Parameters Influencing the Selection of an Optimal Rainwater Tank Size: A Case Study for Melbourne

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Abstract

Melbourne, with nine consecutive below average rainfall years is facing a severe drought. The spatial variability of rainfall in the Greater Melbourne area is high, from 450mm in the west to 1100 in the north-east. Rainwater is a resource which could be used as an alternative source of water for domestic use such as: toilet flushing, garden watering and in the laundry. The selection of the correct size of a rainwater tank is important to optimize the use of rainwater. The rainfall variability in Melbourne confirms that the ‘one size fits all’ approach is not optimal. This study contributes towards determining the optimum size of a rainwater tank taking into consideration variation of the rainfall within metropolitan Melbourne. The sizes are determined after considering the geographic location in Melbourne, daily rainfall, roof size, intended use of rainwater and the supply reliability desired. For example, the study found that for a 2 kL tank, the water supply reliability varied from 87% to 98% for different locations across Melbourne considering the demand for toilet flushing and garden watering from a 250m² roof area. It is important to ensure that there is enough water in the tank to meet the demand reliably. The study concludes that it is important to closely examine the spillage and usage relationship for the desired reliability before selecting the appropriate tank size for domestic use.

1. Introduction

Melbourne leads the world in having the highest quality drinking water. Nevertheless, like other developed cities in the world, it has to confront a growing water demand due to increasing population and economic development. In addition, Melbourne is facing a severe drought having its ninth consecutive year with below average rainfall. According to DSE (2006) the government has set a target for reducing per capita water consumption by 25% and 30% by 2015 and 2020 respectively. Furthermore, the above report stated that the average annual temperature could rise by 0.3°C to 1.0°C and that the stream flow could fall by 7% to 64% by 2055 in the Central Region. Hence, it is essential that water authorities explore the possibility of using alternative water sources to counter this forecasted acute water shortage.

Stormwater is a valuable resource that is currently wasted. However, it could be harvested for productive use. The water from rainwater tanks have been used productively for decades in rural areas and in developing countries where potable water supply networks are not established. Coombes (2004) reported that significant demand reductions could be achieved by supplementing centralised water supply with rainwater collected from roofs and stored in tanks at the urban allotment scale for toilet flushing, hot water and outdoor users. Coombes and Kuczera (2003) analysed the performance of rainwater tanks in Australian capital cities. The above authors assessed the impact of water supply due to use of rainwater tanks ranging in sizes from 1 kL to 10 kL in Adelaide, Brisbane, Melbourne and Sydney where the annual rainfall varied from 520mm, 1110mm, 660mm and 960mm respectively and identified opportunities for significant average annual mains water savings.

In September, 2001 the Victorian Government declared that town planning (except in heritage zones) approvals are not required throughout Victoria for the installation of rainwater tanks up to 4,500 litres capacity (Urban rainwater systems, 2007). The study also noted that Victorian legislation conferred legal rights to property owners for using rainwater.
Amendments to the Water Act 1989 passed in April 2002, explicitly provide for property owners’ continued rights to the unrestricted use of rainwater for domestic purposes on their property free of charge. The benefits of rainwater are maximised if it is used for toilet flushing, garden watering and for laundry. Victorian Government policy is to support the use of rainwater tanks for potable substitution whilst meeting the Department of Human Services guidelines and regulations set by the Plumbing Industry.

Rainwater can be collected from individual buildings in isolated tanks or in large central storages constructed to collect runoff from several houses. In the decision making process related to purchasing or constructing a tank, there are a number of important variables that need to be considered. Consumers often install rainwater tanks based on affordability. In addition to considering the cost to maximise the return, it is important to select a tank based on a number of factors including the amount of water that could be reliably collected, the demand for the water and the risk of the rainwater tank running dry. At present a potential user in Melbourne for a rainwater tank has no reference material or guidelines to determine the optimum size of the tank when purchasing a tank other than the area available to install the tank, the aesthetic issues and the money the house holder is willing to spend for the tank. The extent of the catchment (roof area), the rainfall over the area and the anticipated use of the volume of rainwater collected (i.e. demand) are all important variables that would contribute towards determining the optimum size of the tank. The size of the tank will also determine the supply reliability or the water available in the tank to supply the demand satisfactorily. The Water Sensitive Urban Design Manual (2005) provides some guidelines when selecting tank sizes based on mean annual rainfall, roof area, roof water demand for toilet use and supply reliability for three different hydrological regions in Victoria.

