Development and implementation of a large-scale Real Time Control system in Rotterdam

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Highlights

- Design of rule based RTC using sewer and WWTP models
- RTC performance evaluation system
- Balancing CSO emissions to urban canals, CSO emissions to a large river and WWTP performance

Introduction

The city of Rotterdam (664,000 inhabitants) is in the western part of the Netherlands. Rotterdam is the second largest city in the Netherlands while its harbour is the 4th largest of the world. The municipality of Rotterdam is ambitious to develop towards a climate adaptive, circular city. The municipality invests heavily in blue-green solutions, such as green roofs, urban agriculture, floating parks, and water squares. As the transition to blue-green and climate proof systems will take decades, Rotterdam is also investing in Real Time Control (RTC) solutions to optimise the performance of the existing wastewater infrastructure. The wastewater infrastructure of Rotterdam includes 964 pumping stations, 3043 km sewers pipes and 515 Combined Sewer Overflow (CSO) structures. The wastewater is discharged to 9 different wastewater treatment plants (WWTPs), of which WWTP Dokhaven with a hydraulic capacity 19,500 m^3/h is the largest.

The first application of Real Time Control (RTC) at the pumping stations in Rotterdam dates from the early 2000s, when a RTC system called CAS (Centrale Automatische Sturing – central automatic control) was implemented (Van Leeuwen, 2003). The CAS system had the objective to minimise CSO emissions to urban canals while not exceeding the annual thresholds for CSO emissions to the river system (Geerse and Lobbrecht, 2002). Due to several practical issues, the CAS system was rapidly taken 'out of service' and the control was switched back to manual control by system operators. In 2018, preparations started to develop CAS2.0. The new RTC system should benefit from the expansion of the sewer monitoring network in Rotterdam as well as developments in the field of RTC and automation. In 2023, full scale implementation of the CAS2.0 RTC system started. The site acceptance test is scheduled for January 2024. This abstract describes the use of sewer and WWTP models to develop the RTC control rules and proposes a system to evaluate the performance of the wastewater system and the CAS2.0 RTC system.

Methodology

Model development

The sewer model, see figure 1, has been developed using ArcGIS and InfoWorks software as a linear reservoir model, where each (sub)catchment has been schematised as a singular linear reservoir. Model inputs are dry weather flow of households and industry, extraneous water based on monitoring data and rainfall from local rain gauges. The model in ArcGIS is updated automatically by connecting the model to the asset management system. The model has been validated using monitoring data of water flows and levels at pumping stations. The model for the two biggest WWTPs, WWTP Dokhaven and WWTP Kralingseveer, has been developed using the ASM3+ bio P model (Rieger et al., 2001) using SIMBA software. The WWTP model has been validated using monitoring data of WWTP effluent.

