Optimisation of Mains Trickle Topup Volumes and Rates Supplying Rainwater Tanks in the Australian Urban Setting

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Abstract

The use of roof collected rainwater stored in tanks as a supplement to traditional domestic urban water supply systems is becoming increasingly common in Australia, especially given growing environmental awareness and ongoing drought conditions. Rainwater tanks must be appropriately configured in order to effectively meet demand. Two important aspects of this configuration are the preset mains trickle topup rate and trickle topup volume. Improper configuration of these parameters may result in ongoing tank failure. As such, there is a need to improve our understanding of how these parameters influence tank performance in various rainfall climates around Australia. Following from previously published studies, this paper reports ongoing investigations undertaken to address this need. For a range of topup volumes and rates, it is shown that tank performance is highly dependent on demand, and comparatively weakly dependent on tank size. Seasonal variations in tank failure are investigated and correlated with rainfall and yield patterns, in the context of topup rate and volume configurations. Failure and yield surfaces are presented for a range of occupancies, and are discussed in relation to optimal rainwater tank design.

Introduction

Urban domestic water demand has traditionally been met by the construction of large-scale infrastructure. As urban population bases rise and drought conditions persist, attention has been increasingly turned towards consideration of decentralised systems to provide a supplementary source of water (e.g. Barry et al., 2005, Barry & Coombes 2006, Coombes, 2005 and WBM, 2005). One such system is the household rainwater tank.

In recent times, the capacity of tanks to at least partially meet domestic demand has been investigated in a wide range of settings and locations. The primary issue typically addressed is the likely long term average tank ‘yield’ (i.e. delivery volume of rainwater) and commensurate reduction in demand for water from the centralised mains water system. Recent studies have also examined potential downstream impacts of rainwater tanks in terms of their ability to attenuate stormwater flows and reduce flood impacts. Relatively little attention has focused, however, on the optimal configuration of rainwater tanks to ensure a particular level of supply reliability. Whilst some effort has been expended in determining optimum tank size in select locations (e.g. WBM, 2005), little attention has been given to the impact that other tank parameters might have on the reliability of supply. Two such key parameters are the mains trickle topup rate (TTR) and associated trickle topup volume (TTV). These two parameters describe the supply to, and storage of, mains water in the tank for use in times when rainwater supplies have been exhausted.

In order to address this issue, we have conducted a suite of numerical simulations across a wide range of demands, tank sizes, rainfall climates, TTVs and TTRs. We have examined the risk of failure across combinations of these parameters to provide a guide to the likely failure regime of rainwater tanks in several urban settings. This paper describes some of the results from the current study by focusing on long term and seasonal performance trends.
Methodology
The primary investigative tool used in this study was the Probabilistic Urban Rainwater and wastewater Reuse Simulator (PURRS) model developed by Coombes and Kuczera (2001). PURRS uses continuous simulation techniques to assess the long-term performance of source control measures including rainwater tanks, water efficient appliances, wastewater reuse and other stormwater management devices on urban allotments at short time steps (≤ 6 minutes), and determines the impact of rainwater tanks and other lot scale water reuse measures on the provision of water supply, sewage and stormwater infrastructure. Importantly for this study, PURRS uses a climate and behavior based water demand model (Coombes et. al, 2000). As such, the PURRS model accounts for the fact that during dry periods, water demands increase to higher levels than during wet periods.

In this study, multiple PURRS models were configured and executed to simulate a wide range of rainfall climates (and corresponding demands) as well as tank configurations. These are described below.

Rainfall Climates and Demands
Two of the key inputs to PURRS were the rainfall and demand data. These are described below.

Rainfall. Rainfall data was collected from Perth, Darwin, Cairns, Brisbane, Sydney, Melbourne, Hobart and Adelaide. The details of these are as follows:

- Adelaide: West Terrace pluviograph record: 01/01/1937 – 25/03/1979
- Brisbane: Brisbane RO pluviograph record: 01/01/1908 – 24/06/1994
- Cairns: Cairns AP pluviograph record: 01/01/1943 – 30/11/2000
- Darwin: Darwin AP pluviograph record: 01/01/1954 – 12/01/2000
- Hobart: Hobart AP pluviograph record: 01/01/1961 – 13/12/2001
- Perth: Perth RO pluviograph record: 01/01/1962 – 31/07/2001
- Sydney: Observatory Hill pluviograph record: 01/01/1913 – 12/10/2001

We note that most of the above pluviograph records included three or four significant drought periods, even though they excluded the current drought. Due to space limitations, only Sydney results have been presented in this paper.

Demands. Demands were specified for both indoor and outdoor use. The data for the above locations was sourced from State of the Environment reports, water authority web pages WSAA Facts.

