DOMESTIC ROOF RAINWATER HARVESTING TANK SIZING CALCULATOR AND NOMOGRAPH

J. M. Gathenya P. K. Kinyari and P. G. Home
Biomechanical and Environmental Engineering Department, Jomo Kenyatta University of Agriculture and Technology, Nairobi
E-mail: mgathenya@jkuat.ac.ke

ABSTRACT

The importance of roof rainwater harvesting as strategy to meet domestic water demand and to reduce run-off in built-up areas is growing worldwide. Indicators that measure the performance of rainwater harvesting systems have been developed. One such indicator is reliability, which is dependent on the rainfall and water consumption patterns, tank size and effective roof area. A good design should aim at highest reliability at the lowest cost. The aim of this study was to develop a tool that can aid decision making with regard to a question such as 'What size of tank should be installed in a specific location to provide V litres of water per day and with a reliability of R%?'

A computer-based calculator that accounts for tank inflow and outflow and computes system reliability based on monthly rainfall data, effective roof area, daily water consumption and tank size was developed. Based on the results of the calculator, a nomograph for a reliability of 67% was developed. The nomograph can be used to optimally size rainwater harvesting systems in situations where water users do not have access to computers. This tool can be employed by water users to decide on the configuration of tank size and effective roof area that meets the required daily water consumption rate at 67% reliability for a specific location. Nomographs of different reliabilities can be developed based on the rainfall data in the calculator. The higher the reliability, the greater the investment costs in water storage and roof area. However these nomographs can only be used for areas for which the rainfall data used in the calculator is representative. Hardware dealers selling rainwater tanks or contractors in building industry can use it to advice customers on the size of tank to buy or construct.

Key words: Domestic rainwater harvesting, reliability, calculator, nomograph

1.0 INTRODUCTION

The importance of roof rainwater harvesting as strategy to meet domestic water demand and to reduce runoff in built-up areas is growing worldwide. Rainwater is collected from the roofs and stored in closed vessels such as tanks or cisterns. Compared to other water sources, roof rainwater is often of better quality. It is soft and hence ideal for washing. Rainwater also breaks the consumer's reliance on a water supplier (TWDB and CMPBS, 1997). However, rainwater harvesting systems can be costly and systems that meet a household's water needs are often unaffordable. There is need to ensure that tanks and effective roof area are matched properly to meet the water demand at the least cost. In most cases, rainwater users can only afford a system that meets part of their domestic water demand. This means that the rest of the water will be drawn from other alternative sources.

Some terms have been introduced to assess the performance of a rainwater harvesting system. They include reliability, satisfaction, efficiency and water value. Reliability is the fraction of days that demand is met, satisfaction is the fraction of demand volume that is met and efficiency is the fraction of run-off water that is used. These measures can be applied to a typical year, to a typical wet or dry season or to an exceptional year or season, such as the driest in the last decade. They can be expressed for a representative location or for a particular one – for which meteorological data must then be available (Thomas, 2004).

A high satisfaction means that the householder gets most of his water from the rainwater tank. A high reliability means that the portion of his daily needs that comes from rainwater is available more regularly. When the household's domestic water needs are met almost entirely from rainwater, reliability becomes more important than satisfaction. However, increasing the reliability also means that the cost of the system goes up. A trade-off usually is necessary where one chooses a system of lower performance that fits the budget limitations.

The sizing of a rainwater tank depends on rainfall amount and variability, type of roofing materials and daily rate of consumption (Figure. 1). The methods available for sizing a rainwater harvesting tank for a household differ in complexity. The simplest method is to calculate the largest storage requirement based on the daily household consumption rate and average length of the longest dry period in the year. This simple method assumes that rainfall and roof area result in runoff that is sufficient to fill the tank. The method looks only at the demand side and is useful for acquiring rough estimates of tank size.

Another more complex method that considers the supply side makes use of mean monthly rainfall totals and mean monthly water consumption rates. It is assumed that all the roof run-off is utilised. A graph of cumulative harvested water and cumulative demand are drawn and from this, the storage requirement that satisfies the consumption rate of the household can be calculated. This method is suitable for finding the size of tank that is needed to sustain a water consumption rate that is equal to the maximum harvestable water for a specific roof area and rainfall pattern. It takes into consideration the accumulated inflow and outflow from the tank and the capacity of the tank is calculated as the greatest excess of water over and above consumption. This method can be carried out graphically or by use of tables (World Bank, 1986).

