A Desktop Analysis of Potable Water Savings from Internally Plumbed Rainwater Tanks in South-East Queensland, Australia

Author

Beal, Cara D, Sharma, A, Gardner, T, Chong, M

Published

2012

Journal Title

Water Resources Management

DOI

10.1007/s11269-011-9973-0

Rights statement

Downloaded from

Griffith Research Online

Water Resour Manage
DOI 10.1007/s11269-011-9973-0

A Desktop Analysis of Potable Water Savings from Internally Plumbed Rainwater Tanks in South-East Queensland, Australia

Cara D. Beal · A. Sharma · T. Gardner · M. Chong Q2

Received: 30 August 2011 / Accepted: 22 December 2011

Abstract A methodology for the estimation of household potable water saving due to internally plumbed rainwater tanks (IPT) is presented in this paper. The methodology is based on a pairwise comparison of household water billing data between homes with IPT and without rainwater tanks (No Tank). These savings were compared with estimations using measured end use data and rainwater demand predictions using the Rainwater TANK model. The paper describes the application of this methodology to a case study in the south-east Queensland (SEQ) region of Australia. There was a significant reduction in mains water consumption for IPT properties in all regions studied in SEQ. Water reductions from mains supplies varied markedly across regions with mean values ranging from 20 to 95 kL/hh/y with an average mean of 50 kL/hh/y. Median water consumption values, ranged in mains water reductions from 28 to 52 kL/hh/y, with an average median of 40 kL/hh/y. Considering both measures an average water saving between 40 and 50 kL/hh/y can be expected from internally plumbed rainwater tanks. Water restrictions appear to have a strong influence on estimated reductions in mains water use. In regions where water restrictions were severe, water consumption was less varied between No Tank and IPT homes with a consequent reduction in estimated savings observed. Recommendations for further work include a survey to capture confounding factors that could not be fully controlled in the desktop study and a controlled pairwise experiment to monitor water consumption from raintanks.

C. D. Beal (✉)
Q3 Smart Water Research Centre, Griffith University, Southport, Qld 4222, Australia
e-mail: c.beal@griffith.edu.au

A. Sharma
Q4 CSIRO Land and Water, Highett Laboratories, Highett, VIC 3190, Australia

A. Sharma
e-mail: ashok.sharma@csiro.au

T. Gardner · M. Chong
Q17 CSIRO Land and Water, Biosciences Precinct, Dutton Park, Qld 4068, Australia
e-mail: meng.chong@csiro.au

T. Gardner
e-mail: ted.gardner@derm.qld.gov.au

Keywords Water efficiency · Demand management · Statistical analysis · Water restrictions · Rainwater tanks

1 Introduction

Despite south-east Queensland (SEQ) successfully overcoming one of its most severe droughts on record (2006–2009), water security remains one of Queensland's, and Australia's, greatest issues of concern. For this reason, as well as the drivers of high population growth and strong economic development, managing water and its use is a key government priority. Over 750,000 new dwellings are forecast for SEQ to house the expected increase in population from 2.8 to 4.4 million people by 2032 (DIP 2009). Assuming a 'business as usual' approach to development where water is supplied through centralised conventional water supply systems, this would equate to an additional 660,000 ML/year demand on the mains water supplies (MWH 2007).

From 2006, there have been local and state government rebate schemes aimed at encouraging rainwater tank installations. The installation of rainwater tanks is likely to have contributed to a reduction in residential water demand in SEQ in the last 5 years, particularly internally plumbed tanks which substitute mains water in the laundry and toilets, irrespective of outdoor watering restrictions. Various modelling studies on rainwater tank yields, have reported reductions of 26–144 kL/household/year (kL/hh/y) in Queensland with an average of 78 kL/hh/y (*e.g.* Coombes and Kuczera 2003; MWH 2007; NWC 2007). The residential demand for rainwater is strongly influenced by connected roof area, household occupancy, rainfall and tank size (Coombes and Kuczera 2003). However, experimental validation of these savings is limited to small scale studies (*e.g.* Gardner et al. 2006; Beal et al. 2008). Q5

The New South Wales Department of Planning building sustainability index (BASIX) is a regulatory mechanism used to implement minimum sustainability performance for all new dwellings in New South Wales (Sydney Water 2008). The BASIX benchmark for water use was taken as the average household water consumption in New South Wales of ~90 kL/person/year (kL/p/y) or 324 kL/hh/y. Sydney Water linked BASIX data to quarterly mains water consumption data based on the addresses supplied by the BASIX information. When adjusted for actual rather than estimated household occupancy (using results of a telephone survey), the average water consumption was reduced in BASIX homes by 42%. Turner et al. (2005) reported on a desktop study which looked at a 'before and after' scenario from a water efficiency retrofit programme in Sydney. For their study, 24,000 randomly selected single residential homes that engaged in the retrofit programme were paired with non-retrofitters as "geographically close as possible" using a two-year period of pre-intervention water consumption data (Turner et al. 2005). They found that post intervention, each retrofitted house achieved around a 21 kL/hh/y reductions in mains water use compared with the non-retrofitted control households.

