Impact-based integrated real-time control for improvement of the Dommel River water quality

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ABSTRACT
The wastewater system of Eindhoven has been equipped with RTC control stations in the interceptor sewer since the early 1970s. The original volume-based RTC strategy aimed at maximizing the use of the in-sewer storage capacity and of the hydraulic capacity of the downstream WWTP. The water authorities now face receiving water problems related to intermittent discharges from CSOs and WWTP effluent, specifically oxygen depletion and ammonia peaks in the Dommel River. The combination of the availability of control structures and receiving water quality problems makes the Eindhoven case an ideal one to study the benefits of the most advanced application of RTC in urban wastewater systems: integrated impact-based RTC. This paper shows the results of the analysis of its potential for improvement of the water quality of the Dommel River.

KEYWORDS: Real-time control, integrated modeling, monitoring, Water Framework Directive

INTRODUCTION
In many receiving waters, especially rivers receiving substantial discharges from CSOs and WWTPs, transient conditions causing acute effects like DO depletion and ammonium toxicity are the main limiting factor for achieving a good ecological status. WWTP effluent is typically the main cause of ammonium peaks in receiving waters, whereas CSO emissions typically contribute more to DO depletion. This requires multi-objective optimization of the performance of the integrated urban wastewater system (Rauch and Harremoës, 1999).
Integrated real-time control is generally believed to be a good option to cost-effectively meet the water quality objectives (Olsson, 2012). Its potential is determined by the characteristics of the urban wastewater system in terms of control power and the relative impact of the urban wastewater system on the receiving waters.

This paper presents the results of the development of an impact-based RTC strategy in the Eindhoven region (the Netherlands). The wastewater system of Eindhoven and surroundings has already been equipped with RTC control stations in the interceptor sewer since the early 1970s (Figure 1). The original RTC strategy aimed at maximizing the use of the in-sewer storage capacity and of the hydraulic capacity of the downstream WWTP, resulting in a volume-based RTC strategy (see also Langeveld and Clemens, submitted). The water authorities now face receiving water problems related to intermittent discharges from CSOs and WWTP effluent, specifically oxygen depletion and ammonia peaks in the Dommel River.

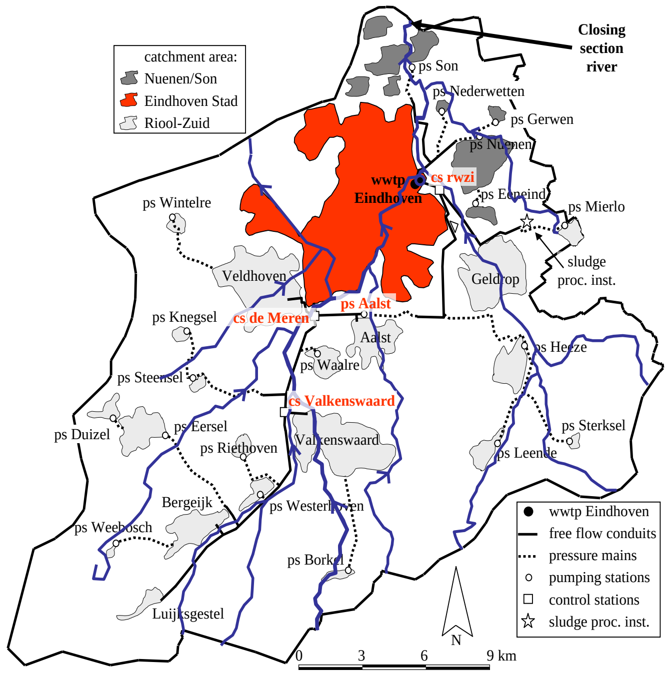

Figure 1. Scheme of the urban wastewater system of Eindhoven and its receiving waters.

The combination of the availability of control structures and receiving water quality problems makes the Eindhoven case an ideal one to study the benefits of impact-based RTC of integrated urban wastewater systems (IB-RTC for IUWS).