The mass-curve analysis technique is a well-established method that has been used for sizing water supply reservoirs (Linsley and Franzini, 1987). The technique can also be used for sizing roof tanks. The method can be used to determine the size of a tank that is needed to meet a specific consumption rate or the daily consumption rate that can be sustained from a given size of tank. In both cases it is assumed that rainfall and roof information is available. The technique can be accomplished using a series of daily or monthly rainfall totals. A series spanning over twenty years is preferable so that all possible variations in rainfall are captured.

There are several computer-based calculators for determining required tank size. These methods involve performing a daily or monthly water budget of the water in the tank. The roof run-off provides the inflow and the outflow consists of water drawn off by the consumer and any overflows that occur. If this water budget is carried out over a period of say twenty years, the reliability of the system can be determined. A daily time step provides the most accurate results but monthly time steps may provide comparable results provided the tank sizes are medium to large in size (Thomas, 2004). One such programme, known as SimTanka2, has been written by an Indian organisation and is available free of charge from the Ajit Foundation Homepage http://homepage.mac.com/vsvyas/science.html.

SimTanka2 takes into account the fluctuations in the rainfall, giving each fluctuation its right importance for determining the size of the rainwater harvesting system. The result of the simulation allows the design of a rainwater harvesting system that will meet demands reliably. The minimum catchment area and the smallest possible storage tank that will meet a specified demand with probability of up to 95% can be found. SimTanka2 can also be used to find out what fraction of a household's total demand can be met reliably. SimTanka2 requires at least 15 years of monthly rainfall records for the place at which the rainwater harvesting system is located. Daily consumption per person is also entered and then the software calculates optimum storage size or catchment size depending on the requirements of the user. SimTanka2 also calculates the reliability of the system based on the rainfall data of the previous 15 years.

Another computer model that can be used to analyse rainwater harvesting systems is the Warwick calculator. This is a computer-based program for calculating optimal tank size or evaluating the performance of a given system consisting of tank size, roof area, daily demand and rainfall pattern. This is an open-access rainwater harvesting system modeling service on the web at http://www.eng.warwick.ac.uk/DTU/rwh/model/index.html. It is driven by user's ten-year monthly rainfall data series and proposed or existing system details. The model converts the monthly rainfall data to daily values, which are then used in the calculation. It then gives reliability, satisfaction and efficiency estimates. The calculator also determines mean daily run-off (MDR) and provides various tank sizes depending on MDR and nominal daily water demand. It also defines how the rainwater will be used by giving a nominal daily demand and choosing between three water management strategies namely constant water demand, varying demand with tank content and varying demand with season.

Nomographs are simple graphical tools that have been developed to solve a variety of problems in water management such as design of pipelines, drainage systems and canals for water conveyance. No water harvesting nomographs have been developed so far. In this study, a spreadsheet based calculator was developed. This calculator can be used to find combinations of roof area and tank size that meet a user-specified daily water consumption with a reliability of 67%. The calculator can be used alone to optimize roof rainwater harvesting systems for a given location whose rainfall data is embedded in the spreadsheet. In addition, nomographs of different reliabilities, which are based on the same data as in the spreadsheet can be developed. In this example, nomographs of 67% reliability have been developed. Such nomographs can be used to size rainwater harvesting systems without reference to the spreadsheet-based calculator.

2.0 MATERIALS AND METHODS

The Jomo Kenyatta University of Agriculture and Technology's Rainwater Harvesting (JKUAT-RWH) performance calculator is based on the Microsoft Excel spreadsheet application. A complete, long-term time series of daily rainfall spanning over 30 years would be preferred. However due to difficulties in obtaining such series for many areas, a minimum of 20 years monthly rainfall series is used for this study. The calculator works on the mass balance principle. At each time-step, the roof runoff belonging to that step is added to the volume in the tank and the user's draw-off is subtracted. Tests and corrections are applied to cover three cases, namely 'tank overflows' (Fig. 2), 'tank runs dry' (Fig. 3) and 'demand exceeds the water available'. The calculations are carried out on a monthly time-step. Inflow is assumed to precede draw-off within any one time-step. The calculator allows the user to vary the roof area, tank size and daily consumption rate. For each time step, the calculator determines if demand has been met and it sums up the months when demand is met over the entire data period. Reliability at the end of twenty years is given by the percentage of the months when demand has been met. The basic water balance equation applied for any month is:

