Rainwater Harvesting Systems: Design Considerations for Stormwater Management

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Highlights

- Applied six performance metrics to explore RWH stormwater management metrics.
- Innovative visualisation of all six metrics as a function of size and demand.
- Proposed sizing systems to retain 1 in 10-year events as a pragmatic design approach.

Introduction

Past research on domestic rainwater harvesting (RWH) has focused mainly on the ability of systems to deliver a reliable alternative water supply, with their capacity to manage stormwater only more recently examined (Campisano et al., 2017). Consequently, literature and design standards are predominately centred around the sizing of RWH tanks for water supply. Stormwater management guidance that does exist stipulates complete retention during extreme events (1 in 100 year; Woods-Ballard et al., 2015). This approach can result in considerable tank size and cost. Cost has been cited as a significant barrier to installing RWH tanks by UK housebuilders, so minimising size while maintaining adequate performance is crucial to the broader implementation of these systems (Parsons et al. 2010). Therefore, this paper aims to present a pragmatic approach to balance the size of tanks with the stormwater management they can provide. This methodology is illustrated using a conventional system with rainfall indicative of an average British climate.

Methodology

System Design

A model was constructed in MATLAB to continuously simulate the behaviour of a conventional system using a Yield After Spillage (YAS) model (Fewkes and Butler, 2000). The climatic inputs for the model were taken from the 30-year UK Climate Projections, as detailed in Stovin et al. (2017) with a 5-minute time step. Rainfall is converted to stormwater runoff using roof area (30 m^2), with an initial loss of 0.2 mm per event plus a 0.2 mm/day evaporative loss. The impact of different demands and storage sizes on performance was examined by modelling storage volumes between 0.5 m^3 and 5 m^3 and demands between 10 L/day and 300 L/day. The average non-potable water demand in the UK is 120 L/day (Quinn et al., 2021).

Performance Metrics

Quinn et al. (2021) proposed a set of performance metrics that quantify the stormwater management potential of RWH systems. These metrics (Table 1) provide a robust characterisation of both long-term and event-based performance. Event-based performance is generally seen as being more relevant when designing for stormwater management performance. The event-based metrics were based on median performance values for the 30 highest volume events in the time series. If the median retention efficiency for significant events is 1.0, this implies that the system fully retains runoff for at least 50% of the events, i.e., for events with a return period of up to 2 years. However, higher return periods, are typical applied in conventional drainage design. If the 90th percentile retention efficiency over 30 events is 1.0, the system fully retains runoff for events up to a return period of 10 years. To examine the impact of different demands and storage sizes on retention during extreme events, a contour plot is used to show the performance of a wide range of tank volumes under an array of demands. Scatterplots are used to examine the impact of utilising two tank sizes (one with a median retention efficiency of 1.0 and the other with a 90th percentile retention efficiency of 1.0) on retention during all significant events.

