Impact of Residential Irrigation Area and Roof Size on the Economics of Rainwater Harvesting Systems

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Abstract: *Rainwater harvesting (RWH) has grown in popularity over the last 15 years and has attracted a significant amount of research. The economic viability of RWH systems has been reported with various outcomes. The water demand profile is complex and of all domestic demands, outdoor irrigation use is potentially the largest and most variable. The quantity of water available for harvest is influenced not only by the rainfall pattern and tank size, but also by the area of the roof used to harvest the water (the RWH system's catchment). Roof area can vary considerably with the size of the house, or because parts of the roof are unsuitable for harvesting (e.g. due to overhanging trees, practicality and/or cost of the guttering arrangement). A versatile economic evaluation tool named ERain has been developed to analyse the economics of various RWH system arrangements. ERain combines performance analysis using daily rainfall data with life cycle cost analysis. Outputs from the model include economic indicators such as benefit cost ratio (BCR) and net present value (NPV) reported against performance indicators such as reliability (% of days the demand is met) and efficiency (% of available water used – i.e. that not lost to overflow). Here ERain has been used to assess the effects of varying roof size or irrigation area on the economic viability of RWH systems for tank sizes ranging from 1-7kL. Results show that excluding outdoor use, the BCR increases with roof size along with reliability while efficiency decreases. Interestingly, the larger roof area has the most significant effect in terms of reliability on the smaller tanks. Including outdoor use reduced reliability overall and increases efficiency and BCR indicating that it is better financially to use the RWH system for outdoor use when reliability is not a concern. However, the pattern of BCR and NPV is different from when no outdoor use is attached. When outdoor uses are not connected reliability is high even with a smaller tank, and so a larger tank offers little advantage. However, once outdoor use is connected small tanks have a low reliability which can be increased with a larger tank. When analysing various irrigation areas tank sizes up to 15kL were considered. The larger NPVs and BCRs occur with the larger irrigation areas as this increases water use and hence monetary water savings. The highest BCR occurs with a 15kL tank; while the highest (least negative) NPV occurs with a 10kL tank as it did without outdoor use connected. Within the 1-7kL tank range, the 7kL tank is the most favourable when outdoor irrigation use is connected.*

Keywords: Rainwater tank, rainwater harvesting, economic analysis, roof area, tank size.

1. INTRODUCTION

As a result of the millennium drought rainwater harvesting (RWH) has become a significant feature in Australian suburbs. Australia has the highest RWH system adoption rate in the world at 34% of households. With this has come a significant amount of research and installation guidelines from various sectors including universities, government and other research organisations such as Commonwealth scientific and industrial research organisation (CSIRO). For example, in 2008 the Master Plumbers and Mechanical Services Association of Australia (2008) developed and published a Rainwater Tank Design and Installation Handbook (HB 230-2008) for regulatory authorities, installation professionals and homeowners. In 2010 the Environmental Health Committee produced a timely revision of the 2004 Guidance on use of rainwater tanks (EnHealth 2010) in response to the ongoing interest in using RWH systems. Various rebate schemes were introduces which have now been reviewed by several authors and government departments (Gato-Trinidad et al. 2014; Hall 2013). RWH reports were prepared for the prime minster and cabinet. In many cases RWH systems have been mandated for new constructions. In NSW, for example, they were included in Building Sustainability Index (BASIX) requirements Now we are starting to see reviews of RWH system use globally (Campisano et al. 2017; Christian Amos et al. 2016; Sharma et al. 2016). In Australia since the drought has eased, and in Sydney particularly there appears to be a reduced interest in RWH systems, and the desalination plant also gone out of focus. Basix compliance records from 2005 to 2015 (BASIX 2016) reveal this current trend. However internationally there is heightened interest in RWH systems, Australia has been criticized for its weak water security (Beatty et al. 2009; Burton et al. 2015), so it is likely that RWH systems will continue to be a prominent, if not more prominent feature of the Australian landscape.

The economic viability of RWH systems has been reported with various different outcomes, predominantly at a cost, but some report a positive financial evaluation. Assessing the viability of RWH systems faces a number of challenges. Firstly including all the costs involved, particularly the maintenance and replacements costs which are often neglected. Secondly modelling the systems performance is difficult and often based on various assumptions about water consumption, and a standardised site (roof area and tank size particularly). Irrigation and outdoor use is potentially the most variable household water use, with some owners using virtually no water outdoors, to others using large amounts, especially when there are no restrictions in place. The quantity of water available for harvest is influenced especially by roof area supplying the RWH system (its catchment). Roof area can vary considerably with the size of the house, or because parts of the roof are unsuitable for harvesting (e.g. due to overhanging trees or the practicality and/or cost of the guttering arrangement). The rainfall pattern, tank size and water demand profile will also affect how much water can be harvested. Irrigation use particularly will be influenced by the rainfall and the season.

