Can rainwater tanks meet multiple sustainability objectives? An assessment of water conservation, pollution reduction and frequent flows from rainwater tanks in Sydney's Marrickville LGA

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ABSTRACT
In established urban areas, rainwater tanks can contribute to water conservation, reduced stormwater runoff and reduced pollutant loads. However, rainwater tanks are often assessed solely in terms of their water conservation benefits. This paper seeks to address this imbalance by presenting the results of a study on the multiple sustainability benefits of rainwater tanks. This paper presents data from a rainwater tank incentive scheme in Marrickville LGA and real-time metering of mains water and rainwater use of an individual household in the program. Monitoring of this program included water conservation, pollutant load reductions and reduction in frequency of runoff. Water quality monitoring was undertaken through grab samples of the rainwater and reductions to frequent flows were assessed through monitoring of the tank overflow.

INTRODUCTION

In recent years, due to the long drought that most capital cities in Australia experienced in the 2000s, rainwater tanks (RWTs) received an increase in popularity, funding, commercialisation and research. Due to the significant impacts that the drought had on urban water supply, the effectiveness of RWTs during this period were assessed solely in terms of their water conservation benefits.

For example Marsden Jacob Associates (2007) authored a report for the Australian Government's National Water Commission (NWC) on the cost effectiveness of rainwater tanks in urban Australia. The NWC put forward in their "Position" on RWTs in the report that "the model developed in this analysis to measure the cost and yield of rainwater tanks could form the basis of a standard methodology in Australia for assessing the cost effectiveness of tanks at the household level." Furthermore the NWC in their Position note that "cost effectiveness to households is not the only prism through which to assess rainwater tanks as a water supply option. Rainwater tanks should also be assessed for their contribution to integrated urban water cycle management." However Marsden Jacobs in the executive Summary to the report write that the "The purpose of this study is to review only the first of these objectives, i.e. the cost efficiency of installing rainwater tanks as a substitute for reticulated or 'scheme' water use."

Hence, by recommending the approach adopted by Marsden Jacobs Associates, rather than promoting more transparency in the evaluation and assessment of urban RWTs, the NWC continue to entrench the practice of assessing the cost effectiveness of RWTs on a single objective: as a water conservation measure.

In the NSW Government's Metropolitan Water Plan (2010) for Sydney, rainwater tanks receive very little mention. The *only* major future initiative identified with regard to RWTs is a "monitoring study to measure the long-term water and energy performance of rainwater tanks with the aim of identifying potential improvements".

This approach typifies the ongoing difficulty and inability of alternative water supply management to be assessed as part of an *integrated* water cycle management solution rather than as a single-objective device for potable water supply, wastewater management or stormwater management.

Academic and industry research into rainwater tanks has focussed on two key areas:

- The effectiveness of RWTs as a potable water conservation measure (for example Coombes et al., 2000; Imteaz et al., 2011; Knights and Wong, 2007).
- The quality of water for reuse to minimise health risks for microbial pathogens and heavy metals (for example Kus et al., 2010; Ahmed et al., 2011; Sinclair et al., 2005).

As an example, a literature review by the CRC for Water Quality Treatment (2005) found that only one academic paper had reported water quality concentrations of total nitrogen and total phosphorous in RWTs. No papers reviewed in the academic literature had monitored or determined the effectiveness of RWTs in nutrient load removals. This is in comparison to a wide range of literature on pollutant load removal for other treatment measures such as bioretention systems, wetlands or gross pollutant traps.

This paper seeks to address this imbalance by presenting the results of a study on the multiple sustainability benefits of rainwater tanks. The following aspects were investigated:

- Water conservation,
- Reduced stormwater runoff volumes
- Reduced frequency of stormwater runoff
- Reduced pollutant loads to receiving waters

Marrickville Council's rainwater tank incentive scheme

Marrickville Council is in the inner western suburbs of Sydney approximately 5 to 10 km from the Sydney CBD. Marrickville Council's Rainwater Tank Incentive Scheme (RTIS) commenced in October 2008 as part of a Council-wide strategy to decrease potable water consumption, decrease stormwater runoff and increase fit-for-purpose water use within the LGA. The stated aim of the RTIS is to "introduce SUWM [sustainable urban water management] in the private domain by reducing the 'effective impervious surface area' of Marrickville LGA" (Marrickville Council, 2007a).

The RTIS comprises three main strategies targeted at the local population including: providing Marrickville citizens with knowledge and skills to implement rainwater harvesting systems; offering a financial incentive by providing rebates for tanks installed in private properties; and capturing data about behaviours of rainwater tank users to improve industry knowledge.