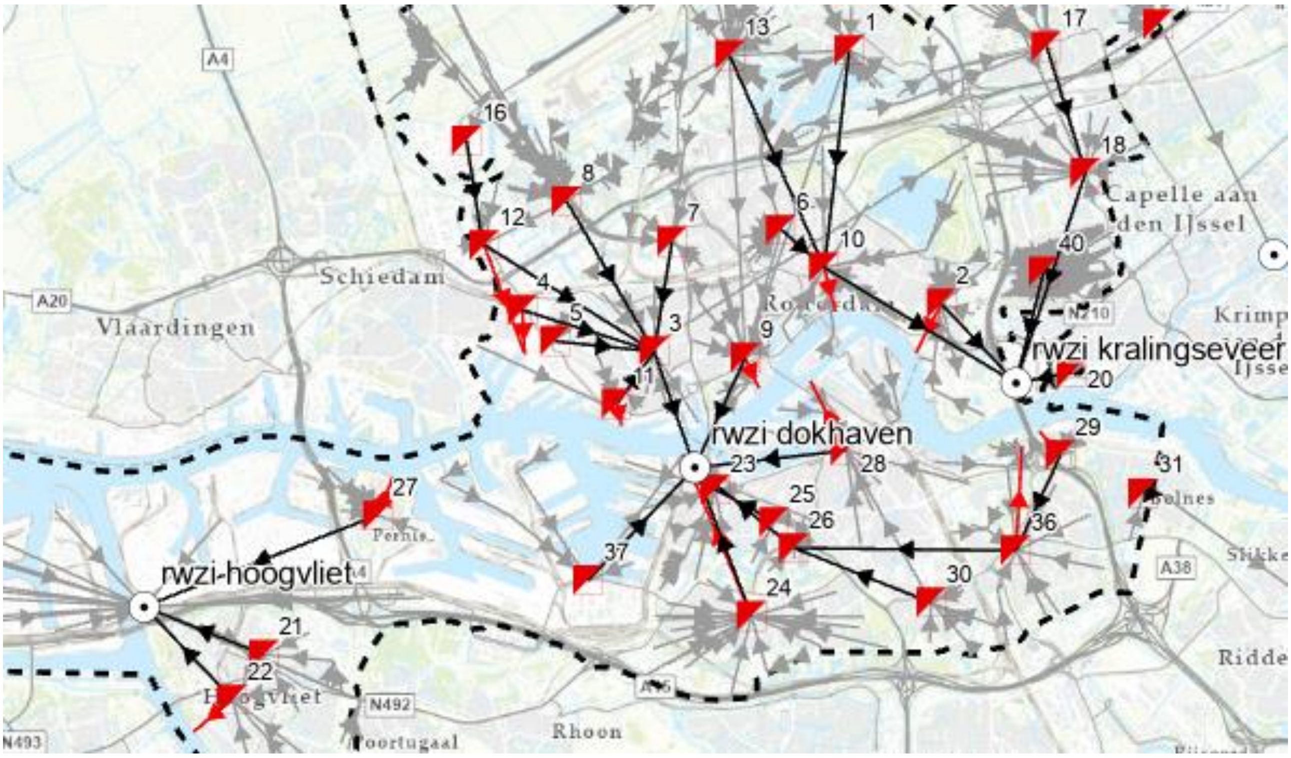

Figure 1. Part of the model of the Rotterdam sewer system in ArcGIS with the main pumping stations (indicated red blocks), the smaller pumping stations (indicated with grey arrows), and the location of the WWTPs (indicated as 'rwzi').

RTC strategy & RTC rule development

The RTC strategy has been developed iteratively. At first, an indicative 'span of control' for the RTC system was defined by assessing the range in performance that can possibly be achieved by the sewer system and by assessing the potential impacts on receiving water bodies downstream CSOs and downstream WWTP's. This first step was a combination of expert judgement, monitoring data analyses and simulations using above mentioned models. Secondly, the RTC objectives have been defined and prioritised, with the prioritisation being condition dependent:

- During dry weather and small storm events, priority will be given to an optimal WWTP performance.
- During moderate storm events, the goal is minimising total CSO emissions to urban canals by balancing the degree of filling of the sewer systems.
- During heavy storms prevention of urban flooding will get priority.

Thirdly, a RTC strategy has been developed which balances the (conflicting) objectives. Fourthly, a sensitivity analysis has been performed to select sewer subcatchments that should be part of the RTC system and to identify subcatchments where RTC will not result in an improvement, e.g., due to their small contribution or due to a lack of control potential. Finally, RTC scenarios and heuristic RTC rules have been developed and tested using the sewer model.

Development of RTC performance indicators

The evaluation of RTC performance is developed based on the method of van Daal et al. (2017). The following performance indicators are being implemented in the control software PCS7 and the monitoring software Pro-Inf that the process operators use to evaluate the performance of the pumping stations:

- Indication of the actual stage (which is related to the degree of filling of the sewer system) and the actual CAS setpoint,
- Automated graphs of time series of level, stage, setpoint and flow of each pumping stations,
- Colour coded map with performance indicator flow / setpoint per pumping station within a user specified time frame,
- Percentage of the dry weather days in which dry weather flow (DWF) peak reduction is achieved,

- Comparison of calculated emissions within a user specified time from two reservoir model simulations: one based on local setpoints (without RTC) and the other one based on CAS setpoints,
- Performance indicator volume of 'unnecessary' 'pumped CSO' spills that could have been stored in the sewer system.

Results and discussion

RTC rules

The RTC system in Rotterdam should meet the following objectives (with *in italics* the connected strategy and the stage when the strategy is active, see figure 2):

