Assessing the Effectiveness of Household Rainwater Tanks

Shirley Gato-Trinidad

Abstract**—**Rainwater tanks have been recognised as alternative source of water supply for households in Greater Melbourne, Australia. Rainwater tanks benefits included not only water savings for households but also in water supply systems design . Analysis of 4000 households who availed the Victorian Government Rebate Scheme and another 4000 households who did not install rainwater tanks revealed that rainwater tanks contributed to the 42.5% reduction in average household annual water consumption. The results also show that rainwater tank sizes with indoor plumbing have longer payback period than those solely for outdoor purposes due to higher capital and operating costs even with higher rebates from the government. It was also revealed that the tank size>4500 had the highest NPV and a lowest levelised cost of water of 9cents/kL. The effect of household rainwater tanks on the diurnal patterns of water usage and on peak demand factors were also investigated on100 households whose water consumption were monitored by Yarra Valley Water at 5-minute interval. Analysis of the data revealed that water usage of households with rainwater tanks is lesser than households without. The diurnal patterns showed almost the same peak in the morning due to non consumption from rainwater tanks. However the afternoon peak is lower in households with rainwater tanks due to garden watering from rainwater tanks.

Keywords**—**rainwater tanks, cost effectiveness, payback period, water savings, peak demand factor.

I. Introduction

RAINWATER tank is an alternative source of water which has been widely practiced in Australia for many years [1, 2]. The Australian Bureau of Statistics [3] reported that rainwater tanks as a source of water for Australian households continues to increase. Twenty six per cent of households used a rainwater tank as a source of water in 2010 compared with 19% of households in 2007 and 17% in 2004. From March 2007 to March 2010, households with a suitable dwelling which had a rainwater tank installed increased from 24% to 32%. During this period, households in capital cities experienced the greatest increase in the proportion of rainwater tanks installed at their dwelling (from 15% in 2007 to 26% in 2010). Rainwater tanks are mandatory in New South Wales, Australian Capital Territory, Victoria and South Australia for all new dwellings. Rainwater tanks were also mandatory for new dwellings in Queensland from 2006 to 2013. The increase in the installation of rainwater tanks in Australian households could be attributed to a number of factors, including the increasing cost of distributed (mains supply) water in Australia, the availability of subsidies for households installing rainwater tanks, and the implementation of mandatory building regulations requiring water efficiency savings for new dwellings.

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The Victorian Government implemented 'The Water Smart Gardens and Homes Rebate Scheme' in January 2007 to reward residential water users who are connected to a mains water supply for purchasing water-saving devices and services to reduce their water consumption. Rebates of up to $1000 per household, depending on the size of the tank and connection for indoor water uses, in particular for toilet flushing and clothes washing were available to eligible households. By July 2011 the program was renamed as "Living Victoria Water Rebate Program" and extended until 30 June 2015 increasing the rebate up to $1500.

Water use from rainwater tanks increased by 8% in 2006 to 2011 and water use by households in 2010 and 2011 is 12% of total household use [3]. With the increasing use of water from rainwater tanks by households for their garden watering, toilet flushing and laundry, the maximum demand from the mains water supply system will likely reduce. This reduction in both maximum and average demand from mains water supply system will have an effect in the design of water supply and wastewater supply systems which are traditionally based on these demands. With increasing reliance on rainwater tanks and rebates given by governments, there is a need to assess the effectiveness of the rebate scheme to both household owners and the government providing the rebates as well as the effect of rainwater tanks system in the design of water and wastewater supply systems. This report presents the results of the preliminary analysis conducted on the cost effectiveness of the rainwater tanks rebates provided by the Victorian Government to a number of Melbourne households as well as the effect of rainwater tanks system on peak demand factors.

II. Literature Review

Rainwater tanks can save a significant amount of water mains use. There have been a number of studies conducted in Australia and overseas on possible water savings and the cost benefits from installation of rainwater tanks. However, these studies were either a hypothetical study or based on limited number of data which restrict household owners or a government to make informed decisions on whether to have rainwater tank installed or to continue with the rainwater tank rebate scheme respectively.