Most recently, McBeth (2011) attempted to quantify the savings from rebated rainwater tanks for a range of connection configurations. Similar to the BASIX study, water consumption from homes retrofitted with raintanks were compared with a benchmark water consumption for single detached dwellings across the water supply catchment. The author reported an average of 27 kL/hh/y savings from tanks connected to toilet and laundry and external fixtures. McBeth (2011) estimated that the external only savings was 43 kL/hh/y. This somewhat surprising result was explained by the fact that homes that had the external water only connections had higher pre-tank metered water use thus translating to a higher post tank saving. This work also suggests that when supply is sufficient, external end use demand can be a substantial offset to mains water. This is not surprising as external end uses are usually the main source of variation and high volume use across seasonal water consumption end use datasets (Willis et al. 2011; Water Corporation 2011).

The aim of the research was to develop a methodology for assessing the savings in mains water use from internally plumbed rainwater tanks installed in new developments in the SEQ region of Australia, constructed after 2007 as these developments will have homes with mandated rainwater tanks connected to toilet and laundry. However, the methodology can be applied in any part of the globe, where rainwater tanks are used as part of the integrated urban water management tool to reduce reliance on mains water supply. The constraints in the application of the methodology and future research needs to overcome these constraints are also highlighted in this paper.

2 Water Saving Assessment Methodology

In this study, properties approved and constructed post 2007 were not able to be directly identified in the raw datasets provided. Therefore a methodology had to be developed to extract the relevant information from typically available household databases (Beal et al. 2011a). This section describes the methodology and the following section describes the application of this method. A number of assumptions and 'proxy' data fields were used to categorise between internally plumbed rainwater tanks (IPT) and without any rainwater tanks (No Tank) properties. Key data fields and proxy data fields that facilitated the isolation of mandated properties and allowed for similarly matched pairs are shown in Table 1.

Table 1 Key data fields required for filtering properties

Data Field	Comment
Property/meter ID	This was used to identify duplicate data and match properties.
Registration date/application date/meter installation date/water connection date	Used to indentify property age (i.e. pre or post 2007). Note that water meter installation date might include new/replaced water meters on pre-2007 properties, so at least 2 fields were used to identify post 2007 properties.
Street and suburb name	Used to match pairs of same suburb/street. This is also a proxy for rainfall and climate similarities and, in the absence of higher resolution data, a proxy for similar socio-demographic factors.
Land Use Code	Used to filter for detached single dwellings.
Tank rebated properties	Used to exclude pre 2007 properties that have an existing rainwater tank.
Water tank available	Used to exclude (pre 2007) or include (post 2007) properties with rainwater tanks.
Dual reticulation	Used to exclude properties with dual reticulation (Pimpama-Coomera, Gold Coast).
Lot size	Used to match pairs of similar lot size categories (≤ or > 700 m^2).

[1] dual reticulation refers to a third pipe system where recycled water is supplying irrigation and toilet flushing end uses

The main steps and assumptions in the analysis are listed below and summarised in Fig. 1.

1. The raw data set was filtered for duplicate and ambiguous data (*e.g.* incomplete, repeated records) using Microsoft Access (NB: MS Excel can also be used for this). This data set was then filtered for the Land Use Code representing Class 1 building (building classification used in Australia for detached dwellings with less than 12 persons) as per the Queensland Development Code mandate requirements (DIP 2009). Q7 Only single, detached dwellings were selected which represented around 70% of the house type in SEQ and up to 60% of SEQ regional consumption (MWH 2007).
2. No Tank and IPT properties were isolated by using property registration, meter installation and connection dates where available. In the case of Gold Coast Water (now Allconnex Water), the data was supplied in predefined No Tank and IPT samples to protect household privacy.
3. No Tank and "IPT data were divided into two lot size categories based on the median lot size for new detached dwellings in SEQ i.e. all properties: ≤ 700 m^2 and > 700 m^2.
4. No Tank and IPT properties were further grouped into suburbs within each lot size category. Where sample size was insufficient for a suburb grouping, the broader grouping of post code was used. The suburb data field was used to pair properties in the same suburb and also served as a proxy for rainfall and climate similarities and, in the absence of higher resolution data, a proxy for similar socio-demographic factors.
5. Each No Tank property was chosen randomly for pairing with IPT for each suburb (or post code). Where identifiable data (*e.g.* Real Property Description) was provided, No Tank properties were excluded that had installed rainwater tanks under the recent tank rebate programmes. By excluding rebated tank properties, the differences in water use between No Tank and IPT houses can be maximised. Note that approximately 240,000 rebates were given of which only around 2,500 were internally plumbed to one or more appliances.

