SAVINGS FROM RESIDENTIAL RAINWATER TANKS ON THE NSW FAR NORTH COAST

A detailed statistical analysis on usage between January 2002 and December 2009

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Abstract

Rous Water supplies potable water to approximately 100,000 persons in the Ballina, Byron, Lismore City and Richmond Valley Local Government Areas (LGAs) on the Far North Coast of NSW. This is an area of high and consistent rainfall, but with a growing population forecasts suggest water demand will exceed current supply between 2018 and 2030. A range of demand management strategies have been developed to delay the need to build new sources, including, from 2003, a residential rainwater tank rebate.

This paper evaluates the metered water savings attributable to tank installation by households receiving this rebate and how these savings are affected by water demand, tank-house connections and tank volume. Results indicate average metered water savings of 50kL/household/year with tank installation, ranging from 27kL/household/year for tanks connected for toilet, laundry and external use, to 43kL/household/year for external only connections, and 107kL/household/year for houses connected for all-of-house use.

Connection choices appear to relate to water use behaviour, with differences in pre-tank metered water consumption between groups choosing different connection options. Metered water consumption in properties receiving the rainwater tank rebate, both pre- and post-tank installation, is closely related to residential water demand in the greater community, but with reduced metered water use after tank installation. People who install large tanks yet do not connect them for all-of-house use seem to develop high water-use habits, with high rates of demand for reticulated water when tanks are empty.

Introduction

Widespread water restrictions during eastern Australia's prolonged drought of the 2000's highlighted the importance of conserving water held in centralised water storages. In response to this, rainwater tanks have been embraced by both governments and individuals as an important component of a secure water supply system. Recent estimates suggest that water tanks currently provide water to approximately 26% of Australian households, up from 19% in 2007 and 17% in 2004 (ABS 2010). In regional NSW the number of dwellings sourcing water from rainwater tanks is estimated at 28% (ABS: 2010). Rebates for the purchase and installation of household based rainwater tanks in the Rous Water supply area are currently provided by Federal, State and Local Governments.

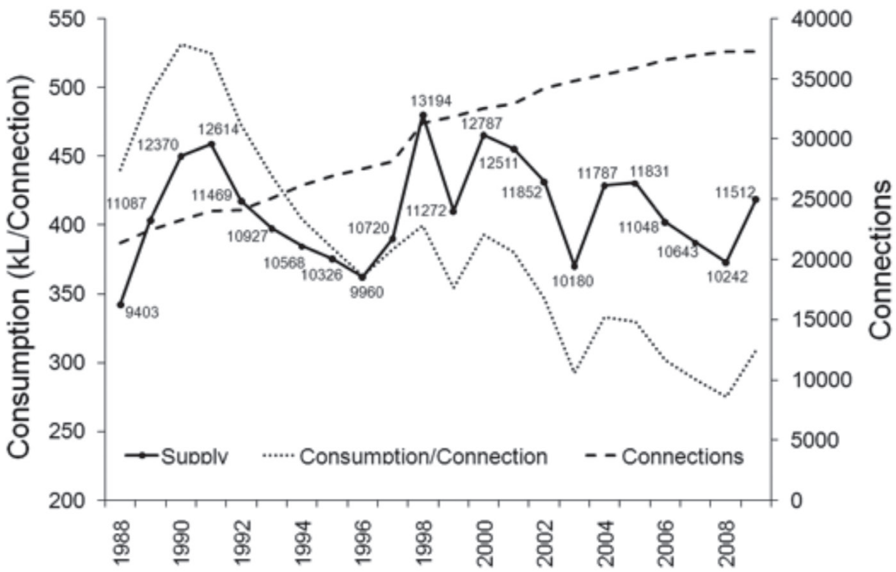

Figure 1: Rous Water Connections, Supply and Supply per Connection, 1988-2009. Data labels on the Supply line show total bulk water supply in ML/annum.

Rous Water supplies reticulated water to approximately 100,000 people in the Local Government Areas (LGAs) of Ballina, Byron, Lismore City and Richmond Valley on the Far North Coast of NSW (GeoLink: 2005). Although this region receives relatively high and consistent rainfall, the region's population is predicted to rise in the medium term (GeoLink: 2005; NSW DoP: 2006) and this is likely to place pressure on existing water supplies. Additional pressures include a "most likely" reduction in secure yield of 7.4% between 2006 and 2030 due to climate change (Kirono, 2006). Projections of future water supply and demand in the region have a large level of uncertainty, but generally suggest that demand for reticulated water will exceed current supply between 2018 and 2030 (GeoLink: 2005; Kirono, 2006).

In response to forecasts of future supply shortfalls, Rous Water formally adopted a policy in 1995 (Rous County Council 1995) which included a demand management program and two new water sources. The first new source is the Wilson River Source, which was constructed in 2008 and extracts water from the Wilson River tidal pool near Lismore. The second is the proposed Dunoon Dam on Rocky Creek, which will be constructed at a future time depending on the adequacy of water supplies. This policy was last reaffirmed by Rous County Council in December 2005 (Rous Water 2005).

