A Desktop Analysis of Potable Water Savings from Internally Plumbed Rainwater Tanks in South East Qld

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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region's emerging urban water issues.

As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO's Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.

Chris Davis
Chair, Urban Water Security Research Alliance

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EXECUTIVE SUMMARY

In 2007, under the Queensland Development Code MP 4.2–Water savings targets (QDC 4.2), it became mandatory to incorporate a method of reducing mains water consumption in all new residential properties in Queensland. Installing rainwater tanks internally plumbed to the washing machine cold water tap, toilets and at least one outdoor tap is the typical compliance method chosen.

A desktop study was carried out on four South East Queensland (SEQ) councils to explore the potential savings in potable water from internally plumbed rainwater tanks (IPT) installed in post-2007 detached dwellings. This was achieved by developing a desktop methodology using existing council water billing data. A further objective of this study was to provide baseline data and identify key areas for further experimental work to be conducted in Stage 2. This study forms a component of a larger project on the Decentralised Systems within the Urban Water Security Research Alliance (UWSRA).

Council water billing data from 2008 were used to compare paired cohorts of households with IPT and without rainwater tanks (No Tank) in Moreton Bay Regional Council (comprising the previous Pine Rivers local authority area), Redland City Council and Gold Coast City Council. Over 1,100 data pairs for the year 2008 were analysed where water restrictions at this time ranged across the SEQ region from strict (Pine Rivers), through moderate (Redland), to liberal (Gold Coast).

The water billing data obtained for Caboolture was not detailed enough to determine if the properties under study were constructed post or prior to 2007 and revealed several inconsistencies. Consequently, the data for this council was not considered in the final analysis.

Comparative analysis of water consumption between No Tank and IPT properties overall clearly showed that consumption was greater for homes without IPT. Mains water consumption for No Tank homes averaged 197.8 kL/household/year compared with an average of 148.3 kL/household/year for IPT homes. Within councils, this trend continued with Gold Coast and Redland City Council No Tank homes consuming the most main water, at an average of 246.9 and 184.5 kL/household/year respectively. The high consumption for the Gold Coast properties was attributed to the low external water restrictions occurring in this council area in 2008.

Water reductions from mains supplies based on mean water consumption figures varied markedly across councils, with values ranging from 20 to 95 kL/household/year, which equated to an average of 50 kL/household/year. The water analysis was also conducted using median water consumption figures due to the skewness in the frequency distribution curve for water consumption. This analysis resulted in lower water saving values ranging from 28 to 52 kL/household/year with an average of 40 kL/household/year.

Because the analysis used data from 2008 when external water restrictions were still in place for Moreton Bay Regional Council, the maximum achievable reductions were unlikely to be realised for this area during this study. However, in council areas with no water restrictions (e.g. Gold Coast), higher mains water use correlated with greater water reductions in the IPT households as rainwater partially substituted for potable water for the various external end uses.

Statistical analysis results were cross-checked with two other approaches used to estimate mains water savings from IPT. Firstly, water consumption from the IPT-sourced toilet and cold water laundry tap were calculated using measured water end use data from recent SEQ residential end use research (Beal *et al.*, 2011; Willis *et al.*, 2011). Results from these calculations demonstrated that an average savings of 44 kL/household/year could be expected from offsetting mains toilet and laundry supply alone.

Secondly, the Rainwater TANK model showed that predicted rainwater use for allowable internal uses ranged from 46 to 54 kL/household/year, at an average 50 kL/household/year, for a 5 kL tank connected to 100m^2 roof area and using the 2008 climate data for each council. Therefore, the baseline mains water savings one could expect is between 44 and 50 kL/household/year from internal water usage only.

The variation in savings found from the desktop statistical analysis may be partially attributable to different external water restrictions across the councils, variation in household occupancy (and thus demand) and presence of water efficient household appliances and fixtures (e.g. front-loading washing machines). While design/fixtures can provide improved efficiencies, water usage is also dependent on householder's behaviour e.g. length of shower time even though a 3-star WELS showerhead may be installed.

Another source of variation may be explained by some ambiguities identified in using the water billing data alone without additional knowledge of household occupancy for the new dwellings and number of occupants at that time.

One aim of this desktop report was to provide baseline data for further experimental work in assessing the role of rainwater tanks as an alternative urban water supply (Stage 2 of the project). Due to some limitations in attempting to quantify the water savings using billing data exclusively, it is suggested that Stage 2 should consist of these critical components:

1. 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); and
2. a benchmark analysis on the water savings from *known* IPT homes and a subsequent controlled pair-wise statistical analysis and validation on the mains water savings from IPT homes.

Nevertheless, results presented in this report show that newer properties constructed under the QDC 4.2 (i.e. post-2007) generally have lower mains water consumption than older properties. The results also provide further supporting evidence that water restrictions are an effective tool in demand-side water reduction strategies. Stage 2 of the project will build on the results and methods developed from this preliminary analysis to provide a sound estimate of water savings from internally plumbed rainwater tanks.

1. INTRODUCTION

1.1. Introduction and Scope

This report is part of a series summarising the output from rainwater tanks investigated under the Decentralised Systems project, one of key themes researched through the Urban Water Security Research Alliance. In 2007, under the Queensland Development Code MP 4.2–Water savings targets (QDC 4.2), it became mandatory to incorporate a method of reducing mains water consumption in all new residential properties in Queensland that are located in a reticulated town water supply area (under the *Water Act 2000*). Installing rainwater tanks internally plumbed to the washing machine cold water tap, toilets and at least one outdoor tap was one such method. A desktop study was carried out on four South East Queensland (SEQ) councils to explore the potential savings in potable water from internally plumbed rainwater tanks (IPT) installed in post 2007 detached dwellings (class 1 buildings). This report is the first stage of the investigation into reductions from IPT homes. The scope of the report is specifically limited to a desktop analysis rather than a more detailed, field investigation of rainwater tank end uses. The advantages of undergoing a Stage 1 desktop study for this area of investigation include:

- identification of the general areas where internally plumbed rainwater tanks are located within each council, thus facilitating a second stage targeted monitoring programme including household surveys and metering rainwater tank end uses;
- providing a baseline data range of mains water supply reductions that may be expected from internally plumbed rainwater tanks; and
- providing data which can be used as a guide for determining statistically representative samples sizes and standard deviations for future monitoring experiments (Stage 2).

The study only used council water billing data to extract knowledge on the water consumption from new and old developments. There was insufficient or an absence of other physical and/or socio-demographic data as this type of information requires expensive, detailed surveys to be undertaken.

1.2 Research Objectives and Hypotheses

The aim of the research is to conduct a desktop assessment using statistical analysis of the potential mains water reductions from internally plumbed rainwater tanks in new developments in South East Queensland (SEQ). To achieve this aim, the associated objectives were:

(i) to develop a desktop methodology using existing council water billing data to estimate reductions from internally plumbed rainwater tanks; and

(ii) to provide baseline data for further experimental work (Stage 2) for the Decentralised Systems project.

The following hypotheses were considered for the statistical analyses:

Null hypothesis (H_0): Water consumption in houses with internally plumbed rainwater tanks (IPT) is not significantly different from the water consumption for houses without internally plumbed rainwater tanks (No Tank).

Alternative hypothesis (H_1): Water consumption in houses with internally plumbed rainwater tanks is significantly different from the water consumption from houses without internally plumbed rainwater tanks.

Sample selection has been based on the assumption that the treatment group (i.e. IPT) included single, detached houses approved and constructed post 1 January 2007 (the commencement date of QDC 4.2 in SEQ) and will have an internally plumbed rainwater tank. Houses constructed prior to this date were used as the control group (i.e. No Tank). Additional filtering of the data was carried out to account for confounding factors inherent with this assumption. This is explained in detail in Section 4.

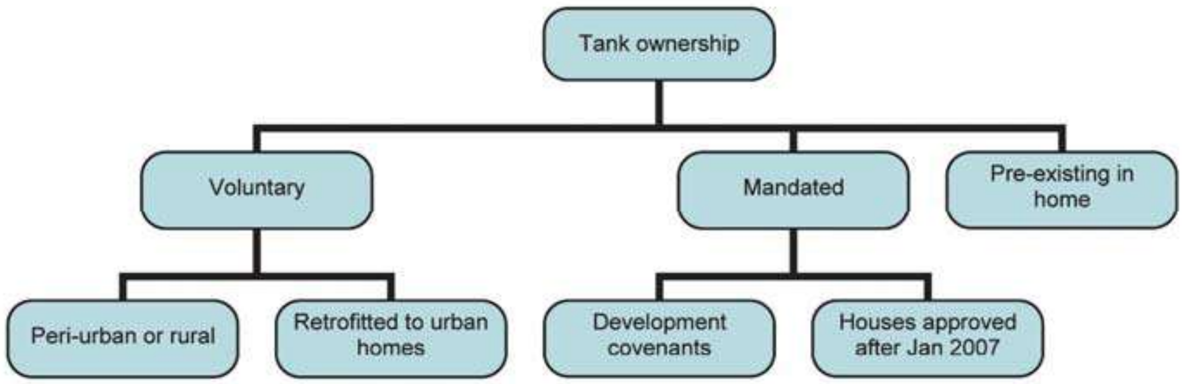
2. RESEARCH CONTEXT

2.1 Legislative and Policy Background

Over 750,000 new dwellings are forecast for SEQ to house the expected increase in population from 2.8 million in 2009 to 4.4 million people in 2031 (DIP, 2009). The SEQ Water Strategy estimates this will create an additional demand of around 660,000 ML/year on the mains water supplies (Queensland Water Commission, 2010). From 2006, there have been local and state government rebate schemes aimed at encouraging rainwater tank installations in Queensland. Initially, the rebates were offered to existing home owners who installed a rainwater tank irrespective of whether they were plumbed into the house or not. Rebates were not available with the installation of rainwater tanks in the construction of new houses. In early 2008, rebates were only offered if the rainwater tank was plumbed into household fixtures i.e. washing machine cold water tap, toilets, and at least one external tap. This reflected the QDC 4.2 requirement which stipulated that all new detached residential households needed to achieve potable water savings from a Class 1 building (DIP, 2009). The QDC 4.2 water savings targets range from 16 to 70 kL/household/year depending on the local government area in Queensland.