METHODS

To monitor the multiple benefits of rainwater tanks for water conservation, water quality and runoff frequency a number of different methods were used to assess the impact of RWTs.

Water quality benefits

In order to determine typical pollutant loads single grab samples were taken at ten properties (9 private residences and 1 business) who have installed RWTs. Three grab samples were also taken, after three separate rainfall events, at one household to understand what variation there is in the water quality at different times.

Grab samples were taken directly from the rainwater tank and all but one sample was taken without filtration. The samples were sent to a NATA accredited laboratory for analysis for the following pollutants:

- Total suspended solids (TSS)
- Total phosphorus (TP), dissolved phosphorous
- Total nitrogen (TN), nitrates, ammonia and TKN

Taking samples from the tank only provides a partial indication of the total pollutant loads that are removed by RWTs. Grab sample concentrations, particularly for TSS are expected to be lower than the runoff from roofs, because sediment will settle out in the RWT.

Water conservation benefits

Marrickville Council has undertaken data collection as part of the RTIS. The data collection is a key part of its program to monitor the effectiveness of the program as well as part of a broader education program. Data is collected six months after installation to measure changes in water consumption and tank use. Council does this through monitoring the change in the water consumption of the property (through assessment of water bills provided by the Water Supply Authority) before and after the installation of the RWT (Hanley, 2011).

Individual Household Case Study – Water Conservation and Runoff Frequency

A more detailed assessment of water conservation and runoff frequency has been undertaken at an individual household. This household has a 4 kL RWT which collects water from the entire 140 square metre roof. The RWT is plumbed internally into all indoor uses except for the cold water tap for the kitchen sink. The RWT is not used for irrigation. The RWT is fitted with an automatic mains water switching device.

The two-person household uses the following efficient fixtures and appliances: 3-star shower head 10L/min, dual flush toilet 6L/3L, and a 4.5-star rated washing machine using 62 L/wash. Greywater is used for external irrigation.

A water meter has been installed on the outlet of the rainwater tank pump to the household. The meter records rainwater reuse when there is water within the tank and potable water use when the tank is empty. A data-logger with a pulse counter has been installed on this meter to log water use at 30 second intervals. A standard mains water meter is also installed on the mains water supply, which measures total mains water usage. Daily meter readings of the potable water meter have been taken.

A pressure gauge was installed to measure the level of water within in the RWT. Daily readings were taken and were used to calculate the volume of rainwater in the RWT and to determine the frequency of overflow from the RWT.

RTIS Rebate Structure

The RTIS rebate structure determines the cost to Council of the cost benefits of installing RWTs. Marrickville Council’s rebates for tank installation are calculated on the size of the tank and the number of connections within the residence or business (Table 1).

This method of calculating the rebate was designed to encourage residents and businesses to optimise the size of the tank and plumb it into as many services as possible up to a maximum of three: toilets, washing machine and hot water. The program has been running for three years and has installed a total tank capacity of 350 kL. Tanks have been installed in approximately 0.5 % of single dwellings in the LGA.

Table 1: Marrickville Council rebate calculation schedule *(*LIH - Low-income household)

Installation	Rate/ litre	LIH[+] rate/ litre
Tank only	10c	15c
Tank internally plumbed to 1 use – toilet(s) or laundry or hot water*	13c	20c
Tank internally plumbed to 2 uses – toilet(s) and/or laundry and/or hot water	18c	27c
Tank internally plumbed to 3 uses – toilet(s) and laundry and hot water	20c	30c
Tanks used in common areas of flats, units and apartments	Additional $500 flat rate to body corporate	

The rebate fee structure has been influential in ensuring that rainwater tanks are plumbed into two or more internal uses (toilets, laundry or hot water) in more than 70 % of rainwater tanks installed. More than 50 % of tanks are less than 4 kL in size and more than 85 % of tanks are less than 6 kL in size. Hence the program has generally encouraged householders to install relatively small rainwater tanks plumbed into multiple household uses.

It should be noted that Council's rebates were not the only rebate available to householders during this period. The local water authority offered a RWT rebate until 30 June 2011 and a Federal Government rebate was also available for tanks installed prior to 10 May 2011.

RESULTS AND DISCUSSION

Water Conservation

Potable water consumption of residents who had installed RWTs declined after installation of the RWT. Potable water consumption

- declined by 110 litres per household per day on average
- reduced between seven litres per household per day up to 390 litres per household per day (Figure 1 for all houses in Marrickville LGA who have installed tanks under the RTIS and provided data about consumption to Council)
- reduced by an average 25 % and varied between 10 % and 90 %

Single dwellings account for approximately 45 % of the water consumption in Marrickville LGA. If all single dwellings in the LGA adopted rainwater tanks in this manner total potable water consumption in the LGA would be reduced by approximately 11%.