In order to improve water efficiency a range of demand management strategies have been deployed by Rous Water. These strategies, combined with changing community attitudes to water use, have resulted in reductions to per connection water consumption that have offset increases in population and resulted in no net change to the community's total water consumption over the last 20 years. Figure 1 shows bulk water supply, number of connections and supply per connection from Rous Water's monthly reports from 1988 to 2009. Linear correlations on the Connections (R2=0.9785, p-value=2.2e-16) and Consumption/ Connection (R2=0.8173, p-value=8.2e-9) lines are highly significant; however, the linear correlation on their product, Supply, is insignificant (R2=0.0025, p-value=0.8246), indicating no change in bulk water supplied over the period.

Rous Water introduced a rebate for residential rainwater tanks on 20 February 2003. The rebate is based on tank size and connections for toilet flushing and washing machine. 913 rebates were granted between February 20, 2003 and November 18, 2010. A large increase in applications from 2007 coincided with the introduction of the State-administered NSW rainwater tank rebate.

Rainwater tanks are increasingly used by supply authorities as a tool in the management of water demand, yet very little evaluation has been conducted on the actual water saving from their installation (Turner *et al*., 2007). One study in South-East Queensland found a saving of approximately 20kL/household/ annum (Snelling *et al*., 2006), while another study in the ACT found savings of 12kL/household/annum (Lee, Plant and White, 2008, as cited in Retamal, Turner and White, 2009). Yet rainwater tank models commonly suggest water savings of between 30kL and 90kL/ household/annum, depending on tank-house connections, catchment area, tank volume, rate of water demand, rainfall characteristics, and a range of other variables (Marsden Jacob Associates: 2007; Teng, 2009; McCardell, 2009).

Rainwater tanks operate in a different manner to other demand management strategies in that they are a water source that, when plumbed into permanent water fixtures such as the toilet, laundry and outdoor taps, act to offset the demand for reticulated water rather than to reduce overall water consumption. Further, they differ from centralised water sources such as dams in that they can provide a very high yield for their capacity, providing their catchment is large and their rate of use high. Another feature of rainwater tanks is that roof catchments are generally non-permeable, and so create a greater proportion of runoff than natural catchments, which require the soil to be sufficiently saturated before runoff occurs. This may be crucial during dry periods when a rainfall event will have a proportionally greater effect on rainwater tank storage than on dam storage (Marsden Jacob Associates: 2007).

The aims of this paper are to measure the effect of rainwater tanks on the consumption of potable reticulated water in those properties receiving the Rous Water rainwater tank rebate. Effects of tank installation, water demand, household connections and tank volume are analysed.

Methods

General approach

This analysis compares pre- and post-tank metered water use (mwu) to determine the effect of rainwater tank installation on mwu between January 2002 and December 2009. The contributions of underlying water demand, tank-house connections and tank volume are assessed using multiple regression.

Property selection

Metered water consumption data was collected from Rous Water's constituent councils in early 2010 for all properties that had received the Rous Water rainwater tank rebate. Of the 607 properties to have received rainwater tank rebates at the time of data acquisition, 303 were chosen for analysis based on the following criteria:

- Properties have at least four meter periods (one year) of water consumption prior to and after tank installation;
- Properties are urban single residential dwellings (houses);
- Properties have valid data for all independent variables.

Dependent variable: metered water use (mwu)

The dependent variable mwu is sourced from Councils' water billing databases. mwu is the average daily metered water use at a house during a quarter. Each house has at least four values of mwu pre- and post-tank installation.

mwu is a non-normal right-skewed variable because it is limited to zero water consumption as a minimum, but has no limit on maximum water consumption (Figure 2, top). Non-normal data such as this is not suitable for statistical analysis and it is common practice to transform such data to a normal distribution prior to statistical analysis (Grafen and Hails, 2004). Choice of transformation depends on the direction and degree of skew; for this data a square root transformation of mwu achieves a normal distribution, as shown in Figure 2 bottom. All statistical analyses are conducted on the square root of mwu (√mwu) with results converted back to mwu for display where appropriate. Linear correlations derived using √mwu become second-order polynomials when converted back to mwu.

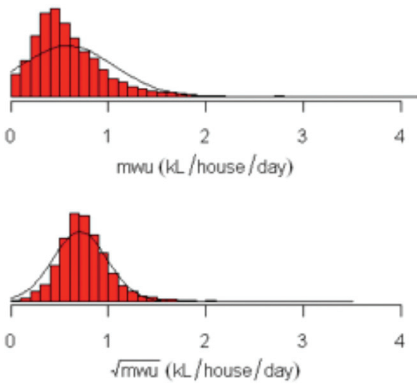

Figure 2: Histograms and normal curves showing normalisation of the right skewed variable 'metered water use' (mwu) by square root transformation. Top and bottom histograms show pre-tank mwu and pre-tank √mwu respectively.

Household mwu is highly variable, and a large proportion of this variability is likely to be due to differences in occupancy between dwellings. While statistical analysis based on per capita mwu would be preferable to per household mwu, it is not currently available (nor is it likely to become available) at either the household, LGA or Rous Water supply area, due to substantial difficulties in its estimation (e.g. GeoLink: 2005).

Independent variables: tank installation, tank volume, household connections, water demand

Rainwater tank installation is the first and primary factor by which mwu is analysed. Each meter reading is defined by whether the tank is installed (post-tank) or not (pre-tank). During the period where the tank installation date is uncertain, affected meter reads are removed from the analysis. The 303 properties used in this analysis contribute 5,533 pre-tank meter reads and 3,309 post-tank meter reads.

