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Ahead of the game; exploring the benefits of 7-day forecasts in real-time controlled rainwater harvesting systems

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Highlights

- Real-Time Control can enhance a rainwater tank's ability to mitigate flooding and restore baseflow.
- Using 7-day lead-time rainfall forecast further increases the ability of RTC to reduce flooding risk.
- Using 7-day rainfall forecast allows the controlled release to mimic reference streamflow regime.

Introduction

Real-Time Control (RTC) technology is increasingly applied in rainwater harvesting systems to optimise simultaneous outcomes related to water supply, flooding, and baseflow provision (Gee et al. 2016; Xu et al. 2018). These systems are designed to release water prior to the event (termed here as pre-storm release) to minimize the magnitude and frequency of uncontrolled overflow. The released volume is determined by comparison of rainfall forecast from the local meteorological authority with current available headroom.

One important concern in relation to the pre-storm release is that without attention to the flow regime, it could simply mimic the 'uncontrolled' overflow, but shifted in time, thus leaving the flow regime highly disturbed, with consequences for downstream receiving waters. This is because they are managed at best using a 24-hr forecast, meaning that the release needs to be rapid (high flow rate) in order to be completed before the predicted rainfall. Therefore, the system outflow will retain the magnitude and flashiness of peak flows which characterise impervious runoff, potentially a posing risk of erosion and degradation to downstream receiving waters.

Current Numeric Weather Prediction (NWP) can anticipate the rainfall event in the next 7 days. In theory, this would allow RTC systems to perform pre-storm release long before the actual event, at a lower rate that is much closer to the natural hydrology. However, the use of 7-day forecast and the associated effect on pre-storm release remain largely untested.

We aim to design the RTC strategy to operate rainwater harvesting system and assess its effects using different forecast lead-time. This includes: (1) developing control strategies to make optimum use of 7-day forecast (2) understanding the effect of RTC in relation to water supply, flood mitigation and flow regime restoration (3) understanding the effect of forecast lead-time (i.e. 1-day versus 7-day).

Methodology

We compared two RTC strategies which utilised rainfall forecast in different way. RTC using 1-day forecast released the predicted overflow uniformly during 24-hr to minimize any uncontrolled overflow. In contrast, RTC using 7-day was designed to expand this pre-storm release to the maximum duration, aiming for a longer detention time and lower peak flow rate. For example, if overflow was predicted on 3rd and 6th days, the 1-d RTC released on the day of prediction (Fig.1 (a)) while 7-d RTC released them over 2 and 5 days respectively (Fig. 1 (b)). Moreover, both RTC strategies were designed to restore stream baseflow through a persistent release (i.e. every 6-min if pre-storm release was not performed). The volume was determined by the daily Q50 flow (also know as median flow) from a reference natural stream (forested catchment) stream, considering seasonal variation (Smakhtin et al. 1997).

We used continuous simulation to predict the performance of two different RTC systems and compare them to conventional RWH systems. We assumed that a 3750L storage tank drained a roof of 150 m² and was connected to a range of domestic water demands (i.e. toilet flushing, dishwasher and cloth washing). Inflows were predicted using 6-years of 6-min rainfall observations in eastern Melbourne. Overflows in any systems were unregulated — i.e. they occurred whenever inflows exceeded system capacity. For the two RTC system, pre-storm release was determined by 1-day and 7-day mean daily precipitation prediction sourced from the local meteorological organization (Bureau of Meteorology 2020).