$$RRO_i - MC_i - OF_i = VT_i - VT_{i-1} \quad \text{...(1)}$$

where RRO_i is roof runoff for month i (m^3), MC_i is monthly consumption for month i (m^3), OF_i is overflow during month i , VT_i is volume in tank at end of month i and VT_{i-1} is volume in tank at end of month i-1. The roof runoff generated at each time step is given as:

$$RRO_i = ERA*RAIN_i*RCOEFF \quad \text{...(2)}$$

where RRO_i is roof runoff during month i, ERA is effective roof area, $RAIN_i$ is rainfall received in month i and RCOEFF is the runoff coefficient assumed to be 0.85. The Warwick Rainwater Performance Calculator also uses a coefficient of 0.85 (http://www.eng.warwick.ac.uk/DTU/rwh/model/index.html (accessed July 2005). The initial volume in the tank is set at zero. Overflow from the tank occurs when the tank capacity is exceeded and is calculated as:

$$OF_i = VT_{i-1} + RRO_i - MC_i - TC \qquad (3)$$

where OF_i is overflow during month i and TC is tank capacity. The results derived from the JKUAT-RWH Performance calculator were used to design a nomograph that can be applied to obtain the rainwater harvesting system that gives a reliability of 67%. The calculator can be used alone and in this case a lot of flexibility in the choice of tank size, roof area, consumption rate and reliability is possible. A unique nomograph for the preferred reliability can be prepared for each location for which representative rainfall data is available.

3.0 RESULTS AND DISCUSSION

A Microsoft Excel-based rainwater harvesting performance calculator was developed. One can input different combinations of roof area, daily water use and tank size and the calculator gives out the reliability for each combination. The calculator can be used to size rainwater harvesting systems. For those who cannot access a computer, a nomograph for a reliability of 67% was made. This nomograph achieves the same purpose as the calculator. However, in any one nomograph, the reliability had to be fixed in order to reduce the variables to three. The advantage of a nomograph is that it is simple to use and it can be used as a decision support tool by rainwater users. More importantly, dealers selling rainwater tanks or contractors in building industry can use it to advice customers.

Three examples of nomographs for Nairobi Dagoretti Meteorological station, Magadi Rainfall station and Nzoia rainfall station are given in Fig 4, 5 and 6 respectively. The mean annual rainfall for the twenty years used is 1068 mm, 454 mm and 1296 mm for Nairobi, Magadi and Nzoia respectively. For a fixed roof area, the mean daily runoff increases with the rainfall. From the nomograph in Fig. 4, one can see that a roof area of 160 m^2 and a tank size of almost 12 m^3 can provide about 300 litres per day with a reliability of 67%. A roof area of 220 m^2 and a tank of 6 m^3 can provide this same amount of water. A user who knows the daily water requirements can therefore make a cost analysis to decide whether to increase effective roof area by providing more gutters or to buy a larger tank. Since the cost of gutters is typically 20% of the entire system (Still and Thomas, 2003), it is advisable to ensure that the entire roof area is exploited as this will result in a smaller tank. The y-axis to the right gives the mean daily runoff (MDR) for a specific roof area. This is the upper limit of harvestable water for a specific roof area and rainfall pattern. The daily water consumption cannot exceed MDR. For rainwater water harvesting systems, the reliability should be between 50 and 80%. For reliability below 50%, the user does not benefit sufficiently; and for reliabilities of over 80%, the cost implications become a hindrance. Therefore for a roof area of 160 m^2 around Dagoretti Meteorological Station in Nairobi, MDR is 400 litres/day. This illustrates how the tool can be used to decide on the configuration of tank size and roof area that meets a given water requirement. For wider applicability, nomographs of varying reliability and for other locations can also be developed. Nomographs have been developed for 50 towns in Kenya for which long-term rainfall data was available.

The reliability values given by the JKUAT-RWH Performance Calculator for various configurations of rainwater harvesting systems has been compared with those obtained using the Warwick calculator and the results are comparable even when monthly rainfall data is used. The Warwick calculator requires internet access, while the JKUAT-RWH Performance calculator does not.