Tank volume data is collected in the rebate approval process. The distribution of tank volumes in the analysed group is shown in Figure 3 to range from 2kL (the minimum size required to receive the rebate) to 85kL, but with 75% of tanks less than or equal to 10kL.

Household connectivity information was collected during the rebate approval process. Connectivity is defined as connection to the bathroom, kitchen, laundry, toilet and external use. Properties may have any combination of these connections. All houses with internal connections to the rainwater tank are required to be plumbed so that metered water replaces tank water when the tank becomes empty. The distribution of household connection combinations in the rainwater tank group is shown in Figure 4. Approximately 60% of households have opted for external use only (1-e) connections.

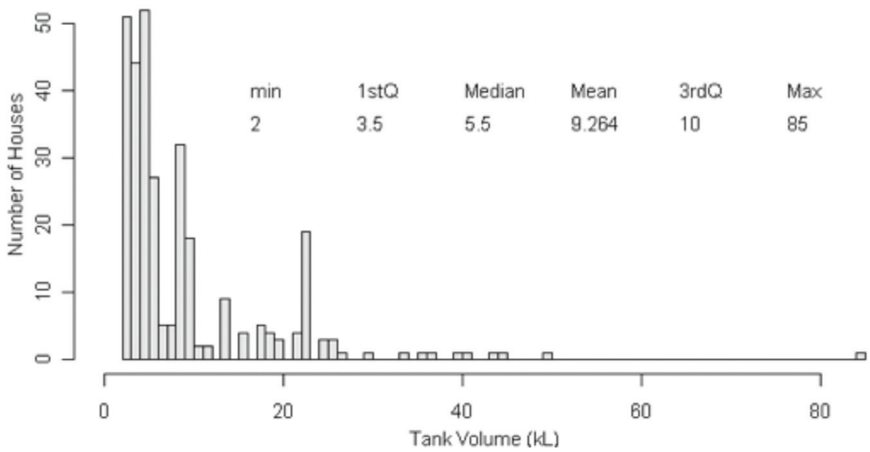

Figure 3: Histogram of tank volumes.

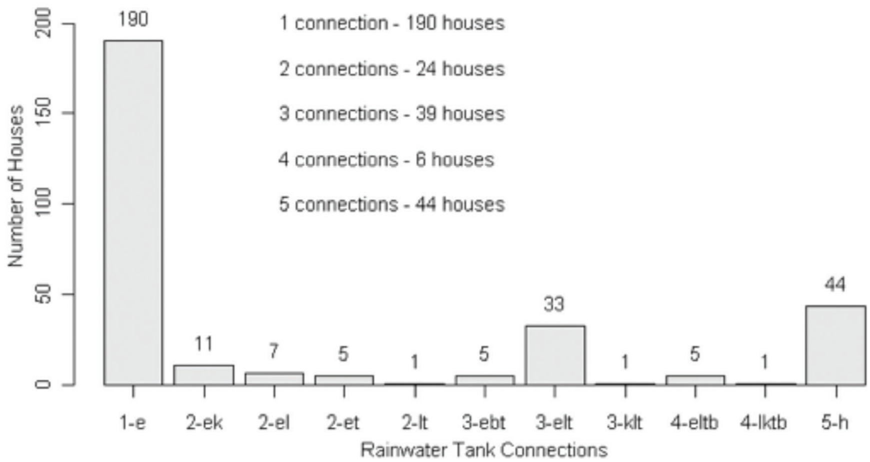

Figure 4: House-tank connection types. Number-letter codes beneath each bar indicate the number and type of connections: e-external; k-kitchen; l-laundry; t-toilet; b-bathroom; h-whole house.

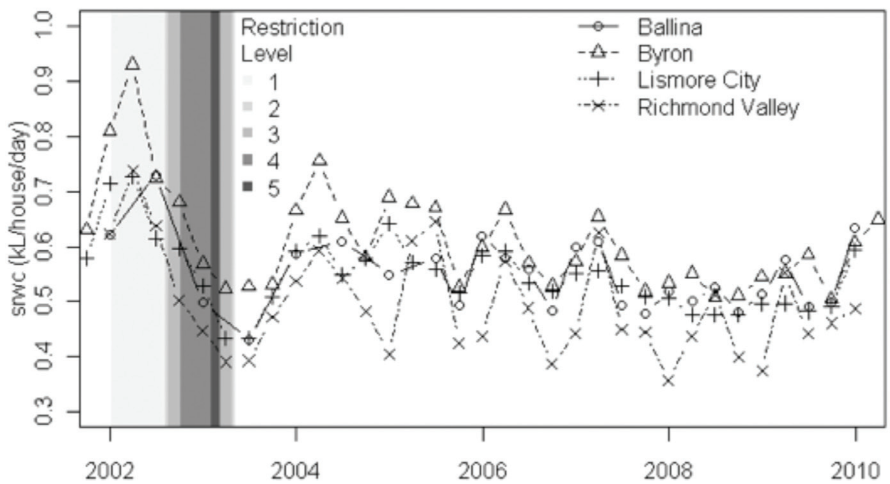

Figure 5: Time-series of single residential water consumption (srwc) and water restrictions for the four constituent council areas supplied by Rous Water, 2002-2010.

