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Enhance the performance of stormwater networks using real-time controlled rainwater harvesting systems

Améliorer la performance des réseaux d'eaux pluviales en utilisant des systèmes de collecte des eaux de pluie contrôlés en temps réel

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RÉSUMÉ

La récupération de l'eau de pluie (REP) avec gestion en temps réel (GTR) peut atténuer les risques d'inondation à l'échelle d'un site individuel, mais ces avantages restent largement inconnus pour les réseaux d'eaux pluviales en aval. Dans cette étude, nous avons modélisé la façon dont les systèmes de récupération des eaux de pluie à la source influencent le comportement d'un réseau d'eaux pluviales dans le climat actuel et futur. La simulation a montré qu'un tel système peut réduire le volume d'inondation et le débit de pointe, conduisant à une atténuation potentielle des risques d'inondation urbaine. La mise en œuvre de la GTR dans un plus grand nombre de réservoirs de récupération d'eau de pluie apporte des avantages plus importants que la simple augmentation de la capacité de stockage. Nos conclusions indiquent que les réservoirs de REP GTR répartis dans un bassin versant peuvent améliorer considérablement les performances des réseaux existants, ce qui pourrait permettre d'éviter ou de différer des mises à niveau coûteuses du système. Les investissements dans la technologie de gestion en temps réel semblent plus prometteurs que les investissements dans le seul volume de rétention, surtout si l'on considère leur capacité à faire face aux changements climatiques à venir.

ABSTRACT

Real-time controlled (RTC) rainwater harvesting (RWH) can mitigate flood risks at an individual site scale, however, such benefits remain huge unknown at downstream stormwater networks. In this study, we modelled how at-source RTC RWH systems influence the behaviour of a stormwater network in both current and future climate. Simulation showed that such a system can reduce flooding volume and peak flow, leading to a potential mitigation of urban flooding risks. Implementing RTC in more of RWH storages lead to greater benefits than simply increasing storage capacity. Our finding indicate that RTC RWH storages distributed throughout a catchment can substantially improve the performance of existing drainage systems, potentially avoiding or deferring expensive network upgrades. Investments in real-time control technology would appear to be more promising than investments in detention volume alone, especially considering its capability in cope with future climate change.

KEYWORDS

Real-Time Control, Rainwater Harvesting Systems, Stormwater Control Measures, Flood Mitigation, Source Control

1 INTRODUCTION

Urbanization results in challenges relating to runoff control and flooding risks (Jongman et al., 2012; Nirupama & Simonovic, 2006). Addressing these challenges would ideally be delivered by Stormwater Control Measures, capable of managing stormwater at its source, to mitigate high flow runoff. Rainwater harvesting systems, a storage-based SCMs, have already been shown by some studies to deliver flood mitigation benefits at individual site scale, while simultaneously supplementing potable water supplies. (Roman et al., 2017; Xu et al., 2020a). There is, however, scope to further understand whether such benefits gained at each parcel can be accumulated and translated to a larger scale such as the stormwater network scale. In this study, we explicitly consider the behaviour of a distributed network of RTC RWH systems and the hydraulic behaviour of the stormwater network, using SWMM model and RTC model developed in the previous studies Xu et al. (2020b). The RTC strategy we adopted aims to mitigate floods (for further details see Xu et al., 2020b), and modelled their impact on a stormwater network across a range of system settings, under two different climate scenarios (i.e. current and future climates), during a 7-month simulation period. Network flooding volume and peak flow reduction were characterised, with a more detailed analysis on the network outflow regime.

2 METHODS

To predict the impact of RTC RWH systems on the performance of a stormwater network, we used a modelling approach which combined outputs from a volumetric RTC RWH behaviour model coded in R software (version 4.1; R Core Team, 2021), with the 1-D hydraulic model in the Stormwater Management Model (SWMM version 5.1 executed by PCSWMM 7.4; Rossman, 2015). Modelling procedure contains three different modules which illustrate in Figure 1. Rainfall-runoff module (M1) uses a hydrological model, providing the 6-min catchment runoff and daily runoff forecast as input to RTC module (M2). M2 generates the outflow from each at-source RTC system using the pre-defined RTC strategy, which is then utilised by M3 to predict the flow dynamics in the drainage network.

The RTC strategy used in this study was adopted from Xu et al. (2020b): Strategy S1 ('Flood Mitigation'). This was designed to minimise storage overflows. Any overflows predicted to occur within the next seven days are released uniformly over the next 24-hr window.

The analysis was undertaken on a stormwater network located in a city in the province of Quebec, in Canada, for which the SWMM model was adapted from Shishegar et al. (2021). It is approximately 7.3 ha in area, includes 70 houses with an average roof area of 188.8 m². The study catchment consists of 10 subcatchments, 10 nodes and 10 pipes with diameters varying from 200 mm upstream to 600 mm downstream. Rainfall observations were obtained from a rain gauge near the study stormwater network. In total, 77 rain events were extracted from a 7-month period (i.e. 1st April to 31st Oct 2013), with total precipitation of 796.4 mm.