In the individual household case study potable water consumption for the 2 person household prior to rainwater tank installation was 52 kl/yr or 142 L/p/d with the majority of water (75%) used for laundry and showers. The use of potable water within the case study dwelling after the rainwater installation is 8 L/p/d (based on daily readings of the utility's water meter at the household) and has therefore reduced overall household water use by approximately 90 %. Detailed monitoring of the use of the rainwater tank over a 4 month period is shown in Figure 2. The figure shows the monitoring of the volume of the water in the tank, the rainfall and the water consumption from the tank. The tank has been empty once over this period. Rainfall over this period is approximately 442 mm which is 10 % above the average rainfall for this period (399 mm). As noted above, in this case rainwater tank use is not affected by seasonal water use as neither potable water nor rainwater is used for irrigation purposes.

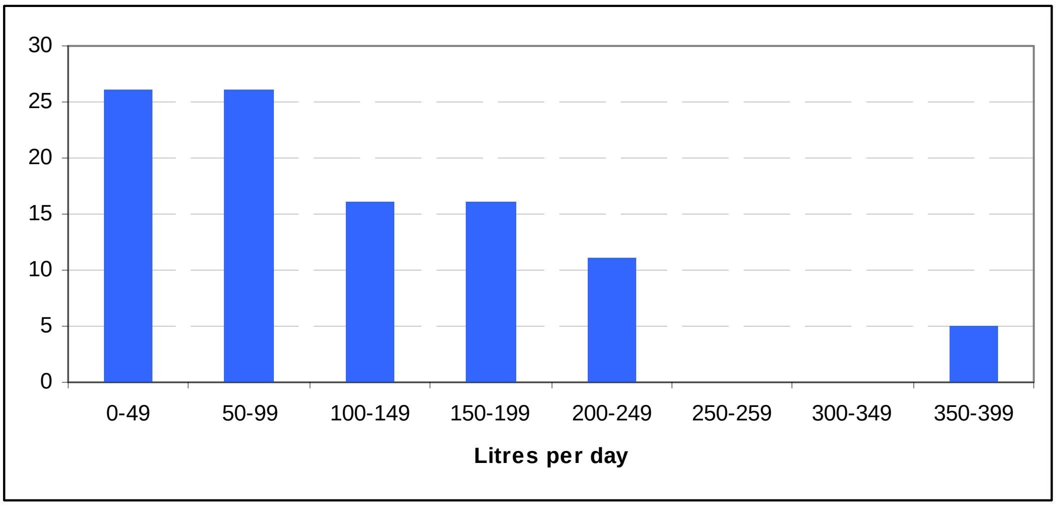

Figure 1: Daily potable water reduction in households after installation of RWT

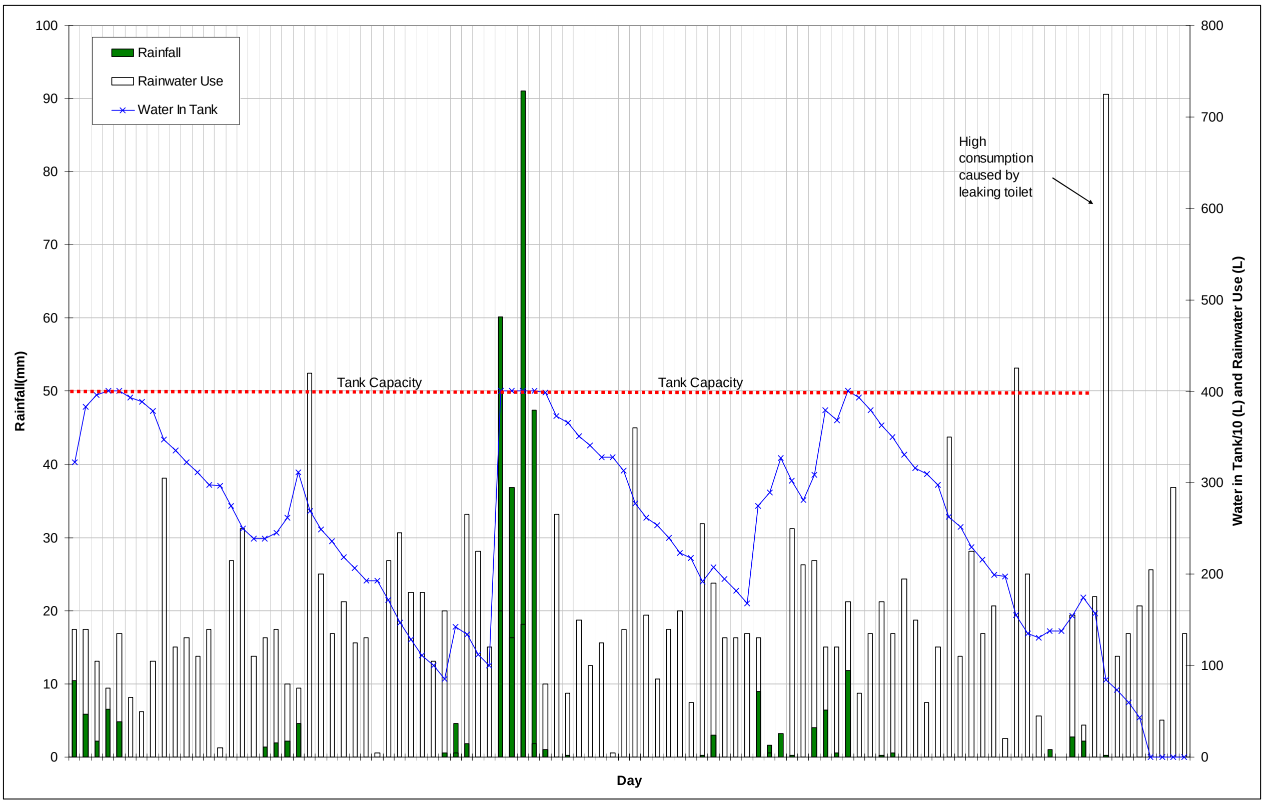

Figure 2: Rainwater tank use, rainfall and volume of water in tank over 4 month period

Water Quality

The results from the water quality testing of the RWTs are shown in Table 2. The results show that while there is some variability in the water quality data across the rainwater tanks, the data is fairly consistent and the results are within a relatively well defined range.

Table 2: Rainwater Tank Water Quality Results

Parameter	Samples	Mean (mg/L)	SD	Min (mg/)	Max (mg/)
TSS	10	5	3.5	1	16
TN	10	0.47	0.21	0.2	0.8
Nitrates	10	0.23	0.08	0.13	0.39
TKN	10	0.25	0.18	0	0.5
TP	10	0.054	0.09	0.01	0.26

The results for the three samples taken at an individual RWT are shown in Table 3. The samples were taken as follows:

- Sample 1 was taken after 0 mm in the previous day and 20 mm in the previous week
- Sample 2 was taken after 1 mm in the previous day and 6 mm in the previous week
- Sample 3 was taken after 12 mm in the previous day and 12 mm in the previous week

The results show that while there is some variability in RWT water quality, this variability is within a fairly consistent range. Also in the three samples taken there does not appear to be any strong correlation between volume of rain and water quality. Hence while runoff from roofs typically shows a first flush effect, this is not necessarily reflected in the overall tank water quality as the tank water quality was worst after the largest rainfall event for TN and TP in the three samples.