Most studies use a standard roof size and quantity of water used for irrigation. The Australian Bureau of Statistics (2013) report that in NSW approx. 48% of people use mains water to irrigate. Here we have developed a versatile economic evaluation tool named ERain to investigate the effect of varying roof size and irrigation water use on RWH system performance and the economic viability. ERain combines performance analysis using daily rainfall data and various water demand profile data with a detailed life cycle cost analysis based on AS/NZ Standard AS4536 “Life Cycle Costing – an Application Guide” (Standards Australia 2014). Model outputs include both performance and economic indicators which can be compared. Economic measures reported include the benefit cost ratio (BCR) and net present value (NPV) and performance indicators include reliability (% of days the demand is met) and efficiency (% of available water used – i.e. not lost to overflow). In this study ERain has been used to assess the economic implications of varying the roof size and the irrigation area of RWH systems with tank sizes ranging from 1-7kL.

2. MATERIALS AND METHOD

2.1. Scenarios

This study considers a single occupancy house of 4 occupants with site dimensions similar to those used in previous studies (Hajani et al. 2013; Rahman et al. 2012) excepting that the overall site area is reduced from 450 m^2 to 400 m^2, reflecting the tendency towards smaller lot sizes. This also reduces the nominal landscaped area from 150 to 120 m^2. Irrigation use is modelled on landscape area and so areas of 40, 80, 120, 160 and 200m^2 are considered to reflect variation in water use. There is a tendency in Sydney at the moment towards larger houses, and so a standard roof area of 200 m^2 is considered with variation of 100,150,200,250 and 300m^2 to cover the majority of the roof sizes in Sydney.

The RWH system is used for the toilet laundry with and without irrigation and outdoor use. Tanks sizes ranging from 1-7 kL and including 10 and 15kL tanks when irrigation use is included reflecting the tank sizes commonly installed to fulfil or exceed the BASIX legislation requirements. The vast majority of tanks are in the 0-2kL, and 2-3kL range, with a few larger than 10kL in the Parramatta area. For costs "Slimline" tanks have been assumed as these are the most common in urban areas where space is limited. Losses of 1mm per m^2 of roof area, a first flush volume equivalent to the first 0.5mm of rain and a mains top up level of 5% of the tanks volume are adopted.

2.2. Rainfall Data

The Rainfall data from Parramatta (Station no-066124) which has data for 1965 – 2015 was used in this study being located approximately in the centre of Greater Sydney. Its average annual rainfall is 964mm while the 5th Percentile is 612.

2.3. Water Demand Profile

The profile chosen in this research was designed around looking at each specific water use and calculating estimates for each starting with quantities obtained from the Reece Sustainable Bathroom Guide and the distribution of water use between uses reported by Kuczera et al. (2003). The overall usage that these specific values yielded where then compared with the averages given by Sydney water, 297 L/person per day. This resulted in an average consumption of 172 L/person/day excluding outdoor use (which varies and is ultimately shared between the occupants) and a maximum outdoor use of 1233 L/household. Toilet use is based on two full flushes and one half flush of a 3 star toilet per person/day resulting in 23.5L/d/p. Laundry use is based on 3 loads for every 2 people each week in a 3 star washing machine resulting in 150 L/p/week or approximately 10.7L/p/d. Outdoor uses include washing one car per household every 2 weeks at 180L/wash, and a low estimate for washing hard surfaces of 8min per week (at 18L/min) resulting 20L/day assuming that some people may also water the garden or wash the car at the same time. Irrigation use is calculated at 10mm depth of irrigation per household per day multiplied by the irrigation area assumed for the property (generally 120m^2) giving 120m^2*10mm = 1200L/hh/day, which is comparable with assumptions used in other studies (Hajani et al. 2013; Rahman et al. 2012). A sprinkler may use 1000L/hr so it is not unreasonable to think that a property may have 2 sprinklers running for 30-40 min per day which would result in approximately the 1200L of water as assumed in this study. Irrigation is assumed to stop when there are consecutive days of rain. Variation in irrigation use between users is modelled by changing the area of irrigation considering 40, 80, 120, 160 and 200m^2.