A domestic water demand profile was adopted from local authority data (Ministry of Municipal Affairs and Housing, 2020), which indicates a daily water consumption of 275 L/person/day. A population of 2.1 person per household was assumed according to the census in the nearby catchment (Statistics Canada, 2017). RWH systems were assumed to supply toilet flushing, which counts for 30% of the domestic demand, with two peak usages at 9 am and 7 pm in the diurnal pattern.

A range of scenarios were designed to test the impact of RTC system settings on network performance. We considered five rainwater storage capacities, relative to the roof areas (i.e. 5, 10, 20, 40, 80 L/m²) and five different storage capacities to which RTC is applied (e.g. 100% represents all RWH systems are operated by RTC). All of these were compared to a baseline scenario (i.e. no RWH system). Two climate conditions – current and future – were applied to evaluate the performance of the proposed RTC strategies in the context of climate change. Future rainfall is projected by adding a fixed factor of 15% to all rainfall data values (Bilodeau et al., 2018; Shishegar et al., 2021).

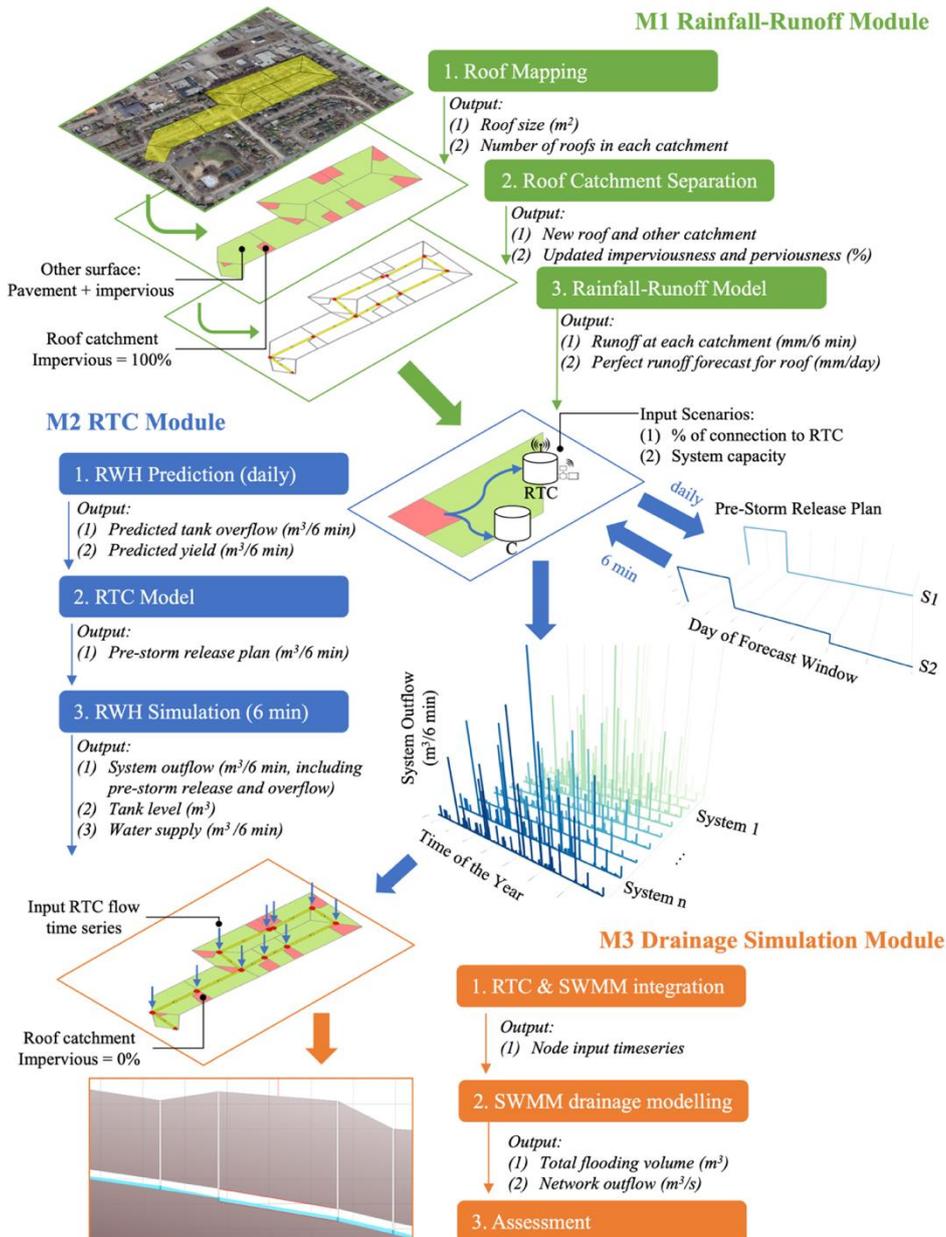


Figure 1. Conceptual representation of modelling procedure, including three modules: (1) M1 Rainfall-Runoff Module, (2) M2 RTC Module, and (3) M3 Drainage Simulation Module. RTC represents for Real-Time Control systems, while C represents for Conventional RWH systems.

