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Performance evaluation of a smart buffer control at a wastewater treatment plant

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ABSTRACT

Real time control (RTC) is increasingly seen as a viable method to optimise the functioning of wastewater systems. Model exercises and case studies reported in literature claim a positive impact of RTC based on results without uncertainty analysis and flawed evaluation periods. This paper describes two integrated RTC strategies at the wastewater treatment plant (WWTP) Eindhoven, the Netherlands, that aim to improve the use of the available tanks at the WWTP and storage in the contributing catchments to reduce the impact on the receiving water. For the first time it is demonstrated that a significant improvement can be achieved through the application of RTC in practice. The Storm Tank Control is evaluated based on measurements and reduces the number of storm water settling tank discharges by 44% and the discharged volume by an estimated 33%, decreasing dissolved oxygen depletion in the river. The Primary Clarifier Control is evaluated based on model simulations. The maximum event NH4 concentration in the effluent reduced on average 19% for large events, while the load reduced 20%. For all 31 events the reductions are 11 and 4% respectively. Reductions are significant taking uncertainties into account, while using representative evaluation periods.

1. Introduction

Following regulations like the Water Framework Directive, water governing authorities are turning to more integrated optimisation of their wastewater systems (Blumensaat et al., 2012; Rauch et al., 2005). Technological advances in monitoring, modelling and data communication, see e.g. (Benedetti et al., 2013; Campisano et al., 2013), make the application of real time control (RTC) an increasingly accepted method to do so.

RTC aims at enhancing the performance of a system by improving the use of the available infrastructure, as opposed to changing the infrastructure itself. In wastewater management several strategies are reported: i) volume based, making optimal use of the available system capacity (e.g. Dirckx et al., 2011; Weyand, 2002), ii) quality based, exploiting differences in pollution levels (Lacour et al., 2011; Seggelke and Rosenwinkel, 2002; Vezzaro et al., 2014), and iii) impact based, taking differences in the vulnerability of the receiving waters into account (Erbe and Schütze, 2005; Langeveld et al., 2013; Risholt et al., 2002).

All references mentioned report on modelling exercises only, some applied to real cases, as they make up the bulk of literature available. Some practical applications of RTC in wastewater system management have emerged. Early examples of the application of integrated volume based RTC can be found in Québec (Pleau et al., 2005) and Barcelona (Puig et al., 2009). In (Grum et al., 2011) one of the first descriptions of the integrated, impact based RTC for Copenhagen is described, while a case study in Wilhelmshaven can be found in (Seggelke et al., 2013). Quality based RTC has been implemented in the sewer system of Wuppertal (Hoppe et al., 2011).

(Van Daal-Rombouts et al., 2017) noted that no uniform methodology is available for the performance evaluation of RTC in wastewater systems for case studies. Further they state that the period applied in the evaluation should be carefully considered and uncertainties should be explicitly taken into account. They propose

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List of abbreviations

ASM2d	activated sludge model No.2D
BS	booster pumping station between PCs and activated sludge tanks
CSO	combined sewer overflow
DO	dissolved oxygen
DWF	dry weather flow
EFF	effluent
ES	catchment Eindhoven Stad
INF	influent
H	water level
m AD	Normal Amsterdam Water Level
MG	mixing gutter after influent pumping station
NH4	ammonium
NS	catchment Nuenen-Son
PC	primary clarifier
Q	flow
Q_{BIO}	total flow to the activated sludge tanks
Q_{BIO_max}	maximum current hydraulic capacity of the activated sludge tanks
Q_{ES}	influent flow from catchment ES
Q_{INF}	total influent flow from all three catchments
Q_{INF_max}	maximum current total influent capacity from all three catchments
Q_{NS}	influent flow from catchment NS
Q_{RZ}	influent flow from catchment RZ
Q_{SST}	flow toward the SST
RMSE	root mean squared error
RTC	real time control
RZ	catchment Riool Zuid
SST	storm water settling tank
WWF	wet weather flow
WWTP	wastewater treatment plant

a methodology that incorporates these aspects but have not demonstrated its applicability.