MATERIAL AND METHODS

The Dommel River is a relatively small lowland river with a base flow of 2-4 m^3/s. It receives the effluent from a 750,000 PE WWTP and 200 combined sewer overflows (CSOs), in a system draining 4000 ha of impervious area. In summer time and for dry weather flow conditions, the WWTP effluent can constitute up to 50% of the base flow of the river.
Waterboard De Dommel (the responsible water authority) has launched in 2010 a comprehensive applied research project in order to identify the most cost effective set of measures for meeting the EU Water Framework Directive (WFD) requirements by adopting an integrated approach, combining impact-based control and a minimum of additional measures (Weijers et al., 2012).
The following approach has been applied to derive directly applicable impact based control strategies (for details, see Langeveld et al., submitted):

- upgrade of existing monitoring network in sewer system, WWTP and river, including
    - 400 level sensors and 40 flow sensors in the sewer system, 5 well equipped rain monitoring stations combined with rainfall radar
    - modern instrumentation, automation and control at the WWTP
    - extensive monitoring in the river, comprising continuous monitoring of dissolved oxygen and ammonia, combined with automated sampling and ecological surveys.
- calibration and validation of fully detailed models of sewer system, WWTP and receiving water
- simplification and integration of the sub-models into a single sewer-WWTP-river model in the WEST simulator (www.mikebydhi.com);
- a global sensitivity analysis (GSA) to identify the control structures with a significant impact on receiving water quality, i.e. the wastewater system comprises over 80 pumping stations, 4 RTC control structures, a controllable river diversion works and full process

control at the WWTP. The GSA revealed the key control structures for the RTC strategy.
- compose and evaluate RTC strategies; the RTC strategies are evaluated on three storm events at critical locations in the river. The three storm events have been selected to represent 3 types of events: from vary rare events that occur once every 5 year to events that occur respectively 4 and 13 times per year (5-y, 0.25-y and 0.075-y return periods).

This paper presents results of the final step: composition and evaluation of RTC strategies.

RESULTS AND DISCUSSION

Impact of storm events on receiving water quality

Figure 2 shows the impact of the three storm events on the receiving water quality for dissolved oxygen (left) and ammonium (right). With respect to oxygen depletion, there is a very large difference between the different types of storm events, with a minimum concentration of 1.5 mg O_2/l for a T=5 year storm event and 4 mg O_2/l for a T=0.075 year storm event. For ammonium concentration levels in the river, the difference between the large and small storm events is much smaller. This is due to the fact that even in the smallest storm event, the full hydraulic capacity of the WWTP is already used, resulting in only a modest increase in WWTP effluent ammonium levels during larger storms. The oxygen depletion reflects the influence of the CSOs, whose impact increases with higher intensity storm events. Consequently, figure 2 reflects the main cause of the receiving water quality problem, being the WWTP effluent with respect to ammonium and the CSOs with respect to oxygen depletion during large storm events.

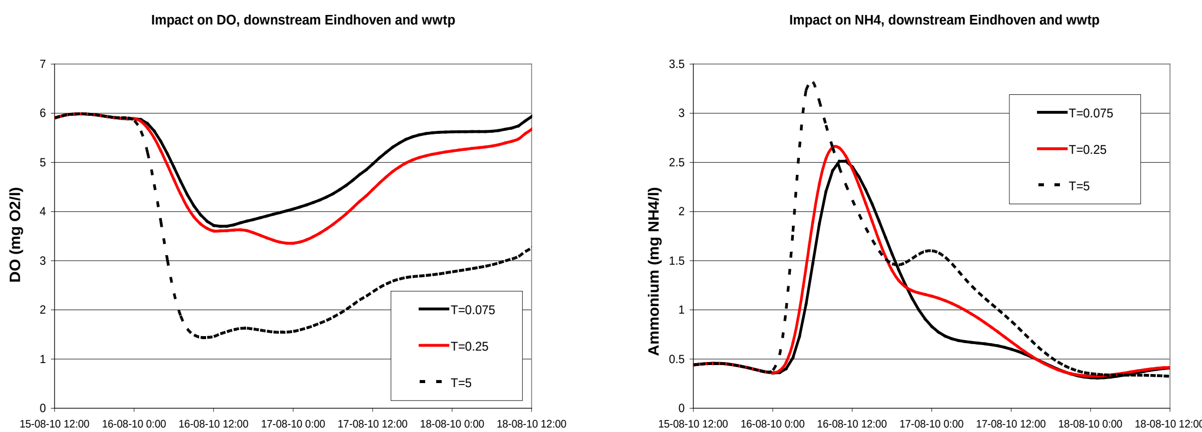

Figure 2. Impact of storm events on DO (left) and ammonium (right) in the Dommel River

Evaluation of RTC strategies

Three strategies have been developed and tested with the integrated model, all having different objectives:

Strategy 1. Minimization of ammonia peaks in the river. This strategy minimizes the impact of storm events on WWTP performance by retaining the flow as much as possible by dynamically activating the in sewer storage (indicated as “RTC NH4”).