In Melbourne, annual rainfall varies from 450 mm in the west to 1100 mm on the north-east. The main objective of this study is to investigate the variability in rainwater tank size with the intended use and for a given location in Melbourne to provide a reliable supply. The study reported herein demonstrates that there is a significant difference in tank sizes selected to meet a given demand, even within the greater Melbourne area. In addition, the paper introduces the concept of supply reliability for rainwater tanks and highlights key decisions a user must make before investing in a rainwater tank. In effect, the concept of reliability provides the rainwater tank user with a feel for the ratio between the volume of water used from the rainwater and potable supply assuming that the rainwater tank is connected to the mains supply. The paper presents the simulation methodology adopted to calculate the size of the rainwater tank and details the relationship between the size, the number of occupants within a dwelling, roof area and the supply reliability at different geographic locations within the metropolis. It is also important to minimise the probability of spill (wastage) from the rainwater tank to the urban drainage system during rainy periods. This paper will address the relationship between spillage and usage for different types of domestic demands and help the potential customer to choose an appropriate rainwater tank size for an acceptable ratio of spillage to usage for the customer selected supply reliability. The paper concludes that the decision related to determining the size of the rainwater tank to be installed in ones property is ultimately a compromise between maximising the use of the available rainwater, the reliability of meeting the demand throughout the calendar year, the investment required and the space available.

2. Study areas

The data base for the study consists of 10 rainfall stations distributed across the Greater Melbourne metropolitan area (Figure 1). The daily rainfall data were used for the analysis.
3. Estimation of the rainwater tank size

A simple water balance model was used to calculate the tank size. The volume of rainwater in the tank depends on the volume of water flowing into the tank and the demand for rainwater as an alternative water source to conventional supply. It is important to ensure that there is enough water in the tank to supply the demand with minimum risk of the tank being empty (maximum reliability). The daily storage level of the water tank would depend on the frequency and the amount of rainfall and the end use. The water balance equation used for the study is given in Equation 1. A daily time period was considered for the study as it is important to ensure that there is sufficient water for the domestic use intended.

\[ S_{t+1} = S_t + Q_t - D_t \quad 0 \leq S_{t+1} \leq C \]  

where,

- \( S_{t+1} \) = Storage volume in the tank at the end of \( t^{th} \) day
- \( S_t \) = Storage value at the beginning of \( t^{th} \) day
- \( Q_t \) = Runoff from the roof into the tank on the \( t^{th} \) day
- \( D_t \) = Total demand for water on the \( t^{th} \) day
- \( C \) = Active tank capacity

The inflow (\( Q_t \)) depends on the daily rainfall. The daily demand for water (\( D_t \)) depends on a number of factors. It is a regulatory requirement in Victoria, Australia to limit the use the rainwater for toilet flushing, laundry use, hot water systems and for garden use. As a result the water demand depends on a number of factors such as the number of occupants in a house, the garden size and also the weather. Equation 1 is applied at the end of each time step (daily) to obtain the water storage level at the end of the day. On a particular day if \( S_{t+1} \) was greater than the tank capacity (\( C \)) the excess water will spill over and the tank storage level at the end of the day will be readjusted to \( C \). The amount of water spilled is calculated using Equation 2.
Spill on the \( t^{th} \) day = \( S_{t+1} - C \) \hspace{1cm} (2)

The probability of failure during the availability of data is computed using Equation 3.

\[ P_f = \frac{p}{N} \times 100 \] \hspace{1cm} (3)

where, \( P_f \) is the probability of tank being empty as a percentage; \( p \) and \( N \) are the number of days the tank is empty and total number of days respectively after the tank was full for the first time. The reliability of meeting the demand is computed using Equation 4

\[ R_e = 1 - \frac{P_f}{100} \] \hspace{1cm} (4)

where, \( R_e \) is the reliability of meeting the demand and \( P_f \) is as given in Equation 4.

If the desired reliability (selected by the user) is not achieved with the assumed capacity, a new tank size (\( C \)) is assumed and the above procedure is repeated until the required reliability level is achieved.

**Determination of roof runoff (\( Q \))**

The amount of water that could be collected is important to optimise the size of the rainwater tank for sustainable water use. Equation (5) was used to calculate roof runoff into the water tank.

\[ Q = I_{eff} \times C \times A \] \hspace{1cm} (5)

where, \( Q \) is the daily runoff (L), \( I_{eff} \) is the daily effective rainfall (mm) calculated using Equation 6, \( C \) is the coefficient of runoff and \( A \) is the roof area connected to the tank (m\(^2\)).