Water demand is affected by a range of factors including household occupancy, weather, climate, water outlets, garden water use, personal habits and a range of other variables, so it varies widely between dwellings. Except for weather/climate, none of the variables affecting water demand are available for analysis.

Prior to tank installation, total household water demand can be measured exactly as the metered water consumption of the household. After tank installation, because the proportion of the household's water use that comes from the rainwater tank is unmetered, total household water demand is unknown. This study uses the average daily water consumption of all single residential dwellings within an LGA during a quarter meter period as the measure of underlying water demand during that quarter. This is termed single residential water consumption and is abbreviated to srwc hereafter.

srwc is the product of all factors driving household water demand and so provides a quantified rate of water demand against which the metered water use of individual households or groups of households can be compared. srwc acts as a control group in this analysis.

There are a number of factors limiting the accuracy of srwc to deliver a true measure of total (metered plus unmetered) water demand. Among these are that it was not possible to remove water use by the rainwater tank rebated dwellings analysed by this study, or by dwellings constructed under BASIX building requirements, from the calculation of srwc. Both of these factors should result in progressive underestimation of srwc over time, resulting in an underestimate of water savings from tank installation. These groups are small in number relative to the total number of single residential dwellings in the Rous Water supply area (at most 5% of all single residential dwellings), so their affect on srwc is likely to be small.

Figure 5 shows a time-series of srwc for each LGA across the period of this study. The timing and severity of water restrictions is indicated. srwc was very low during the summer of 2002–03, a period of hot, dry (drought) conditions during which water restrictions were imposed between January 9, 2002 and May 10, 2003. The very low rates through the summer of 2002–03 coincide with category 3, 4, 5 water restrictions. There have been no periods of water restriction in the Rous Water supply area since May 2003, and all but two of the 3,309 post-tank meter records are from quarters without restrictions. Linear correlation of srwc over time shows that, from 2002 to 2010, srwc declined significantly ($p < 0.05$) in all LGAs except Ballina ($p=0.11$).

The validity of using srwc as a measure of water demand can be tested with a linear regression and correlation of srwc against pre-tank √mwu. Figure 6 (left) shows this linear regression and correlation within a 95% confidence band. Despite the wide variation in household √mwu (possibly due in large part to occupancy differences between dwellings) for any given level of water demand (as measured by srwc), the overall correlation of √mwu against srwc is very strong ($F = 209$, $P < 2.2e-16$). Conversion of this linear correlation to show the relationship between mwu and srwc is given in Figure 6 (right). Squaring the linear correlation on √mwu produces a polynomial correlation on mwu with a slope over the range of srwc very close to 1:1. This indicates that total water consumption in the rainwater tank group is consistent with that of the rest of the community and validates the use of srwc as a measure of water demand in the rainwater tank group. So, while we expect total water use to differ between dwellings (based on occupancy, water-use habits, garden size etc), we expect the average total water use in the rainwater tank rebate group to be consistent with srwc.

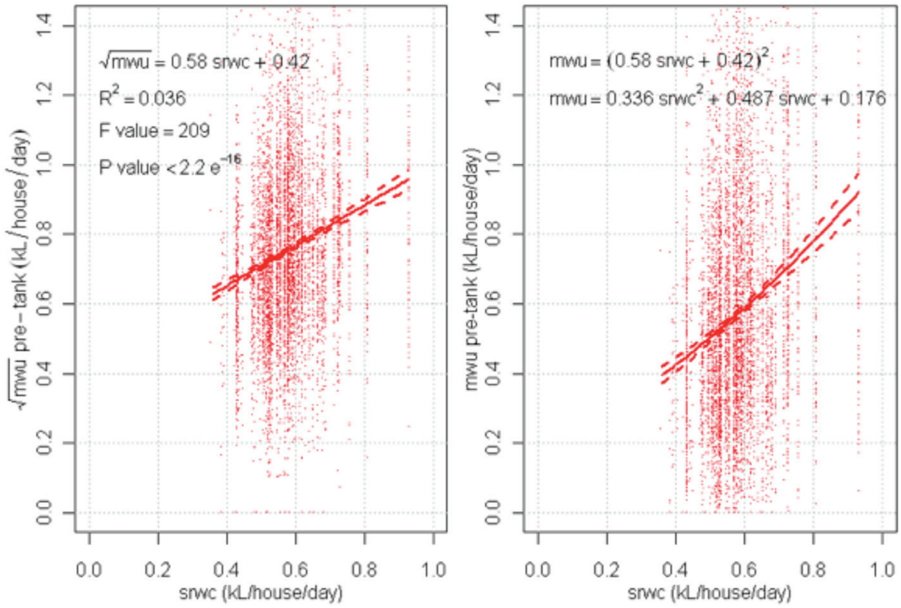

Figure 6: Correlation between single residential water consumption (srwc) and metered water use prior to tank installation. The polynomial regression of mwu by srwc (shown in the right-side graph) is derived by squaring the linear regression line of √mwu by srwc (left-side graph)

Analysis

All statistical analysis is conducted in R version 2.10.0 using standard statistical procedures including t-tests, linear correlation and regression, and ANOVAs. The purpose of the analysis is to describe the effects of tank installation, demand, tank/house connectivity and tank volume on metered water use. The steps in this analysis are:

- Determine whether tank installation has resulted in a reduction in metered water use;
- Consider whether a change in community water demand has occurred over the period of the study, and adjust the reduction in metered water in relation to this change;
- Analyse how reductions in metered water use differ between houses with different connectivity to the tank and in response to demand; and
- Analyse how tank volume interacts with demand and connectivity to affect metered water use post-tank installation.