The demand splitting within PURRS was set so that the rainwater tank supplied laundry, toilet, bathroom and hot water demands, as well as outdoor use. This is an ‘extreme’ application, but was selected to provide a ‘worst case’ scenario in terms of potential failures. No demand management was applied to any water stream, indoor or outdoor. Whilst we acknowledge that this scenario is unlikely to hold in practice, we note that further research beyond this study is planned to include more realistic scenarios and address impacts of water saving devices. It is noted that combinations of water efficient appliances and rainwater harvesting can produce greater synergistic benefits that are likely to mitigate these concerns but, nevertheless, adequate design of these systems is needed.
**Household and Tank Configurations**

The key model configuration inputs included occupancy (via demands), tank size, TTV, TTR and roof area. These are briefly discussed below.

**Occupancy.** Australian Bureau of Statistics (ABS) Census data was obtained to disaggregate the above demands into those corresponding to occupancy rates of 1 through 6 people. This data was obtained from the ABS webpage. A linear relationship between demand and occupancy was assumed.

**Tank Size.** Tank sizes of 2kL, 3kL, 5kL and 10kL were selected for all locations. These were chosen to capture the typical spectrum of tanks expected in an urban setting. A stormwater attenuation volume of zero was adopted.

**TTV.** A range of TTVs was selected to be representative of those in typical households. These were chosen to be 200L to 1100L in 100L increments.

**TTR.** A range of TTRs were used as: 20, 40, 80, 120, 200, 240, 280, 330, 620, 910 and 1200L/hr. Only simulations for Sydney were executed for TTRs less than 330L/hr, with the exception of 40L/hr, where all locations were considered.

**Roof Area.** A single effective roof area of 150m$^2$ was selected for this study. This is considered to be representative of the proportion of roof that can be connected to a rainwater tank from an average size residential dwelling in Australia.

The above specifications required the execution of 11,280 PURRS simulations. Consideration of variation in other parameters forms part of a larger study program being concurrently implemented.

**Data Analysis**

A large volume of output data was produced during the study. As such, attention was focused on a subset of the complete output. The parameters selected for subsequent analysis were long-term daily rainwater yield and daily hazard index, presented as functions of various input parameters. Daily hazard index has been computed as the maximum duration for which a simulated tank failed to meet demand (by supply of either rainwater or mains trickle topup) across each year. The same parameters were also computed on a seasonal basis.

**Results**

The results presented below comprise part of a larger study, and as such are fluid. Subsequent reanalysis may alter the results presented here. Attention has been focused on a subset of results, in order to provide an indication of the overall study findings and the importance of designing a rainwater harvesting system.

**Rainwater Yield**

To date, rainwater yield has typically been presented as line plots of yield against occupancy or tank size. Typical plots are shown below for Sydney.
With the more comprehensive data available from the current study, the above information can be represented more succinctly in a single colour contour plot, rather than a series of line plots. Long term average daily yield is shown below, as a function of occupancy and tank size, with colours corresponding to yield as per the colour bar.

One key feature of the data presented in Figure 2 is that yield increases with occupancy. In other words, the greater the demand placed on the tank, the greater the yield of rainwater. This is consistent with previous studies. More importantly, the Figure clearly demonstrates the non-linear relationship between yield, occupancy and tank size, even when a linear relationship between demand and occupancy is assumed, as is the case in this study. Put simply, scaling or linear interpolation (or worse still, extrapolation) of yield with either occupancy or tank size will not provide robust yield predictions. Finally, it is suggested that the style of presentation shown in Figure 2 be considered by those wishing to achieve a pre-selected long-term average yield for a given configurational arrangement (i.e. TTV, TTR, roof area and so on). It is noted that corresponding figures can be generated for any desired arrangement (and for any combination of x- and y- axes), thus providing a suite of ‘design curves’ (such as Figure 2(b)) for use in decision support systems.

**Tank Failure**

In addition to the above, some knowledge of the probable failure hazard is also required to inform tank selection and specification. As such, below we present the corresponding
The average annual maximum failure durations (in hours per day) for the same configurations presented in Figure 2. Figure 3a presents line contoured hazard data together with the same contoured yield data presented in Figure 2.

The Figure 3 shows that, as expected, failure is a weak function of tank size, yet a strong function of occupancy. This is because failure typically occurs during periods of prolonged drought, and as such tank size (i.e. its ability to store rainwater) is of no consequence to systems that are operating on mains trickle topup. Conversely, as occupancy increases, so does demand on the tank, thus increasing failure. Moreover, both data sets, as presented in Figures 2 and 3, should be considered when selecting, or regulating, rainwater tank configurations. The most appropriate style of data presentation to do so is shown in Figure 3b where failure line contours overlie yield colour contours, allowing simultaneous interrogation of both data sets. This data presentation methodology can be adopted for any tank configuration and geographical location desired.