The quality of initial runoff from a roof surface or from an impervious surface after an event is usually poor due to accumulation of dust, sediments, bird and animal droppings, and leaves and debris from the surrounding areas. Coombes (2001) reported that many researchers allow a fixed amount of the first portion of rainfall to be wasted when calculating the discharge into the rainwater tank and this portion is called the first flush. As given in Equation 6 the daily effective rainfall is calculated after subtracting the first flush amount.

Daily effective rainfall, \( I_{eff} = \) Daily rainfall - First flush \hspace{1cm} (6)

Yaziz et al (1989) and Coombes (2002) reported that subtracting the first 0.33 mm of rainfall from the total daily rainfall as the first flush would significantly improve the roof water quality. A runoff co-efficient value of 0.8 was used in the study to account for loss of water due to evaporation, minor infiltration from the roof surface (Lancaster 2006, DEHA 1999) and in some instances, to cover overflow from roof gutters.

**Determination of the demand for water (\( D_d \))**

As detailed earlier, the Victorian Government regulations limits the rain water use to toilet flushing, garden watering, and laundry use and in hot water systems. Only the first three demand types were considered in the study and the water used in the hot water system was not considered. Anecdotal evidence from water authorities suggests that the % of users connected to the hot water system at present is minimal. However, this may change in the future and if necessary the methodology presented herein is sufficiently robust to incorporate this. Toilet flushing and laundry use are considered as indoor use whereas garden watering is an outdoor use. The inhouse demand for water depends on the number of occupants in a house. This is applicable for toilet and laundry use. However, garden watering depends on the
outdoor area and the season, summer or winter. For instance, the demand for garden watering was constrained to be occurring only in the summer season.

Gato (2006) reported results from analysing end use data during three monitoring periods in summer 2002, and in the summer and winter period in 2004 from 24, 99 and 80 households respectively. Based on above authors recommendations 16 L/person/day (Lpcd) and 40 Lpcd were taken as the demand for toilet and laundry use in this study. In addition to Gato (2006) study, Roberts (2004) also reported on garden water usage. Considering recommendations from both studies, the demand is taken as 190 L/day for typical water usage for gardening in Melbourne. It is also considered that garden watering will be carried out only during summer season on every odd day of the month. These approximations are used to examine the spatial variability of sizing tanks across Melbourne. Further refinements for garden water use are planned based on the area available within ones property and watering habits later.

4. Relationship between tank size and reliability for different stations in the study area

The curves in Figure 2 depict the relationship between the water supply reliability and the size of the water tank for different roof sizes in Berwick, a suburb in Melbourne (see Figure 1). It is clear from these curves that the water supply reliability will change with the roof size (supply). Figure 3 depicts the reliability and tank size for different demand types for three occupants in a house from a 250 m² roof in Berwick. The reliability of using the rainwater collected from the 250 m² roof size with a 2 kL tank reduces from 97% to 86% when the harvested water is used from only laundry use to, laundry, toilet and garden use. Based on Figure 3, to attain a 93% reliability, the tank size varies from 4.3 kL (toilet, garden and laundry) to 1.1 kL (laundry).

The differences in tank sizes to meet similar demands and the impact of the spatial variability of the 10 stations are evident in Figure 4. The figure depicts the relationship between the supply reliability and rainwater tank sizes for different locations in Greater Melbourne for use in toilets and gardens from a 250m² roof area for a house with 3 occupants. The average annual rainfalls for these stations vary from 450mm to 1050 mm. From Figure 4 it is evident that for a supply reliability of 90%, the tank size varies from 0.6kL in Kinglake in the Northeast of Melbourne to 2.1kL in Altona, in the west of Melbourne to meet the toilet and garden demand. Although the annual rainfall values in Werribee, Rockbank and Altona are around 450mm (Figure 1), due to temporal variation of the rainfall the optimum tank size varied considerably if 95% or more reliability was required. To summarize, it can be concluded that the annual rainfall (geographic location) and the temporal distribution of rainfall are important in determining the optimum rainwater tank size.

A potential customer of a rainwater tank has to also consider the cost of the rainwater tank and the area available for installing it before selecting the appropriate rainwater tank. The cost of installing and running a rainwater tank is impacted by installation costs (tank cost, plumbing cost, installation/fitting cost, tank foundation cost and water pump cost) and the ongoing cost (energy and maintenance cost). Table 2 details the differences in tank sizes and the costs of the tanks with 90% reliability for three locations in Melbourne designed to meet the same demand. For example, for a maximum demand of indoor (toilet & laundry) and outdoor the tank size varies from 2kL in Kinglake to 14 kL in Werribee to meet the same supply reliability. If this demand is to be supplied (assuming that the tank can be fitted) the cost of the tank would vary from $975 in Kinglake to $7000 in Werribee (Rainwater tanks 2007) significantly penalizing the consumer in the Werribee area. Moreover, Jacobs (2006) reported that the levelised cost of a rainwater tank in a Melbourne household with the
catchment size of 50 m$^2$ varied from $8.40/ \text{kL}$ to $10.41/ \text{kL}$ when the tank size varied from 2 kL to 10 kL. Thus it is very important to select the correct size of the tank based on the intended use of the rain water and the desired reliability before investing in the tank.