- Enhance WWTP performance by 'flattening' the DWF diurnal curve. *DWF peak reduction is achieved by maximising the total inflow of the WWTP to a predefined $Q_{DWF,max}$ and temporarily storing any additional DWF wastewater volume in the sewer systems discharging directly to the WWTP*. DWF peak reduction is applied in stage I.
- Enhance WWTP performance at the onset of storm events. *Pumping capacity is increased slowly from DWF setpoints to wet weather flow (WWF) setpoints by using an intermediate 50% WWF setpoint at 50% filling degree of the in-sewer storage*. Incremental step wise increase in pumping capacity is applied in stages II, III and IV.
- Minimise CSO discharges to urban canals. *Active use of 'pumped CSOs', large pumps that discharge directly to the river, switch off pumping stations located at the outside of river and sea dikes, switch of pumps off storm sewer systems and balance available pumping capacity over the sewer catchments to minimise CSO discharges to urban canals*. Focus on CSO emission reduction is central in stages V and VI.
- Minimise emission of pumped CSOs and pumping stations outside the dikes. *This control strategy uses weather predictions to identify the moment to switch off the pumped CSOs and switch on the pumping stations outside the dikes*. The return after a large event is controlled by stage VII. The return to DWF after a small event is controlled by stages VII, IX, and X.

The actual degree of filling of the combined sewer systems determines which of the objectives gets priority. The actual degree of filling is derived from the water level sensors in the sewer catchments. These levels can be used, as the performance of the combined sewer systems of Rotterdam is dominated by the (in an international context) relatively large storage volumes of on average 9 mm or 90 m^3/ha. Figure 2 gives an example of measured system dynamics, with an indication on the stage of the RTC system being based on the measured water level in the sewer system. In addition, the degree of filling of downstream catchments also determines the maximum flow for the discharge of the upstream catchments.

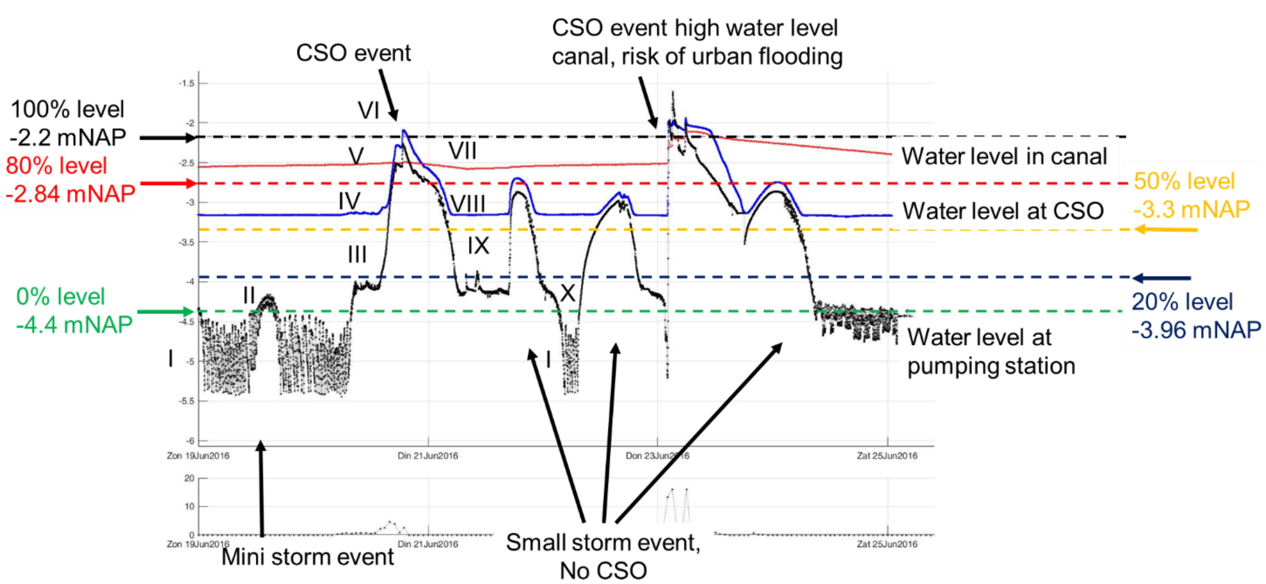

Figure 2. Typical events (DWF, mini storm event, small storm event and very large storm events) and filling degree thresholds determining the stage of the RTC system. NAP indicates mean sea level. Horizontal coloured lines indicate the water levels that determine the stage of the sewer system. The stage determines the RTC objective which gets priority.

Implementation

In second half of 2023, the RTC design was programmed and implemented in the process control system PCS7 (Siemens) that is used to control the pumping stations. At the end of 2023, CAS2.0 has been implemented for the first pumping stations and the system is functioning under the continuous control of a process operator. Figure 3 shows a part of the control panel with the CAS block icons.

