Studying the hydrological performance of a rainwater harvesting cistern with real time control collecting stormwater runoff from a green roof

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Highlights

- Over the monitoring period, the green roof retained 65.2% of the rainfall on the roof, while the roof and cistern together retained and detained 75.6% of the total rainfall.
- Stormwater capture for the cistern was greatest for summer and fall seasons, intermediate storm sizes (2 to 25 mm), and storms with long antecedent dry weather periods (> 2 days)
- The 10.4% increase in total on-site retention + detention was 2.15 mm storage per storm, a 1.37 m^3 storage volume for the site, making the real time control technology cost effective.

Introduction

One challenge involved with the implementation of rainwater harvesting is cistern overflow. When cisterns remain full from prior storms, they are more likely to overflow during the following storm (Shannak et al. 2014). Rainwater harvesting systems are only effective for stormwater management when harvested rainwater is used or released between rain events, freeing capacity for future stormwater capture. Real time control (RTC) technologies can allow capture of more stormwater than traditional rainwater harvesting systems via controlled releases of water from the system that lower tank water levels before rains begin (Xu et al. 2018). Further work is needed to benchmark the performance of RTC in stormwater systems (Kerkez et al. 2016).

The objective of this research was to monitor the performance of an advanced rainwater harvesting cistern that collects stormwater runoff from a green roof. The cistern was programmed with RTC sensors that communicate with local weather forecasts to drain before expected storms to make room for calculated rainfall volumes.

Methodology

Green Roof

The green roof was installed in October, 2012, in the Bronx, New York City, at 40°50’50’’N, 73°52’13’’W. The roof, a total of 638 m^2, was divided into four quadrants, and the monitored quadrant was 180 m^2. This quadrant had 127 mm of a soil media blend with a reported organic content of 3% to 6% and a maximum water retention of 38%.The roof was planted with grasses, forbs, and shrubs native to New York State and was irrigated during the summer and early fall during dry conditions.

Cistern with real time control

Stormwater from each quadrant drained into individual cisterns located beneath the green roof in the auto garage. Each cistern was sized to store an 8 mm storm. The cistern controller was also programmed with RTC sensors that communicate with local weather forecasts (Kerkez et al. 2016), using the Continuous Monitoring and Adaptive Control (CMAC) technology provided by OptiRTC, Inc. (Opti, Boston, MA, USA; www.optirtc.com). When there was less than 0.05 inches rainfall forecast with less than 60% probability within the next six hours, the controller assumed dry weather and the 24-hr post-storm period began. After 24 hours, this temporarily detained water was drained from the cisterns into the combined sewer system. However, if a storm was forecast while the system was still in the 24-hr post-storm period, the controller estimated an expected volume that could enter the tanks during the storm. The system drained the tanks ahead of storms to make room for just this calculated volume.

Analysis

Rainfall and water level heights were monitored between February 22, 2013 and December 16, 2017. The rainfall depth of each recorded storm was calculated using a minimum twenty four-hour dry period to separate storm events, which resulted in 358 storms. Quality control of storms suitable for analysis were the same as those adopted by Carson et al (2013). These elimination criteria resulted in 203 storms that were considered suitable for analysis.

Results and discussion

The cistern with RTC reduced the total amount of water that left the site during wet weather for all storms (Figure 3). The cistern provided the most benefit for larger storms, statistically greater than the green roof alone for storms with rainfall depths between 2 to 10 mm ($p < 0.0001$), 10 to 25 mm ($p = 0.0002$), and greater than 25 mm ($p = 0.027$).

