

Evaluating the Hydrologic Performance of Passive and Active Release Systems Retrofitting Rainwater Harvesting Cisterns

Évaluation des performances hydrologiques de systèmes de libération passive et active après réadaptation de citernes de récupération des eaux pluviales

Sarah Waickowski¹, Ph.D., PE ; Amy Scaroni², Ph.D. ; Mitchell Woodward³

¹ Clemson University, swaicko@clemson.edu

² Clemson University, ascaron@clemson.edu

³ North Carolina State University, mdwoodwa@ncsu.edu

RÉSUMÉ

Des études antérieures ont démontré que la collecte des eaux pluviales peut répondre aux besoins en eau non potable, éliminer les polluants des eaux de ruissellement et atténuer les débits de pointe et volumes de ruissellement sans nécessiter une grande surface au sol. Elles ont également montré que les systèmes de collecte des eaux pluviales sont plus efficaces pour la gestion des eaux de ruissellement lorsque la citerne dispose d'une capacité de stockage suffisante entre les épisodes de pluie. Cette capacité peut être obtenue par intervention humaine (ex : irrigation) et/ou par un système de libération passive ou active. Cependant, les systèmes de libération passive peuvent contribuer au ruissellement lors des orages, et les systèmes de libération active sont généralement composés d'éléments brevetés qui peuvent être coûteux. Nous observons actuellement les performances hydrologiques (ex : by-pass) d'un système de libération active, composé de contrôleurs et capteurs facilement disponibles, installés sur une citerne de 7949 L, et les comparons à celles d'un système de libération passive installé sur une citerne de même capacité (7949 L) à Georgetown, en Caroline du Sud (États-Unis). Le suivi a débuté en septembre 2025 et se poursuivra jusqu'en septembre 2026. Les données préliminaires indiquent que le système de libération passive a capté 92 % des eaux de ruissellement provenant d'une toiture de 97 m² et a évacué lentement 74838 litres des eaux captées. Le système de libération active a quant à lui capté 73 % des eaux de ruissellement de la même toiture et a évacué lentement 57023 litres des eaux captées.

ABSTRACT

Previous research has shown rainwater harvesting can be used to meet non-potable demands, remove pollutants from stormwater runoff, and mitigate peak flow rates and runoff volumes without requiring a large footprint. Studies have also shown that rainwater harvesting is the most effective at managing stormwater runoff when the tank has sufficient storage available between storm events. Storage may become available through human intervention (e.g., irrigation) and/or through a passive or active release mechanism. However, passive release systems can contribute to runoff during storms, and active release systems typically consist of proprietary components that can be expensive to obtain. We are currently monitoring the hydrologic performance (e.g., bypass) of an active release system comprised of readily available controllers and sensors retrofitting a 7,949 L cistern compared to a passive release system retrofitting a 7,949 L tank in Georgetown, South Carolina, USA. Monitoring began in September 2025 and will continue through September 2026. Preliminary data indicate the passive release system has captured 92% of the runoff generated from a 97 m² roof and slowly drained 74,838 L of captured runoff. The active release system has captured 73% of the runoff from a 97 m² roof and slowly drained 57,023 L of captured runoff.

KEYWORDS

Monitoring, optimization, rainwater harvesting, stormwater management, sustainable drainage systems

1 INTRODUCTION

It is well documented that urbanization increases runoff volumes, peak flow rates, and pollutant loads discharged to downstream water bodies (Booth et al., 2002; Gold et al., 2019). Stormwater best management practices are implemented to mitigate these impacts and include devices such as constructed stormwater wetlands and wet detention basins. However, these larger practices are less feasible in ultra-urban areas, residential settings, or where space is limited. Also, these practices may not mimic natural processes that help to create more resilient and environmentally friendly urban areas. Rainwater harvesting is a type of practice that can be installed in these settings to manage stormwater runoff while making urban areas more resilient and environmentally friendly. Rainwater harvesting uses a cistern or tank to collect and store runoff that can be slowly released and/or used for a designated purpose (e.g., flushing toilets). Previous research along the east coast of the United States has demonstrated rainwater harvesting can be used to meet non-potable water demands (DeBusk et al., 2013), remove pollutants from stormwater runoff (DeBusk & Hunt, 2014; Wilson et al., 2014), and mitigate peak flow rates and runoff volumes (Braga et al., 2018; Gee & Hunt, 2016) without requiring a large footprint. Studies have also shown that rainwater harvesting is most effective at managing stormwater runoff when the tank has sufficient storage capacity between storm events (DeBusk et al., 2013; Jones & Hunt, 2010; Shetty et al., 2022). Storage may become available through human intervention (e.g., draining for irrigation) and/or a passive or active release mechanism (Figure 1; Quinn et al., 2021; Xu et al., 2018).