4.0 CONCLUSION

A computer-based calculator that can be used to optimise the sizes of roof rainwater systems was developed. The results of the calculator were further synthesized to develop a nomograph that can be used for the same purpose as the calculator but for a fixed reliability which in the example given here is 67%. The calculator and nomograph are specific for that location from which the rainfall data is collected. For other locations, the rainfall data has to be availed and entered into a rainfall data field in the calculator. In order to limit the variables in the two-dimensional nomograph to three, nomographs can only be applied for a specific reliability. A similar approach can be used to develop nomographs for other locations and reliabilities.

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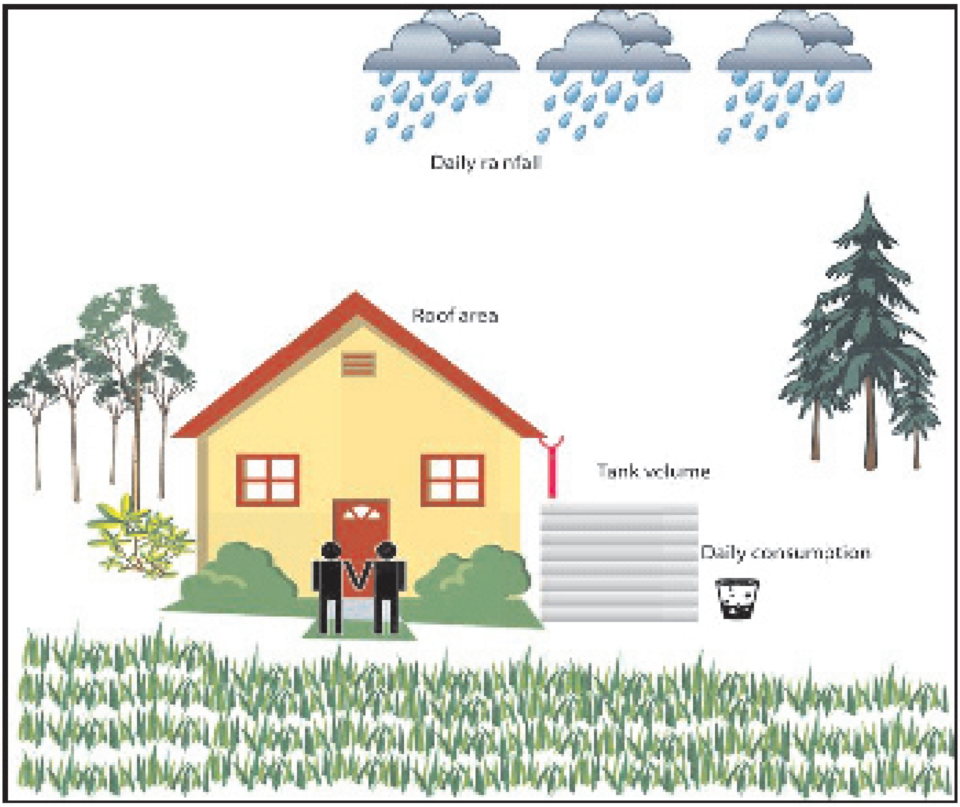

Figure1: Domestic rainwater harvesting system

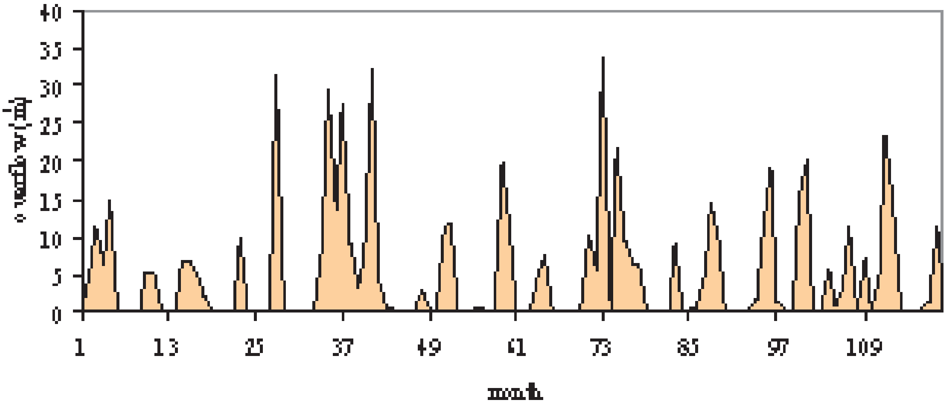

Figure 2: Overflows for a 2.8 m^3 tank, roof area 100 m^2, daily water use 100 litres/day for Nairobi Dagoretti station.