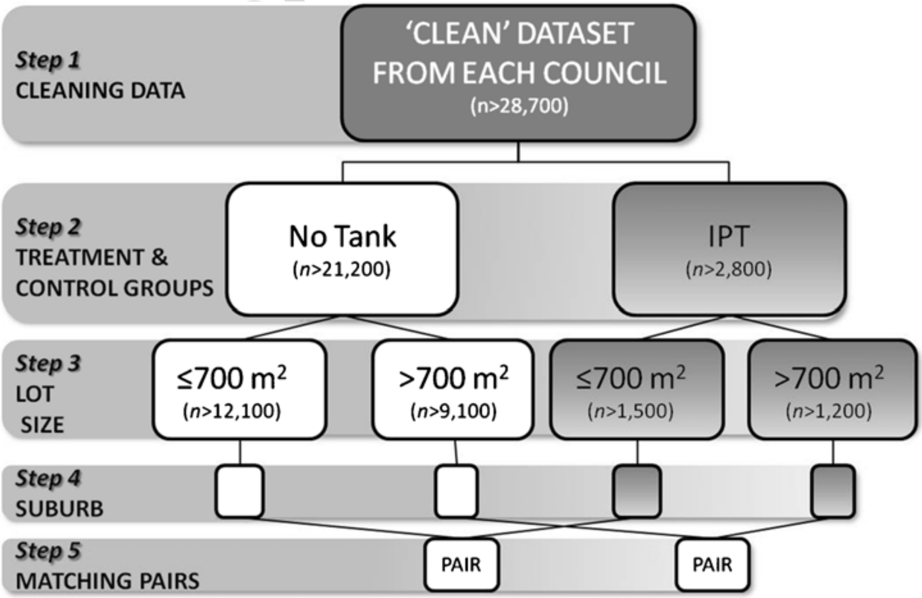


Fig. 1 Flow chart of analysis process

Q1

Only consumption data recorded in 2008 (calendar year) was used for comparative analysis. This method reduced the likelihood of selecting new developments that were constructed after January 1st 2007 but were yet to be fully occupied, or developments that were approved *before* January 1 2007 but *constructed only after* 2007.

3 Application of Methodology

3.1 Case Study Area

Three SEQ councils: Pine Rivers City Council (now Moreton Bay Regional Council), Gold Coast City Council and Redland City Council were included in this study. These local authorities were chosen as they represented a good cross section of the socio-economic and climatic conditions in SEQ. At the last 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. Additionally, they were able to readily provide the requested data within a timely manner. The SEQ regions examined are all located along the eastern seaboard either immediately above or below Brisbane city (Fig. 2). The majority of rainfall occurs in the warmer summer months as is typical for the sub tropical climate of SEQ. It is during these hotter and wetter months that internally plumbed rainwater tanks are expected to have the highest capacity for substituting mains water as they would require limited topping up from mains supply. The Gold Coast has the greatest population of the regions studied at over half a million people which equates to around 200,000 dwellings. In comparison, there is an average of around 50,000 dwellings for each of the remaining two regions. From the council databases provided, approximately 8,300 (Pine Rivers), 9,100 (Gold Coast) and 1,000 (Redland) new dwellings in 2008 had been approved (not necessarily constructed) since January 1st 2007.

3.2 Data Collection and Sample Selection

Potable water consumption data was obtained from the water demand management section of each council. Some councils had difficulties in the provision of complete datasets for post 2007 approved dwellings. Due to the smaller sample size in some councils wider confidence intervals (i.e. lower statistical power) were observed for a range of analysed data (*e.g.* Redland). Once the data was collected from the councils, the method described in the previous section was applied to each regional dataset to isolate post 2007 IPT properties (i.e. properties that were assumed to have an internally plumbed in rainwater tank).

Billing data provided for all regions included information on the date of 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 council billing data was divided into No Tank and IPT properties. In accordance with the Queensland Development Code, residential properties constructed after January 2007 were considered to have an internally plumbed rainwater tank (DIP 2009). Excluding rebated properties (Step 5 of methodology) could only be performed on Pine