Strategy 2. Minimization of dissolved oxygen dips in the river. This strategy maximizes the use of hydraulic capacity at the WWTP and at the retention tanks in order to minimize the discharge by CSOs (indicated as “RTC DO”).

Strategy 3. Combination of the previous two, resulting in multi-objective optimization, as they have conflicting objectives (indicated as “RTC NH4-DO”).

The impact of the strategies on ammonia and DO in the receiving water quality are respectively given in Figures 3, 4 and 5 for the three storm events. For the smallest event, all RTC strategies delay the DO dip in the river and improve the situation with improvements ranging from 0.5 to 1

mg O_2/l. With respect to ammonia, the RTC NH4 and RTC NH4-DO strategies reduce the ammonia peak concentration in the river from 2.5 mg/l to as little as 1.2 mg/l, whereas the RTC DO strategy improves the performance, but the peak concentration of NH_4 remains 1.7 mg N/l.
For the medium size event (T=0.25 y), the RTC NH4 strategy hardly improves the DO concentration in the river, whereas the RTC DO and RTC NH4 strategy result in a 0.5 mg O_2/l increase in the DO concentration. The RTC NH4-DO strategy shows the best performance for minimsing the impact on the ammonia concentration, with a decrease in the peak level of 0.7 mg NH_4-N /l.
For the largest event (T=5 y), none of the strategies is capable of improving the DO concentration levels and both the RTC NH4 and RTC NH4-DO strategies reduce the ammonia peak concentration in the river from 3.3 mg/l to 2.7 mg/l.

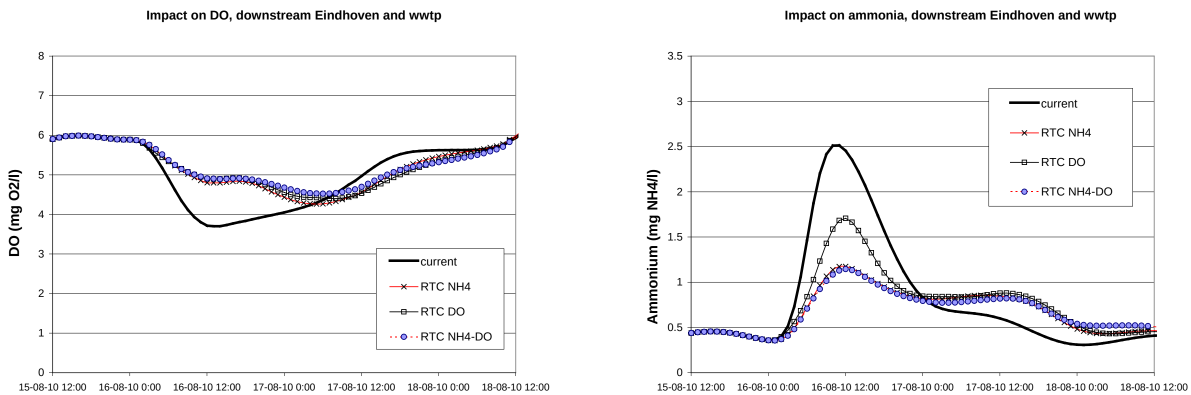

Figure 3 Impact of applying RTC strategies on receiving water quality in the river Dommel downstream of Eindhoven for a T=0.075 y storm event for DO (left) and NH_4 (right).

