EXPLORING OPTIONS TO OPTIMIZE RAINWATER TANK SIZE AND EFFICIENCY INCLUDING POTENTIAL BENEFITS OF COMMUNAL SHARING

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ABSTRACT

Domestic rainwater harvesting is increasingly being used in households in urban areas to reduce dependence on mains water and also to mitigate the adverse impacts of increased stormwater runoff due to urbanization. Most of the literature on rainwater harvesting looks into the installation and use of rainwater tanks by individual households.

Some of the critical factors that have to be taken into consideration when installing rainwater tanks include roof size, non-potable household water demand, the estimated rainfall in the area, cost of tank (i.e. installation and maintenance costs) and the required level of reliability.

Can the size of rainwater tanks be optimized to be more cost-efficient while meeting household demand? This is the focus of this paper. The effect of communal rainwater tank (i.e. multiple households using the same rainwater tank), on cost, tank sizing and the ability to cater to water demand are also examined. The possibility of making the process of communal domestic rainwater harvesting system more robust and sustainable by reducing wastage of stored rainwater and reducing the need for larger rainwater tanks has also been studied.

This paper will discuss the outcomes of three case studies and the factors to consider before practical application of these rainwater tank systems.

KEYWORDS

Domestic Rainwater Harvesting, Optimization, Rainwater Tank Capacity

1 INTRODUCTION

Domestic rainwater harvesting is one of the options for alternative water supply that is being implemented in urban areas to reduce dependence on mains water and also to reduce the impacts of increased stormwater runoff due to urbanization. The benefits of domestic rainwater harvesting as an alternative source of water supply has been tested and proven through various case studies (Kuczera and Coombes, 2001, Villarreal and Dixon, 2005, Ibrahim, 2009, Eroksuz and Rahman, 2010). The literature on rainwater harvesting commonly looks into the installation and use of a rainwater tank by individual households only (Abdulla and Al-Shareef, 2009, Thomas, 1998, Campisano et al., 2013, Villarreal and Dixon, 2005).

Some of the critical factors that have to be taken into consideration when installing rainwater tanks include roof size, non-potable household water demand, the estimated rainfall in the area, cost of the rainwater tank (installation and maintenance costs) and the desired level of reliability.

In this paper, the effect of communal rainwater tank (i.e. multiple households using the same rainwater tank), on cost, tank sizing and the ability to cater to water demand are examined. This paper also investigates the possibility of making the process of communal domestic rainwater harvesting system more robust and sustainable by reducing wastage of stored rainwater and reducing the need for larger rainwater tanks.

The specific aims of this investigation are to:

- Identify an approach to optimize rainwater tank size to ensure that the rainwater tank supply meets non-potable household demands while being cost – effective. The approach will use historical rainfall and demand data in a long-term time series water balance model, so that the resulting optimized rainwater tank size is appropriate to the geographic location.

- Understand the potential benefits of a communal rainwater tank

This paper will discuss the findings of three case studies, which are being carried out as part of this investigation. This paper will also discuss briefly the factors to consider prior to the implementation of these rainwater tank systems.

2 MODEL SETUP

This section describes the inputs and assumptions of this research investigation and gives a brief overview of the modeling methodology.

2.1 INPUTS AND ASSUMPTIONS

AVERAGE DAILY NON-POTABLE WATER DEMAND

- Assumed to be constant daily household demand for non-potable water.

- Non-potable household demand in this investigation consists of average household demand for non-drinking purpose; gardening, toilet and laundry.

- Demand that is not met by the rainwater tank is assumed to be met by mains supply.

- The effects of seasonal variation and changes in number of people in each household have not been considered in this investigation.

- For all the model runs in case study 1 and case study 2, average daily non-potable water demand for each household is assumed to be 325 L/day. This value is estimated to be a typical demand for a 3-member household (ARC, 2003).

- In case study 3, average daily non-potable water demand values within the range of 300 L/day to 400 L/day has been allocated to each of 5 households.

RAINFALL

- For this investigation, 27 years of observed rainfall data for Henderson area in Auckland has been used (NIWA, 2013). The rainfall records show that this catchment has an average rainfall of approximately 1400mm/year. The rainfall records are not complete, and have days with missing information. This is taken into account in the water balance formulation which only carries out the comparison against the actual number of days with data in the rainfall records.

- The rainfall data is assumed to be complete and no further checks or analyses have been carried out.