2.4. Economic Inputs

Values for Interest and Inflation (other than water) were taken as 4.6% and 2.5% respectively from the WACC biannual update report for the water industry produced by Independent Pricing and Regulatory Tribunal (IPART). The primary benefit is the monetary value of the water saved; this is calculated as the annual average amount of water saved as calculated by the daily analysis and summary modules, multiplied by the current water price of $2.28/kL (including a service charge of $114.04) from Sydney waters Prices for customers 2015 which compared with a recent water bill. Water inflation rate was taken from Prices for customers 2016-2020. Costs have been categorised according to AS/NZ 4536:1999 Life cycle costing - An application guide (Australian/New Zealand Standard™ 2014).

Predominantly the Acquisition and Use and Maintenance Support categories are considered while renewal and adaption and disposal were not.

Life Cycle Phase A – Acquisition

Costing a RWH system installation is a complex issue as there are so many varieties of installation type that are possible as well as the level of advice that may be used to design the system. In this analysis the focus has been the effect of tank size on the economic viability of the system. For this reason a middle of the road price has been adopted for most aspects of the system and special attention given to costs that would vary with different size tanks. Prices were obtained from various suppliers and compared with Cordell and Rawlinsons (Rawlinsons 2015; Solutions 2015) where they had comparative pricing. The hourly rate for the various trades was average values from taken from "payscale" an online guide for trade rates. An example of some of the capital costs are shown in Table 1, labour costs are included elsewhere.

Table 1. Acquisition costs

	units	per unit	Total
Catchment and Drainage System			
Roof Treatment to adequate standard		-	
Downpipes to tank	1	\$43	\$43
Guttering		-	
Tank			
Tank volume (kl)=(m^3)	3		
Tank slab area	2.37		
Cost of land /m^2	2.37		
Levelling ground (m^2)	2.37	\$13.87	\$32.89
Concrete base for tank (exclude labour) (m^2)	2.37	\$104.22	\$247.16
Number of Tanks	1	\$990.91	\$990.91
Tank Delivery			\$0.00
Water Treatment			
Gutter and downpipe screening	1	\$15.00	\$15.00
Tank and inlet screening, passive treatment, outlet height			
First Flush device	1	\$17.00	\$17.00

Life Cycle Phase B – Use and Maintenance Support

Dividing the RWH system into separate sections helps identify the various maintenance issues. These costs occur on a scheduled basis rather than at acquisition. Repair and replacements are considered to carry more cost to the owner than general maintenance which the owner is assumed to do himself. The pump is assumed to run for 2 hrs/day using 0.9KW/h at \$0.2122 per kWh.

3. RESULTS AND DISCUSSION

3.1. Varying roof size (toilet and laundry only installation)

Results from varying roof area for a 3kL tank show that the reliability and BCR increase with roof size while the efficiency decreases (Figure 1). Only 30% of the available water is being used even with a small roof area. Reliability increases to over 70% with a larger roof area even though the efficiency decreases to a little above 10%.

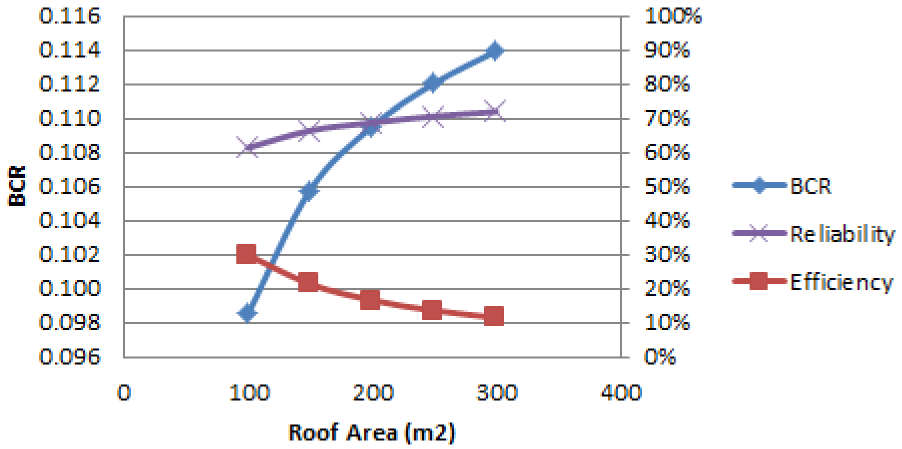

Figure 1. Roof area vs. BCR, reliability and efficiency for 3kl tank (toilet and laundry use)

Interestingly it is with smaller tanks that the increased roof area has the biggest effect in increasing the reliability. For a 1.1kL reliability increases from a minimum of 61.4% to max of 72% (a 10.6% increase); for a 7kL tank this is only from 95.1% to 99.6% (only a 4.5% increase). This then is reflected in the NPV and BCR. For example a 1.1kL with 300m^2 of roof area tank has a better NPV (i.e. less negative) than a 3kL tank with only 100 m^2 of roof area.