Table 1. Summary of RWH System Performance Metrics

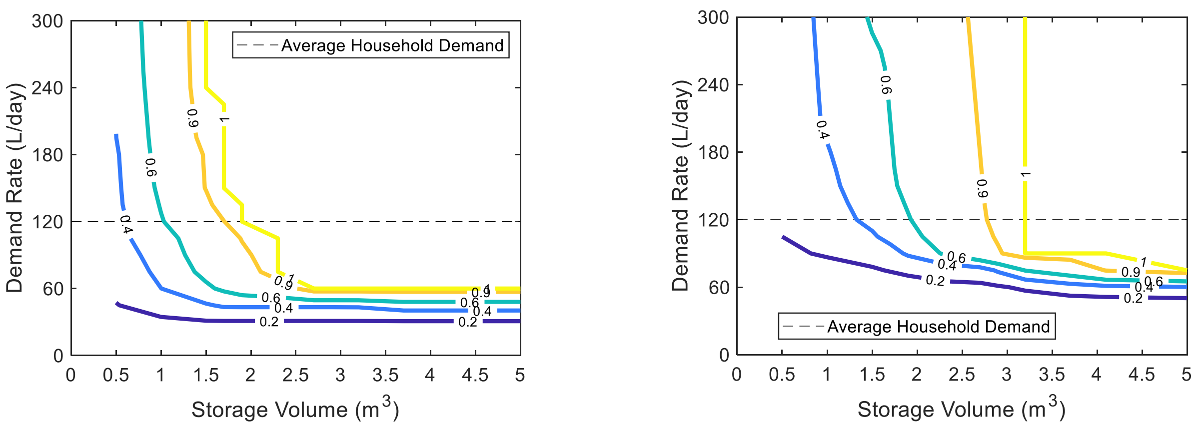
Performance Metric	Description
	Long-term Performance
Retention Efficiency (-)	Average annual proportion of roof runoff prevented from entering drainage network
Inflow Control Efficiency (-)	Average annual proportion of roof runoff controlled to greenfield runoff rate (5 l/s/ha)
Annual Time Above Greenfield Runoff Rate (hours/year)	Average annual time where the outflow from rainwater harvesting is above greenfield runoff rate
	Event-based Performance
Median Retention Efficiency	Median per-event proportion of roof runoff prevented from entering drainage network over a sample of significant events
Median Inflow Control Efficiency	Median per-event proportion of roof runoff controlled to greenfield runoff rate over a sample of significant events
Median Peak Outflow	Median per-event peak outflow over a sample of significant events.

Combined Performance Visualisation

Our performance visualisation aims to combine all performance metrics and show whether they meet a threshold requirement depending on demand and storage volume in a single scatter pie figure. Pie charts are plotted at fixed values of storage volume and demand; a pie chart segment represents each metric with green shades representing long-term performance metrics and blue shades representing event-based performance metrics. A filled pie chart indicates that the maximum level of performance is achieved. For example, for Retention Efficiency, the maximum value achievable is 1.0.

Results and discussion

Figure 1 shows the variation of median and 90th percentile Retention Efficiency for a sample of 30 significant events for a conventional system using Sheffield rainfall data. The plots clearly show that no additional benefit can be achieved beyond a specific storage volume, as the systems become demand-limited. Similarly, increasing demand can help to increase performance, but this effect is storage-limited. Note that, a considerable size increase is required to improve from achieving a median (1.9 m^3) to a 90th percentile (3.2 m^3) retention efficiency of 1.0 for an average household water demand of 120 L/day.



(a) Median Retention Efficiency (-) (1 in 2 year event) (b) 90th Percentile Retention Efficiency (-) (1 in 10 year event)

Figure 1. Retention Efficiency Contour Plots

Figure 2 shows the Retention Efficiency of all 30 significant events when tank sizes which provide a median (1 in 2 year) and 90th percentile (1 in 10 year) Retention Efficiency of 1.0, are used. Although the larger tank size provides greater retention during all events (including 0.7 for the most significant event), the smaller tank still prevents 40 % of runoff from entering the drainage network during the largest event.

Figure 3 shows a novel method of displaying all potential performance criteria on one graph and shows the demand and storage size required to achieve maximum performance. For an average demand rate, a considerably higher storage volume is required to achieve complete long-term volumetric retention (4.9 m^3) than either the median or 90th percentile significant event-based performance. Therefore, we propose designing for complete retention of a 1 in 10-year event. This approach provides substantial stormwater management at a far lower storage size than a system that provides complete retention. Supplementary analysis (not shown here) shows these findings hold for a range of UK climates.