OTHER FACTORS

- Wastage factor. This factor is used to calculate the percentage of the roof runoff that is captured by the rainwater tank. In all three case studies, the wastage factor is assumed to be 15% (Rainwater Harvesting Ltd, 2010). Therefore, the amount of runoff that is actually captured and received by rainwater tank is assumed to be 85%.

- Warm-up period. Approximately 10% of total record is ignored from the analysis, and is used to establish initial model conditions.

2.2 OPTIMIZATION MODEL

As specified in Section 1 of this paper, the main purpose of this investigation is to develop an approach to optimize rainwater tank size so that it meets the required proportion of household demand for non-potable water while being cost-efficient.

Three case studies are being carried out as part of this investigation. Each case study consists of a residential site with a certain number of different households, each with its own set of input parameters such as contributing roof size and household demand. Two types of analysis have been carried out for each case study; an individual rainwater tank optimization and a communal rainwater tank optimization.

In both the individual and communal rainwater tank analysis, three outputs play a major part in the optimization process. These outputs are:

- Rainwater tank capacity. This is the main focus of the investigation. The model aims to find the optimal rainwater tank capacity for each model run in the case studies.

- Rainwater tank reliability. Temporal reliability, more commonly referred to as reliability, is defined as the percentage of time for which the target water demand can be supplied (Shamseldin, 2011). For this investigation, the target reliability is set as 80%, i.e. the probability of the rainwater tank being able to supply the daily household demand for non-potable water is 80%. In other words, probability of failure is 20%.

- Rainwater tank cost. In the case studies, the rainwater tank cost is calculated as the initial cost of installation (a fixed amount regardless of rainwater tank size) and purchase cost only. The ongoing maintenance cost and other costs involved are not considered.

In the individual rainwater tank analysis (refer to Figure 1), the size of the rainwater tank is optimized for each house hold to obtain the rainwater tank size that meets the target reliability while being cost-effective. In the communal rainwater tank analysis (refer to Figure 2), all the households at the site are connected to a single central rainwater tank. The communal rainwater tank is then optimized to obtain the optimum rainwater tank that meets the target reliability while minimizing the total rainwater tank cost.

The rainwater tank reliability is calculated via a daily water balance model which takes into account the actual observed daily rainfall data and the contributing roof area to calculate the inflow to the rainwater tank from the roof (note: wastage factor is also applied). Due to the non-linearity of the water balance model, a constrained non-linear optimization approach has been adopted for this investigation.

Figure 1: Individual Rainwater Tank System

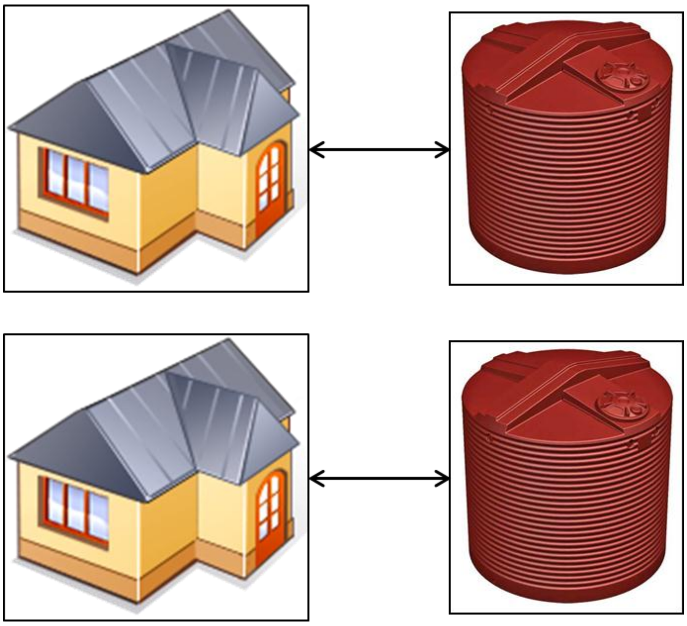
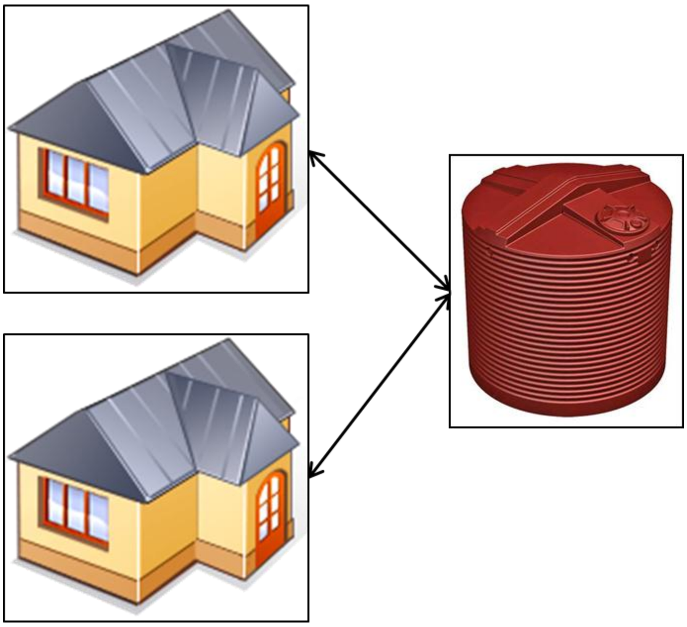