Larger rainwater tank means more possible water savings [4]. An evaluation of the performance of 1 – 10 kL rainwater tanks for small dwellings in four Australian capital cities revealed that the water mains savings per year of 1 kL and 10 kL rainwater tanks ranged from 18 – 35 kL and 25 – 144 kL respectively [4]. Rainwater tank could produce an annual reduction in mains water from 31 to 144 kL/household per year [5]. Gato-Trinidad and Gan [6] stated that rainwater tanks contributed to possible water savings of 74 to 139 kL per household per year.An investigation conducted in Sweden revealed that possible savings of 30% of the total mains water consumption can be achieved from a 40 kL rainwater tank and large roof areas with indoor plumbing for toilet flushing and laundry [7].

While savings on rainwater tanks installation have been studied and reported, only few papers report the effect of rainwater tanks on peak demand factors. Traditionally the design of water supply and wastewater supply systems are based on peak demand factors which are calculated as the ratio of the maximum demand to the average demand. The peak demand usually occurs in the afternoon due to garden watering [6]. With rainwater tanks most households tend to water their gardens with water from rainwater tanks. This will possibly reduce the peak demand which could reduce peak demand factor.

III. Methodology

If you are using *Word,* use either the Microsoft Equation Editor or the *MathType* add-on (http://www.mathtype.com) for equations in your paper (Insert | Object | Create New | Microsoft Equation *or* MathType Equation). “Float over text” should *not* be selected.

A. Data Collection

Yarra Valley Water (YVW) provided the following data used in the analysis:

- Quarterly water consumption records of 4391 households who received government rebates before and after the installation of rainwater tanks and the corresponding rainwater tanks sizes and of 4400 households who did not avail the government’s rainwater tank rebates in 158 suburbs of Greater Melbourne. The households who did not avail the rebate scheme were chosen based on the similarity of their consumption patterns to the 4391 households prior to their tank installations.
- Hourly water usage of 100 households in Greater Melbourne from September 2010 to April 2012. The average consumption of households with rainwater tanks were compared with the average consumption of those without rainwater tanks to determine the advantage of rainwater tanks in terms of water consumption.

B. Cost effectiveness of rainwater tanks to household owners

The cost effectiveness of the scheme to householders was determined using the average Payback Period (PP) approach. The Payback period (PP) is perhaps the simplest method of looking at one or more investments. The PP method focuses on recovering the cost of investments. PP represents the time that it takes for a capital project to recover its initial cost [8], therefore considering all other things equal, the better investment is the one with the shorter payback.

The average payback period was determined using the average water savings and the cost of rainwater tank, its installation, and ongoing maintenance from these households. Household potable water savings was calculated by comparing the water consumption of each household before and after the installation of rainwater tanks (12 quarters gap in between). The cost of the project is comprised of the tanks and installation costs shown in Table 1, the cost of maintaining the rainwater tank of $20 per year and the annual energy cost for those with indoor connections of 5 cents per kilolitre of water pumped [9]. The annual cash inflows were based on water savings. The cost of water saved was based on YVW pricing structure (10). A discount rate of 6% was adopted as the increase in the cost of water over time. This is a conservative assumption since the prices of water increases by Melbourne Metropolitan water retailers (City West Water, Yarra Valley Water and South East Water) is 14% in January 2009 prices [11]. The annual average GDP real growth rate for Australia for 2000 – 2010 is 3% [12].

C. Cost effectiveness of rainwater tanks rebate scheme to the Victorian Government

The Average Payback Period approach was also adopted in determining the cost effectiveness of the scheme to the Victorian Government. The cost benefit was calculated by comparing the total amount given to customers as rebates for installing rainwater tanks and the water savings achieved due to the rainwater tanks installation. The 4400 households without rainwater tanks were used as a control group to determine the amount of water savings that can be achieved by rolling out rainwater tanks to these households.