One acceptable solution for achieving a reduction in mains water use is through the installation of a 5 kL rainwater tank connected to 100 m^2 roof area and plumbed to the washing machine cold water tap, toilets and at least one external tap. While this was the typical inclusion with new houses, other options are available, these being a greywater treatment plant, communal rainwater tanks, dual reticulation of recycled water or treated stormwater, or a combination of these. Internal fixtures supplied from a rainwater tank must have a backup supply of mains water using either a trickle top-up system or an automatic switching device.

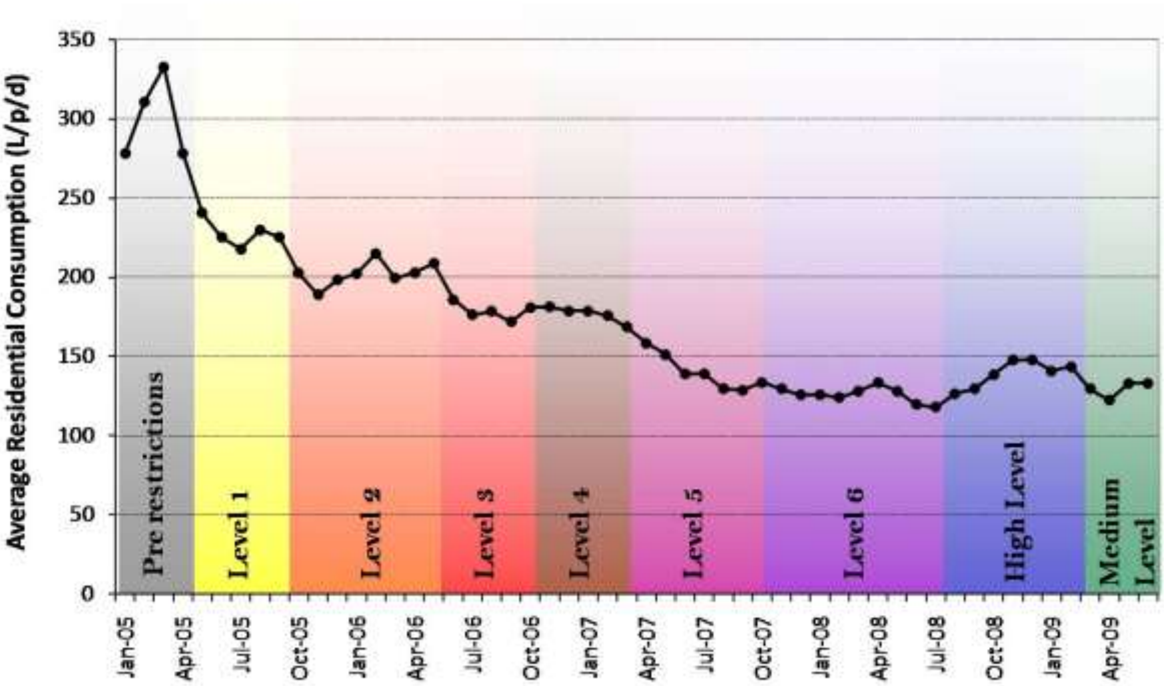
Gardiner (2009) described the different circumstances under which residential rainwater tanks have been installed in SEQ (Figure 1), noting there are over 300,000 tanks in SEQ installed under subsidy with about 30,000 installed under the QDC (up to 2008).



Note: sourced from Gardiner (2009).

Figure 1: Categories of tank installation in South East Queensland.

The combination of state and local government rebate programs for water efficient fixtures (such as washing machines and toilets) and rainwater tanks, and enforced water restrictions have resulted in a large reduction in household water use in SEQ. The QWC has regularly provided consumption data showing the success of its demand management programs (including Target 140), culminating in an average water use of less than 140 L/person/day for many months under Level 6 restrictions. This was an enormous reduction from the pre-drought water use, when average residential water consumption across all local government areas in SEQ was 282 L/person/day (QWC, 2010, p. 53) (see also Figure 2). As such, it is worth noting that a water saving study in such times of frugal water use is likely to return small mains water saving results.



Note: sourced from Queensland Water Commission (2009).

Figure 2: Per capita average water consumption in SEQ pre and post water restrictions.

The key water restrictions enforced during this time are explained in Table 1. Essentially, there were several restriction levels, culminating in the severest (Level 6) during the height of the drought in late 2007 to early 2008. Following substantial rainfall in mid 2008 and a return to an average rainfall year in 2009, restrictions eased from high level to medium level, and then to the current Permanent Water Conservation (PWC) measures (Table 1). Restrictions varied between councils and more details are given later in this report about the restriction levels applying to the councils that were examined during the period of this analysis (2008).

2.2 Summary of Reported Rainwater Tank Performance

Various modelling studies on rainwater tank yields have reported reductions of 26 to 144 kL/household/year in Queensland with an average of 78 kL/household/year (e.g. Coombes and Kuczera, 2003; MWH, 2007; NWC, 2007). The residential supply and demand for rainwater is strongly influenced by connected roof area, household occupancy, rainfall and tank size. Coombes and Kuczera (2003) predicted annual reductions ranging from 31 to 144 kL/year in Brisbane, depending on tank size and household occupancy. However, the modelling assumed rainwater was also used for hot water supply whilst rainfall data was taken from pre-Millennium drought conditions (i.e. pre-2006).

An average reduction of 26 to 31 ML/year for SEQ was forecast by MWH (2007) resulting from the introduction of mandatory rainwater tanks in new developments. Marsden Jacob Associates (NWC, 2007) presented a number of modelled scenarios for Australian cities where base case rainwater tank scenarios suggested yields from 42 kL/household/year (externally plumbed only) to 71 kL/household/year (internal and external). For Brisbane, the range was 41 to 99 kL/year depending on connected roof area. A number of different rainwater tank scenarios using the PURRS model (Probabilistic Urban Rainwater and wastewater Reuse Simulator model, developed by Coombes and Kuczera in 2001) were investigated for various SEQ councils by WBM Oceanics Australia (2006). Results predicted rainwater tank yields ranging from 52 to 133 kL/household/year. This is the model that was used to generate the data behind the QDC 4.2.

Table 1: Summary of key water residential restrictions for each restriction level based on information from the Queensland Water Commission.

Category of reticulated mains water use	Restriction level declared by Queensland Water Commission								
	Level 1 (May '05)	Level 2 (Oct '05)	Level 3 (Jun '06)	Level 4 (Nov '06)	Level 5 (Apr '07)	Level 6 (Nov '07)	High (Jul '08)	Medium (Mar '09)	PCM (Dec '09)
Established gardens/lawns									
irrigation systems	Note 1	X	X	X	X	X	X	Note 11	Note 13
hand held hose with trigger/ twist	✓	Note 1		X	X	X	Note 10	Note 12	✓
bucket / can	✓	✓	✓	Note 1	Note 1	Note 1	✓	✓	✓
New gardens/lawns									
irrigation systems	Note 2	Note 2	X	X	X	X	X	Note 11	Note 14
hand held hose with trigger/ twist	✓	✓	Note 5	Note 5	Note 5	Note 5	Note 5	✓	✓
bucket / can	✓	✓	✓	Note 1	Note 1	Note 1	Note 1	✓	✓
Topping up existing pools/spas	Note 1	Note 3	Note 3	Note 7	Note 8	Note 8	Note 8	Note 12	Note 15
Filling new pools/spas	Note 4	Note 4	Note 6	Note 7	Note 9	Note 9	Note 9	Note 12	Note 13
General outdoor cleaning (house/cars/boats/caravans)									
hand held hose with trigger/ twist	✓	✓	X	X	X	X	Note 10	Note 12	✓
bucket / can	✓	✓	✓	✓	✓	✓	✓	✓	✓

Notes:
1. Restricted times across 3 non-consecutive days. Not on Mondays.
2. As for Note 1 and must be an automatic shut-off sprinkler only.
3. As for Note 1 but hose to be hand held only.
4. Children's pools of <1000 L filled anytime. Hose does not need to be attended.
5. One hour of day using trigger/nozzle hose for 14 days after establishment only.
6. No portable / child pools to be filled by mains water.
7. Only when Qld Government recommended water efficient measures are shown to be used on the property.
8. As for Note 7 and restricted to 3 hours on non-consecutive days.
9. Requires written approval from local government to construct pools and spas.
10. Only hand held allowed for half hour every 7 days.
11. Only if systems emit < 9 L per minute with a timer for up to 30 minutes a day.
12. Filled at anytime but requirements as per Note 7. Child pools less than 500 L capacity.
13. As for Note 11 but 4 pm to 10 am. No Mondays and must use water efficient irrigation equipment.
14. As for Note 13 but can be watered anytime on day of establishment.
15. Only after all rainwater has been used to top up and 3 out of 4 water efficient devices installed in property.

2.3 Other Approaches to Quantifying Mains Supply Savings

Drought conditions and resultant water demand management schemes have not been limited to Queensland. The New South Wales Building Sustainability Index (BASIX) is a regulatory mechanism used to implement minimum sustainability performance for all new dwellings in New South Wales. The BASIX benchmark for water use was taken as the average household water consumption in New South Wales of ~90 kL/person/year or 324 kL/household/yr. Sydney Water linked BASIX data to quarterly mains water consumption data based on the addresses supplied by the BASIX information. Results for 2008/09 showed that the BASIX target of 40% reduction in water use was achieved, with an average consumption of 192 kL/household/yr, representing a 40.5% reduction compared with the BASIX benchmark of 324 kL/household/yr (Sydney Water, 2008). When adjusted for actual rather than estimated household occupancy (using results of a telephone survey), the average reduction increased to 42%. Whilst this difference is not substantial, the approach demonstrates the value of knowing the actual household occupancies in order to calculate unbiased household water consumption from newly constructed dwellings. This is particularly important given the trend for newer dwellings to have a higher household occupancy rate than existing households (Sydney Water, 2008). Moreover, knowing household occupancy allows calculation of per capita water use.