Figure 2: Communal Rainwater Tank System



2.3 CASE STUDIES

The three case studies that are investigated consist of the following:

- Case Study 1: 2 households
- Case Study 2: 5 households, all with the same average daily non-potable water demand
- Case Study 3: 5 households, each with different average daily non-potable water demand

In case study 1, two households with different roof sizes are considered, however, both households are assumed to have a constant daily demand for non-potable water (i.e. demand does not vary day by day, and we assume the same demand for each household). This case study aims at investigating how two households; with the same demand perform with their individual rainwater tank systems. This would provide an insight into the social considerations and fairness, where one household is contributing more runoff to the tanks compared to the other. For this case study, a maximum rainwater tank capacity of 10,000L is applied, i.e. the optimum rainwater tank size generated by the model cannot exceed 10,000L.

In case study 2, there are five households, each with a contributing roof size ranging from $150m^2$ to $400m^2$. All the households have a constant daily demand for non-potable water (i.e. demand does not vary day by day, and we assume the same demand for each household). Two supply options have been considered for the communal rainwater tank system in case study 2.

- Option 1 - Available supply shared equally between 5 households.
- Option 2 - Available supply proportionally allocated to households based on roof size. Therefore, the household with biggest roof (who contributes the most roof runoff), receives majority of water from the rainwater tank.

For case study 3, the same roof sizing setup as in case study 2 is used. The only difference is in the different daily demand for each of the households (i.e. demand does not vary day by day, and each household has a different daily demand). Furthermore, the available supply is allocated proportionally to households based on household demand. Therefore, the household with the largest non-potable water demand will receive the most available water.

The details for all the model runs in the 3 case studies, including the roof size and average daily non-potable water demand for each household in the case study, are provided in Table 1 in Section 3.

3 RESULTS AND DISCUSSION

3.1 MODEL RUN DETAILS

Table 1 presents the details of the various model runs that were carried out as part of the individual and communal rainwater tank analysis for each of the three case studies. The "Tank Model" column specifies the type of analysis, individual or communal rainwater tank optimization.

The following examples interpret the results from an individual and communal rainwater tank analysis from the results table:

- Case study 1, model run 1, has a household with a roof size of $100m^2$ and an average daily non-potable water demand of 325 L/day. When optimized individually, this household requires a rainwater tank with a capacity of 6,300 L. This is the most cost-efficient solution and has an initial cost of approx. \$9,536 and meets the reliability target of 80%.

- Case study 1, model run 3, is a communal rainwater tank optimization. In this model run, the two households from model runs 1 and 2 are connected to a communal rainwater tank, and have a total daily water demand of 650 L/day. The optimum solution is a single communal rainwater tank with a capacity of 6,000L. This rainwater tank has an initial cost of $9,479 and meets the reliability target of 80%. It is important to note that this initial cost will be shared between the households (i.e. each household only have to pay approx. $4,750 towards the rainwater tank), which means a significant cost-savings for the household.

3.2 CASE STUDY RESULTS

Table 2 and Figure 3 show a summary of the results from all three case studies. In Table 2, the model results for the individual rainwater tank analysis have been aggregated, to allow comparison with the communal rainwater tank analysis results. For example, case study 1 individual tank solution has a total capacity of 9,100L (6,300L + 2,800L), a total initial cost of $18,700 ($9,536 + $9,160 = $18,696) and an average reliability of 81.8% ([80% + 83.7%] / 2 = 81.8%).

The results consistently show that compared to an individual rainwater tank system, a communal rainwater tank system is the better option, since it requires a smaller rainwater tank witha lower cost associated with it. In case study 1, there is a reduction of approximately 35% in optimized rainwater tank size and a 50% reduction in cost in the communal rainwater tank system. In case studies 2 and 3, there is a reduction of approximately 65% and 80% in optimized rainwater tank size and cost in the communal rainwater tank system.