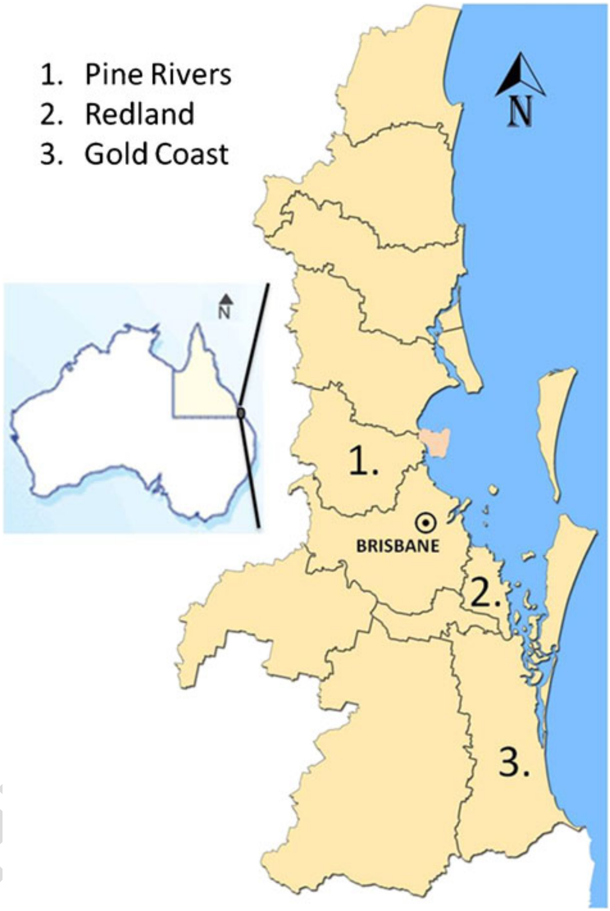


Fig. 2 SEQ Local Authority areas examined in desktop analysis

Rivers (n=12,342 rebated properties) and Redlands (n=4994 rebated properties) where Lot and Plan data was supplied by council. In the case of Gold Coast, where Lot and Plan data was unable to be provided, there was a field that indicated the presence or absence of a tank, but it was not clear as to whether this was a state rebated tank or not (although there was a field that indicated a local council rebated water tank). It is anticipated that future stages of this project will see the availability of identifiable property data for the Gold Coast region. The final number of pairs for the IPT and No Tank groups are shown in Table 2.

Table 2 Sample statistics for each region

Region	IPT homes (number of pairs)	No Tank homes
Pine Rivers	648	32,718
Gold Coast	422	2,993
Redland	112	33,117
Total	1,182	68,828

3.3 Statistical Analysis

Mean values were used to statistically compare water consumption for this desktop study using a two-tailed, independent *t* Tests in Microsoft Excel and SPSS© software packages. Although the distribution curves are 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* Tests was based on equal variance and equal samples between the "No Tank" and "IPT" properties. However, to test the null hypothesis that the distribution of mains water reductions were not the same for both the "IPT" and "No Tank" populations, a non-parametric rank test (Wilcoxon Rank sum) was used in SPSS v17©. As both statistical tests had two-sided hypotheses, the critical region lies in both tails of the probability distribution. The null hypothesis was rejected at the 0.05 (5%) significance level (shown in the resulting plots as error bars reflecting the 95% confidence interval).

3.4 Cross-Checking Desktop Analysis

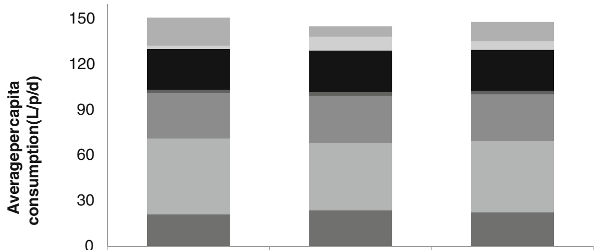
The examination of savings from internally plumbed rainwater tanks is not an easy task, particularly given the paucity (or accessibility) of specific data required for a pairwise analysis. Therefore, two approaches have been used to assist in evaluating and providing a 'ball park' reality check on the results of the desktop analysis. Note that while the statistical analysis assumes a proportion of outdoor water use, the two cross-checking approaches only consider indoor end uses. Predicting outdoor end uses with a high degree of accuracy is extremely difficult due to the number of influencing factors associated with its use (*e.g.* climate, lot size, soil type and council restrictions). Indoor water consumption is considered a far more homogenous dataset that has less variability and is therefore easier to predict (Wang 2011; Fox et al. 2009).

3.4.1 Bottom Up End Use Calculations

In addition to the requirement to achieve a mains water savings target, all new residential developments must install water efficient toilet and laundry fixtures under the Queensland Development Code (MP 4.1 Sustainable Buildings) (DIP 2009). The proportion of mains water reductions from "IPT" that can be attributed to rainwater tanks alone rather than a combination of tank and water efficient fixtures is obviously unknown for this desktop study. To fully account for the influences of different water fixtures and appliances on water consumption and end use, a specific investigation would be needed on a number of homes where all internal and external end uses were measured and analysed over time (*e.g.* Willis et al. 2011). The next stage of this project aims to conduct such an investigation. Nevertheless, some estimations can be made of how much water would be consumed from water efficient fixtures such as toilets and washing machines. Subsequent estimation of reductions from mains water can then be made.

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 (Willis et al. 2010) and from a recent SEQ End Use Study (Beal et al. 2011b). These studies have reported a range of consumption data for various internal fixtures including the washing machine (cold water tap) and toilet where rainwater tanks are required to be connected in Queensland. The combined water demand from these internally connected end uses can provide a baseline estimation of indoor mains water savings from an "IPT" (Fig. 3).