Table 3: Rainwater Tank Water Quality Variation

Parameter	Sample 1	Sample 2	Sample 3	Average
TSS	11	8	5	8
TN	1	1	0.4	0.8
Nitrates	0.07	0.27	0.15	0.16
TKN	0.8	0.7	0.3	0.6
TP	0.12	0.06	0.04	0.074

These results compare well with typical rainfall water quality runoff from other Australian studies (refer Table 4). The values found in RWTs in Marrickville are typical of RWT quality with the one key exception being the value for nitrates found in Newcastle in the Evans et al. (2008) study.

As discussed above, the sampled rainwater quality is likely to be an underestimate of pollutants captured as it does not account for pollutants which settle in the rainwater tank. Only one study in the literature reviewed (Morrow et al., 2010) has looked at the difference between rainwater collected directly from the roof and RWT water. This study found that the values from water in the tank can be considerably lower than the values for water running off the roof. This study found that TP concentrations in tank water were more than two times less than those in roof water.

Pollutant Load Removal

Pollutant load removal and the cost effectiveness of nutrient removal are shown in Table 5. These results have been based on the average pollutant concentrations in tanks based on the water quality samples taken (i.e. mean concentrations from Table 2), average water used per year in the tanks and the typical rebate cost per tank to Council. These values have been compared to the cost effectiveness of a typical small streetscape system that has been implemented by Marrickville Council to treat small residential catchments. These treatment systems have typically been bioretention systems less than 100 m^2 in size treating catchment areas of typically 1 hectare or similar of road, roof and pavement runoff. Based on MUSIC modelling, estimates of pollutant load removal for these treatments systems have been made. The typical cost of such treatment systems is \$500/m^2 (Knights et al., 2010). These values compare with typical values for Melbourne Water stormwater quality projects which range from \$83 to \$332 per kg of N (De Beurs and Fahrner, 2010).