Turner *et al.* (2005) reported on a desktop study which looked at a 'before and after' scenario from a water efficiency retrofit program in Sydney. For their study, 24,000 randomly selected single residential homes that engaged in the retrofit program 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/household/yr reduction 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 rainwater tanks was compared with benchmark water consumption for single detached dwellings across the water supply catchment. The author reported an average of 27 kL/household/year savings from tanks connected to toilet and laundry and external fixtures. McBeth (2011) estimated that the external only saving was 43 kL/household/year. This somewhat surprising result was explained by homes that had the external water only connections having had higher pre-tank metered water use; thus translating to higher post-tank savings. This work also suggests that, when supply is sufficient, external end uses 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).

Clearly, pre-intervention knowledge (as per the Turner *et al.,* 2005 and McBeth, 2011 studies) are not available for this study comparing water use in new homes with existing homes. However, this current study used a similar paired statistical approach involving a large post-2007 database (>28,000 dwellings) available for IPT households. Desktop estimate of the mains water savings from using rainwater for some internal uses were calculated from a tank water balance analysis based on conservative assumptions. This provided a theoretically sound baseline estimate against which our empirical statistical estimates could be compared.

3. RESEARCH METHODS

3.1 Overview of Councils Selected for Analysis

Data was obtained and initially analysed for four SEQ councils: Caboolture and Pine Rivers (recently amalgamated into Moreton Bay Regional Council), Gold Coast City Council and Redland City Council. All the SEQ councils examined are located along the eastern seaboard, either immediately above or below Brisbane city (Figure 3). These councils were selected as they had readily accessible datasets that generally had a good level of information that could be used to extract consumption data for the required timeframes. They also represented high growth areas for new homes, and as such would have a number of IPT properties in the dataset.

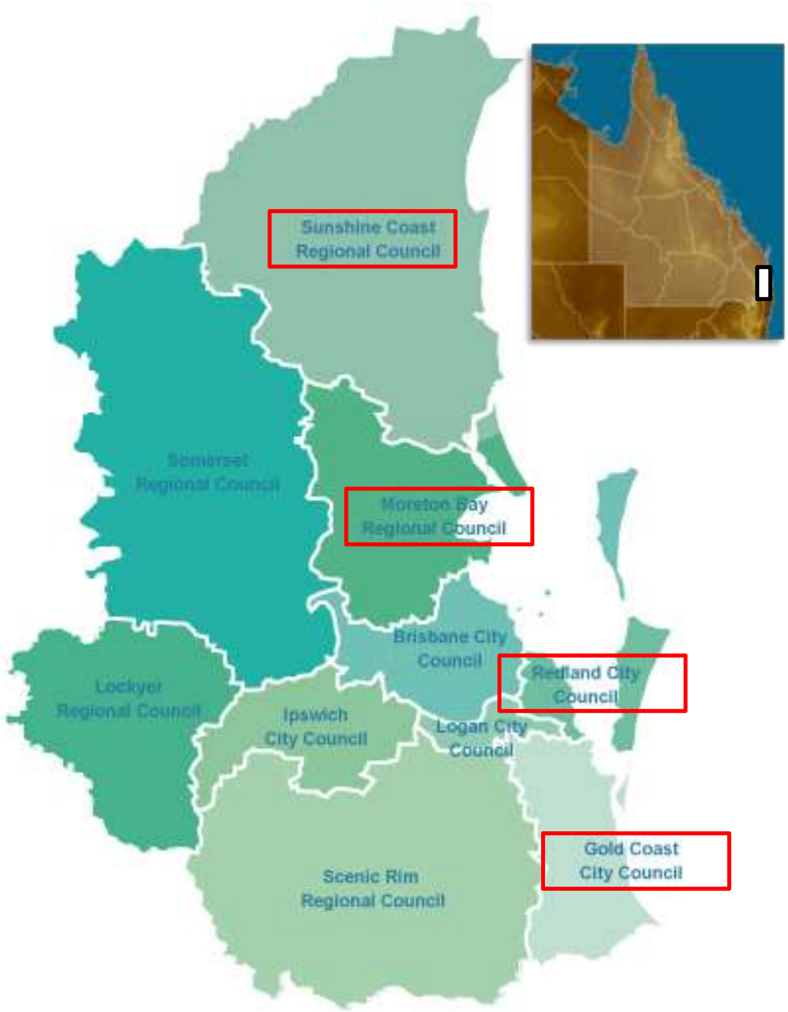


Figure 3: SEQ councils examined in desktop analysis. Inset: location of SEQ.

The last Australia Bureau of Statistics (ABS) census was in 2006, and the four councils collectively comprised almost 40% of the SEQ population (DIP, 2009). Average household size for each council from 2006 ABS data is shown in Figure 4. The resolution of the geographical boundaries is the Collection District which represents the second smallest geographical area developed by the ABS. For the 2006 Census, there was an average of about 225 dwellings in each Collection District.

Information on household occupancy will allow greater accuracy in matching similarly sized households for more representative statistical comparisons between pre- and post-2007 constructed homes. Clearly, these newer developments will not be included in the 2006 census. These new developments, where a majority of IPT households will be located, are more likely to have a larger household occupancy than more mature suburbs. This was found to be the case in the Sydney Water BASIX report (Sydney Water, 2008).

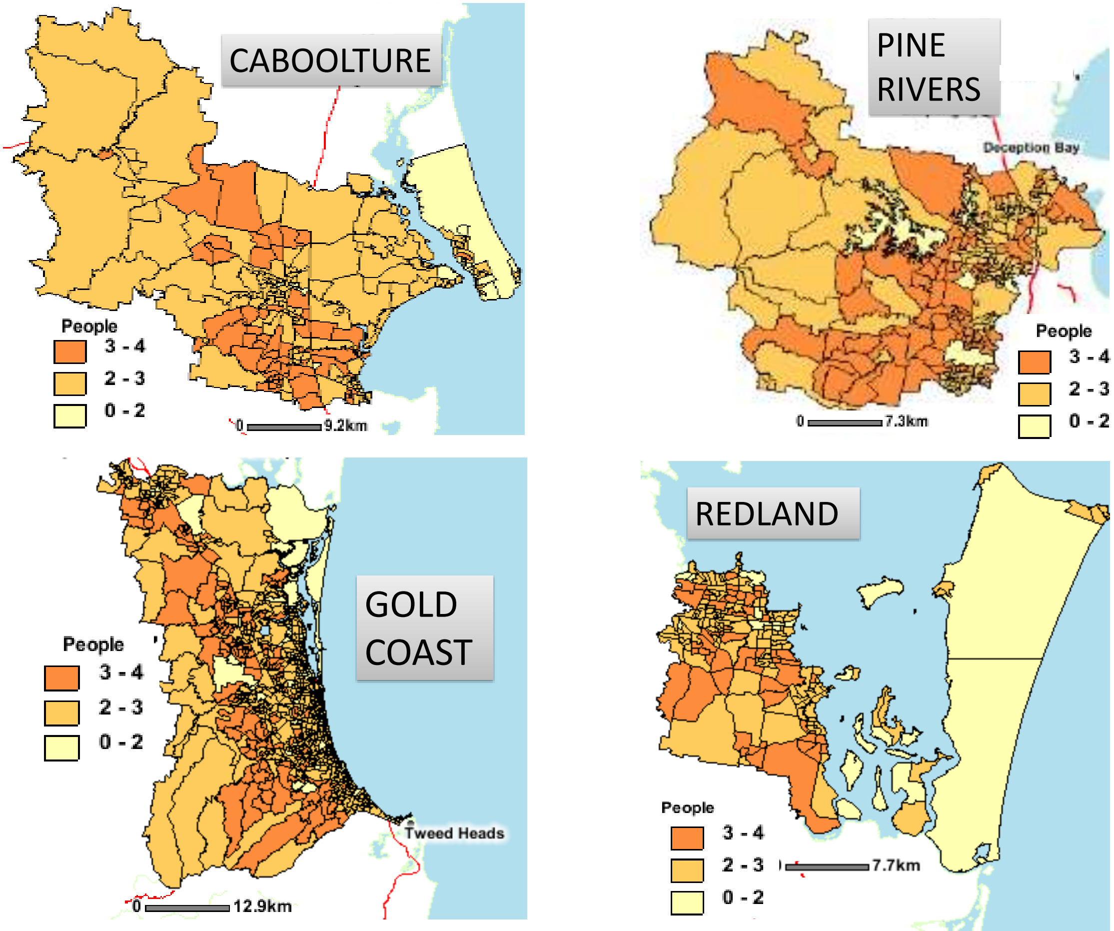


Figure 4: Household occupancy (ABS 2006) for SEQ councils examined in desktop analysis.

3.2 Assessment Methodology

Once the data was collected from the councils, a method was developed to isolate post-2007 IPT properties (i.e. properties that were assumed to have an internally plumbed in rainwater tank). Water billing data provided for all councils except Caboolture included information on the date of meter installation and/or the date of house construction. This information was useful when differentiating properties between pre- and post-2007 construction. Unlike previous studies such as Turner *et al.* (2005) and the Sydney Water BASIX study (Sydney Water, 2008), comparison of identified properties using known household occupancy data was not possible for this analysis. Unfortunately, in this study, properties approved and constructed post-2007 were not able to be identified in the datasets that were provided and therefore a number of assumptions and 'proxy' data fields had to be used to categorise between IPT and 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 2.

Table 2: Key data fields required for filtering IPT and No Tank properties.