Results and Discussion

Effect of tank installation

The first step in this analysis is to determine whether there has been an overall decline in mwu with rainwater tank installation.

Figure 7 shows histograms of √mwu for all meter reads pre- and post-tank. The normal distribution curve for each dataset is shown as a line. Not only has the average declined with tank installation, but the large number of zero consumption meter reads in the post tank period is indicative of the potential for water tanks to completely replace metered water when conditions allow it.

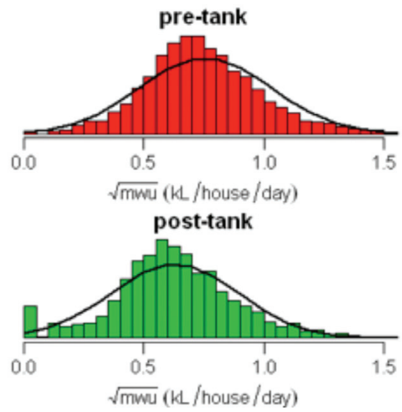

Figure 7: Histograms and normal curves of pre-tank √mwu (top) and post-tank √mwu (bottom).

The significance of the difference between pre- and post-tank mwu is statistically proven with a t-test, which confirms that the reduction in water consumption with tank installation is highly significant ($t = -21.6422$; $p < 2.2e-16$). The results of this test are presented in Figure 8, which shows pre- and post-tank meter reads and their mean and 95% confidence intervals. Pre-tank mwu averaged 0.573kL/house/day and post-tank mwu averaged 0.394kL/house/day, an average reduction of 0.179kL/house/day after tank installation.

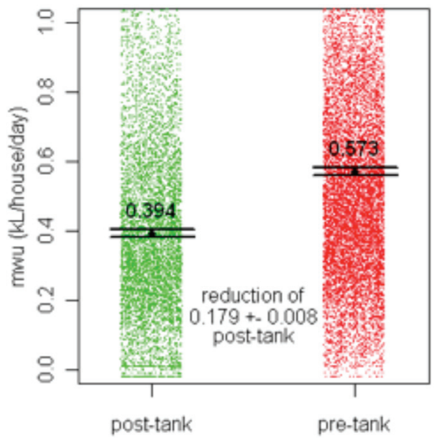

Figure 8: Metered water use (mwu) pre- and post-tank installation. Averages and 95% confidence intervals are shown.

Effect of changing demand

Figure 1 shows that srwc has generally declined over the period of the study and, given the close relationship between pre-tank mwu and srwc (Figure 6), we should expect the same decline in water use by the rainwater tank group.

Figure 9 shows srwc relative to pre- and post-tank meter reads, with means and 95% confidence intervals. The difference between average srwc pre- and post-tank may be regarded as the average change in water demand expected in these properties if tanks were not installed; a reduction of 0.043kL/house/day. Thus the average change in mwu with tank installation should reduce from 0.179kL/house/day to 0.136 kL/house/day or 50 kL/house/annum.

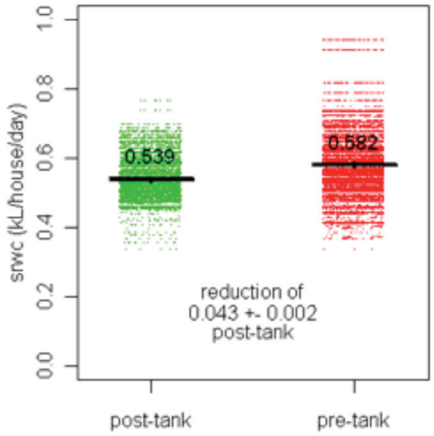

Figure 9: Single residential water consumption (srwc) relative to pre- and post-tank meter reads. Averages and 95% confidence intervals are shown.

The next question to ask with regard to water demand is whether the performance of rainwater tanks is affected by changes in water demand. This may be answered statistically with a two-way analysis of variance of √mwu by tank installation and srwc. This analysis shows that tank installation (F=280, p<2.2e-16), srwc (F=317, p<2.2e-16), and their interaction (F=7.73, p=0.005) are all significant factors contributing to mwu. The interaction between tank installation and srwc indicates that there are linear effects of srwc on √mwu but with different slopes for the pre- and post-tank meter reads.

Figure 10 shows these relationships, giving lines of best fit, 95% confidence bands and equations for pre-tank mwu by srwc, post-tank mwu by srwc, and the saving in mwu by srwc calculated as the difference between the pre- and post-tank lines.

Figure 10 illustrates that tank installation gives a significant saving in mwu but that this generally reduces as community demand increases. High community demand generally corresponds with hot, dry weather, during which time rainwater tanks are more likely to be empty, so it is not surprising that average mwu among the rainwater tank group should rise towards the average consumption in the LGA when demand is high.