Figure 2 Relationship between the water supply reliability and tank size for different roof sizes in Berwick

Figure 3 Relationship between the water supply reliability and tank size for different demand types from a dwelling with a 250m$^2$ roof area in Berwick (T - toilet flushing; G - garden watering; L - laundry use.)

Figure 4 Relationship between the water supply reliability and tank size for different roof sizes and one demand type (toilet and garden use) for 10 different stations (See Fig. 1 for locations)
Table 2 Relationship between tank size, reliability and variation of price of the selected tank for different demands

<table>
<thead>
<tr>
<th>Demand</th>
<th>90% reliability (kL)</th>
<th>Price range of the tanks($) depending on location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Berwick (710 mm)</td>
<td>Werribee (453 mm)</td>
</tr>
<tr>
<td>Toilet</td>
<td>1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Toilet + Garden</td>
<td>1.9</td>
<td>1.6</td>
</tr>
<tr>
<td>Toilet + Garden + Laundry</td>
<td>5.7</td>
<td>14.0</td>
</tr>
<tr>
<td>Garden</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>Laundry</td>
<td>0.8</td>
<td>3.5</td>
</tr>
<tr>
<td>Garden + Laundry</td>
<td>1.6</td>
<td>6.0</td>
</tr>
<tr>
<td>Toilet + Laundry</td>
<td>1.9</td>
<td>8.2</td>
</tr>
</tbody>
</table>

5. Spillage and usage

In selecting the rainwater tank and the intended use, it is also important to minimise the spillage (or overflow) from the tank to maximise the usage. The demand for rainwater, the size of the tank, roof size and the location all have a direct impact on both spillage and usage. The customer would also want to secure a reasonable supply reliability as well to minimise potable use. For a typical household in Berwick of a roof size of 250m\(^2\) and a household of three people, Table 3 details the relationship between reliability, spillage, usage and tank size for a demand capable of meeting toilet flushing, garden watering and laundry use needs.

Table 3 Spillage, Usage and Reliability relationship for different tank sizes

<table>
<thead>
<tr>
<th>Tank Size (kL)</th>
<th>Spillage/Usage</th>
<th>Reliability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.2</td>
<td>61</td>
</tr>
<tr>
<td>2</td>
<td>1.59</td>
<td>75</td>
</tr>
<tr>
<td>3</td>
<td>1.37</td>
<td>82</td>
</tr>
<tr>
<td>4</td>
<td>1.26</td>
<td>85</td>
</tr>
<tr>
<td>5</td>
<td>1.18</td>
<td>88</td>
</tr>
</tbody>
</table>

From the above table, it is evident that with the increase of tank size, the ratio of spillage to usage decreases as a larger tank can accommodate more water providing a higher reliability. The decision has to be taken by the potential user of the rainwater tank as to what the appropriate size of the tank is after considering the demand that is planned to meet, the reliability of supply required, the cost and the land area required to install the rainwater tank.

6. Conclusions

The study analysed the collecting of catchment runoff in rainwater tanks within the Greater Melbourne area with volumes ranging from 1 kL to 5 kL restricting the use to some indoor use and outdoor garden watering only. The rainfall pattern of Melbourne indicates that there is significant rainfall variability in the Greater Melbourne Region. Similar variability is expected in areas surrounding other major cities in Australia, such as Sydney, Brisbane and Adelaide. The study shows that to meet the same demand (toilet and garden use), and to achieve the same reliability (90%), the tank size required varied from 0.6kL to 2.1 kL across Melbourne. In summary a consumer in Werribee would need to invest $3000 in a rainwater tank to meet the same reliability achieved by a person living in Kinglake where the latter had
to only invest $700. This study clearly demonstrates the disadvantages and social inequity resulting from mandating the installation of rainwater tanks across the Greater Melbourne area. A potential user also needs to predetermine what demand it wants to satisfy garden (external) or internal use (toilets only or (toilet and laundry both)) prior to selecting the appropriate size. Moreover, the user also needs to appreciate the concept of reliability as there are significant costs related tradeoffs to be made prior to purchasing a rainwater tank.

7. Acknowledgements

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