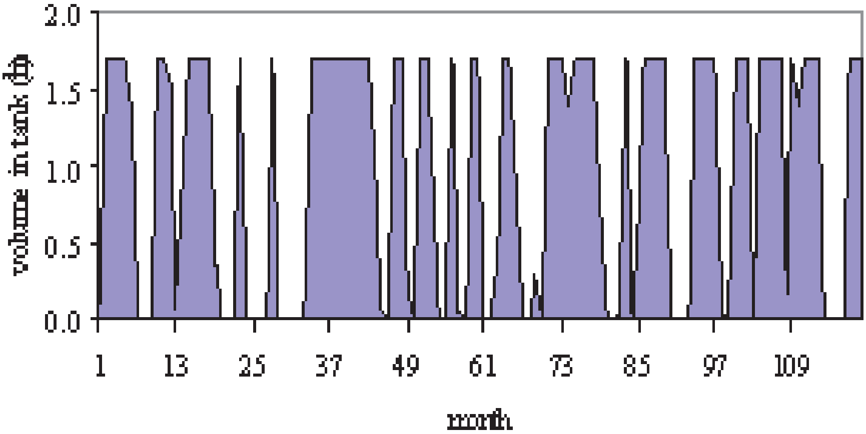

Figure 3: Water in tank for 1.7 m^3 tank, roof area 100 m^2, water use 100 litres/ day for Nairobi Dagoretti Station.

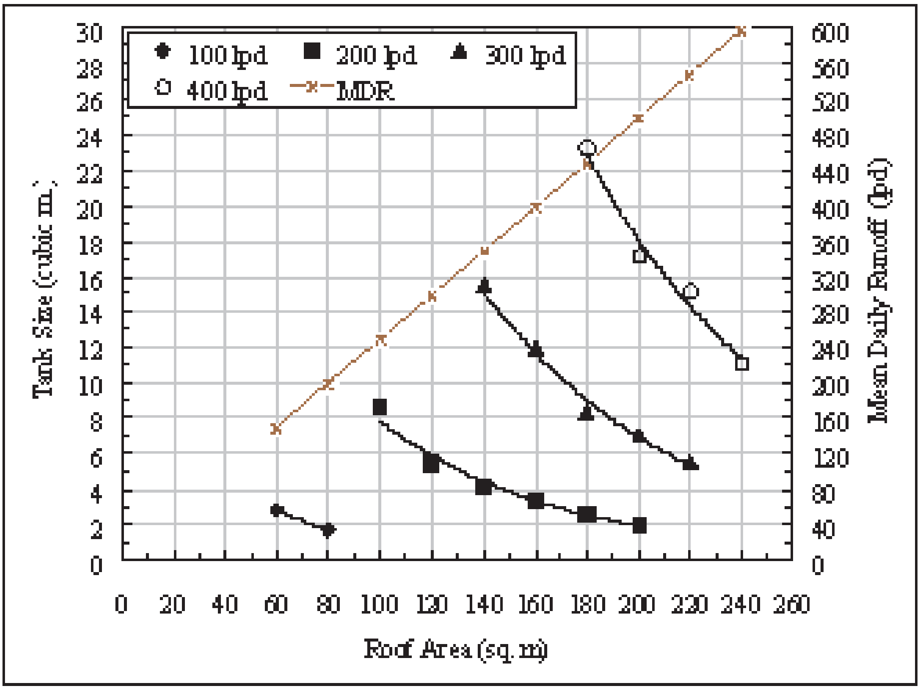

Figure 4: A 67% reliability nomograph for Nairobi Dagoretti Meteorological Station (annual rainfall 1068 mm).