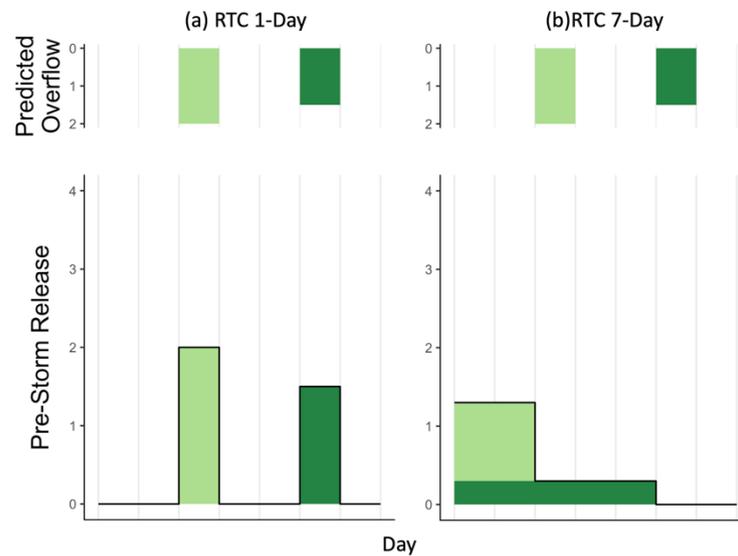


Figure 1. Example of two RTC strategies using 1-d (left) and 7-day (right) rainfall forecast.

Results and discussion

Our modelling results show that the Real-Time Control (RTC) technology increases the ability of rainwater harvesting system to reduce flooding risks and restore stream baseflow, while still providing water supply. Compared to conventional systems, RTC systems using 1-day and 7-day forecasts reduce uncontrolled overflow by 37% and 47% respectively (Figure 2.). This is because the excessive inflow that would have become overflow was instead largely released prior to the event through pre-storm release. Moreover, such a benefit is further enhanced by pro-actively releasing tank storage to restore stream baseflow. With minor detriment to yield, it indicates a promising opportunity to enhance the environmental benefits of RWH systems.

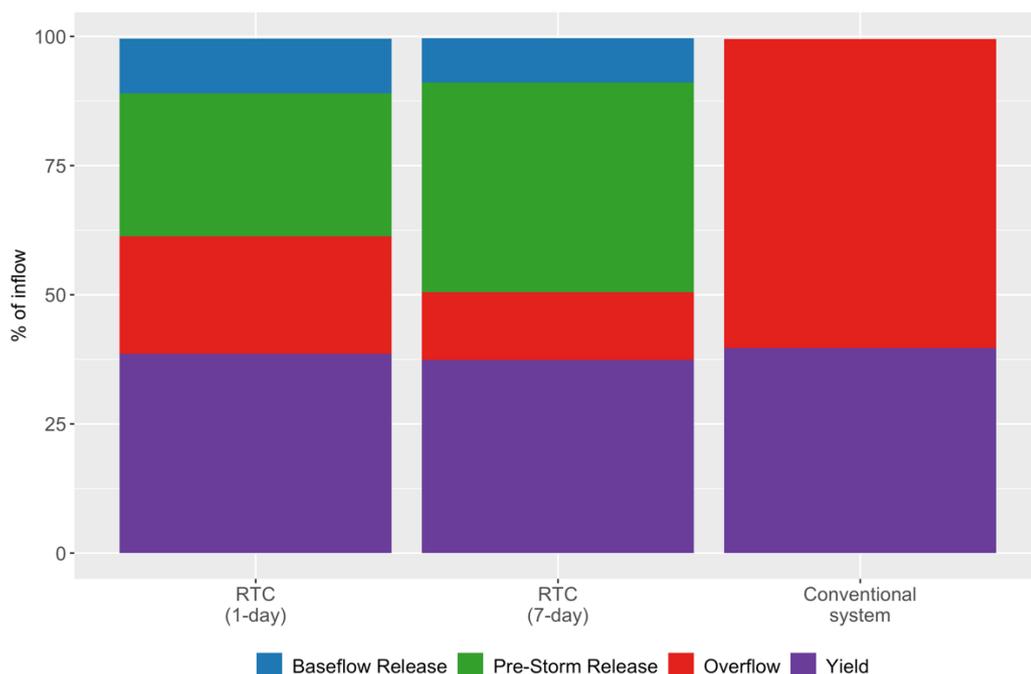


Figure 2. Water Balance of tank behaviour during Mar 2014 – Sep 2019 in three different systems.

