pairs), particularly when yield is likely to be lower due to small tank sizes, or singular (indoor or outdoor) plumbing connections.

3.7 REFERENCES

ACT Government (2004). Think Water, Act Water Strategy: Strategy for sustainable water resource management in the ACT. Australian Capital Territory Government, 2004, http://www.thinkwater.act.gov.au/.

Adeyeye K. (ed.) (2014). Water Efficiency in Buildings: Theory and Practice. John Wiley & Sons Ltd, UK.

Agudelo-Vera C. M., Keesman K. J., Mels A. R. and Rijnaarts H. H. M. (2013). Evaluating the potential of improving residential water balance at building scale. *Water Res*, http://dx.doi.org/10.1016/j.watres.2013.10.040.

Australian Government (2014). http://www.waterrating.gov.au/. Website (accessed 15 July 2014).

Beal C. D. and Stewart R. A. (2011). South East Queensland Residential End Use Study: Final Report. Urban Water Security Research Alliance Technical Report No. 47, November 2011.

Beal C. D., Gardner T., Sharma A., Barton R. and Chong M. (2011a). A Desktop Analysis of Potable Water Savings from Internally Plumbed Rainwater Tanks in South East Qld. Urban Water Security Research Alliance Technical Report No. 26, Queensland, Aust.

Beal C. D., Stewart R. A., Huang T.-T. and Rey E. C. (2011b). SEQ residential end use study. *Australian Water Association Journal*, **38**(1), 80–84.

Beal C. D., Sharma A., Gardner T. and Chong M. (2012). A Desktop Analysis of Potable Water Savings from Internally Plumbed Rainwater Tanks in South-East Queensland, Australia. *Wat Res Man*, **26**(6), 1577–1590.

Chong M. N., Umapathi S., Mankad A., Sharma A. and Gardner T. (2011). A Benchmark Analysis of Water Savings by Mandated Rainwater Tank Users in South East Queensland (Phase 2). Urban Water Security Research Alliance Technical Report No. 49, Queensland, Aust.

DIP (2007). Queensland Development Code. Queensland Government. January 2007.

DIP (2009). South East Queensland Regional Plan 2009–2031. Department of Infrastructure Planning, Queensland Government, 2009.

Eroksuz E. and Raham A. (2010). Rainwater tanks in multi-unit buildings: A case study for three Australian cities. *Resources, Conservation and Recycling*, **54**(12), 1449–1452.

Fyfe J., Mohr S., May D. and Rickwood P. (2010). Statistical Evaluation of Water, Electricity and Greenhouse Gas Savings from the Think Water, Act Water Residential Efficiency Programs, report prepared for the ACT Environment and Sustainable Development Directorate, Institute for Sustainable Futures, University of Technology, Sydney.

Fyfe J., May D., Tuner A. and White S. (2011). Techniques for Estimating Water Saved Through Demand Management and Restrictions. In: Integrated Resource Planning for Urban Water — Resource Papers, Waterlines report, National Water Commission, Canberra.

Gardner T. and Vieritz A. (2010). The role of rainwater tanks in Australia in the twenty first century. *Architectural Science Review*, **53**(1), 107–125.

Ghisi E. and Ferreira D. F. (2007). Potential for potable water savings by using rainwater and greywater in a multi-storey residential building in southern Brazil. *Building & Environment*, **42**, 2512–2522.

Ghisi E., Bressan D. L. and Martini M. (2007). Rainwater tank capacity and potential for potable water savings by using rainwater in the residential sector of southeastern Brazil. *Building & Environment*, **42**, 1654–1666.

Hajani E. and Rahman A. (2013). Effectiveness of Rainwater Harvesting System in Peri-Urban Region: A Case Study for the Greater Sydney. *Journal of Hydrology and Environment Research*, **1**(1), 21.

Johnson N. J. (1978). Modified *t* Tests and confidence intervals for asymmetrical populations. *J Amer Stat Ass* **73**(363), 536–544.

Marsden Jacobs Associates (2007). The Cost-Effectiveness of Rainwater Tanks in Urban Australia. A report prepared for the National Water Commission – Waterlines, March 2007.

Makki A., Stewart R. A., Panuwatwanich K. and Beal C. (2011). Revealing the determinants of shower water end use consumption: enabling better targeted urban water conservation strategies. *Journal of Cleaner Production*, (doi:10.1016/j.jclepro.2011.08.007).