3.2. Varying roof size (toilet and laundry and outdoor installation)

Adding outdoor use to the RWH system reduces the reliability considerably but increases the efficiency and the BCR. This indicates that it is financially advantageous to use the RWH system for outdoor use if reliability is not a concern. Figure 2 shows results for a 5kL tank.

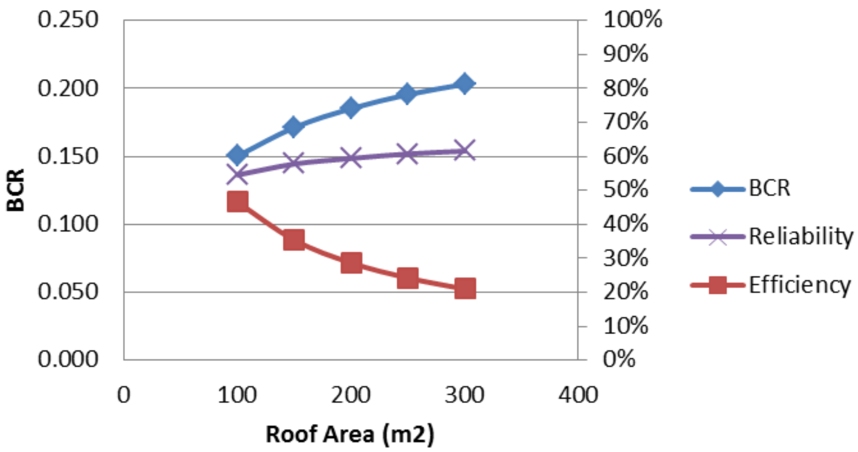

Figure 2. Roof area vs. BCR, reliability and efficiency for 3kl tank (toilet and laundry and outdoor use)

Reliability increases with roof area because the larger catchment means the smaller rainfall events become more effective in filling the tank. Efficiency decreases because the larger rainfall events result in a larger overflow. Unlike the toilet and laundry only installation the NPV of a 1.1kL tank with a roof area of 300m^2 is not more favourable than the 3kL tank with a roof area of only 100m^2. This is because when outdoor uses are not connected reliability is quite high even with a smaller tank, and so with the larger tanks there is not much room for improving reliability. Once outdoor use is connected the reduced reliability leaves room for greater increases with tank size. The highest NPV is still negative ($16657) and the BCR less than 1. Interestingly the highest (least negative) NPV occurs with a 10kL tank, while the highest BCR is 0.355 with a 15kL tank. It appears that generally the BCR leads to a larger tank size being more favourable than the NPV.

3.3. Varying irrigation area (toilet and laundry and outdoor installation)

Results for varying irrigation area with a set a roof area of 200m^2 are shown in Figure 3 for 1.1, 3 and 5kL tanks.