Using the 7-day lead forecast further increases the ability of RTC to reduce flooding risk by reducing the magnitude and frequency of uncontrolled overflow. RTC using 7-day forecast result in 44% less overflow volume than system using 1-day forecast (Figure 2). Such an advantage can be further demonstrated in reducing the magnitude and frequency of peak system outflow (i.e. overflow + release), especially Q_5 flow (Figure 3). More importantly, the outflow duration curve of RTC (7-day) shows a similar trend to the reference streamflow while increasing the flow in the low aspect. This indicate that longer forecast window, which allow system a longer duration to perform pre-storm release at a lower rate, can mimicking the natural streamflow, thus potentially helping to restore the degraded urban flow regimes.

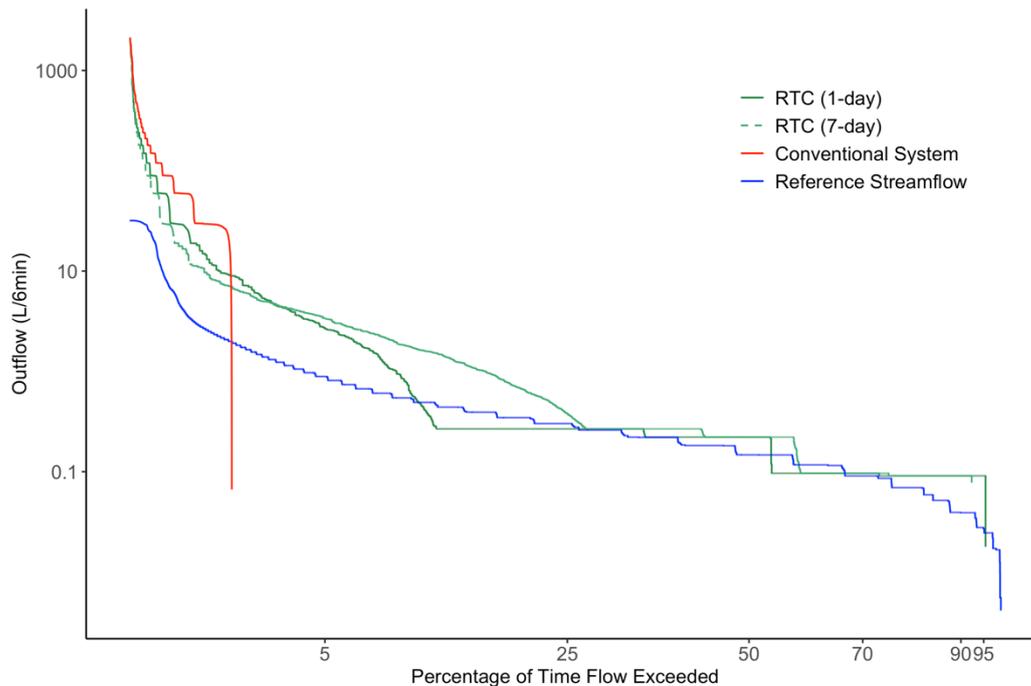


Figure 3. Flow duration curves of (1) conventional system overflow (2) RTC systems outflow (i.e. overflow + release) and (3) reference streamflow.

Conclusions and future work

In this study, we aimed to develop and model the first reported RTC strategies using 7-day forecast for the optimisation of Rainwater Harvesting (RWH) systems in relation to water supply, flood mitigation and flow regime restoration. We concluded that RTC technology can increase the ability of RWH systems in reduce system overflow and restore baseflow. Such an improvement can be further enhanced using 7-day rainfall forecast in reducing the magnitude and frequency of peak system outflow. More importantly, longer lead-time forecast allows the controlled release mimicking natural streamflow, indicating a promising potential to restore degraded urban flow regime. Such a finding opens up a new possibility for practitioner to implement smart technology in managing the urban stormwater. Future study should test and optimize the performance of proposed RTC strategies at the catchment scale.

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