As specified in Section 2.3, the communal rainwater tank optimization for case study 2 has been carried out for two different supply options. The results show that if the water in the rainwater tank is split equally between the five households, a 11,300L tank is required. However, if the supply is split proportionally between the households by roof size, a smaller rainwater tank is required. The decrease in rainwater tank is quite small (approx 6%), and the difference in pricing is almost insignificant. The difference in pricing can be explained by the fact that the majority of the initial cost of the rainwater tanks is made by the installation cost. The purchase price of rainwater tanks is not significantly different, especially for reasonably large rainwater tanks.

The small decrease in optimized rainwater tank size could be due to the method used to calculate the reliability. In option 2, the proportional splitting of supply from the rainwater tank will only really have an effect on days where there is not enough rain, which in turn means that the total amount of water in the rainwater tank is not sufficient enough to meet total demand. When calculating reliability for the case studies with communal tanks, only days where the total demand is met are counted (i.e. all households should receive supply to meet the demand). Therefore, if even one of the household does not receive enough supply from the rainwater tank, that particular day is treated as "failure to meet demand", and thus, not taken into account in the reliability calculation. This is reasonable since it reality, we would want the rainwater tank to meet the demand for all the connected households.

3.3 COMPARISON WITH TP10

Table 3 shows the results from the individual rainwater tank analysis from all three case studies listed against the recommended rainwater tank size obtained from TP10 (ARC, 2003). Except for model runs 1, 4 and 5, all the remaining model runs have an estimated rainwater tank size from TP10.

From the table, it can be observed that the model results in general are approximately 15 – 30% smaller than the TP10 recommended sizes for households with similar characteristics (roof size, average daily demand and % water supplied). The TP10 recommendations are based on rainfall data from three locations; Warkworth, North Shore and Pukekohe, while the case studies in this paper are based on rainfall data from Henderson. It can be noted that in most of the runs, the optimum rainwater tank capacity from the model gives a higher reliability than the 80% target, hence, has been compared to the TP10 recommended capacity for similar percentage water supplied.

Table 1: Summary of Model Results from Case Studies 1 – 3

Case Study	Model Run	Roof Size (m^2)	Average Daily Demand (L/day)	Tank Model	Optimal Rainwater Tank Capacity (L)	Initial Rainwater Tank Cost ($)	Reliability (%)
1	1	100	325	Tank 1	6,300	$9,536.30	80.0
1	2	200	325	Tank 2	2,800	$9,160.70	83.7
1	3	100, 200	650	Communal	6,000	$9,479.60	80.0
2	4	100	325	Tank 1	8,400	$9,924.30	83.6
2	5	150	325	Tank 2	6,600	$9,583.70	91.8
2	6	200	325	Tank 3	6,100	$9,498.50	94.8
2	7	250	325	Tank 4	5,900	$9,451.00	96.5
2	8	300	325	Tank 5	5,600	$9,402.90	97.1
2	9	100, 150, 200, 250, 300	1625	Communal Tank Option 1	11,300	$10,332.00	80.0
2	10	100, 150, 200, 250, 300	1625	Communal Tank Option 2	10,600	$10,278.00	80.0
3	11	100	325	Tank 1	8,400	$9,924.30	83.6
3	12	150	400	Tank 2	7,700	$9,791.10	86.5
3	13	200	300	Tank 3	5,900	$9,458.90	96.0
3	14	250	350	Tank 4	6,000	$9,472.00	95.4
3	15	300	400	Tank 5	6,000	$9,479.10	94.7
3	16	100, 150, 200, 250, 300	1775	Communal Tank Type 1	13,200	$10,476.00	80.0

Note: The optimal rainwater tank capacity has been rounded to the nearest hundred for reporting purpose.

Table 2: Summary of Results from Case Studies 1 - 3

Description	Total Optimised Tank Capacity (L)	Total Cost for Tanks ($)	Reliability (%)
Case Study 1 - Individual Tanks	9,100	$18,700	81.8
Case Study 1 - Communal Tank	6,000	$9,500	80.0
Case Study 2 - Individual Tanks	32,600	$47,900	92.7
Case Study 2 - Communal Tank - Option 1	11,300	$10,400	80.0
Case Study 2 - Communal Tank - Option 2	10,600	$10,300	80.0
Case Study 3 - Individual Tanks	34,000	$48,200	91.3
Case Study 3 - Communal Tank	13,200	$10,500	80.0

Note: The optimal rainwater tank capacity and the total cost of the rainwater tank have been rounded to the nearest hundred for reporting purpose.