Fig. 3 Summary of internal water end uses from recent SEQ end use studies



	GoldCoast (n=151) [Willis et al. 2009]	SEQREUS (n=252) [Beal et al2011]	Average
External	18.6	7.0	12.8
Leaks	2.1	9.0	5.6
Taps	27	27.5	27.3
Dishwasher	2.2	2.5	2.4
Clotheswasher	30	31.0	30.5
Shower/bath	50	44.5	47.3
Toilet	21	23.7	22.4

Clothes washing machines were not assumed to have 100% of their mains water use replaceable by rainwater tank. The reason is that in the SEQ End Use Study (Beal et al. 2011b), 78% of participants indicated that they used cold water exclusively. The remaining 12% used a warm water wash cycle noting that hot water is not accessible for rainwater replacement. There were similar trends in the Pimpama-Coomera study (Willis et al. 2010). Therefore to factor in that not all water from washing machines in the "IPT" group sourced water exclusively from the rainwater tank, a conservative assumption that 60% of washing machines used the cold water tap exclusively, was made.

3.4.2 Rainwater TANK Modelling

The Rainwater TANK model is an Excel-based spreadsheet model linked to a FORTRAN executable (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 the urban allotment. For the purposes of this study, TANK was used to provide a first approximation of the performance of rainwater tanks for comparison with the statistical desktop results.

The key assumptions and mathematical formula for the model are described in Vieritz et al. (2007). In summary, the initial tank water level in the tank is set to the user-defined top up point. Within each daily time step the order of calculations depends on the Run setting chosen.

All default value input parameters were used in each run of the TANK model unless shown in Table 3. Values for washing machine and toilet were based on averages from end use studies by Willis et al. (2011) and Beal et al. (2011b). The model year for the runs was 2008.

4 Results

4.1 Water Consumption and Savings Between No Tank and IPT Homes

There was a significant reduction ($p<0.05$) in mains water consumption for IPT properties in all regions. For 2008, total average mains water consumption for No Tank properties ranged from 162 to 247 kL/hh/y (Fig. 4). Average mains water consumption for IPT properties

Q1

Table 3 Input parameters and assumptions for TANK

Parameter	Value	Parameter	Value
People household	3.0 *Pine Rivers,* 2.9 *Redlands,* 3.2 *Gold Coast*	External use	None
Combined toilet/cold water only laundry use	41 L/p/day (see Section 3.2.1)	Trickle top-up	Yes
Climatic Regions	Petrie (Pine Rivers), Redland Bay (Redland), Southport (Gold Coast)	Tank Volume	5 kL
Connected Roof	100 m²	Tank Intake height	0.15 m
Internal household use	140 L/p/day	Initial Volume	0 kL

ranged from 142 to 151.7 kL/hh/y. The average savings of mains water across the councils was 50 kL/hh/y, ranging from 20 to 95 kL/hh/y. Water consumption between No Tank and IPT homes was analysed for the two lot size categories, where sample size allowed this, and while there was a trend for larger allotments to use more water, there were only limited statistically significant results between regions hence the data is not presented and discussed herein. In terms of suburb scale analysis, sample size prohibited any significant differences or strong trends to be identified for the regional datasets.

4.2 Cross-Checking Desktop Method

The result of the two approaches used to cross-check the statistical analyses are presented in Table 4. Both of these approaches only looked at indoor water consumption. The predicted mains water savings from indoor rainwater usage for toilet and cold tap to washing machine ranged from an average of 44.5 kL to 50 kL/hh/y.

Using the end use data, under the assumptions discussed in the methods section, the expected internal water reductions from the toilet and washing machine fell in the range of 30–42.3 litres per person per day (L/p/d), with an average of 40.6 L/p/d. 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 42.7–46.3 kL/hh/y, an average of 44.5 kL/hh/y, regardless of outdoor uses of rainwater. This figure assumes that mains water was substituted for rainwater

Fig. 4 Total average water use and estimated mains water savings in 2008 for the four SEQ Local Authorities examined

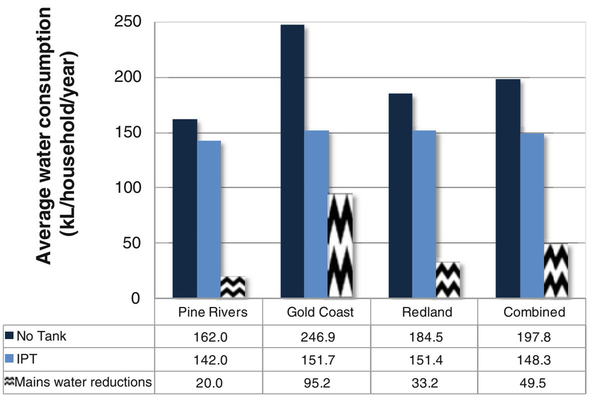


Table 4 Results of expected mains water savings using End Use Data and TANK modelling for statistical analysis verification

Region	TANK modelling results[1] for internal water use		Predicted mains water savings using End Use data for internal water use (kL/household/year)
	Annual Rainfall in 2008 (mm)	Rain water Supply (kL/household/year)	
Pine Rivers	1,201	49	42.7 to 46.3
Gold Coast	1,766	54	
Redland	1,348	46	
Average	1,460	50	44.5

[1] assumes trickle top up available

at all times i.e. the rainwater tank levels were sufficient for unrestricted substitution. The reasonableness of this assumption for 2008 will be explored below.