The research presented here focusses on the wastewater treatment plant (WWTP) of Eindhoven, the Netherlands. The wastewater system is characterised by a densely populated area that poses a large stress on the local receiving waters, consisting of small lowland rivers and creeks, through WWTP effluent and numerous combined sewer overflows (CSOs). Ecological water quality is affected by dissolved oxygen (DO) depletion and ammonium (NH4) peaks. Previous research by (Langeveld et al., 2013) has shown the WWTP to be an important source for both NH4 peaks and DO depletion and that application of integrated, impact based RTC could help mitigate these problems.

This paper deals with two complementary impact based RTC scenarios and their performance evaluation. Both aim at improving the use of the available tanks at the WWTP and storage volume in the contributing catchments: i) Storm Tank Control. Optimises the operation of the WWTP storm water settling tank (SST) with respect to the contributing catchments to reduce unnecessary discharges of the SST and subsequent DO depletion. And ii) Primary Clarifier Control. Optimises the operation of the primary clarifiers (PCs) and influent pumping station to reduce peak loading of the activated sludge tanks and subsequent NH4 peaks.

The performance evaluation is carried out following the methodology described in (Van Daal-Rombouts et al., 2017). To the authors knowledge it is the first real world case were both a representative evaluation period is applied as well as uncertainties are explicitly taken into account.

This paper is organised as follows. Section 2 introduces the wastewater system and WWTP under consideration, the RTC scenarios and the methods applied in the performance evaluation. Section 3 describes the results of the performance evaluation, which is followed by a discussion on the results in section 4. Finally, conclusions are presented in section 5.

Supplementary material is presented in the appendix. Section A supplies additional figures to support some descriptions and claims in this paper. The reader will be referred to the appendix at the appropriate locations. Section B elaborates on the implementation of the RTC scenarios. Section C supplies details about a field test to investigate the impact of applying only one PC instead of three during dry weather flow (DWF) conditions.

2. Materials and method

2.1. Wastewater system Eindhoven

The wastewater system of Eindhoven is displayed in the appendix section A, and consists of a WWTP, three contributing combined sewer catchments and the river Dommel as receiving surface water for both the WWTP effluent and approximately 200 CSOs.

Sewer catchment 'Eindhoven Stad' (ES) serves the city of Eindhoven and contributes approximately 45% to the total influent of the WWTP. Catchment 'Riool Zuid' (RZ) serves seven municipalities south of Eindhoven through a 31 km transport sewer and also contributes approximately 45% to the WWTP influent. Catchment 'Nuenen-Son' (NS) is located to the northeast of Eindhoven and represents less than 10% of the influent; In terms of optimisation of the wastewater system NS is considered insignificant. As the WWTP is located in Eindhoven, with a connected area of approximately 2000 ha and which sewer consists of one looped gravity system, the functioning of ES is strongly influenced by the operation of the influent pumping station. This influence is much less significant for RZ due to the transport sewer, where a pumping station acts as a barrier and several municipal sewer systems are connected through pumps. In the transport sewer between the WWTP and the pumping station approximately 10,000 m^3 idle storage is available.

The receiving waters consist of a network of small lowland rivers that eventually combine into the river Dommel that originates in Belgium and flows northward into the river Meuse. In dry summer periods the WWTP effluent can constitute up to 50% of the rivers base flow, under storm conditions this increases to 90%.

2.2. WWTP Eindhoven

A schematic overview of WWTP Eindhoven is displayed in Fig. 1. The WWTP has a capacity of 750,000 population equivalent and a maximum hydraulic capacity of 35,000 m^3/h. It generally consists of an influent pumping station with a pumping chamber for each catchment and three identical treatment lines. Each treatment line has a maximum hydraulic capacity of 8750 m^3/h and consists of one PC, an activated sludge tank and four secondary clarifiers. In between the PCs and the activated sludge tanks the water is mixed at