Figure 3: Summary of Results from Case Studies 1 - 3

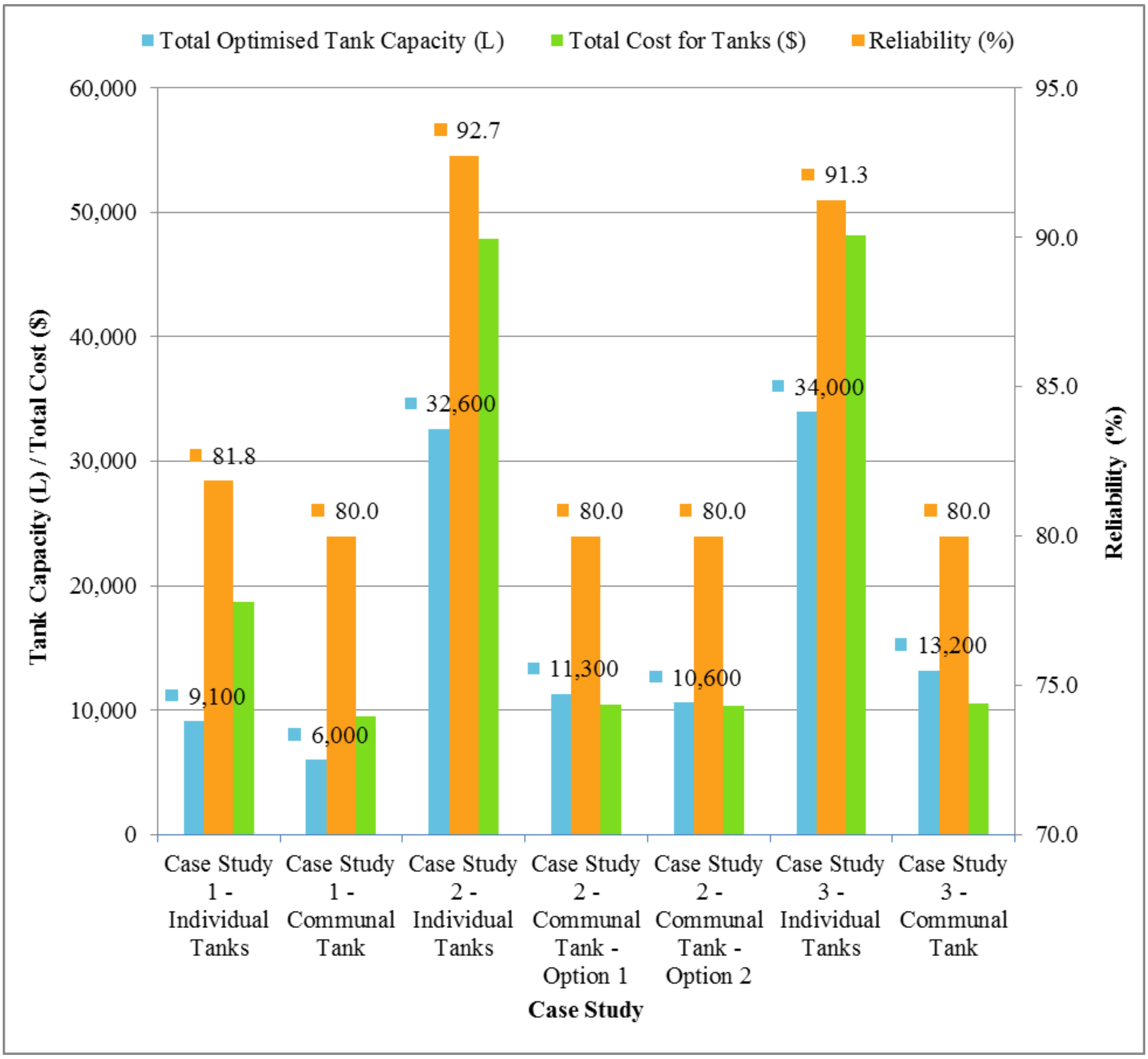


Table 3: Comparison of Individual Rainwater Tank Analysis against Recommended Capacities from TP10