IV. Results and Discussions

A. Tanks sizes, costs and installations

There are different types and sizes of rainwater in Australia from small rainwater tanks, slim line tanks, under deck rainwater tanks, bladder tanks, underground poly tanks and underground concrete tanks. The capacities of these rainwater tanks range from 200L to 45,000L [13]. In this study, rainwater tank sizes were based on YVW groupings shown in Table 1. The groupings were made in order to determine the water savings and the cost benefit of each rainwater tank size group.

The prices of rainwater tanks shown in Table 1 are based on average price of the respective range sizes [13]. The costs for installation and plumbing were assumed to be the same for all sizes of rainwater tanks. The cost of the pump was added to a rainwater tank system which required indoor plumbing.

TABLE I
RAINWATER TANKS' SIZES AND INSTALLATION COSTS IN MELBOURNE, $

Item	For outdoor use only						For indoor & outdoor use*		
	600–1000L	1001–1700L	1701–2250L	2251 - 3600L	3601 - 4500L	>4501L	2000-4999L	5000L	5000L
Tank	570	680	960	965	1200	1520	870	1260	1260
Installation	550	550	550	550	550	550	550	550	550
Plumbing	730	730	730	730	730	730	730	730	730
Pump	0	0	0	0	0	0	355	355	355
Total	1850	1960	2240	2245	2480	2800	2505	2895	2895

Note: * - rainwater is also used for toilet and/or laundry

B. Water Savings

The average water savings per year was calculated for each rainwater tank rebate recipient as the difference in households' water consumption before and after installation of rainwater tanks. The data received from YVW showed the date the rebates were received by the 4391 households and not when the rainwater tanks were installed. In this case, it was assumed that the rainwater tanks were installed when the rebates were received. Household owners started receiving rebates in September 2006 until January 2009. There might be cases when rainwater tanks were used before the rebates thus in the calculation of the water savings it was assumed that the "before installation" was from July 2005 to June 2006 and the "after installation" was from July 2009 to June 2010.

The average water consumption and water savings per household for each tank size are shown in Table 2. Based on 4391 households, the average annual water consumption per household is 247 kL before the tank installation (July 2005 to June 2006) and 142 kL after the tank installation (July 2009 to June 2010). This resulted to average water saving of 105 kL per household per year. Since water restrictions and a strong water conservation campaign were in forced over the whole period of analysis, the calculated water savings may include savings due to these initiatives other than rainwater tanks.

A potential household water savings of up to 66 kL per household per year can be achieved by converting into water efficient appliances such as front loaders, dual flush toilets and AAA shower heads [14]. Based on the above, the resulting water savings from rainwater tanks would only be around 40 kL/household per year if the average household installed efficient water appliances after the tank installation period considered in this study. However due to limited information for each household the saving of 105 kL per household per year was adopted in the following analysis and discussion.

The water savings for each tank size (Table 2) revealed that households with higher consumption would choose larger rainwater tanks with the highest (306 kL) chose >4501L tanks and those with lowest annual water consumption (204 kL) owned 600-1000L tanks. For households where rainwater tanks are connected to toilet and/or laundry, those with the lowest average annual consumption per household (216 kL) chose 2000 – 4999L tanks and those with the highest annual consumption (273 kL) owned >5000L tanks. Householders tend to choose bigger sizes of rainwater tanks when uses also include toilet flushing and/or laundry. Due to the limitation of the data, it could not be inferred if the choice of the rainwater tank size was based solely on the household's water consumption or on the roof size of the home, garden/lawn size and household size.

TABLE II
AVERAGE WATER CONSUMPTION AND AVERAGE WATER SAVINGS PER HOUSEHOLD FOR EACH TANK SIZE (KL/YR)

Tank Size	No. of Households	Before Tank Installation	After Tank Installation	Annual Savings	Percentage Savings
All	4391	247	142	105	42.5
600-1000L	237	204	130	74	36.3
1001-1700L	279	224	137	87	38.3
1701-2250L	855	236	142	95	40.2
2251-3600L	846	253	151	102	40.3
3601-4500L	211	254	153	101	39.8
>4501L	409	306	167	139	45.4
2000-4999L T&orL	507	216	119	96	44.4
>5000L TorL	482	273	154	119	43.6
>5000L T&L	565	244	122	122	50.0

C. Payback Period for the household owners

Based on the analysis undertaken the resulting PP ranges from 12 to 47 years depending on the tank size and the uses of rainwater (Figure 1). All those with connections to toilet and/or laundry take longer years to recover the capital and operating costs than those for outdoor purposes only due to pumping and plumbing costs. However, in terms of water savings more can be achieved in the former than the latter.