McKibbin J. and Fane S. (2011). Water Balance: a new integrated water management tool for households, businesses, and precincts. In: International Conference on Integrated Water Management, Perth, 2–5 February.

Mukheibir P., Boyle T., Moy C. and White S. (2013). Estimating the reliable residential water substitution from household rainwater tanks. In: Proceedings of the 7th IWA International Conference on Efficient Use and Management of Water, Paris, 22–25 October.

Siems R., Sahin O., Talebpour R., Stewart R. and Hopewell M. (2013). Energy intensity of decentralised water supply systems utilised in addressing water shortages, European Water Resources Association 8th International Conference. 26–29 June, European Water Resources Association, Porto, Portugal.

Sullivan J. and Dawson R. (2008). BASIX: Building Water Efficiency in NSW: Results from the First 5 years of BASIX: Sydney Water, NSW Department of Planning.

Sullivan J. and Wilson S. (2009). 'BASIX: The proof is in the water savings', AWA Ozwater 2009 Conference and Exhibition, Melbourne Convention and Exhibition Centre, Melbourne, Victoria, 16–18 March 2009.

Sydney Water (2008). BASIX Monitoring Report: Water Savings for 2007–8, Final Report November 2008, Sydney, New South Wales, Australia.

Talebpour M. R., Stewart R. A., Beal C. D., Dowling B., Sharma A. and Fane S. (2011). Rainwater tank end usage and energy demand: a pilot study. *Journal of the Australian Water Association*, **38**(1), 85–89.

Turner A., Fyfe J., Rickwood P. and Mohr S. (2013). Are we there yet? The importance of evaluating efficiency programs. *Water*, **40**(3), 60–65.

Vieritz A., Gardner T. and Baisden J. (2007). Rainwater TANK Manual. Department of Natural Resources and Water, 2007, Queensland.

Walton C. and Holmes K. (2011). How much water efficiency does $321 million buy? In: Proceedings of the 5th IWA Specialist Conference 'Efficient 2009', eds. International Water Association (IWA) and Australian Water Association, Sydney, Australia.

Wang Y. C. (2011). Separating indoor and outdoor water consumption. *Journal of the Australian Water Association*, **38**(3), 63–67.

WBM Oceanics (2006). Rainwater Tank Modelling Investigation: South East Queensland Regional Water Supply Strategy. WBM Oceanics Australia. Document ID: R.B15894.002.00.doc.

Willis R., Stewart R. and Emmonds S. (2010). Pimpama-Coomera dual reticulation end use study: pre-commission baseline, context and post-commission end use prediction. *Water Science and Technology: Water Supply*, **10**(3), 302–314.

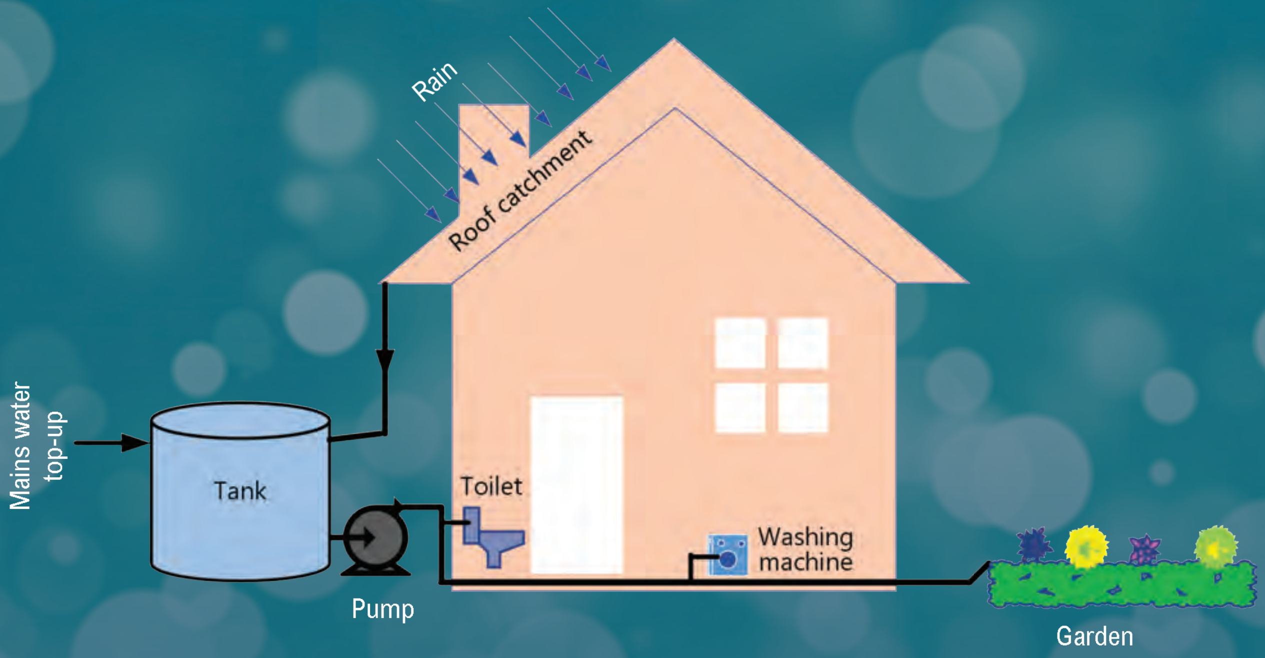
This title was made available Open Access through a partnership with Knowledge Unlatched.