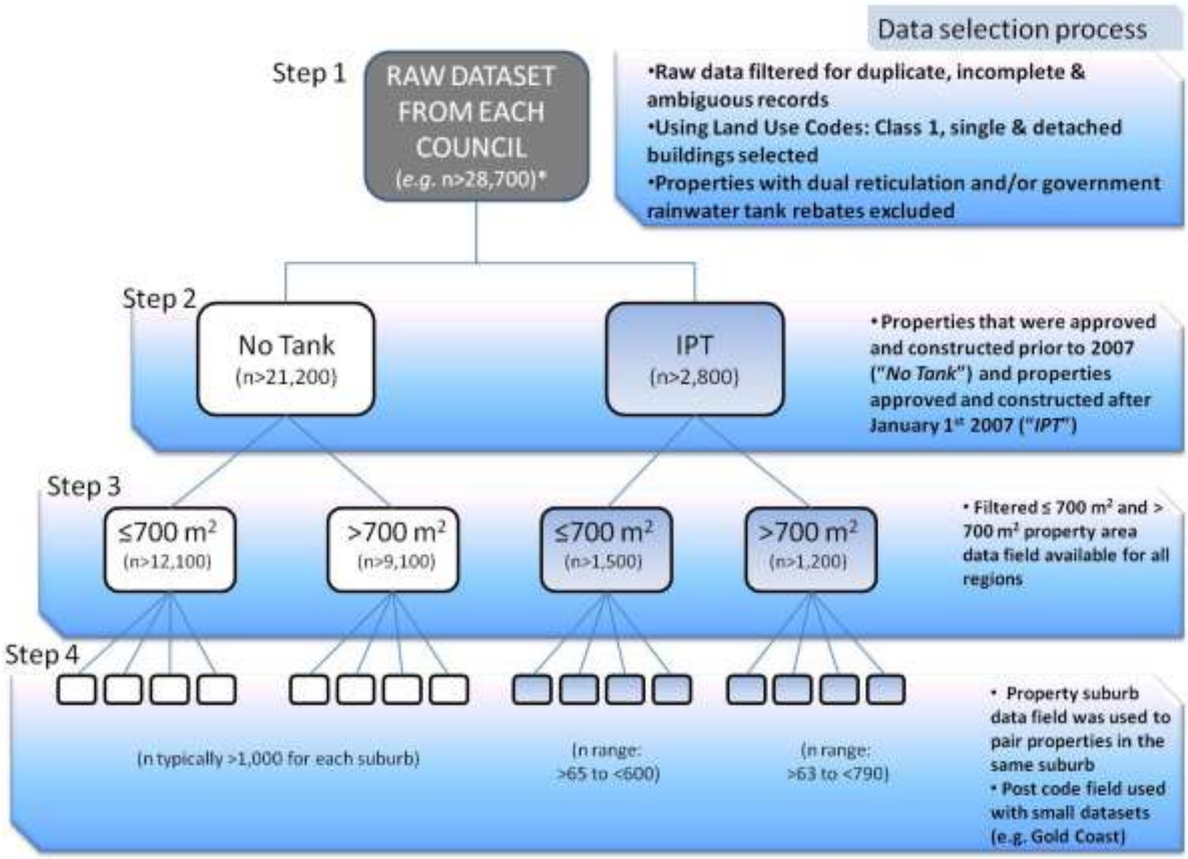
Data Field	Comment
Property/meter ID	This can be used to identify duplicate data and match properties.
Registration date / application date / meter installation date / water connection date	Used to indentify property age (*i.e.* pre- or post-2007). Note that water meter installation date might include 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 more detailed data, is a proxy for similar socio-demographic factors.
Land Use Code	Used to filter to identify 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).

The main steps and assumptions in the analysis are listed below and shown schematically in Figure 5.

1. The raw data set was filtered for duplicate and ambiguous data (e.g. incomplete, repeated records) using Microsoft Access or Microsoft Excel database software. This dataset was then filtered for the Land Use Code representing a Class 1 building as per the Queensland Development Code mandated requirements. Only single, detached dwellings were selected, which represent 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. For the Caboolture dataset, where it was not possible to isolate properties based on this information, all properties in post 1 January 2007 datasets that were not matched in any of the pre-2007 datasets were isolated as potential IPT properties. In the case of Gold Coast Water, the data was supplied in predefined No Tank and IPT samples.
3. IPT 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 after developing a probability distribution curve for all councils (Figure 6).
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 postcode 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.

Each No Tank property was chosen randomly for pairing with an IPT for each suburb (or postcode) and each lot size category using the random number generation tool in Microsoft Excel. All properties that were identified as having 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 was supplied by council. By excluding rebated tank properties, the differences in water use between No Tank and IPT houses were likely to be maximised.

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 1 January 2007 and were yet to be fully occupied, or developments that were approved *before* 1 January 2007 but *constructed after* 2007.



Note: Example of sample sizes taken for the billing period January to June, 2008 for Caboolture data only.

Figure 5: Flow chart for steps taken in data selection and analysis process.

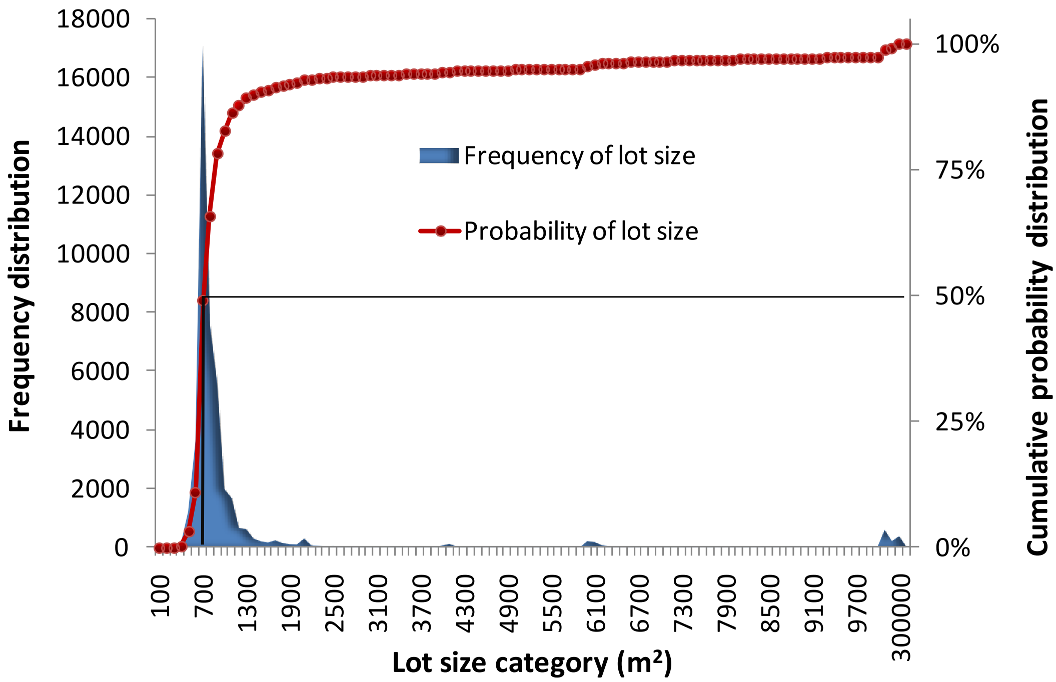


Figure 6: Typical lot size frequency and probability distributions (n=45,000).

3.3 Data Collection

3.3.1 Data Collection

Water consumption data was obtained through the water demand management section of each council. To identify the age of the property a mixed method approach was used to isolate the pre- and post-2007 constructed properties. There was also some difficulty in obtaining identifiable data (e.g. Real Property Description) for the Gold Coast City Council. Therefore, it was not possible to adjust the control group by excluding properties that had installed rainwater tanks resulting from the recent tank rebate programmes. It is hoped that future stages of this project will see the procurement of identifiable data for the Gold Coast. Additionally, Redland City Council reported some major difficulties in the provision of complete datasets for post-2007 approved dwellings. Consequently, only a small percentage of the actual post-2007 approved and constructed houses in Redland could be used for analysis.

It is acknowledged that this is not ideal in terms of the robustness of the data as it will introduce a range of confounding factors that are difficult to adjust for. However, the scope of this study is to estimate the reductions in mains water use of internally plumbed rainwater tanks using available data. The analysis will also indicate the direction for more detailed investigations which will need to eliminate confounding factors such as existing rainwater tanks in pre-2007 houses, influence of mandated water efficient fixtures (part of the QDC MP 4.1–Sustainable buildings), and consistent bias from differences in household occupancy.

3.3.2 Limitations to Sample Size

As expected, the No Tank sample for all councils was substantially larger (n>100,000) than the IPT sample (n>28,000). Sample size became smaller as the data pairs were more similarly matched. That is, the IPT samples reduced from over 28,000 properties to just over 4,000 properties that had populated (and sensible) data for every billing period in the year. If less than 12 months of billing data had been used, the sample size could have increased substantially, but there would not have been the seasonal representation captured from using all the periods. It is commonly accepted that the penalty of matching to reduce confounding variables (i.e. suburb, lot size, etc.), is usually a reduction in statistical power. A small increase in sample size can result in a sharp decrease in standard error and hence a similar reduction in the width of the confidence interval. This relationship is shown in Figure 7, using 95% confidence intervals generated from a range of No Tank and IPT data pairs selected from each council.

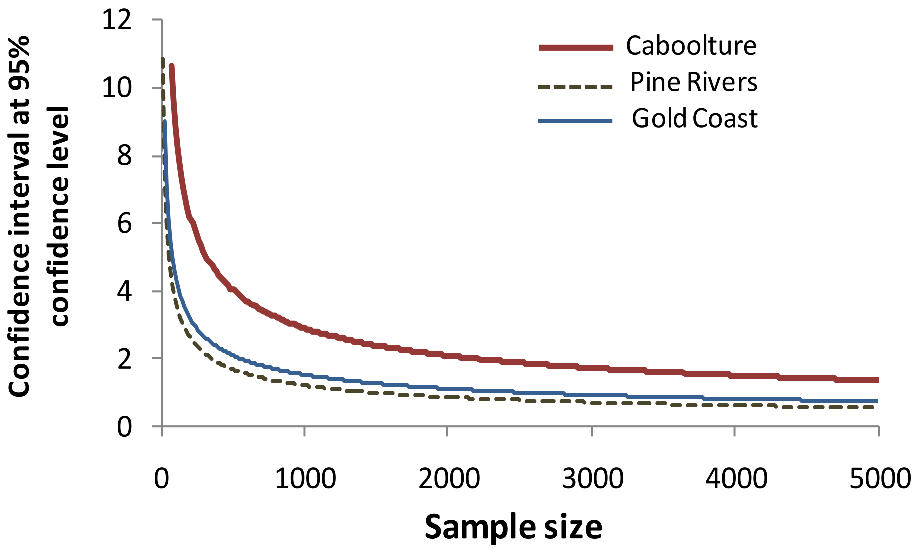


Figure 7: Relationship between sample size and confidence intervals represented by the 95% confidence level.

From Figure 7, it can be seen that a small increase in sample size can result in a sharp reduction in the width of the confidence interval (CI). This relationship becomes less sensitive once an asymptotic relationship (tending to infinity) is reached. Unfortunately, due to a smaller sample size in Redland, wider confidence intervals (i.e. lower statistical power) were observed for a range of analysed data (and thus have not been represented in Figure 7).