All sizes except the 2000-4999L tank with connection to toilet and or laundry have payback periods of less than 20 years which is the expected life of rainwater tanks. This is due to pumping costs and lower rebates when compared to other systems with indoor connections. A 10% increase in total costs (capital and operating) will result to an average 25% increase in payback periods.

D. Payback Period for the government

To determine the payback period of the scheme to the government, a set of control data was also analyzed. The control data contains a record of water usage from 4400 households who did not receive government rebates as per YVW records. However, it can be argued that some may have installed rainwater tanks without availing the rebates and this could not be reflected in the record. This was not verified within this study and it is then assumed that all the households in the control group did not received rebates.

A comparison of the water usage revealed that the control group used less water than those that received government rebates before the installation of rainwater tanks (July 2005 – June 2006) but after the installation (July 2009 – Jun 2010) their water usage surpassed those that installed rainwater tanks. The water savings adopted as savings for the control group was calculated as the average water saved per household per year of those who received rebates (Method 1) and as the calculated average percentage water savings (Method 2). The payback period of the scheme to the government ranged from 1 to 12 years (Figure 2).

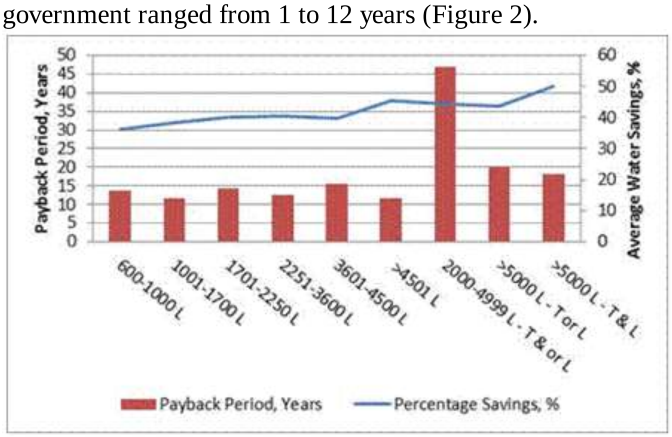

Fig. 1: Payback periods (Years) for different rainwater tank sizes to the households and the corresponding percentage of water saved

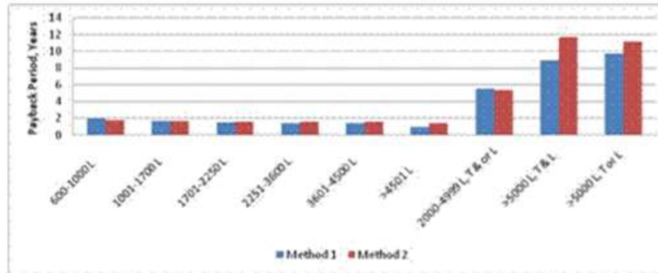

Fig. 2: Payback periods (Years) for different rainwater tank sizes of the scheme to the Government

E. Net present value (NPV)

NPV analysis was also conducted to determine the cost effectiveness of the scheme to the government using a discount rate of 6% and the expected life of the tank of 20 years. The price of water adopted was \$1.13 kL^{-1}, the long run marginal cost of supply augmentation to the Melbourne system (*Pers. Com. with YVW staff*).

Results revealed that with the rebates given, the rainwater tank size in the range of 2251-3600L without indoor plumbing yielded the highest NPV of \$980,566 (Table 3). If the scheme will be extended to the 4400 households (control group), the analysis showed that tanks with indoor plumbing have lower NPVs than those without with the >4500L tank having the highest NPV of \$7.32M.