The results show that rainwater tanks are significantly less efficient than treatment devices at removing TSS but are reasonable at removing TN. It is noted that these rates are likely to significantly underestimate the pollutant removal performance of RWTs. As Morrow et al. (2010) found, roof water quality is significantly poorer than water quality within RWTs and therefore the cost effectiveness of RWTs could be at least 2 times more effective than the values shown here.

Table 4: Rainwater Tank Water Quality – Values from Literature

Parameter	Average mg/L	Location	Samples	No of Tanks	Reference
TSS	5.7	Broken Hill	12	4	CRCWQT, 2008
TSS	2.32	Sydney	33	11	Kus et. al., 2010
Nitrite	0.006	Adelaide	12	6	CRCWQT, 2008
Nitrite	0	Sydney	3	1	Kus et. al., 2010
Nitrate	1.2	C, S, M, B	58	Not reported	CRCWQT, 2008
Nitrate	0.44	Sydney	33	1	Kus et. al., 2010
Nitrate	2.2	Newcastle	11	1	Evans et. al. 2006
Ammonia	0.074	C, S, M, B	44	Not reported	CRCWQT, 2008
Ammonia	0.18	Melbourne	6	1	CRCWQT, 2008
Ammonia	0.064	Sydney	33	1	Kus et. al., 2010
Orthophosphate	0.03	Sydney	33	1	Kus et. al., 2010
Phosphorous	0.054	Newcastle	104	2	Martin et. al., 2010
Phosphorous Roof	0.047	-	32	4	Morrow et. al, 2010
Phosphorous Tank	0.018	-	32	4	Morrow et. al, 2010

Table 5: Rainwater Tank Pollutant Load Removal and Cost Effectiveness

	Removal per tank (kg/yr)	Tank Cost Eff $/kg	Removal per m^2 treatment sys (kg/yr)	Treatment system Cost Eff ($/kg)
TSS	0.24	$636	12.1	$1
TP	0.002	$5535	0.021	$476
TN	0.24	$636	0.094	$106

Runoff Volume and Runoff Frequency

Runoff frequency and runoff volumes have been determined from the individual house case study. From visual observations of roof runoff it was estimated that approximately 0.5mm of rainfall was required to create runoff on the roof. Hence days with les than 0.5mm of rain were excluded from the analysis. The results show that:

- runoff volume was reduced by 37 % over the monitoring period
- the number of runoff days was reduced from 43 days to 12 days (over a 6 month period)

If all single dwellings in the Marrickville LGA installed a RWT of a similar size and number of connections to the RWTs installed in the LGA to date, runoff from the LGA would be reduced by more than 5 %. This is based on multiplying the current typical volume removed by rainwater tanks (110 L/hh/d) by the total number of single dwellings in the LGA. The total volume of runoff has been estimated using MUSIC and the overall impervious areas in the LGA.

CONCLUSIONS

The results from this study show that RWTs can provide multiple sustainability benefits including:

- provide reasonable nitrogen load reductions at a cost to Council comparable to other structural management methods
- reduce the number of runoff days from over 43 days to 12 days over a 6 month period
- reduce roof runoff volumes by 37 % over a 6 month period
- reduce water consumption by on average 110 L/d and up to 90 % of household consumption

Governments throughout Australia and the water industry in Australia generally advocate the principle of an integrated urban water cycle. However in practice when it comes to assessing water supply options the standard metric that is used is the cost of water saved or produced. Hence as

RWTs are perceived as predominantly an alternate water supply they are solely assessed in terms of their efficacy as a water supply measure. This is seen in the way that governments and the industry in general assesses RWTs against $/kL of water supplied and the way that research into RWTs has predominantly focused on the water conservation benefits and potential public health impacts of RWTs. Encouragingly, recent research (for e.g. see Burns et. al. (2010)) is looking at the economic benefits of RWTs in terms of stream health.

This paper attempts to highlight and address these gaps by applying some basic research to quantify the multiple benefits of RWTs. For sustainable water management to progress the industry, in its broadest sense, needs to shift from a single metric analysis to a more considered analysis which fully quantifies all of the sustainability benefits (and costs) of water management options.

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