Effect of tank-house connectivity

Figure 11 shows mwu pre- and post-tank installation for the three most common rainwater tank connections: external (1-e); external, laundry and toilet (3-elt); and whole house (5-h). Once the expected reduction in mwu is subtracted due to the reduction in srwc over the corresponding period, water savings from these three connection types average 0.117, 0.075 and 0.294kL/house/day (43, 27 and 107kL/house/annum) respectively. T-tests show that these reductions in mwu with tank installation are significant for all connection types (T=-20.4, -8.8 and -11.6 respectively, p values are all <2.2e-16).

Figure 11 shows that for these three connection options, 5-h connections result in greater water savings than the other connection types. Surprisingly, the 1-e group achieves higher water savings than the 3-elt group, which may be explained by the 1-e group having a significantly higher pre-tank water mwu (0.595 kL/house/day) than the 3-elt group (0.472 kL/house/day). Connection options may be related to differences in water-use habits, as external-only connections appear to be preferentially chosen by households with high water use, whereas external, laundry and toilet connections appear to be preferentially chosen by low water users. External use of tank water is presumed in all cases, as all tanks are fitted with a tap and it is a requirement of the rebate that tanks be available for external water use; however, the actual volumes of tank water used for each purpose is at the discretion of the occupants.

The combined effect of tank installation, water demand and connectivity on mwu is analysed with a 3-way ANOVA. The results of this analysis show that connectivity is a strong predictor of √mwu (F=30.7, p<2.2e-16) even after the effects of tank installation (F=336, p<2.2e-16) and srwc (F=306, p<2.2e-16) are taken into account. In addition, the interaction between tank installation, srwc and connectivity is also significant (F=4.13, p=1.05e-5), so we can say that tank installation reduces mwu; however, the amount of this reduction during any given meter period is dependent on both connection type and srwc.

These relationships are illustrated for the 1-e, 3-elt and 5-h groups in Figure 12. Water savings rise with srwc in the 1-e group (Figure 12 top), and fall as srwc rises in the 3-elt (Figure 12 middle) and 5-h (Figure 12 bottom) groups. This indicates that, while rainwater tanks connected for external-only use (1-e) generate relatively small water savings, they are less likely to fall empty during dry periods and so continue to contribute water to the dwelling. Whereas rainwater tanks that supply for the consistent

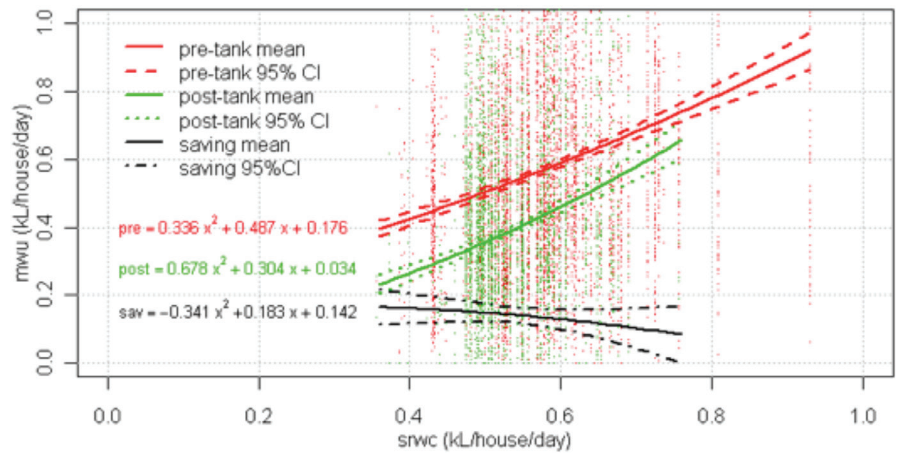

Figure 10: Lines of best fit and 95% confidence range for mwu pre- and post-tank installation, and metered water savings, relative to the community's single residential water consumption (srwc).

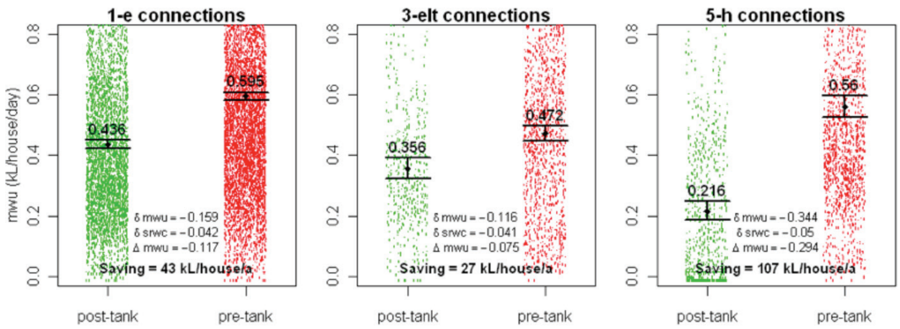

Figure 11: mwu pre- and post-tank for external only (1-e); external, laundry toilet (3-elt); and whole house (5-h) connection groups. Averages and 95% confidence intervals are shown. Change in metered water use (δmwu) is adjusted by the corresponding change in single residential water consumption (δsrwc) to give the reduction in metered water use (Δmwu) and the annual water saving.

demand of internal use tend towards being empty during dry periods and so provide reduced savings at this time. A second point to note is that the 5-h group has very high water savings during periods where srwc is low, yet these savings diminish rapidly when srwc rises to be at a similar level as the 1-e group when srwc approaches 0.7kL/house/day. The 3-elt group has relatively modest water savings at any time, with this saving reducing to insignificance when srwc approaches 0.57kL/house/day.