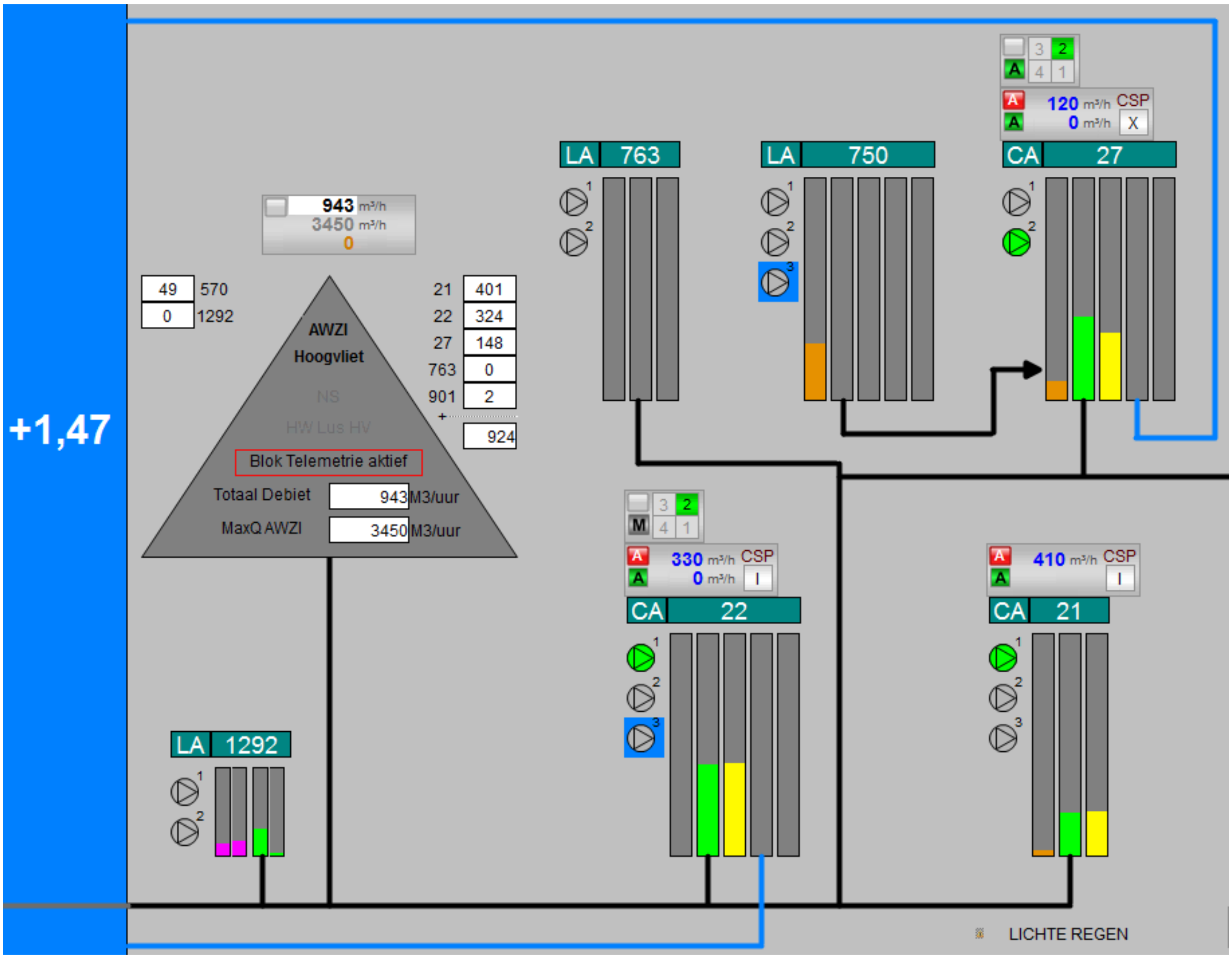

Figure 3. Part of the control panel of the wastewater transport system discharging to WWTP Hoogvliet. CAS2.0 RTC has been implemented at the pumping stations 21, 22 and 27. The current stage of the sewer system, the current setpoint and the current maximum flow are indicated in the CAS block icons. Pumping stations 22 and 27 have a 'pumped CSO' (blue line); during large rainfall events diluted wastewater is pumped directly to the river.

Conclusions and future work

This abstract only shows a small part of the current RTC development as it is work in progress at the end of 2023. The developed heuristic RTC rules will be fully operational in Q1 of 2024 for three WWTPs, including WWTP Dokhaven. The performance indicators in Pro-Inf are currently implemented. Once the system is stable, model based RTC will be developed as an add-on to the heuristic control rules.

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