3 RESULTS AND DISCUSSION

Implementing RTC RWH systems can reduce the flooding risks. Increasing the proportion of RTC mitigate network flooding volume (Figure 2a). Operating all RWH system using RTC (i.e. 100% RTC) reduced the network flooding volume up to 82%. Equipping roof areas with 10 L/m² RTC RWH systems doubled the flooding volume reduction achieved by much bigger (80 L/m²) conventional RWH systems, with total flooding volume of 352 and 609 m³, respectively. More importantly, the performance gain from increasing the proportion of controlled tanks was larger for small sized system (i.e. < 20 L/m²), decreasing in relative terms where larger rainwater storages were used.

A similar trend in flooding volume reduction was modelled under the future climate, across all scenarios. While both the conventional and RTC demonstrated approximately 5% decrease in performance under future climate, the smallest RTC system (i.e. 5 L/m²) outperformed the largest conventional system (i.e. 80 L/m²), with 29% and

21% flooding volume reduction, respectively.

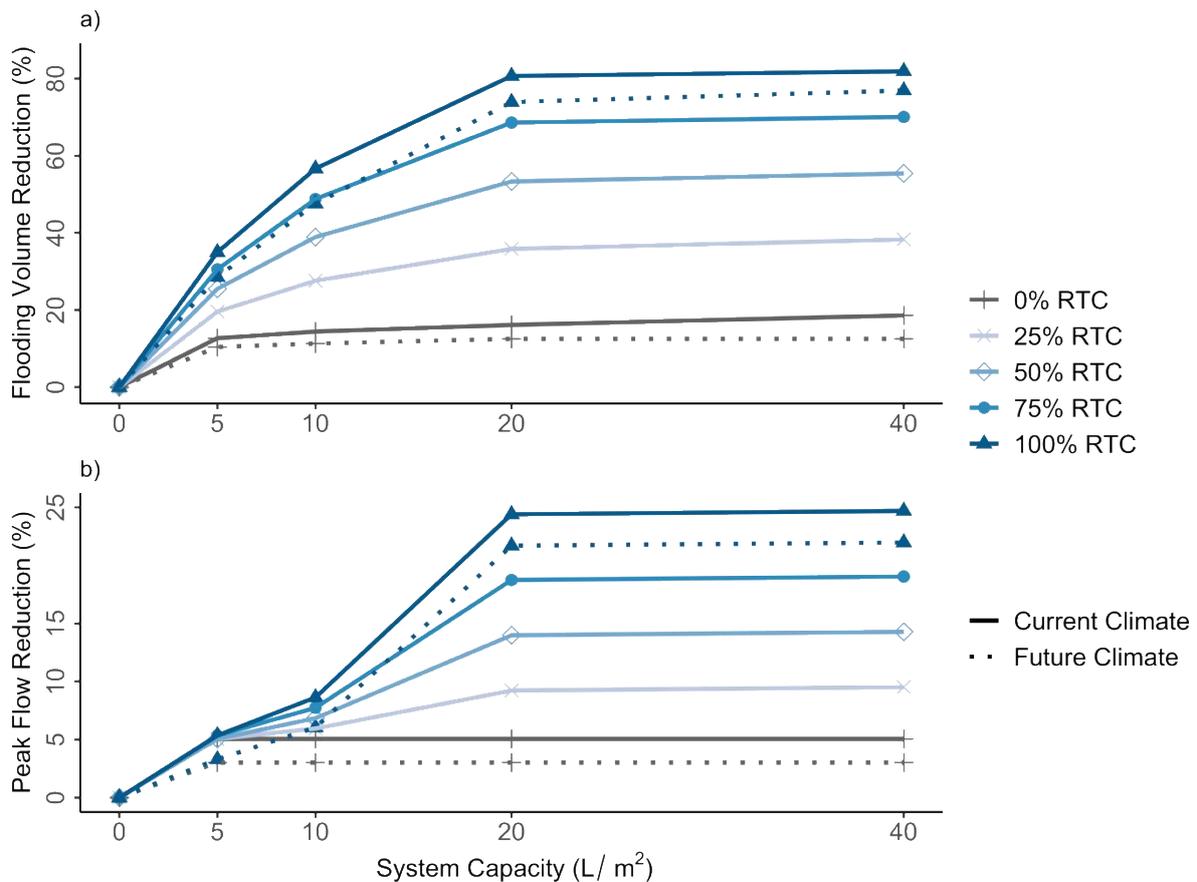


Figure 2. Evaluation of a) flooding volume and b) outlet peak flow reduction performance in a range of scenarios under current and future climates for the 7-month simulation period.

4 CONCLUSION

- The impact of at-source RTC RWH systems on the behaviour of a stormwater network was modelled, through the integration of a RTC model in R software and a 1-D hydraulic model in SWMM.
- The use of RTC can substantially reduce the network flooding volume and peak flow in both current and future climates and mitigate the risks of urban flooding
- Implementing higher proportions of RTC systems provided larger relative benefits than simply increasing the storage capacity of RWH systems.
- RTC storages distributed throughout a stormwater network can substantially improve its performance, potentially avoiding or deferring expensive sewer network upgrades. Investments in RTC technology would appear to be more promising than investments in detention volume alone.

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