Tank volume

Tank volume is an important factor governing both the duration of the tank's water supply (in the absence of additional rain) and the volume of storage available for additional inflows. Both storage duration and storage availability are dependent on supply to, and demand from, the tank. Although we can expect metered water use in individual properties with rainwater tanks to rise as demand rises in the greater community, large tanks should continue to provide supply longer into dry periods and so continue to provide reductions in metered water use during these periods.

The effects of srwc, connection type and tank volume on post-tank √mwu are analysed using a 3-way analysis of variance, the results of which are shown in Table 1. For a variable or interaction to be significant Pr (>F) must be less than 0.05; thus tank volume is an insignificant factor (F=0.0003, Pr(>F) =0.9866) on √mwu when considered in isolation, but is significant in its interactions with other factors. The coefficients column shows the direction and magnitude of each factor/interaction on √mwu post-tank installation. A visual representation of the statistical relationships given in Table 1 are shown in Figure 13a-d.

The relationship between tank volume and metered water use shown in Figure 13a is somewhat surprising in that properties with large tanks appear to use more metered water than properties with small tanks during high demand periods. This relationship holds true for 1-e and 3-elt properties; however, it is reversed for 5-h properties, where mwu is less during high demand periods for properties with large tanks (Figure 13d).

One possible explanation for these relationships is that high water users choose larger tanks and so empty their tanks quicker than low-demand households with smaller tanks. However, this theory is not supported by a linear regression of tank-volume to pre-tank √mwu which shows no correlation between the variables. A second possible

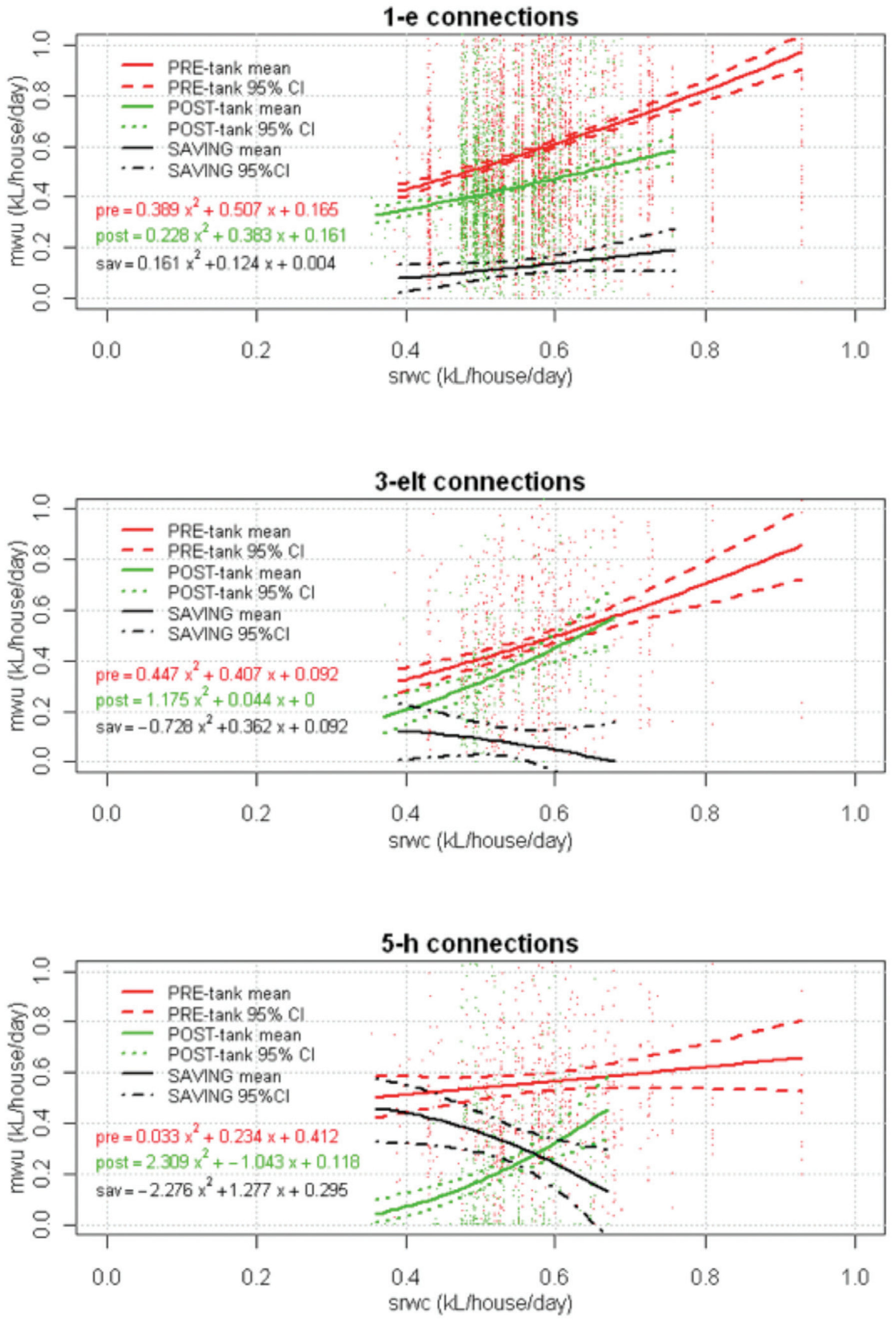

Figure 12: mwu and 95% confidence bands pre- and post-tank installation relative to the community's single residential water consumption (srwc) for: external-only (1-e); external, laundry, toilet (3-elt); and whole house (5-h) connection types. The water saving lines and confidence bands are the difference between the pre-tank and post-tank lines and confidence bands.