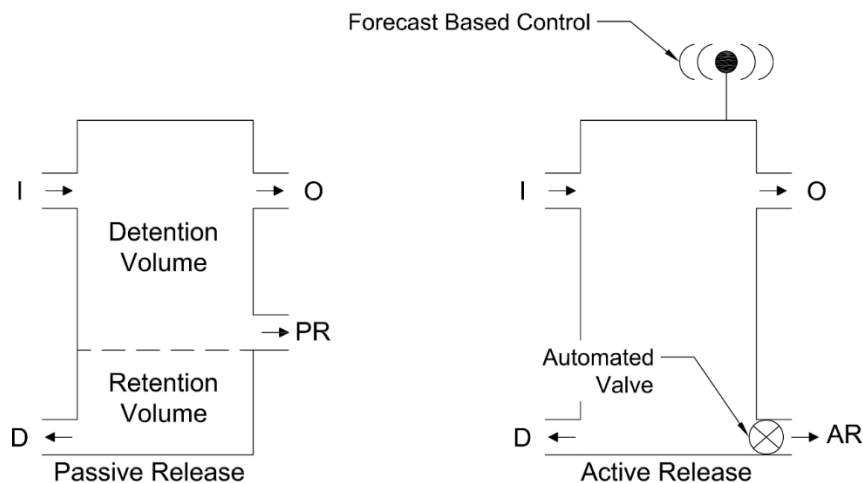


Figure 1. Passive release (PR, left) and active release (AR, right) configurations with inflow (I), overflow (O) or bypass, and demand (d) inputs and outputs. Adapted from Quinn et al. (2021) and Xu et al. (2018).

Using irrigation to drawdown cisterns can provide substantial storage volume but the amount of drawdown that occurs is dependent upon the season (growing versus non-growing) (DeBusk et al., 2013) and the type of vegetation being irrigated. This method is typically not feasible for ultra-urban areas as these settings generally have little or no irrigation needs. Additionally, irrigation requires extensive human intervention, which may dissuade homeowners and designers from installing rainwater harvesting systems. On a broader scale, most studies have only modeled the hydrologic performance of passive release (Quinn et al., 2021; Xu et al., 2018) and little to no research has evaluated the performance of an active release system comprised of readily available materials. More importantly, few if any studies have assessed how well retrofitting the passive release orifice with an active release system limits discharge that occurs during storm events.

2 METHODS

Clemson University is currently monitoring two cisterns located in Georgetown, South Carolina, USA to address these research objectives, and monitoring will continue through September 2026. Each cistern receives runoff from 97 m² of a sloping, metal roof and was designed to capture 87% of the average annual runoff and release the detention volume within three days (NCDEQ, 2020). The cisterns were retrofitted with either a passive or active release system. The active release system consists of a residential 24 V irrigation controller and rainfall and soil moisture sensors that control a solenoid valve attached to the passive release orifice. The rainfall sensor closes the valve during storm events, and the soil moisture sensor keeps the valve closed until the soil's