Case Study	Model Run	Roof Size (m^2)	Average Daily Demand (L/day)	Tank Model	Optimal Rainwater Tank Capacity (L)	Reliability (%)	Recommended Tank Capacity from TP10 (Table 11-5)
1	1	100	325	Tank 1	6,300	80.0	N/A
1	2	200	325	Tank 2	2,800	83.7	3000L (75%), 4500L (95%)
2	4	100	325	Tank 1	8,400	83.6	N/A
2	5	150	325	Tank 2	6,600	91.8	4500L (80%), 9000L (90%)
2	6	200	325	Tank 3	6,100	94.8	3000L (75%), 4500L (85%), 9000L (95%)
2	7	250	325	Tank 4	5,900	96.5	3000L (80%), 4500L (85%), 9000L (95%)
2	8	300	325	Tank 5	5,600	97.1	3000L (80%), 4500L (90%), 9000L (95%)
3	11	100	325	Tank 1	8,400	83.6	N/A
3	12	150	400	Tank 2	7,700	86.5	Demand: 325 L/day – 4500L (80%), 9000L (90%) Demand: 500 L/day – 25000L (75%)
3	13	200	300	Tank 3	5,900	96.0	3000L (75%), 4500L (85%), 9000L (95%)
3	14	250	350	Tank 4	6,000	95.4	3000L (80%), 4500L (85%), 9000L (95%)
3	15	300	400	Tank 5	6,000	94.7	3000L (80%), 4500L (90%), 9000L (95%)

Note: The optimal rainwater tank capacity has been rounded to the nearest hundred for reporting purpose.

3.4 IMPLICATIONS OF THIS RESEARCH

The result of the present study supports the theory that in the case of new residential developments it is beneficial to implement communal rainwater tank systems.

It is important to note that there are other factors to be taken into account before a communal rainwater tank system can be implemented. These factors include;

- Difficultly in designing this system in an aesthetically pleasing manner.
- Is it practically possible to setup such a system? What are the extra costs involved?
- How to implement a fair usage policy to prevent one household from using up all of the water, e.g. if one household had a spa pool or a large vegetable garden, would a different arrangement be needed?
- Ongoing maintenance costs, are all the residents going to be willing to pay for this? Rental versus home-owners. Perhaps the rainwater tank system should be maintained by Council with monthly rental charged to residents? Experience from water utilities in Australia during the drought showed that many owners eventually stopped maintaining their rainwater tanks and that providing a maintenance service would improve the ongoing use of the rainwater tanks. Commitment from all households would be needed for the scheme to succeed.
- Where would responsibility sit for maintaining and operating the communal rainwater tank? Would an agreement be needed between owners to establish responsibilities? How would this be enforced?
- The scenarios considered in this work are for average daily demands. What would the implication be for peak summer period? How would a fair use policy be introduced, for example, when watering gardens during dry periods when consumption will likely increase?

The above noted factors also need to be considered in the case of retrofitting existing residential developments. In addition to these, additional effort and cost is required in the consent process for retrofitting an existing development. Feasibility studies will have to be carried out for each case to assess whether it is possible to install a communal rainwater tank, and to better understand the cost implications involved. It is important to keep in mind, that the investment made in retrofitting has the ability to pay itself back over several years via water savings.

4 CONCLUSIONS & FURTHER WORK

The main objectives of this research paper are to investigate whether it is possible to develop an approach to optimize domestic rainwater tank capacity, so that it meets household non-potable water demands while being cost-efficient. Secondly, this paper intended to investigate whether communal domestic rainwater harvesting systems provide a better and more cost-efficient solution compared to individual rainwater harvesting systems.

The results of the investigation show that the optimization methodology is able to generate the rainwater tank capacity that is required to meet the minimum reliability. The approach takes into account the contributing roof area, the average non-potable daily water demand, roof runoff and cost of the rainwater tanks. Furthermore, the case studies presented in the paper show that communal rainwater tanks are more cost-efficient and require less overall rainwater tank capacity to meet the minimum percentage water supplied.

In future research, further analysis needs to be carried out to understand impact of spatial locations on the optimization approach. This will be carried out by running simulations for the case studies using rainfall data from several different stations in New Zealand. Moreover, sensitivity analysis needs be carried out in order to understand a number of factors that can influence the optimization approach and the rainwater tank sizing. These factors include; wastage, warm-up period and the approach used to calculate the percentage water supplied (i.e. temporal reliability and/or volumetric reliability).

ACKNOWLEDGEMENTS

We would like to thank James Hughes (AECOM) and our colleagues for providing assistance and guidance during this project and in preparation of this paper.

We also wish to acknowledge AECOM for providing the opportunity to develop and present this paper.

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