Real Time Control in Urban Drainage Systems: Risks associated with rainfall and system capacity uncertainty

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Highlights

- Assuming the system capacity in optimisation procedures can lead to RTC efficacy loss
- Erroneous rainfall forecast only moderately reduces RTC efficacy
- The interplay between rainfall and system capacity uncertainty cannot be predicted

Introduction

Real Time Control (RTC) has frequently described as an effective method to optimise the operation of urban drainage systems (UDS). In RTC, real-time information about the system is used to make decisions on the operation of actuators, either through pre-determined heuristic rules or through model-based optimisation (Garcia et al., 2015). Including rainfall forecasts can further improve the operation of the system, enable the pro-active management of the UDS through model predictive control (MPC). However, when determining the set points of actuators in UDS using predictions, efficacy loss might occur due to suboptimal setpoints resulting from inaccurate forecasts and assumptions about the system capacity (storage volume and pumping capacity). Given the high impact of pump failure events on CSO loadings (Korving and Clemens, 2005), it is important to understand if this impact is exacerbated through RTC. This papers aims to understand the risks of using uncertain rainfall forecast and system capacity for RTC of urban drainage systems.

Methodology

Case Study

The case study of Eindhoven was selected as it has been widely used in both modelling and RTC research (van Daal-Rombouts, 2017; Moreno-Rodenas, 2019) The branch Riool-Zuid (Southern-Sewer, RZ) serves 7 municipalities through a main transport pipe with a pumping station (PS Aalst) in the middle, expected to operate at 10,000 m^3/h. The section upstream of PS Aalst was used this research and has been shown to be susceptible to RTC-based optimisation (van der Werf et al., 2021). This sections consists of a large transport line with two Control Stations (CS) and three main CSOs along with smaller CSOs in the municipalities (Figure 1). The main CSOs serve as a proxy for municipal discharges

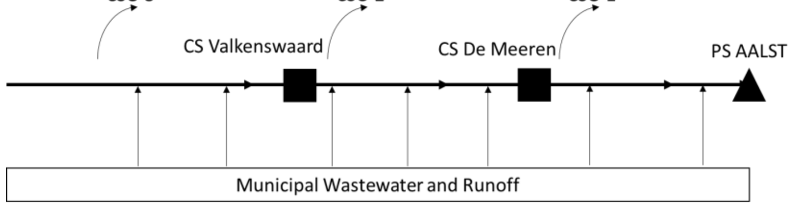

Figure 1 - Layout of catchment.

Model and Data

A detailed hydrodynamic model of the system was developed in EPA SWMM5 containing 9884 nodes. To enable model predictive control, the complexity of the system was reduced. The municipal sections were modelled and calibrated in previous work (van der Werf et al., 2021).

Two radar rainfall data sets were used: rain-gauge adjusted (RGA) and radar reflectivity forecast (RRF) with a two hour forecast horizon both maintained by the Royal Netherlands Meteorological Institute (KNMI). The event selected for this campaign had a maximum intensity of 12.1 mm/hr, with a total volume of 29.2 mm over a total of 17 hours. During the event, PS Aalst had various moment when the flowrate setting of 10,000 m^3/h was not reached (Figure 1), a frequent occurrence in the system.

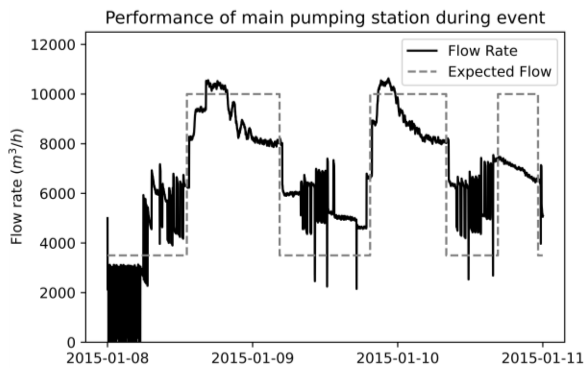

Figure 2 - Difference between expected flow and performed flow by main pumping station

Real Time Control Procedures

Using the aforementioned optimisation model, an MPC procedure was set up using the pyswmm open source tool (McDonnell et al., 2020). The optimisation objective was the minimisation of CSO volume and standard deviation in filling degree between different sections. The CSO volume was given a weight of 10,000 times higher compared to the equal filling degree objective, meaning the controller would prioritise the CSO volume reduction when forecasted in the optimisation model.

Scenarios

Four scenarios were developed related to the information type parsed to the optimiser (Table 1) to assess the relative influence. The perfect forecast refers to the RGA dataset and Real Forecast to the RRF. The reflectively values were adjusted using an empirical equation as used by the KNMI. The full capacity uses the maximum available pumping capacity during WWF, where the perfect knowledge uses the reduced capacity from the data as the maximum available capacity at each time-step within the optimisation model.

Table 1 - Scenarios analysed

Scenario	Rainfall I	System Performance
Scenario 1	Perfect Forecast (RGA Dataset)	Perfect knowledge
Scenario 2	Perfect Forecast	Full Capacity assumed
Scenario 3	Real Forecast (RRF Dataset)	Perfect knowledge
Scenario 4	Real Forecast	Full Capacity assumed

Initial Results and discussion

Using the four scenarios described above, the total CSO loading per main CSO was calculated (Table 2). A clear decrease in efficacy was observed due to the assumption of the full capacity being available to the model (Scenario 2). This increase in total volume derives from a significant increase in the CSO 1 volume and not sufficiently offset by the decrease of CSO 2 volume. In the optimisation model, assuming full pumping capacity, the settings for CS De Meeren were higher compared to the perfect forecast ability as an additional capacity of 2,000 m3/h was assumed for the downstream most part.

Table 2 - Results from the event per CSO in m^3

Scenario	CSO 1	CSO 2	CSO 3	Total CSO
1	4,918	3,027	0.000	7,945
2	8,305	1,101	0.000	9,406
3	3,907	4,382	0.000	8,297
4	7,730	1,245	0.000	8,975

The RRF dataset slightly reduced the efficacy when perfect knowledge of the pump capacity was assumed. The use of both RRF rainfall and wrong assumptions about pumping capacity did not decrease the efficacy of the system further but rather reduce the efficacy loss compared to using RGA dataset and wrong assumption about the pumping capacity. The RRF dataset predicted the rainfall to occur more downstream of the system, thereby causing CS De Meeren to reduce flow rates similarly to the RGA with perfect system capacity knowledge (Table 2).

From this event, it appears that the MPC related risks are related more to the system capacity uncertainty than the rainfall uncertainty. This is consistent with earlier observations about the influence of erroneous rainfall forecast in MPC research. It should be noted that this work only included a single event. More rainfall events are being computed to investigate if the trends observed here are constant.

Conclusions and future work

This work aims to identify the risks associated with inherent uncertain rainfall forecasts and system performance Based on the initial investigation we can conclude that the risks associated with system capacity uncertainty has a greater influence on the RTC potential compared to rainfall forecast uncertainty for the analysed system. Additional rainfall events need to be done to be able to assert the initial conclusions with confidence. With these runs, more detailed conclusions about the relation between RTC performance and forecast and system performance uncertainties could be drawn, from which more robust MPC strategies can be developed.

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