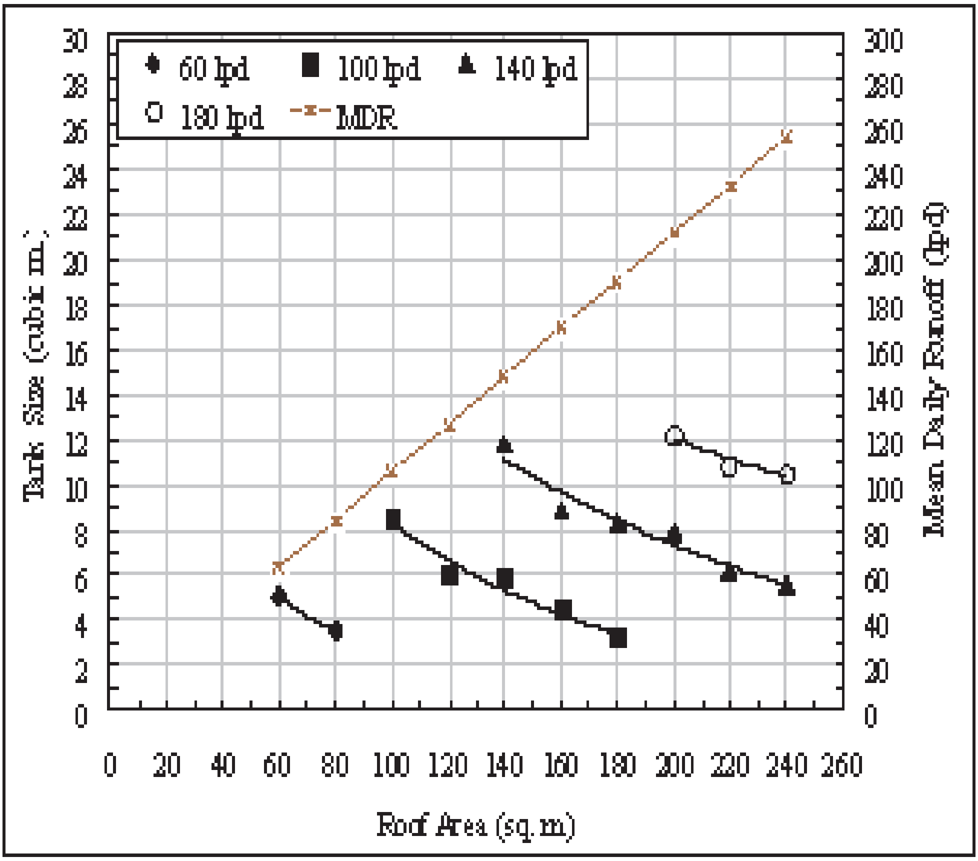

Figure 5: A 67% reliability nomograph for Magadi Meteorological Station (annual rainfall 454 mm).

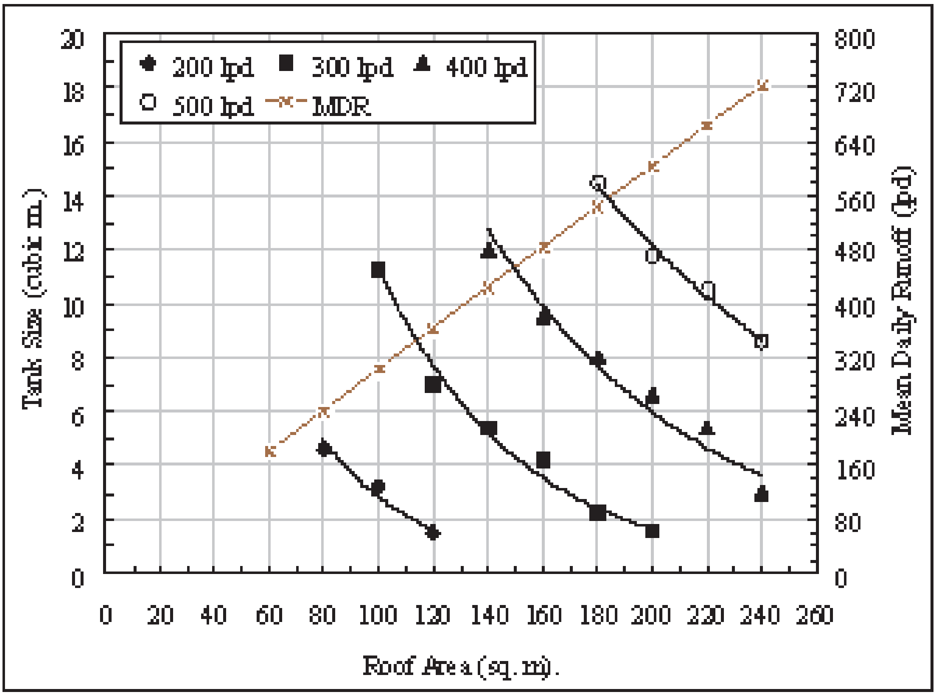

Figure 6: A 67% reliability nomograph for Nzoia Rainfall station (annual rainfall 1296 mm).