To test statistical differences between annual water use in No Tank and IPT properties, a *t*-Test of equal sample size was performed, limited by the smallest billing quarter. For example, to get the average annual water consumption for Pine Rivers and the associated CIs of the average, the sum of all four quarters of billing data for each property was needed. Therefore the sample size for the annual water use dataset was limited by the billing quarter with the smallest number of properties.

3.4 Selection of Final Datasets

A preliminary assessment indicated that the datasets for Pine Rivers, Redland and Gold Coast were suitable for further analysis. The billing data for Caboolture did not include any information that could be explicitly used to categorise whether a property was constructed pre- or post-2007. Initial analysis on the Caboolture dataset has shown inconsistent and questionable results which are likely to be attributable to the absence of explicit information on property age. From preliminary results, it appears that there is a high variance between suburbs across Caboolture and that some specific areas may be responsible for influencing the overall low mains water reductions for IPT properties observed for the area. Without specific and clear water consumption data for this area it is difficult to unambiguously evaluate the Caboolture dataset. For this reason, the Caboolture data has not been included in any subsequent sections of this report. However, in future reports, following a reanalysis of data using a more comprehensive dataset, mains water savings from internally plumbed in tanks in the Caboolture area will be assessed. This will be presented in combination with results from water consumption behaviours surveys and, potentially, some measured end use data from a smaller sample of homes.

3.5 Mains Water Reduction Analysis

3.5.1 Statistical Analysis

The frequency and probability distribution curves of water use data in the original council datasets are shown in Figure 8. This data relates to properties across all councils for 2008. The No Tank sample was selected randomly from an original dataset of n>100,000. The high water use from a small number of properties skewed the distribution to the right (Figure 8). For example, the highest 1% of all household water users made up almost 3% of the total water consumption (Figure 8). Athuraliya *et al.* (2008) also reported a residential water use distribution tailing toward high end users.

Two-tailed, independent *t*-Tests and other descriptive statistics were performed on the data using Microsoft Excel and SPSS© software packages. The two-tailed sample, *t*-Test with equal variances can be defined as:

$$t = \frac{(\overline{x}_1 - \overline{x}_2) - d_0}{s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}, \text{ where } {s_p}^2 = \frac{(n_1 - 1){s_1}^2 + (n_2 - 1){s_2}^2}{n_1 + n_2 - 2}, \text{ and } df = n_1 + n_2 - 2$$

where: t is the test statistic; $\overline{x}$ is the sample mean of each sample 1 and sample 2; d_0 hypothesized population mean difference; n is the sample size; s is sample standard deviation; s^2 is sample variance; s_p is the weighted average of the two sample variances; and *df* is the degrees of freedom.

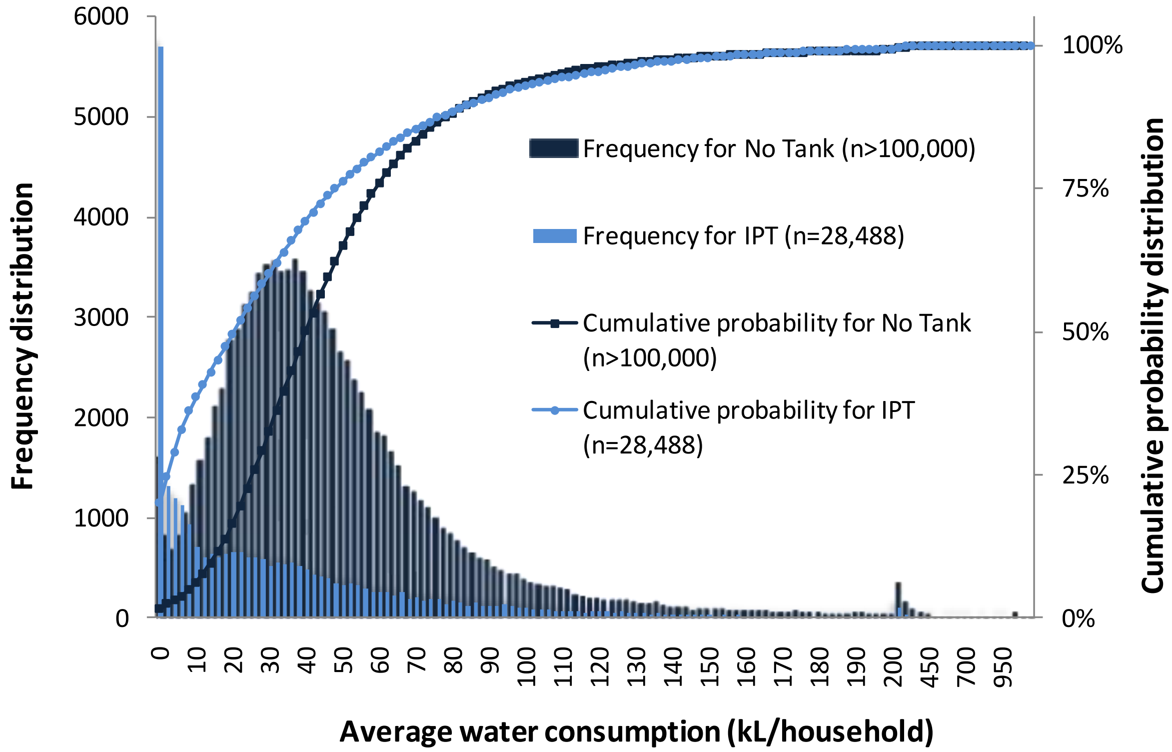


Figure 8: Frequency and probability functions of raw water consumption data for No Tank and IPT.

The unpaired, or "independent samples" *t*-Test is used when two separate, independent and identically distributed samples are obtained, one from each of the two populations being compared. Once the IPT data had been cleaned (Step 1 above) and zero values removed, the distribution curves for both No Tank and IPT samples were sufficiently similar to apply the independent *t*-Test.

Although the distribution curves are skewed to the right (Figure 8), the *t*-Test is more robust than other tests (e.g. z-Test) to deviations from normality (Johnson, 1978; Sawilowsky and Blair, 1992). This is particularly the case where sample sizes are large, equal and two-tailed (Sawilowsky and Blair, 1992) as is the case for this analysis. 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 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©.

The statement for the *t*-Test may be formulated as:

Null hypothesis = H_0: $\mu_{IPT} = \mu_{No\ Tank}$

Alternative hypothesis = H_1: $\mu_{IPT} \neq \mu_{No\ Tank}$, where μ is the sample population mean.

The statement for the Wilcoxon Rank Sum test may be written as:

H_0: the distribution of the mean_{IPT} is equal to the distribution of the $\text{mean}_{No\ Tank}$

H_1: the distribution of the mean_{IPT} is not equal to the distribution of the $\text{mean}_{No\ Tank}$

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. Note: the 95% confidence interval is shown by error bars on the plotted data presented in the Results section.

3.5.2 Cross-Checking Statistical Analysis

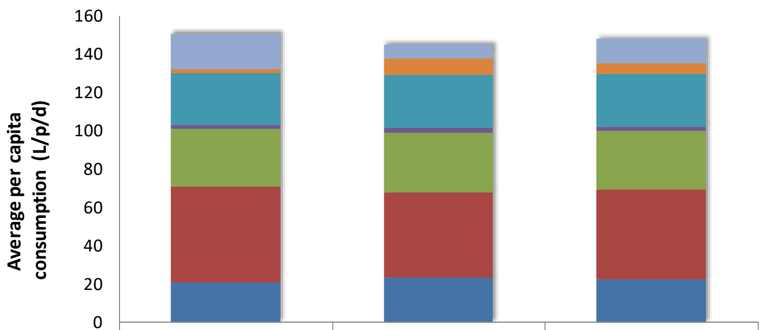
As detailed in the previous sections, the examination of savings from internally plumbed rainwater tanks is not an easy task, particularly given the paucity (or accessibility) of specific data required for a pair-wise analysis. Therefore, two approaches have been used to assist in evaluating and providing 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).

3.5.2.1 Estimating Internal Water Savings

In addition to the requirement to achieve a mains water savings target, all new residential developments must install water efficient toilet, shower rose and tap fixtures under the QDC 4.1– Sustainable buildings. In 2008, these were minimum 3-star Water Efficiency Labelling and Standards (WELS) rated toilets (6/3 litre flush) and 3-star WELS rated showerheads (9 litres/minute flow rate). 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.,* 2009). Stage 2 of this project aims to conduct such an investigation. Nevertheless, some estimation 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 in the Pimpama-Coomera area described earlier in this report (Willis *et al.,* 2010) and from a recent SEQ end use study (Beal *et al.,* 2011). 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 (Figure 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 9: Summary of internal water end uses from recent SEQ end use studies.

Clothes washing machines were not assumed to have 100% of their mains water use replaced by rainwater tanks. The reason is that in the SEQ End Use Study (Beal *et al.*, 2011), 78% of participants indicated that they used cold water exclusively. The remaining 22% 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 for washing machines in the IPT group was sourced exclusively from the rainwater tank, a conservative assumption was made that 60% of washing machines used the cold water tap exclusively.

3.5.2.2 Rainwater TANK Modelling

The Rainwater TANK model is an Excel-based spreadsheet model linked to a FORTRAN executable file (Vieritz *et al.,* 2007). 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 tank water volume for the current day is determined from mass balance.

$$TW = Yest\_TW + TopUpW + TankInflow - IWU_{tank} - EWU_{tank}$$ (Vieritz *et al.*, 2007).

where:

TW is the tank water volume (m^3);
Yest_TW is yesterday's tank water volume (m^3);
TopUpW is the volume of mains water added to the tank by trickle top up or trucked water to top it up to its specified Top Up Mark Volume (m^3) for the current day;
TankInflow is the flow of rainwater into the tank from the roof for the current day (m^3);
IWU_{tank} is the Internal Water Use for tank water (m^3) for the current day; and
EWU_{tank} = the External Water Use for tank water (m^3) for the current day.