F. Levelised cost analysis

Another useful way of measuring water conservation options for the water utility perspective is through the levelised cost or amortised cost of water analysis. The levelised cost of water is calculated as the net present value cost of the scheme divided by the present value of the total amount of water saved under the scheme [15]. The levelised cost analysis shows that the tank size group of >4500L had the lowest cost of \$0.09 kL^{-1} (Table 3).

TABLE III
NET PRESENT VALUE FOR EACH RAINWATER TANK SIZE

Tank Size	No. of Households	Annual Total	Savings (%)	NPV ($)	No. of Households	NPV[1] ($M)	NPV[2] ($M)	$ kL^{-1}
600-1000L	237	74	36.3	191,760	4400	3.56	3.94	0.18
1001-1700L	279	87	38.3	272,753	4400	4.03	4.20	0.15
1701-2250L	855	95	40.2	913,426	4400	4.07	4.44	0.14
2251-3600L	846	102	40.3	**980,566**	4400	5.10	4.45	0.13
3601-4500L	211	101	39.8	247,297	4400	5.16	4.38	0.13
>4501L	409	139	45.4	680,798	4400	7.32	5.10	**0.09**
2000-4999L T&orL	507	96	44.4	377,338	4400	3.28	3.43	0.45
>5000L TorL	482	119	43.6	303,370	4400	2.77	1.57	0.66
>5000L T&L	565	122	50.0	335,725	4400	2.61	1.94	0.71

Note: NPV[1] was based on Method 1 and NPV[2] on Method 2.

G.Effect on Peak Demand Factor

Yarra Valley Water monitored the water consumption of 100 households from September 2010 to April 2012. Of these 100 households, 50 have installed rainwater tanks. Of those with rainwater tanks, 8 have rainwater tanks connected to either toilet or toilet and laundry.

H.Average daily household water consumption

Based on the analysis of 100 households it was found that the average household consumption is 358 L/day; 349 L/day for households with rainwater tanks and 368 L/day average for households without rainwater tanks. Therefore, there is a possible savings of 19 L/day (7 kL/year) per household for installing rainwater tanks. This is very much lower than the savings calculated in previous studies of 31 to 144 kL/household per year [5] and of 74 to 139 kL per household per year [6]. The average daily household water consumption of households with rainwater tanks with indoor plumbing (connected to either toilet or toilet and laundry) was calculated to be 330 L/day compared to 349 L/day for households with rainwater tanks but without indoor connections. This means that an additional 19 L/day is possible if rainwater tanks are connected to either toilet or toilet and laundry.

I. Diurnal patterns

The hourly consumption of the 100 households follow the same pattern of that of previous studies with two peaks, one in the morning and one in the afternoon [16]. A comparison of the diurnal patterns for those households with and without rainwater tanks shows that both patterns have two peaks over the 24 hours (Figure 4). The peak in the morning is created by water use related to preparation to go to work and/or school by the residents while afternoon peak is due to garden or lawn watering. The comparison also shows that the afternoon peak of those without rainwater tanks is higher than those with rainwater tanks. While there is not much difference in the morning peaks and the timing of both peaks, the afternoon peaks of those without rainwater tanks is 1.62% of the hourly average while those with rainwater tanks is only 1.27% of the hourly average. This lower peak for those with rainwater tanks could be attributed to households using water from the tank to water their gardens thus lower demand from the mains. In the early morning, the hourly use is at a minimum of 16% to 25% of the average hourly use before reaching the highest peak around 8 am of 189% of the average hourly use. The second peak in the afternoon occurred around 6 pm which is around 144% of the hourly use.

The summer pattern is in contrast with the average patterns of previous studies [16, 17] which showed that in summer period the highest peak occurred in the afternoon due to garden watering. This is due to water restriction in garden watering in 2010 through to 2012. While it has been shown that water restrictions during this period caused the afternoon peak to be lower than the morning peak, households with rainwater tanks have lower afternoon peak than those without. This shows that households used water collected in rainwater tanks to water their gardens than water from the mains. The similar morning peaks revealed that there is not much difference in households with rainwater tanks and without which can be attributed to the majority of household with rainwater tanks without indoor connections. The rainwater tanks are used solely for garden watering in the afternoon and not for morning use which are dominated by water use for shower, toilet and other related task in preparation for work or school.