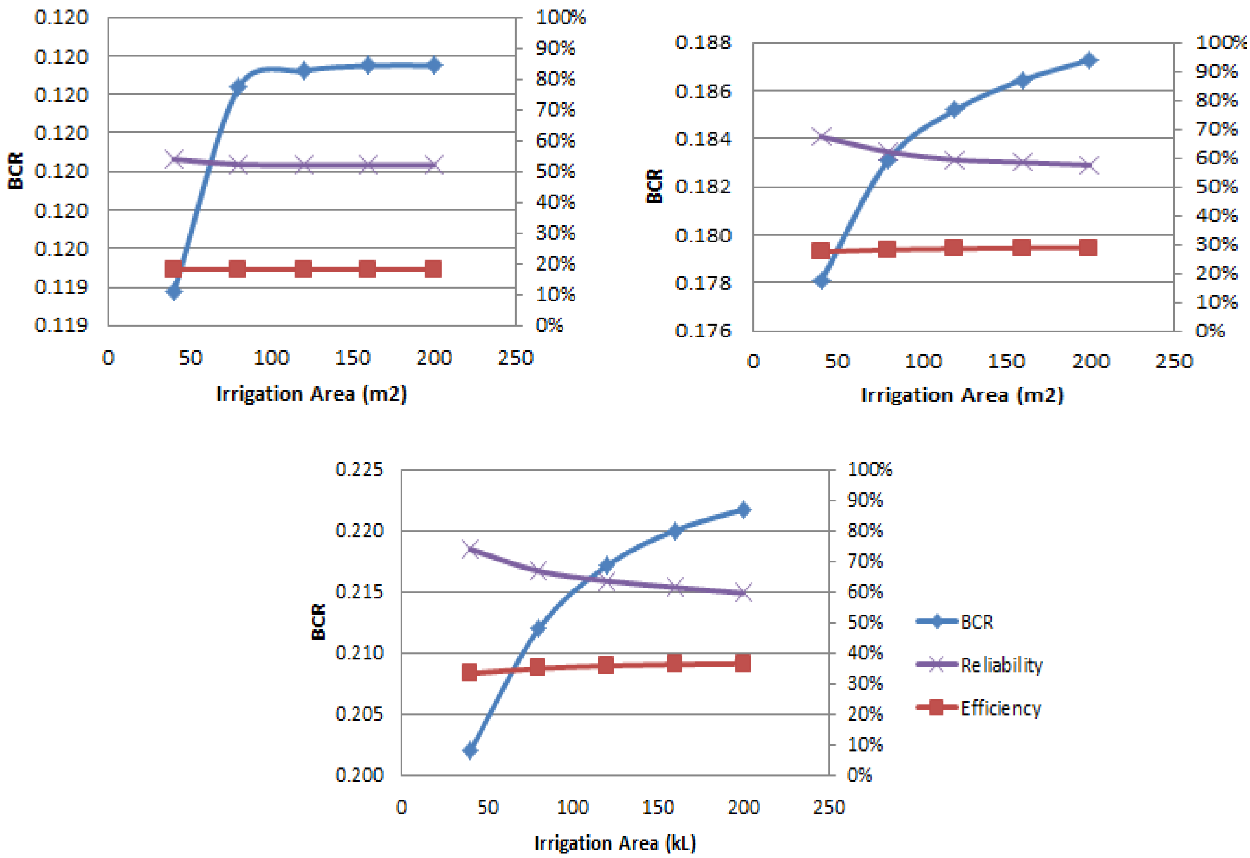

Figure 3. BCR vs irrigation area for a 1.1 tank (top left), 3kL tank (top right), and a 5kL tank (bottom)

For the 1.1 kL tank, there is a slight increase in BCR in going from 40 to 80 m^2 of irrigation area, which hardly increases further with more irrigation area. Efficiency and reliability are virtually unchanged implying that the RWH system has nearly reached its potential to supply water even with a small area of irrigation. With the 3kL tank the BCR is larger overall and shows a bigger increase with irrigation area. Efficiency increases slightly and reliability declines with a larger irrigation area. This implies that the system is approaching its maximum capacity to supply water. However reliability is still below 70% even with a small irrigation area, and efficiency does not get above 30%. The 5kL tank has a more favourable BCR for all areas of irrigation and shows a higher efficiency and reliability. Efficiency appears to be reaching a maximum, implying that this RWH system cannot supply much more water. Results showed that larger NPVs and BCRs occur with the larger irrigation areas as this increases water use and hence monetary water savings. The highest BCR occurs with a 15kL tank; while the highest (least negative) NPV occurs with a 10kL tank. These results could be affected if future rainfall patterns do not reflect those recorded over the last 100 years or less (Haque et al. 2016).

4. CONCLUSION

Increasing roof area for a toilet and laundry only installation increases both the reliability and BCR while decreasing efficiency. For a 3kL tank only 30% of the available water is used with the smallest roof area. This decreases to 10% with the largest roof area while reliability increases to over 70%. Interestingly it is with smaller tanks that the increased roof area has the biggest effect in increasing the reliability.

Including outdoor use reduces the reliability overall considerably while the efficiency and BCR increase. This indicates that it is financially advantageous to use the RWH system for outdoor use where reliability is not a concern.

Increasing roof area for an installation including outdoor uses has a greater effect. The decreased reliability means that there is greater potential for increasing reliability with a larger tank or roof area. This changes the pattern of BCR and NPV. Without outdoor use attached reliability is already high with a small tank and so a larger tank offers little increases in reliability. The lower efficiency at larger roof areas compounds the increase in reliability with increasing tank sizes. Without outdoor uses attached the NPV of a 1.1kL tank with a roof area of 300m^2 is more favourable than the 3kL tank with a roof area of only 100m^2. When outdoor uses are attached this is no longer the case and the 3kL becomes more favourable than the 1.1 kL tank.

Increasing the irrigation use increases the NPVs and BCRs as this increases water use and hence monetary water savings. The highest BCR occurs with a 15kL tank; while the highest (least negative) NPV occurs with a 10kL tank. The BCR of smaller tanks do not increase much with larger irrigation areas because the RWH system has already reached its capacity to supply water even with a small area of irrigation.

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