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. The rainwater tank is assumed to be any regular shape, whereby the volume is calculated from basal area × height of the tank. Household water end uses have a fixed amount of water used per day (nominated by the user) and the primary assumption with respect to internal water use is that the demand must be always fulfilled. This internal water use is assumed to be constant for each day of the run. When the tank runs out of water, the model will automatically meet the internal demand using mains water, thereby providing an estimate of the supply shortfall (Vieritz *et al.*, 2007). External water use is determined by the actual irrigation supplied on the current day. To determine the contribution of tank water to external water use, the Rainwater TANK model distinguishes between irrigation supplied by tank water and irrigation supplied by mains (Vieritz *et al.*, 2007).

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.* (2009) and Beal *et al.* (2011). The model year for the runs was 2008.

Table 3: Input parameters and assumptions for the TANK model.

Parameter	Value	Parameter	Value
People household	3.0 *Pine Rivers,* 2.9 *Redland,* 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

4. COMPUTATIONS AND RESULTS

4.1 Statistical Analysis - Water Consumption and Estimated Mains Reductions in 2008

4.1.1 Per Household Results

There was a significant reduction in mains water consumption for IPT properties in all councils (Figure 10). For 2008, average mains water consumption for No Tank homes across the three council areas ranged from 162 to 247 kL/household/year, with an average of 197.8 kL/household/year (Figure 10). Mains water consumption for IPT properties ranged from 142 to 152 kL/household/year, with an average of 148.3 kL/household/year.

The average reduction of mains water across the councils was 50 kL/household/year, and ranged from 20 to 95 kL/household/year (Table 4). Mean values were used to statistically compare water consumption in this desk top analysis. Water consumption between No Tank and IPT homes was analysed for the two lot size categories where sample size allowed this. While there was a trend for larger allotments to use more water, there were only limited statistically significant results between councils, 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 council area datasets.

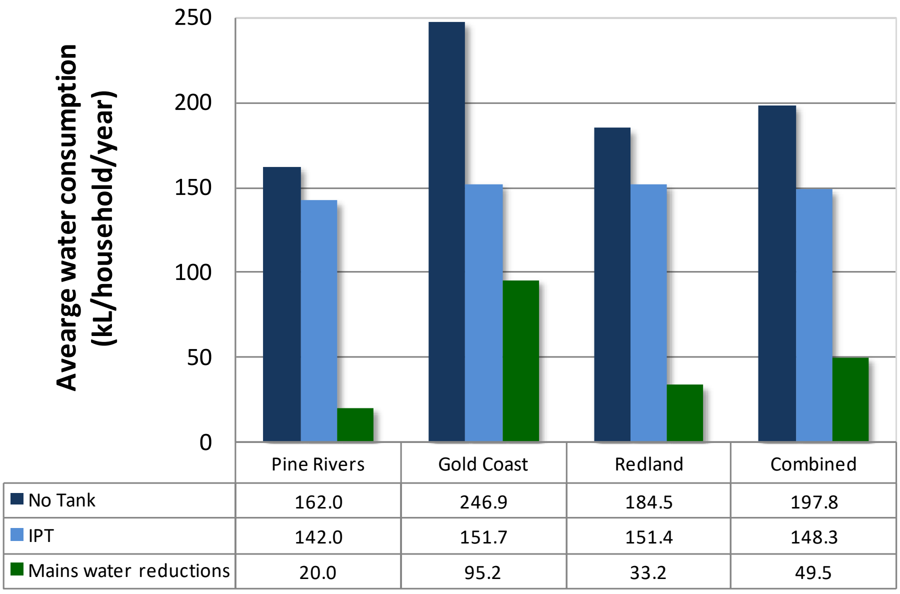


Figure 10: Total average water use and estimated mains water reductions (2008).

Table 4: Estimated mains water reductions for 2008 and sample sizes (n).

Council	Average mains reductions (kL/household/year)
Pine Rivers	20.0 (n=648)
Gold Coast	95.2 (n=422) ≈ 95
Redland	33.2 (n=112) ≈ 33
Average	49.5 (n=1,183) ≈ 50

4.1.2 Per Capita Results

The average daily per capita water use (litres/person/day, or L/p/d) (Figure 11) was estimated using population data from the ABS 2006 Census data. These data were taken using dwellings with permanent residents for each of the studied councils. Average residential water consumption in all local government areas in SEQ for 2008-09 was 143 L/p/d (QWC, 2010, p. 53). Figure 11 demonstrates that the average water usage estimated for IPT properties in 2008 (133 L/p/d) is consistently less than the average residential water consumption for SEQ region during 2008-09. Water consumption for No Tank properties was consistently above the SEQ average for all councils studied (Figure 11). Average mains water reduction per person was about 49 L/p/d.

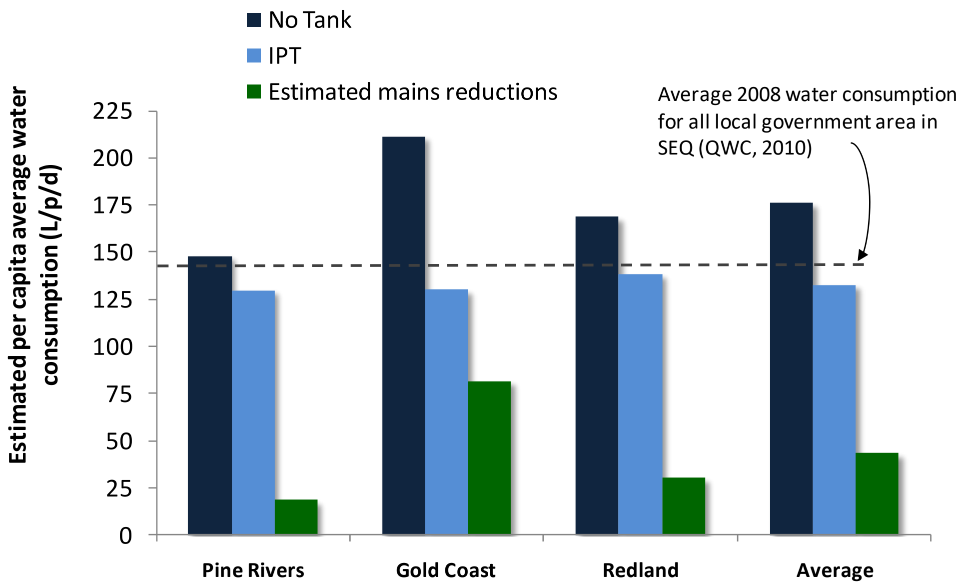
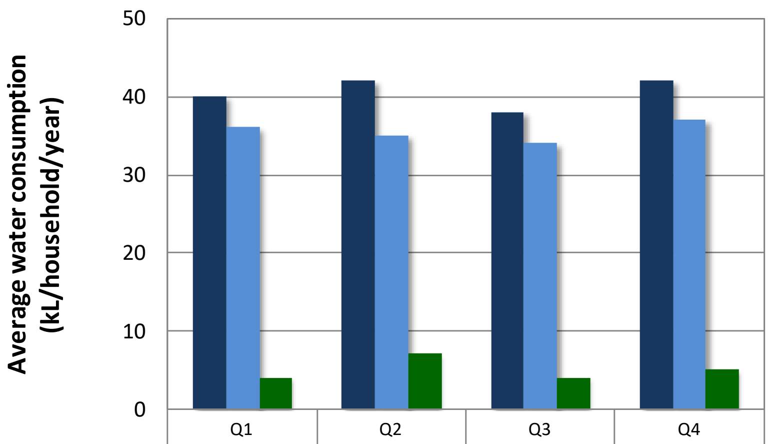


Figure 11: Total average per capita water use and estimated mains reductions for 2008.

4.1.3 Quarterly Water Saving Analysis by Council Area

Pine Rivers

Average water use in Pine Rivers for 2008 was relatively consistent across the four billing quarters for both No Tank and IPT homes (Figure 12).



	Q1	Q2	Q3	Q4
No Tank (n=32,718)	40.0	42.0	38.0	42.0
IPT (n=648)	36.0	35.0	34.0	37.0
Mains water reductions	4.0	7.0	4.0	5.0

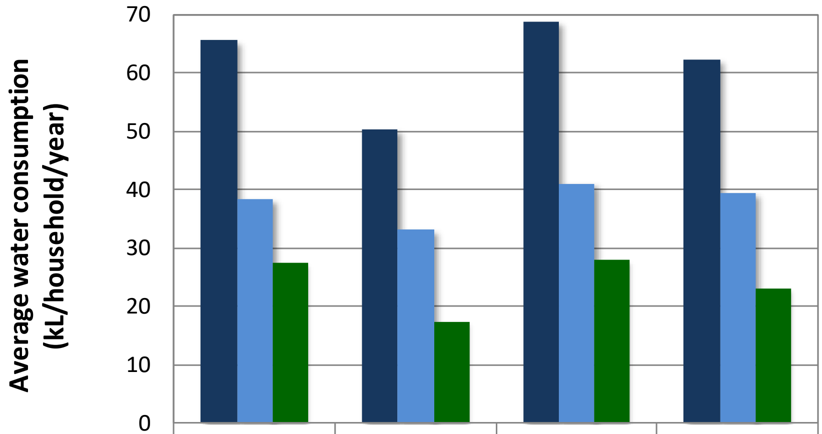
Notes: Q1 - Q4 means Quarter 1 (Jan-Mar) to Quarter 4 (Oct – Dec) billing period.

Figure 12: Quarterly mains water use and mains reductions in Pine Rivers for 2008.

Water use from IPT houses was significantly lower ($p<0.05$) than No Tank houses for each quarter. Mains water reductions are also consistent across the year at an average of 5.0 kL/household/quarter and overall average of 20 kL/hh/year (Figure 12).

Gold Coast

Average water consumption for the No Tank sample in the Gold Coast was the highest for all councils examined, at an average of around 61.7 kL/household/quarter (Figure 13). Water use from IPT houses was significantly lower ($p<0.05$) than No Tank houses for each quarter at an average of 37.9 kL/household/quarter. Estimated mains water reductions for the Gold Coast was the highest for all SEQ councils analysed (Figure 13), reflecting the overall higher water consumption for properties on the Gold Coast. Quarterly mains reductions ranged between 17.3 and 27.7 kL/household, with an overall average of 95.2 kL/household/year.