A comparison of diurnal patterns for both households with rainwater tanks with indoor plumbing (connections to toilet and or laundry) and without revealed that rainwater tanks connected to either toilet and or laundry reduces the highest morning peak at 8 am from 28.92 L (200% of its hourly average) to 25.37 L (184% of its hourly average).

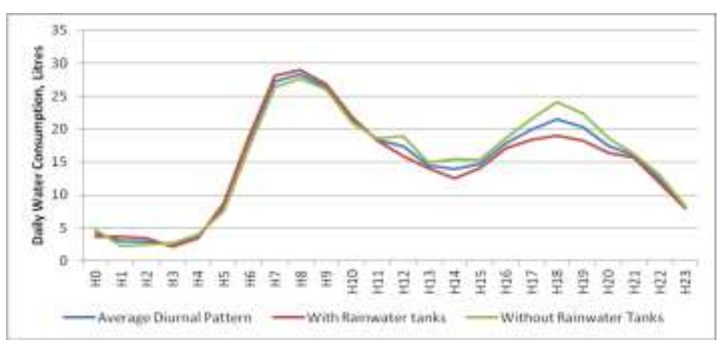

Fig. 4: Comparison of hourly consumption of households with and without rainwater tanks

J. Peak demand factors

Design criteria for water supply infrastructure are traditionally based on the peak hour demand [18]. Peak demand factor is calculated as the ratio of maximum demand to average demand from a long-term consumption records. In the absence of long term consumption records, Water Services of Australia [19] provides peak demand factor values. Based on the consumption of 100 households, the peak demand factors range from 1.69 (summer) to 2.55 (autumn) both from households with rainwater tanks and with connections to either toile and/or laundry. While it is difficult to determine the effect of rainwater tanks on peak demand factors, the calculated values are all below 5, the value suggested for areas with population < 2000 [19]. The peak demand factor values for households with rainwater tanks especially those without indoor connections are higher than the others. These higher values could be attributed to lower average hourly consumption due to garden watering from rainwater tanks but with maximum (unchanged) morning consumption. The maximum peak in the morning is unchanged but the average hourly consumption is reduced, this resulted to a higher peak demand factor.

K. Factors affecting water consumption

A regression analysis to determine the significant factors affecting water consumption revealed that there is a poor correlation between water consumption and household size, type of washing machine, garden size and installation of rainwater tanks with a coefficient of determination, R2 of only 30%. However, household size showed as a significant parameter having p-value < 0.01.

V. Conclusion

Based on the available data and the analysis undertaken it can be concluded that:

1. Installation of rainwater tanks reduced household water consumption and additional savings can be achieved if rainwater tanks are connected to either toilet or laundry.
2. The 2251-3600L rainwater tank without indoor plumbing yielded the highest NPV in water savings of $980,566. If the government extend the scheme to the 4400 households, the rainwater tank size >4500L had the highest NPV in water savings of $7.32M and a lowest levelised water cost of $0.09 per kL.
3. All sizes of rainwater tanks except the 2000L – 4999L tanks have payback periods of less than 20 years for the household owners. For the government, the payback periods ranged from 1 to 12 years.
4. Rainwater tanks changed the diurnal pattern of daily consumption, with much lower afternoon peak due to garden/lawn watering from rainwater tanks and those with connections to either toilet and or laundry have much lower morning peak due to toilet or laundry use from rainwater tanks.
5. Household size remains to be the significant factor of average daily consumption.

VI. Recommendations

To date most of the studies on rainwater tanks relied on hypothetical studies. This study has the advantage of using actual water consumption information from a large number of households. However, some of the information such as lawns/gardens size, roof size and household size needed in determining the most cost effective rainwater tank size in individual households were not included in this enormous set of data. It is therefore recommended that such additional information relating to the sample of households used in this study be collected and further analyzed.

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