**Rainwater Yield and Failure with TTV and TTR**

One focus of the current study was to examine the relationship between yield, failure, TTV and TTR. To date, little attention has been paid the impact that the latter two parameters might have on the former. In the authors’ experience, addressing this relationship typically receives little attention in the formulation of design or operation of rainwater tanks.

To investigate the above, yield and failure have been contoured against TTV and TTR for a typical residence (3 person residence with a 2kL tank) in Sydney. Results are presented below.
The figures demonstrate several key features. Firstly, it is clear that both TTV and TTR have an impact on both yield and failure, to different degrees and in different manners. As such, consideration of both should form part of rainwater tank specification and regulation.

More specifically, yield shows a strong inverse response to TTV for any constant TTR, which is expected, given that as TTV increases, less volume is available in the tank for storage of rainwater and subsequent supply. This storage volume reduction then translates directly to a reduction in long term average daily rainwater yield.

For any given TTV, yield also decreases with increasing TTR, and this is particularly pronounced for lower TTRs. At lower TTRs, the corresponding TTVs are replenished at a lower rate, allowing more rainwater to occupy the tank at any given time, and thus increasing yield. Beyond a certain TTR, however, the rate of decrease in yield for a given TTV decreases to approximately zero. This suggests that a point is reached where, in a long term average sense, replenishment of the TTV is affected sufficiently rapidly to ensure that the entire mains topup volume is (on average) present prior to rainfall subsequently entering the tank and being used to meet demand for water.

Figures 4a and 5a also suggest that this transition point in TTR increases from approximately 75 L/hr to 110L/hr with the increase in occupancy from three to four people. As previously
discussed, occupancy is directly related to demand, and as such a higher TTR is required for a greater occupancy to cope with off-setting increased demand. In particular, this increased demand means that higher TTRs are required to ensure that, again in a long term average sense, the TTV is fully replenished prior to the onset of rainfall re-supplying the tank.

Without consideration of failure, it may appear that reducing TTR will ensure that maximal yields are achieved. Figures 4b and 5b suggest that this is not correct: at these same low TTRs, the highest failures are observed. These failures are largely independent of TTV (except at the lowest TTVs), and decrease to negligible durations above approximately 100L/hr. This is consistent with Figures 4a and 4b in that below approximately 100L/hr TTR, a net deficit in TTV is accrued and during prolonged dry periods, failure results. At lower TTVs, elevated failures are evident at higher TTRs. This is most likely related to the TTV itself, with lower TTVs unable to meet the required demand, irrespective of the rate of renewal. To investigate this further, several addition simulations were executed at a constant TTR of 80L/hr, but with TTVs of 150, 100, 50 and 10L. The failure results are shown below, including the data presented in Figures 4 and 5. These are equivalent to a vertical 'slice' through each of the figures previously presented.

![Figure 6: Extended TTV Range Average Annual Maximum Failure (hours per day) with TTV (L) (a) 3 Person Sydney Residence, 2kL tank. (b) 4 Person Sydney Residence, 3kL tank.](image)

The Figure 6 shows that failure increases markedly with decreasing TTV, at the selected TTR, consistent with the size of the TTR causing failure rather than a decreasing TTR.

**Seasonality of Yield and Failure with TTV and TTR**

One further point of investigation of the current study was to examine the seasonality of yield and failure, as related to TTV and TTR. As such, Sydney data was again examined for the 3 person dwelling with a 2kL rainwater tank. PURRS results were interrogated only over summer (December, January and February) and winter (June, July and August) of each simulation year. Yield and failure statistics were extracted as seasonal descriptors: average yield and maximum failure duration. The combined data sets are presented below, with colour contours corresponding to yield (as per the colour bar) and lines representing failure durations in hours. Only the 1 hour hazard has been labelled, with other lines corresponding to integer hours increasing as arrowed.
Figure 7 demonstrates that summer yields are greater than winter yields, consistent with the higher summer (outdoor) demands. Failure also increases in summer at low TTVs and TTRs, compared to winter for the same reasons. Other trends are as previously discussed.

Conclusions
This paper has presented a small subset of initial findings from a larger concurrent study. It has shown that both trickle topup rate and trickle topup volume play an important role in determining the behaviour and performance of rainwater tanks in the Australian urban setting. As such, TTR and TTV should be considered when specifying, designing and regulating rainwater tanks, particularly if yield and failure regimes are of importance. An outline of methodology has been proposed to do this, and provision of ‘design curve’ style data sets for a range of locations across Australia to inform this methodology will comprise part of the future deliverables of the larger concurrent study.

References