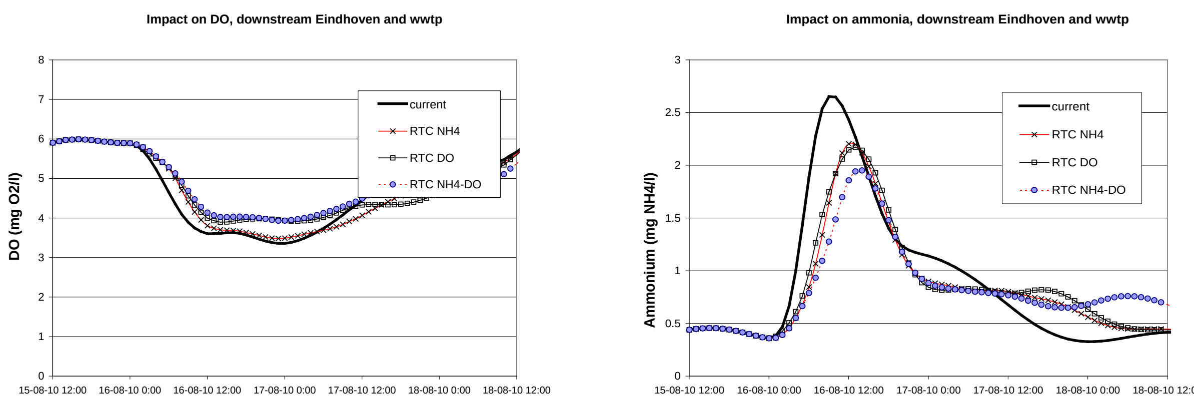

Figure 4 Impact of applying RTC strategies on receiving water quality in the river Dommel downstream of Eindhoven for a T=0.25 y storm event for DO (left) and NH_4 (right).

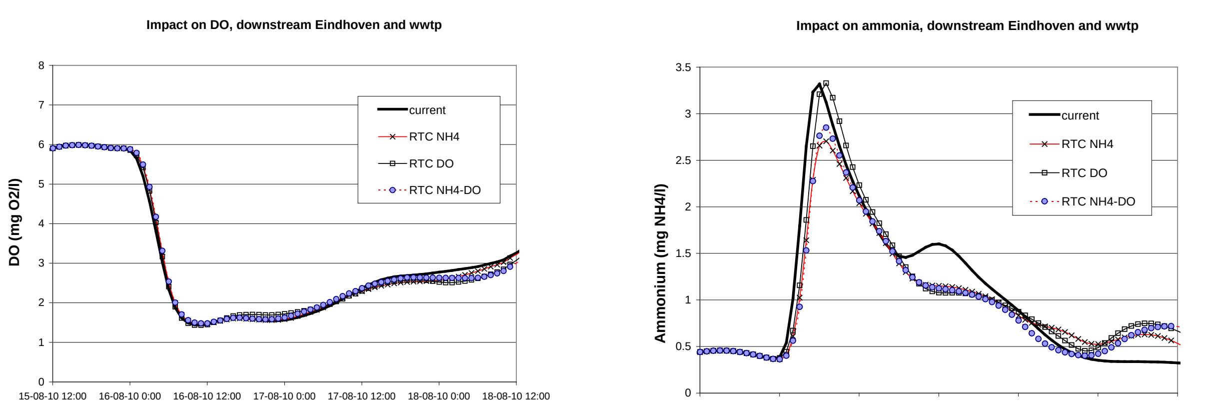

Figure 5 Impact of applying RTC strategies on receiving water quality in the river Dommel downstream of Eindhoven for a T=5 y storm event for DO (left) and NH_4 (right).

The results show that with respect to the DO concentration in the river, RTC can only improve receiving water quality for relatively small storms (<< T =0.25). This means that the RTC potential for improving the DO concentration is limited. For ammonia, however, even for the largest storm event (T=5) a significant improvement can be achieved with RTC, thus illustrating the potential to improve WWTP performance (and indirectly receiving water quality) with impact based RTC. The optimal strategy, however, depends on the type of event and the water quality problem addressed. This indicates that short-term radar weather forecasts should be incorporated in the development and implementation of the control strategy and that a supervisory system is required to select the appropriate control strategy.

CONCLUSIONS

Based on the evaluation of the RTC scenarios it is concluded that for the Eindhoven case:

- Impact-based RTC can improve receiving water quality significantly using available control structures.
- Minimizing DO depletion or ammonium peaks requires different strategies. The 'optimal' strategy in this case will be the one that requires the least additional measures. This issue is addressed further within the Kallisto project, see also Benedetti et al., submitted**.**

ACKNOWLEDGMENTS

The project is funded by KRW-innovation subsidy from AgentschapNL (www.agentschapnl.nl). The Dutch Foundation for Applied Water Research (STOWA) is engaged in the project to communicate and publish the research results.

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