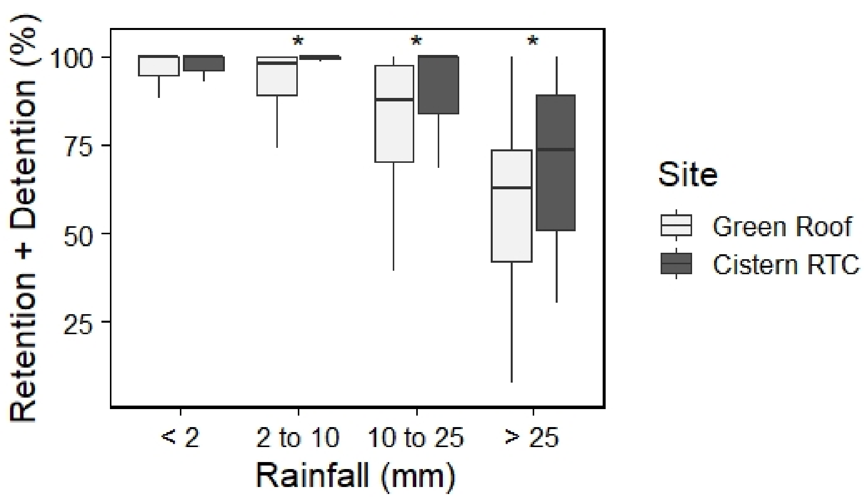

Figure 3. Total on-site retention + detention for different storm sizes. The * at the top denote groups where the difference between Cistern RTC and Green Roof was statistically significant ($p < 0.05$).

We also found that the stormwater capture provided by the cistern beyond the green roof alone was greatest during the summer and fall seasons. In winter, snowmelt caused water to enter the cisterns during dry weather, leaving the cisterns with water even at the outset of storms.

The antecedent dry weather period (ADWP) before the storm events also affected the water level heights. Due to the minimum twenty four hour dry period used to separate storms, one day was the smallest ADWP. The initial water level height when the storm events began was statistically greater ($p=0.047$) for storm events with an ADWP one to two days, compared to storms with larger ADWPs. Similarly, the cistern had statistically greater stormwater capture than the green roof alone when the ADWP was between 2 to 4 days ($p = 0.006$), 4 to 6 days ($p = 0.0001$), and greater than 6 days ($p = 0.007$), but not when the ADWP was one to two days ($p = 0.338$).

The studied cistern with RTC improved the 65.2% retention for the green roof alone to 75.6% total on-site retention + detention over the monitoring period. This 10.4% increase amounts to an average of 2.15 mm detained per storm, or 1.37 m^3 storage volume per storm provided for the entire green roof. Given that investment costs for CSOs are on average 600 to 3600 euros per m^3 (Oberascher et al. 2021). the real time control technology therefore provides New York City 822 to 4932 euros in CSO abatement, which is similar to the annual subscription for the Opti technology. However, real time technology is more cost efficient in larger applications due to the smaller contribution of fixed costs associated with control and communication component (Xu et al. 2018), so increased cost effectiveness can be expected as stormwater systems with real time control grow in popularity and more are installed.

Conclusions and future work

The objective of this research was to monitor the performance of an advanced rainwater harvesting cistern that collects stormwater runoff from a green roof. The cistern was programmed with real time control sensors that communicate with local weather forecasts to drain before expected storms to make room for calculated rainfall volumes. We collected four years of rainfall and runoff data from the green roof, as well as overflow data from the cistern. Over the monitoring period, the green roof retained 65.2% of the rainfall on the roof, while the roof and cistern together retained and detained 75.6% of the total rainfall. Despite the cisterns being designed to drain 24 hours after a storm, we found that season, storm size, and prior storms affected the initial cistern water level height that impacted how likely the cisterns were to overflow during the following storm. We found that the stormwater capture provided by the cistern beyond the green roof alone was greatest for summer and fall seasons, intermediate storm sizes (2 to 25 mm), and storms with long antecedent dry weather periods (> 2 days). We also found that the rainfall forecast both overestimated and underestimated actual rainfall depths. We concluded that the 10.4% increase in total on-site retention + detention amounted to 2.15 mm storage per storm, a 1.37 m3 storage volume for the site, making the real time control technology cost effective.

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