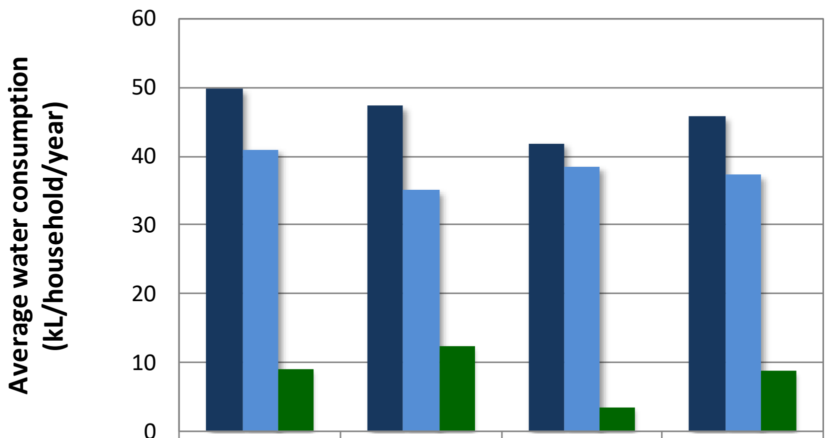


	Q1	Q2	Q3	Q4
No Tank (n=2,993)	65.5	50.3	68.7	62.3
IPT (n=422)	38.3	33.0	41.0	39.3
Mains water reductions	27.2	17.3	27.7	23.0

Figure 13: Quarterly mains water use and mains reductions in Gold Coast for 2008.

Redland

Redland water use and reductions (Figure 14) were generally higher than that of Pine Rivers but lower than the Gold Coast – the least water use restricted area in 2008.



	Q1	Q2	Q3	Q4
No Tank (n=33,117)	49.7	47.2	41.8	45.8
IPT (n=112)	40.8	35.0	38.4	37.2
Mains water reductions	8.9	12.3	3.4	8.6

Figure 14: Quarterly mains water use and mains reductions in Redland for 2008.

In Redland, IPT homes used significantly less ($p<0.05$) water most quarters, though the smaller sample sizes for this council area dataset resulted in wider 95% confidence intervals (Figure 14). There was a trend for the differences in water use between the two groups to converge toward the end of the year, that is, by Quarter 4 (October to December) the IPT and No Tank water use was not significantly different ($p>0.05$). Estimated quarterly mains water reductions ranged between 3.4 kL/household and 12.3 kL/household, with an overall average of 33.2 kL/hh/year mains water reduction.

4.1.4 Influence of Water Restrictions on Consumption and Reductions

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 15). The null hypothesis that mains water reductions were the same between homes with and without water restrictions is therefore rejected ($p<0.05$).

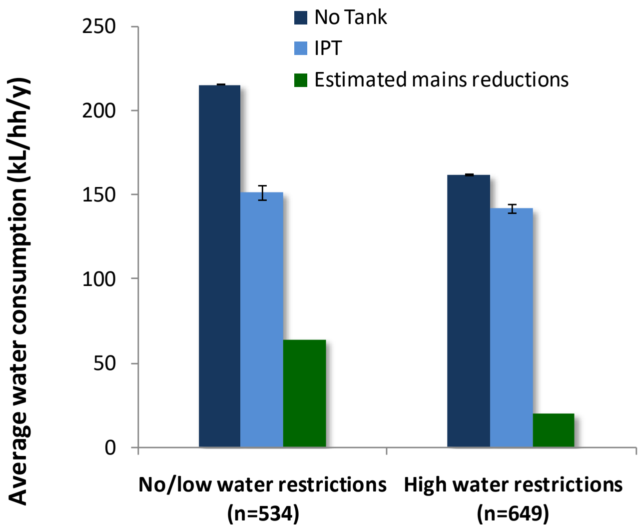


Figure 15: Comparison between water consumption and estimated mains reductions for areas with high and low/no water restrictions.

4.2 Cross-Checking Statistical Analysis Results

The result of the two approaches used to cross-check the statistical analyses are presented in Table 5. 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 between an average of 44 kL/household/year and 50 kL/household/year.

Using the end use data, under the assumptions discussed in section 3.5.2.1, the expected internal water reductions from the toilet and washing machine fell in the range of 30 to 42.3 L/p/d, with an average of 40.6 L/person/day. 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, an average of around 44 kL/household/year, regardless of outdoor uses of rainwater. This figure assumes that mains water was substituted for rainwater at all times, i.e. the rainwater tank levels were sufficient for unrestricted substitution. The reasonableness of this assumption for 2008 will be explored in the next section.

Using the Rainwater TANK model, predicted rainwater supply for unrestricted internal use ranged from 46 to 54 kL/household/year, with an average of 50 kL/household/year (Table 5). Rainfall data for 2008 was used for each council area as shown in Table 5.

Table 5: Results of expected mains water savings using End Use Data and TANK modelling for statistical analysis verification.

Council	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**	**43 to 46**
Gold Coast	1,766	**54**	
Redland	1,348	**46**	
Average	*1,460*	***50***	***44***

Note: [1] assumes trickle top up available.

5. DISCUSSION

Comparative analysis of water consumption between No Tank and IPT properties overall clearly showed that consumption was greater for homes without IPT (Figure 10). Mains water consumption for No Tank homes averaged 197.8 kL/household/year compared with an average of 148.3 kL/household/year for IPT homes. Within councils, 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 under relaxed outdoor watering restrictions in 2008. Water reductions from mains supplies varied markedly across councils with values ranging from 20 to 95 kL/household/year, equating to an average of 50 kL/household/year (Table 4).

Considering the skewed nature of the water consumption data (Figure 8), the analysis was extended to investigate water savings based on median values (as mean values could be skewed by extreme values) to compare water savings. The median mains reduction ranges from 28 to 52 kL/household/year with an average of 40 kL/household/year (see Table 6). It can be highlighted that the water savings would range between 40 and 50 kL/household/year if both approaches are considered.

The results of the desktop statistical analysis demonstrate that water consumption for homes with IPT was significantly lower ($p<0.05$) than No Tank homes (Figure 10). However, there is considerable variation in mains water reductions across the three councils with an average of 50 kL/household/year being estimated (Table 4). By cross-checking the statistical analyses results with the two other modelling approaches, average baseline savings between 44 and 50 kL/household per year would be expected from internally connected fixtures (washing machine cold water tap and toilet) (Table 6). Notwithstanding the high estimated savings from the Gold Coast, where there were no restrictions on 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 shown in Table 6. 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 council billing data used to determine IPT from No Tank homes. Each will be discussed in turn below.

Table 6: Summary of mains water use reductions.

<table>
<tr><th rowspan="2">Council</th><th>Desktop study Mean values</th><th>Desktop study Median values</th><th>End Use approach</th><th>TANK model Internal only</th></tr>
<tr><th colspan="4">(kL/household/year)</th></tr>
<tr><td>Pine Rivers</td><td>20</td><td>28</td><td rowspan="3">43 to 46 (internal only)</td><td>49</td></tr>
<tr><td>Gold Coast</td><td>95</td><td>52</td><td>54</td></tr>
<tr><td>Redland</td><td>33</td><td>41</td><td>46</td></tr>
<tr><td>Average reduction</td><td>50</td><td>40</td><td>44</td><td>50</td></tr>
</table>

5.1 Influence of Water Restrictions on Water Consumption

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). The influence of water restrictions is illustrated in Figure 15, which showed smaller differences in water consumption between IPT and No Tank properties in councils with high-level water restrictions (no or low outdoor watering). Conversely, the differences in mains water use (i.e. the savings) are greater for those homes located in low or no water restriction areas where these differences could be maximised by permitting outdoor water use to be sourced from mains water (Figure15).

A summary of key water restrictions during 2008 for the councils analysed is presented in Table 7. A description and timeline of the water restrictions for SEQ was detailed earlier in Table 1. The most severe water restrictions in 2008 occurred in the Moreton Bay Regional Council area, which encompasses Pine Rivers. Importantly, outdoor watering using mains water was limited to only hand held bucket or watering cans until 1 August 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 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 7).

Table 7: Summary of water restrictions for 2008 for the four SEQ councils examined.

WATER USE	Moreton Bay Regional Council*	Gold Coast**	Redland
Queensland Water Commission notification if ≥800 L/household/day	✓	X	X
Established and newly established gardens/lawns			
Irrigation systems and unattended &/or sprinkler systems	X	✓	X
Hand held hose	X	✓	✓
Hand held bucket &/or watering can	✓	✓	✓
Filling up new pools/spas	✓ Once daily for a limited time	✓	✓ Twice daily for a limited time
Topping up pools/spas & ponds/aquariums	X	✓	✓
Car/boat/caravan washing	X	✓	✓
General outdoor cleaning	✓ extremely limited	✓	✓

Notes:
* Along with other adjacent local councils, Pine Rivers Shire Council was amalgamated into Moreton Bay Regional Council.
** GCCC off QWC restrictions between Feb and Nov 2008.

Daily per capita water use for No Tank properties in all councils studied exceeded the 2008-09 average value for all local government areas in SEQ region of 143 L/p/day (see Figure 11). Conversely, average per capita water use from households with IPT was consistently less than the regional average. Average mains water reduction per person for households with IPT was about 49 L/p/d. This high water usage from No Tank homes should promote the likelihood of rainwater substitution from IPT homes and hence maximise the savings able to be achieved. However, if people are frugal in their water use due to water restrictions and demand management strategies (e.g. Target 140, water efficient appliances, etc) this will be likely to result in small differences between mains water use, and hence savings.

In the last three or so years, SEQ has undergone a significant shift in water consumption, where the average daily water use in 2008 was almost half that of the 2005 values used in the rainwater tank modelling on which the QDC 4.2 target of 70 kL/household/yr was based (WBM, 2006). This is driven largely by the severe outdoor water use restrictions during this period for the councils under investigation.

Two key assumptions from the 2005 modelling are: unrestricted outdoor watering and high internal water use (*e.g.* ~175 L/p/d, compared to 128 L/p/d in 2008 under QWC restrictions). These high end use scenarios will invariably maximise tank yield for any given tank size/connected roof area combination. Similarly, if demand is reduced, as has been the case under water restrictions, then tank yield will also reduce. On this basis we would see lower than expected mains water reductions from IPT properties.