volumetric water content drops below a pre-programmed threshold to reduce the amount of runoff discharged to the stormwater drainage system immediately after storm events. Water levels within each cistern are recorded every two minutes using a pressure transducer logger (Onset Computer Corporation, Bourne, Massachusetts), and bypass is directed to a weir box equipped with a stilling basin, V-notch weir, and pressure transducer (Gee & Hunt, 2016). An additional pressure transducer is located outside of the cisterns and weir boxes to account for atmospheric pressure. After each storm event, the water levels in the tanks and weir boxes are measured using a water level indicator (Humboldt Manufacturing Company, Elgin, Illinois) and tape measurer, respectively to verify the pressure transducers are functioning properly. Total rainfall depths greater than 2.54 mm with an antecedent dry period of six hours or more are considered an individual storm event (Driscoll et al., 1989). Rainfall depth and intensity is recorded using a tipping bucket and manual rain gauge (Davis Instruments Corporation, Hayward, California) installed in an area free of overhead obstructions; the manual rain gauge verifies the accuracy of the tipping bucket. To account for discrepancies between the gauges, a correction factor is calculated by dividing the total manual depth by the total tipping bucket depth and multiplying each 0.25 mm tip recorded by the tipping bucket by the correction factor (Waickowski et al., 2025).

Inflow volumes are calculated using the tank geometry and water level data. Given the area and uniformity of the cisterns' watersheds, influent peak flow rates are calculated using the Rational Method and the maximum 5-minute rainfall intensity (Equation 1; Haan et al., 1994;). For bypass, flow rates are calculated using the weir's stage-discharge relationship and level data; volumes are calculated by multiplying the flow rates by the time interval between data points. The frequency at which overflow occurs is also denoted. If drawdown does not occur during a storm event, the volume of runoff released from the cistern is calculated using the tank geometry and water level data. If drawdown occurs during a storm event, an average drawdown rate based upon the collected data is multiplied by the duration of release to estimate drawdown volumes (Gee & Hunt, 2016). Peak outflow rates are the maximum of the calculated overflow rates and average drawdown rate, and outflow volumes are the sum of the respective overflow and drawdown volumes. On a per storm basis, volume and peak flow rate reductions are calculated using Equation 2 and Equation 3, respectively. At the conclusion of the study, significant differences between the cistern's inflow and outflow volumes and peak flow rates will be compared using the Student's t-test or Wilcoxon Rank Sum Test using RStudio™ (RStudio Team, 2025) to determine if the tank provides stormwater management. Additionally, significant differences between the volume reductions provided by each cistern will be compared to each other using the Student's t-test or Wilcoxon Rank Sum Test to determine if the active release system increases bypass.

$$Q_p = 1000 * \frac{C * i * A}{360} \quad \text{Equation 1}$$

where:

Q_p = peak flow rate (L/s)

C = rational coefficient (unitless)

i = maximum 5-minute rainfall intensity (mm/hr)

A = watershed area (ha)

$$VR_i = \frac{V_{\text{overflow},i}}{V_{\text{overflow},i} + V_{\text{inflow},i}} \quad \text{Equation 2}$$

where:

VR_i = volume reduction for storm i (unitless)

$V_{\text{overflow},i}$ = overflow volume for storm i (L)

$V_{\text{inflow},i}$ = inflow volume for storm i (L)

$$PR_i = \frac{Q_{\text{outflow}} - Q_{\text{inflow}}}{Q_{\text{inflow}}} * 100\% \quad \text{Equation 3}$$

where:

PR_i = peak flow rate reduction for storm i (%)

$Q_{\text{overflow},i}$ = outflow peak flow rate for storm i (L/s)

$Q_{\text{inflow},i}$ = inflow peak flow rate for storm i (L/s)

3 PRELIMINARY RESULTS AND CONCLUSIONS

Preliminary data indicate that the cistern retrofitted with passive release has captured 92% of the runoff generated from the roof, and the total volume drained from the tank is 74,838 L. The cistern retrofitted with active release has captured 73% of the generated runoff, and the total volume drained from the tank is 57,023 L. The average delay caused by the sensors is approximately 23 hr. Both cisterns have an average draw down rate of approximately 7 L hr⁻¹. These results suggest these release mechanisms, particularly passive release, can be used to manage stormwater runoff from rooftops. This is critical given the lack of space available in urban areas to install stormwater best management practices that typically require a larger footprint than rainwater harvesting systems (e.g., bioretention cells).

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