Using the Rainwater TANK model, predicted rainwater supply for unrestricted internal use ranged from 46 to 54 kL/hh/y with an average of 50 kL/hh/y (Table 4). Rainfall data for 2008 was used for each region as shown in Table 4.

5 Discussion

To acknowledge the inherent right-skewed nature of water consumption distribution (that is, a small proportion of the sample accounts for a disproportionate large volume of usage (e.g. Willis et al. 2011; Athuraliya et al. 2008), the analysis was extended to investigate water savings based on median values (as mean value could be skewed by extreme values) to compare water savings. The median mains reduction ranges from 28 to 52 kL/hh/y with an average of 40 kL/hh/y (see Table 5). It can be highlighted that the water savings would range between 40 and 50 kL/hh/y if both approaches are considered.

The results of the desktop statistical analysis demonstrate that water consumption from homes with IPT was significantly lower ($p<0.05$) than No Tank homes (Fig. 4). However, there is considerable variation in mains water reductions across the three regions with an average of 50 kL/hh/y being estimated (Table 5). By cross-checking the statistical analyses results with the two other modelling approaches, average baseline savings between 44.5 and 50 kL/hh/y would be expected, from internally connected fixtures (washing machine cold water tap and toilet) (Table 5). Notwithstanding the high estimated savings from the Gold Coast where there were no restrictions on water use, the other two council areas had lower

Table 5 Summary of mains water use reductions

Region	Desktop study: Mean values	Desktop study: Median values	End Use approach	TANK model Internal only
	(kL/household/year)			
Pine Rivers	20	28	43 to 46 (internal only)	49
Gold Coast	95	52		54
Redland	33	41		46
Average reduction	50	40	44.5	50

Q1

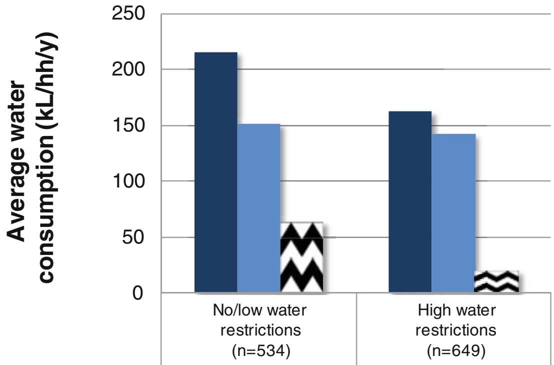
than expected mains reductions when cross-checking them with results from predicted indoor reductions shown in Table 5. There are two main factors that are likely to be influencing the lower estimated reductions calculated from the statistical analyses: the influence of water restrictions during the period of analysis, and the limitations of the interpretation of the council billing data which was used to distinguish IPT from No Tank homes.

5.1 Impact of Water Restrictions on Water Consumption

To explore the influence of water restrictions on water consumption, 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 (Fig. 5). Regions with high level of water restrictions (no or imited outdoor watering) have only small differences in water consumption between IPT and No Tank properties.

Many factors influence the pattern and volume of residential water consumption including water pricing, household income, household size, irrigable outdoor area (*e.g.* garden, lawn), waterwise fixtures and appliances, and water restrictions (Turner et al. 2005; Barrett and Wallace 2009). Q10 The influence of water restrictions is illustrated in Fig. 5, which showed smaller differences in water consumption between IPT and No Tank properties in regions with a high level of water restrictions (no or low outdoor watering). Conversely, there were strongly significant differences ($p<0.05$) in water use for Local Authority areas with low or no water restrictions where these differences could be maximised by permitting outdoor water use to be sourced from mains water. The more severe water restrictions in 2008 occurred in Pine Rivers, now incorporated into the Moreton Bay Regional Council (Table 6).

A summary of key water restrictions during 2008 for the councils analysed is presented in Table 6, where a tick mark represents allowed outdoor water use activities. The most severe water restrictions in 2008 occurred in the Moreton Bay Regional Council which encompasses Pine Rivers. Importantly, outdoor watering using mains water was limited to only hand held bucket or watering cans until August 1, 2008 after which hand held hoses could be used. 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



	No/low water restrictions (n=534)	High water restrictions (n=649)
No Tank	215.7	162.0
IPT	151.5	142.0
Estimated mains reductions	64.2	20.0

Fig. 5 Comparison between water consumption and estimated mains reductions for regions with high and low/no water restrictions

Table 6 Summary of key water restrictions in SEQ during 2008

Water end use	Pine Rivers	Gold Coast*	Redland
Irrigation systems	×	✓	×
Hand held hose	×	✓	✓
Hand held bucket &/or watering can	✓	✓	✓
Filling pools/spas	very limited	✓	✓
Topping up pools/spas, vehicle/boat washing	×	✓	✓
General outdoor cleaning	very limited	✓	✓

* Gold Coast only on Queensland Water Commission restrictions in January and December 2008

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 (Table 6).