IWA Publishing would like to thank all of the libraries for pledging to support the transition of this title to Open Access through the KU Select 2018 program.

Rainwater Tank Systems for Urban Water Supply

Design, Yield, Energy, Health Risks, Economics and Social Perceptions

Ashok K. Sharma, Donald Begbie and Ted Gardner



IWA PUBLISHING

Rainwater Tank Systems for Urban Water Supply

Design, Yield, Energy, Health Risks, Economics and Social Perceptions

Ashok K. Sharma, Donald Begbie and Ted Gardner

Rainwater tank systems have been widely adopted across the world to provide a safe, local supply of water in developing countries, peri-urban areas of developed countries, non potable substitution for mains water in water stressed urban areas, and providing flood mitigation in monsoonal climates such as Korea, and combined sewer systems such as Germany. As cities have grown, water managers have tried to reduce supply constraints of traditional water supply systems by exploring a range of alternative climate resilient water supply options which include water recycling and rainwater tanks. Rainwater tank systems are now often implemented, especially in Australia, under integrated urban water management (IUWM) and water sensitive urban design (WSUD) philosophies, which take a holistic view of the urban water cycle.

Rainwater Tank Systems for Urban Water Supply is based on the results of a comprehensive, multi-million dollar field-based research program that was undertaken in South East Queensland (SEQ) Australia in response to the Millennium drought when the water supply level in the region's drinking water dams dropped to less than 17 % in July 2007, and the area came within 12 months of running out of water. The book provides insights and detailed analysis on the design, modelling, implementation, yield performance, energy use, economics, management, health risk, water quality and social perceptions of roof water runoff collection systems.

The approaches and methodologies included in *Rainwater Tank Systems for Urban Water Supply* provide unique insights into the expected performance and potential pitfalls of adopting rainwater tank systems in urban areas including:

- modelling tools to estimate yield and optimise sizing of rainwater tanks and roof collection area
- methods to estimate the actual yield (kL/year) and the resulting mains water savings
- post-installation physical verification of household rainwater tank systems for design guidelines compliance
- rainwater tank pumping configuration and energy consumption
- expected chemical and microbial water quality and its implications for managing public health risks
- maintenance and management approaches for raintanks at the household scale
- the economics of tanks compared with other alternative water supplies such as sea water desalination plants
- implications of rainfall retention in tanks on catchment scale stormwater runoff characteristics
- community acceptance and homeowner attitudes towards tank installation, maintenance & water use behaviour
- a world wide overview of policy drivers for installing rainwater tanks in urban areas.

The book is suitable for use at undergraduate and post graduate levels, and is of particular interest to water professionals across the globe who are involved in the strategic water planning for a town, city or a region. It is also a valuable resource for urban developers, civil designers, water planners, architects and plumbers seeking to implement sustainable water servicing approaches for residential, industrial and commercial developments.

iwapublishing.com
@IWAPublishing

ISBN: 9781780405353 (Paperback)
ISBN: 9781780405360 (eBook)

ISBN 978-1-78040-535-3
90000
9 781780 405353