Table 1: F values, probability of insignificance (Pr(>F)) and coefficients for the statistical model (with interaction) of post-tank installation √mwu by connections*srwc*tank volume using Type I (adjusted) sums of squares.

Independent variable	F value	Pr (>F)	Coefficient
Connections	156.4	<2.2e-16	-0.130
srwc	98.1	<2.2e-16	-0.099
Tank volume	0.0003	0.987	-0.044
Connections: srwc	25.1	5.849e-07	+0.194
Connections: tank volume	46.7	9.617e-12	+0.005
srwc: tank volume	55.6	1.122e-13	+0.094
Connections: srwc: tank volume	6.11	0.0135	-0.013

explanation is that installing a tank results in a change in water use behaviour that is dependent on water use (connection options) and the relative abundance of tank water (tank volume). Thus large tank households in the 1-e and 3-elt groups may increase their total demand for water in response to their (normally) abundant supply of tank water, whereas 5-h households may be more circumspect with water use, accustomed as they are to being self-reliant for water. Increasing overall water consumption in response to rainwater tank installation is not without precedent; a recent study in South-East Queensland (Turner, Fyfe, *et al*., 2010) found that households with rainwater tanks used marginally more metered water than those that don't in the summer period, while in the winter period this was reversed.

Conclusions

Average water savings as a result of rainwater tank installation in the Rous Water supply area are calculated at 50kL/house/annum; external use connections saved an average of 43kL/house/year; external, laundry and toilet connections saved 27kL/house/year; and all-of-house connections saved 107kL/house/year. The amount of water saved during any period is dependent on the type of connection, the underlying water demand, and to a lesser extent the tank volume.

Choice of connections appears to be related to water use behaviour and external-only use connections seem to be preferentially chosen by households with a high proportion of external water consumption, so make low savings during low-demand (cool-wet) periods but increased savings during high demand (hot-dry) periods. External, laundry and toilet connections are low water users prior to tank installation, and so volume of water savings relative to pre-tank consumption is relatively small. All-of-house connections make very high water savings when demand is low; however, these savings rapidly fall as demand rises. Some level of increased overall water use appears to be occurring in houses with large tanks that have not connected for all-of-house use; these properties exhibit high metered water use during high demand (hot-dry) periods compared to properties with smaller tanks.

The findings of this study will be used to further enhance water savings associated with Rous Water's Demand Management Program.

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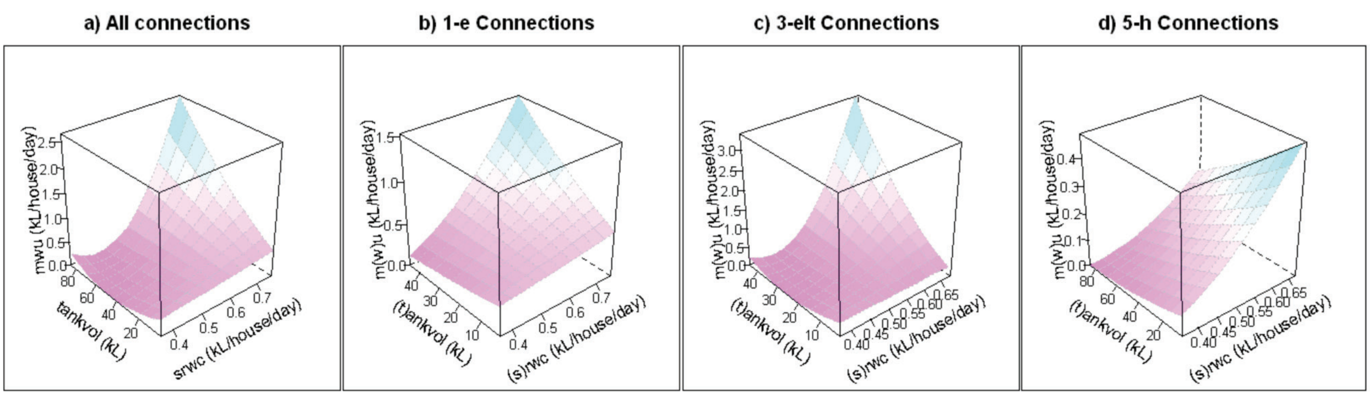

Figure 13 (a-d): 3-dimensional representations of the statistical relationships between metered water use post-rainwater tank installation (mwu) by tank volume and water demand (srwc) for: a) all rainwater tanks; b) rainwater tanks connected for external use (1-e); c) rainwater tanks connected for external, laundry and toilet use (3-elt); and d) rainwater tanks connected for all-of-house use (5-h).