6 Critique of Desktop Method Used

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

- Separating the billing data into IPT and No Tank subsamples could only be done using assumptions and proxy data, as detailed in the methods section;
- Separating out the influence of IPT from 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 were also not able to 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 family using low household water volumes may be matched with a six person IPT family using very high volumes of water, thus confounding the actual results of comparing families of more equal water demand potential.

The same argument follows for controlling for outdoor water demand if garden sizes (as opposed to allotment sizes) were known. Although IPT and No Tank homes were paired based on two lot size categories, there were no obvious or 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 garden area requiring watering. Again, with this knowledge, external water demand can be controlled for to some extent, although external water uses are notoriously difficult to quantify (Beal et al. 2011a, b; Wang 2011). Q11

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 study. Research shows that these efficient features and fixtures can be successful in achieving reductions in domestic water consumption (Willis et al. 2010; Beal et al. 2011b).

7 Conclusions and Recommendations

A methodology for conducting water saving analysis from rainwater tanks was developed. Using this methodology a desktop study was carried out on three SEQ regions using existing council billing data to estimate savings from IPT; and to provide baseline data for further experimental work for on-site rainwater tank monitoring of rainwater usage.

Over 1,100 data pairs were analysed for SEQ councils which had strict, moderate, and liberal water restrictions over the 2008 analysis period. In general, the council areas that used more water also had greater reductions in mains water use for internally plumbed tanks. The range of estimated reductions using mean water consumption values from the desktop study was 20–95 kL/hh/y, with an average of 50 kL/hh/year. The analysis was also conducted using median water consumption values, which resulted in mains water reductions from 28 to 52 kL/hh/y, with an average of 40 kL/hh/y. Thus, considering both measures an average water saving between 40 and 50 kL/hh/y can be expected from internally plumbed rainwater tanks. Water restrictions appear to have a strong influence on estimated reductions in mains water use. In regions where water restrictions were severe, water consumption was less varied between No Tank and IPT homes with a consequent reduction in estimated savings observed.

Cross-checking the desktop methodology with results from two other approaches suggests that mains water savings of an approximate range of 44.5–50 kL/hh/y, for the average residential property with a household occupancy of 2.8–3 people, can be expected from rainwater tank plumbed to toilet and washing machine. Any differences between the statistical analysis and the cross-check results are more than likely due to the high water restrictions for some regions during the period of analysis and some identified limitations of the billing data provided, *e.g.* uncertainties in matching demographic data (especially people per household for IPT/No Tank cohorts). The widespread adoption of retrofitted water efficient features (such as low flow taps and shower roses) in the No Tank homes is also likely to have contributed to the small difference in water consumption between IPT and No Tank homes. Improved water savings can be gained from IPT homes by regular use of the rainwater for outdoor end uses in particular, as this is end use that the drives peak demand of potable water supplies.

Results presented here show that IPT homes (corresponding to newer residential properties - post 2007) generally have a lower water consumption than No Tank homes (older properties). Additionally, the results provide further evidence that water restrictions are a useful tool in demand-side water reduction strategies.

However, while 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 rainwater demand (*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, data and methodological limitations have also contributed to the lower than expected mains water savings. For these reasons, it is recommended that further work include: a survey to capture confounding factors that could not be controlled in the desktop study (*e.g.* household occupancy numbers, family structure, garden size, water wise fixtures, income); a benchmark analysis on the water savings from *known* IPT homes; and, a subsequent controlled pairwise statistical analysis and validation of the mains water savings from IPT homes.

Acknowledgements This project was funded by the Urban Water Security Research Alliance. The authors are grateful for assistance from Moreton Bay Regional Council, Allconnex Water (formerly Gold Coast Water) and Queensland Urban Utilities (formerly Redland Water). We also wish to thank Don Begbie, Dr Sharon Biermann and the QWC for their time and efforts in reviewing this work.