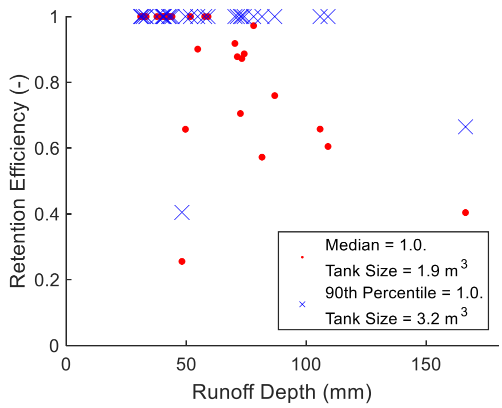
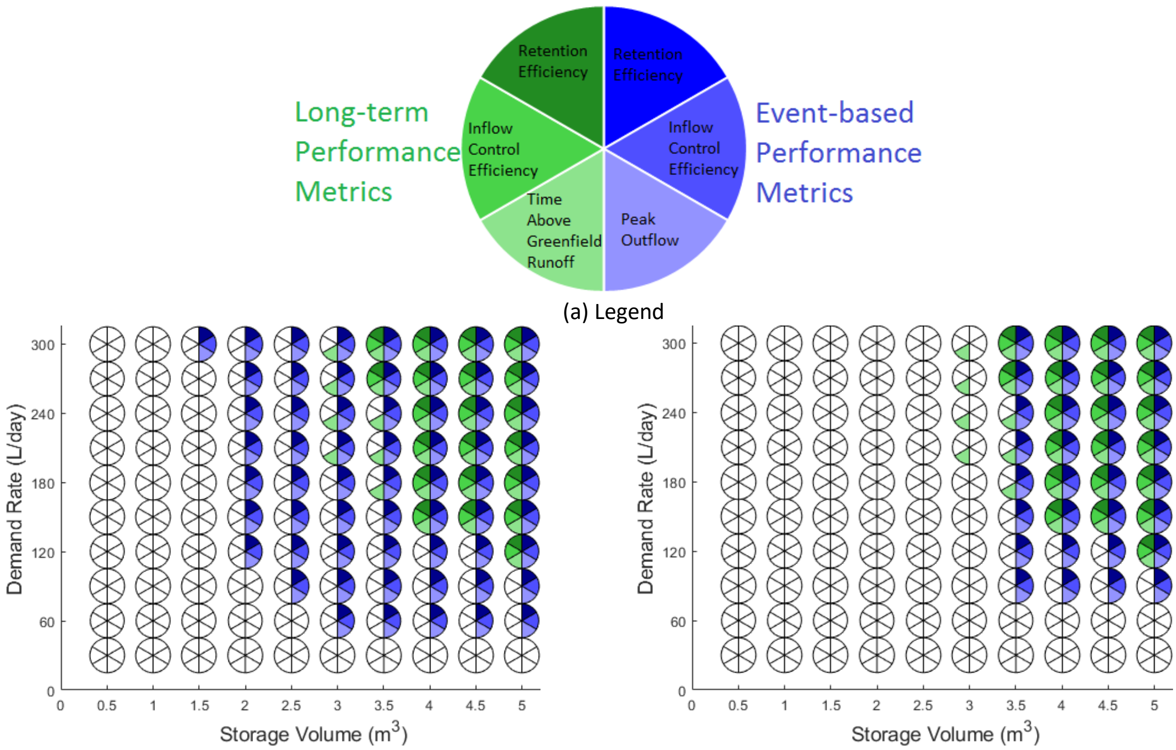


Figure 2. Retention Efficiency for 30 Significant Events



(a) Legend

(b) Median Event-Based Performance Metrics (1 in 2 year)

(c) 90th Percentile Event-Based Performance Metrics (1 in 10 year)

Figure 3. Scatterpie for All Performance Criteria

Conclusions and future work

The requirement for complete retention in existing RWH stormwater management guidance results in large and expensive systems. The methodology proposed in this paper can significantly reduce the size and cost of the tank required while still providing significant, and quantifiable, stormwater management. While we have only considered performance in terms of volumetric retention here, the full set of metrics includes measures based on peak flow and flow relative to the pre-development runoff rate, thereby permitting catchment-specific performance criteria to be set.

References

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