5.2 Limitations of Statistical Analysis

As noted earlier in the report, the Caboolture dataset was removed from the final analysis due to the uncertainty in accurately identifying No Tank and IPT homes. All other council areas could be more confidently indentified into the two groups of No Tank and IPT and then subsequently paired for statistical testing. However, there still remained some important information that could not be gleaned from the data provided, in particular for Caboolture. This absence of information for some or all of the councils unfortunately created the following limitations:

- Separating the billing data into an IPT and No Tank subsamples could only be done using assumptions and proxy data, as detailed in the methods;
- 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 the knowledge of household occupancy, household water demand cannot be controlled for properly. 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.*, 2010: Wang, 2011).

Finally, the role of water-efficient household stock such as high-star WELS rated washing machines, shower roses and water efficient tap ware (in the kitchen, bathroom basins and laundry tubs) 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.*, 2011).

6. RECOMMENDED FURTHER WORK

One aim of this desktop report was to provide baseline data for further experimental work, Stage 2 in assessing the role of rainwater tanks as an alternative urban water source. As discussed above, several limitations have been identified in attempting to quantify the water savings or mains water reductions from the installation of internally plumbed rainwater tanks. These were attributed to lack of specific knowledge on IPT and No Tank homes, socio-demographic data and timing of analysis during a drought-focussed community where external water use was conservative and therefore differences due to supply options harder to detect.

Stage 2 will address the limitation in methodology for the Caboolture dataset by directly identifying IPT homes. Furthermore, to resolve uncertainties in current household occupancy for new and existing dwellings and to fully characterise household socio-demographical factors, Stage 2 of this study should consist of the following critical elements:

1. A market research survey of No Tank and IPT households which is designed to identify all the key household characteristics including occupancy, income, new/established gardens, adult : child ratio and water appliances and fixtures;
2. Benchmark analysis of the water savings from *known* IPT homes and a subsequent controlled pair-wise statistical analysis and validation on the mains water savings from IPT homes; and
3. A controlled, pair-wise experiment on a small sample (n=20) of IPT households and No Tank households where mains and rainwater tank end uses are measured and recorded over at least a period of a year.

As it is widely acknowledged that water pricing, income and household composition are key determinants of residential water consumption (Arbués *et al.,* 2003; Worthington *et al.,* 2009), it is strongly recommended that these factors be quantified and considered in the Stage 2 analysis. This approach would also identify the confounding issue of water-efficient household stock contributing to the savings between IPT and No Tank homes. The appropriate sample size of the household survey and metering experiments should be guided by the desktop report findings.

The pre-2007 dataset was filtered for government rainwater tank rebate data for each SEQ region examined. This involved obtaining all rebated tank property information and matching with property information obtained by council. Discussions with council officers suggest that the remaining number of houses that would have rainwater tanks in the No Tank cohort would be considered low. This will, however, be controlled for during the Stage 2 study where such information will be known.

The above approach outlined for Stage 2 will reduce, if not eliminate, many of the confounding factors that are inherent in a desktop study where IPT and No Tank properties are only inferred. Alternatively, a BASIX approach based on Sydney Water methods could be used to measure the water use of a representative sample of identified mandated tank households and compare their water use with the average per capita value in SEQ for pre-2007 detached dwellings.

7. CONCLUSIONS

A desktop study was carried out initially on four SEQ councils to develop a methodology using existing council billing data to estimate savings from internally plumbed rainwater tanks (IPT); and to provide baseline data for further experimental work (Stage 2) for the Decentralised Systems project. Due to data limitations and subsequent complexities in interpretation the initial analysis, only three SEQ councils; Pine Rivers, Redland and Gold Coast, were ultimately investigated.

Over 1,100 data pairs were analysed for SEQ councils which had strict (Pine Rivers) moderate (Redland), and liberal (Gold Coast) 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 to 95 kL/household/year, with an average of 50 kL/household/year. The analysis was also conducted using median water consumption values, which resulted in the mains water reductions from 28 to 52 kL/household/year, with an average of 40 kL/household/year. Thus, considering both the approaches, average water saving between 40 and 50 kL/household/year can be expected from internally plumbed rainwater tanks. Water restrictions appear to have a strong influence on estimated reductions from mains water use. In councils 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 these results with two other approaches suggests that an approximate range of 44 to 50 kL/household/year mains water savings for the average residential property with a household occupancy of 2.8 to 3 people can be expected from rainwater tank plumbed to toilet and washing machine. This estimation is based on considering rainwater usage for internal consumption only. The differences between the statistical analysis and the cross-check results are more than likely due to the high water restrictions for some councils 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 contribute to the low differences in water consumption between IPT and No Tank homes.

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 suggested that Stage 2 should consist of the following components:

1. 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);
2. a benchmark analysis on the water savings from *known* IPT homes and a subsequent controlled pair-wise statistical analysis and validation on the mains water savings from IPT homes; and
3. monitoring of approximately 20 IPT homes for actual rainwater usage.

Nevertheless, results presented in this report show that newer properties (post 2007) generally have lower water consumption than older properties and that this trend is quite likely to be a result of internally plumbed rainwater tanks along with other factors such as water efficient appliances and fixtures. Additionally, the results provide further evidence that water restrictions are a useful tool in demand-side water reduction strategies.

REFERENCES

Arbués, F., García-Valiñas, M.A. and Martínez-Espiñeira, R. (2003). Estimation of residential water demand: a state-of-the-art review. Journal of Socio-Economics 32: 81-102.

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

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

Barrett, G. (2004). Water Conservation: the role of price and regulation in residential water consumption. Economic Papers, Vol 23:3, pp. 271-285

Barrett, G. and Wallace, M. (2009). Characteristics of Australian urban residential water users: implications for water demand management and whole of the system water accounting framework. Water Policy, 11 413:426.

Beal, C.D., Stewart, R.A. and Huang, T. (2010). South East Queensland Residential End Use Study: Baseline results – Winter 2010. Urban Water Security Research Alliance Technical Report No. 31.

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

Coombes P.J. and Kuczera, G. (2001). Rainwater tank design for water supply and stormwater management. Stormwater Industry Association 2001 Regional Conference. Port Stephens, NSW. 2001.

Coombes, P.J. and 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. and Jeffrey, P. (2009). Classifying households for water demand forecasting using physical property characteristics. Land Use Policy 26, 558-568.

Gardiner, A. (2009). Domestic rainwater tanks: usage and maintenance patterns in south east Queensland. Water 36(1), 73-77.

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 and Environment, 42 (4): 1654-1666.

Grafton, R.Q. and Ward, M.B. (2008). Price versus rationing: Marshallian surplus and mandatory water restrictions. The Economic Record, 48, S57-S65.

Hoffman, M., Worthington, A. and Higgs, H. (2006). Urban water demand with fixed volumetric charging in a large municipality: the case of Brisbane, Australia. The Australian Journal of Agriculture and Resource Economics 50:347-359.

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

Johnson, N.J. (1978). Modified t-Tests and confidence intervals for asymmetrical populations. Journal of the American Statistical Association 73 (363) 536-544.

Kenney, D.S., Klein, R.A. and Clark, M.P. (2004). Use and effectiveness of municipal water restrictions during drought in Colorado. Journal of the American Water resources Association, 40 (1):77-87.

Kenney, D.S., Goemans, C., Klein, R.A., Lowrey, J. and Reidy, K. (2008). Residential water demand management: lessons from Aurora, Colorado. Journal of the American Water resources Association, 44 (1):192-207.

Loh, M. and Coghlan, P. (2003). Domestic water use study in Perth, Western Australia 1998 to 2000. Water Corporation of Western Australia.

McBeth, B. (2011). Savings from residential rainwater tanks on the NSW far north coast: a detailed statistical analysis on usage between January 2002 and December 2009. Journal of the Australian Water Association, 38 (2): 136-142.

Mead, N. and Aravinthan, V. (2009). Investigation of household water consumption using smart metering systems. Desalination and Water Treatment 11, 115-123.

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.

Ott, L. and Mendenhall, W. (1990). Understanding statistics. 5th Edition. PWS-Kent Publishing Company, Boston, USA.
QWC (2009). South East Queensland Water Strategy: Revised Draft November 2009, The State of Queensland (Queensland Water Commission).
QWC (2010). South East Queensland Water Strategy, July 2010, The State of Queensland (Queensland Water Commission).
Renwick, M.A. and Archibald, S.O. (1998). Demand-side management policies for residential water use: who bares the conservation burden? Land Economic, Vol 74, pp. 343-359.
Roberts, P. (2005). Yarra Valley Water 2004 residential end use measurement study. Final report, June 2004.
Sawilowsky, S.S. and Blair, R.C. (1992). A more realistic look at the robustness and type II error properties of the t-Test to departures from population normality. Quantitative Methods in Psychology 111 (2) 352:360.
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., 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., White, S., Beatty, K. and Gregory, A. (2005). Results from the largest residential demand management program in Australia. Water Science and Technology: Water Supply 5 (3-4): 249-256.
Turner, A., Fyfe, J., Retamal, M., White, S. and Coates, A. (2009). The one to one water savings program unpacking residential high water usage. IWA Efficient 09 Conference, Sydney, October 2009.
Vieritz, A., Gardner, T. and Baisden, J. (2007). Rainwater TANK Manual. Department of Natural Resources and Water, 2007, Queensland.
Wang, YC, (2011) Separating indoor and outdoor water consumption, Journal of the Australian Water Association, 38(3), 63-67.
Water Corporation (2011). Perth residential water use study 2008/2009, Water Forever, Water Corporation, Western Australia.
Willis, R., Stewart, R.A., Panuwatwanich, K., Capati, B. and Giurco, D. (2009). Gold Coast Domestic Water End Use Study, Water, 36(6): 84-9.
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.
Willis, R.M., Stewart, R.A., Williams, P.R., Hacker, C.H., Emmonds, S.C. and Capati, G. (2011). Residential potable and recycled water end uses in a dual reticulated supply system. Desalination, 273(1-3), 201-211. doi: 10.1016/j.desal.2011.01.022.
Worthington, A., Higgs, H. and Hoffman, M. (2009). Residential water demand modelling in Queensland, Australia: a comparative panel data approach. Water Policy, 11 427-441.

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