References

Arbués F, García-Valiñas MA, Martínez-Espiñeira R (2003) Estimation of residential water demand: a state-of-the-art review. J Soc Econ 32:81–102 Q12

Athuraliya A, Gan K, Roberts P (2008) Yarra Valley Water 2007 appliance stock and usage patterns survey. Yarra Valley Water, Victoria

Australian Bureau of Statistics (ABS) (2006) Cat. no. 2069.0.30.001- 2069.0.30.007. Commonwealth of Australia

Beal C, Hood B, Gardner T, Lane J, Christiansen C (2008) Energy and water metabolism of a sustainable subdivision in south east Queensland: a reality check. Presented at *Enviro'08*. Melbourne Exhibition and Convention Centre, 5–7 May 2008

Beal C, Gardner T, Sharma A, Barton R, Chong M (2011a) Role of internally plumbed rainwater tanks in supplementing urban water supply: Stage 1: a preliminary desktop analysis of potable water savings from internally plumbed rainwater tanks in South East Qld.. Urban Water Security Research Alliance Technical Report No. 26. Brisbane, Qld, July 2011

Beal C, Stewart RA, Huang TT, Rey E (2011b) Applying smart metering technology to disaggregate residential water end uses in South East Queensland. J Aust Water Assoc 38(1):80–84

Bureau of Meteorology (BOM) 2010 http://www.bom.gov.au/climate/data/ accessed 18/8/2010 Q13

Coombes P, Kuczera G (2003) Analysis of performance of rainwater tanks in Australian capital cities. 28th International Hydrology and Water Resources Symposium, November New South Wales

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

Fox C, McIntosh B, Jeffrey P (2009) Classifying households for water demand forecasting using physical property characteristics. Land Use Policy 26:558–568

Inman D, Jeffrey P (2006) A review of residential water conservation tool performance and influences on implementation effectiveness. Urban Water J 3(3):127–143 Q14

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

Kenney DS, Goemans C, Klein RA, Lowrey J, Reidy K (2008) Residential water demand management: lessons from Aurora, Colorado. J Am Water Resour As 44(1):192–207 Q15

McBeth B (2011) Savings from residential rainwater tanks on the NSW far North Coast-A detailed statistical analysis on usage between Jan 2002 and December 2009. J Aust Water Assoc 38(2):136–142

MWH (2007) Regional water needs and integrated urban water management opportunities report. Report 4 of the SEQRWSSS IUWMA Taskgroup, MWA-01

National Water Commission (2007) The cost-effectiveness of rainwater tanks in urban Australia. A report prepared by Marsden Jacobs Associates for National Water Commission – Waterlines, March 2007

Renwick MA, Archibald SO (1998) Demand-side management policies for residential water use: who bares the conservation burden? Land Econ 74:343–359 Q16

Sydney Water (2008) BASIX monitoring report: water savings for 2007–8. Final Report November 2008. Sydney, New South Wales, Australia

Turner A, White S, Beatty K, Gregory A (2005) Results from the largest residential demand management program in Australia. Wa Sci Technol 5(3–4):249–256

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

Wang YC (2011) Separating indoor and outdoor water consumption. J Aust Water Assoc 38(3):63–67

Willis R, Stewart R, Emmonds S (2010) Pimpama-Coomera dual reticulation end use study: pre-commission baseline, context and post-commission end use prediction. Wa Sci Technol 10(3):302–314

Willis RM, Stewart RA, Williams PR, Hacker CH, Emmonds SC, Capati G (2011) Residential potable and recycled water end uses in a dual reticulated supply system. Desal 273(1–3):201–211. doi:10.1016/j.desal.2011.01.022

AUTHOR QUERIES

AUTHOR PLEASE ANSWER ALL QUERIES.

Q1. Please check the suggested running page title if appropriate. Otherwise, please provide short running title with maximum of 65 characters including spaces.
Q2. Please check captured author name "T. Gardner" in author group if appropriate.
Q3. Please check if the affiliations were presented correctly.
Q4. Please check captured city address in affiliation 2 if appropriate.
Q5. "Gardner et al. 2006" is cited in text but not given in the reference list. Please provide details in the list or delete the citation from the text.
Q6. "Water Corporation 2011" is cited in text but not given in the reference list. Please provide details in the list or delete the citation from the text.
Q7. The citation "DIP 2007" (original) has been changed to "DIP 2009". Please check if appropriate.
Q8. Section 3.2.1 was cited in text body but no data was given. Please check.
Q9. The citation "Athuraliya et al., 2007" (original) has been changed to "Athuraliya et al. 2008". Please check if appropriate.
Q10. "Barrett and Wallace 2009" is cited in text but not given in the reference list. Please provide details in the list or delete the citation from the text.
Q11. The citation "Beal et al., 2011" (original) has been changed to "Beal et al. 2011a, 2011b". Please check if appropriate.
Q12. Arbués et al. (2003) was not cited anywhere in the text. Please provide a citation. Alternatively, delete the item from the list.
Q13. Bureau of Meteorology (BOM) (2010) was not cited anywhere in the text. Please provide a citation. Alternatively, delete the item from the list.
Q14. Inman & Jeffrey (2006) was not cited anywhere in the text. Please provide a citation. Alternatively, delete the item from the list.
Q15. Kenney et al. (2008) was not cited anywhere in the text. Please provide a citation. Alternatively, delete the item from the list.
Q16. Renwick & Archibald (1998) was not cited anywhere in the text. Please provide a citation. Alternatively, delete the item from the list.
Q17. Please check if T. Gardner was correctly affiliated.