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Performance evaluation of real time control in urban wastewater systems in practice: Review and perspective

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ABSTRACT

Real time control (RTC) is generally viewed as a viable method for optimising the performance of urban wastewater systems. A literature review on the performance evaluation of RTC demonstrated a lack of consensus on how to do this. Two main deficiencies were identified: omitting uncertainty analysis and applying limited evaluation periods. A general methodology to evaluate the performance of RTC in practice, that takes into account these deficiencies, is proposed. The methodology is either data or model driven and the (dis)advantages of each are discussed. In a case study for a combined sewer system with limited discharge to a WWTP, it is demonstrated that the successful application of RTC and the possibility to determine a significant effect is very much dependent on the goal. It also clearly illustrates the need for taking uncertainties into account and that careful consideration in the chosen evaluation period is required.

1. Introduction

In the past decades real time control (RTC) has been a research topic of interest in the field of urban wastewater systems (Schilling, 1989). describes some of the first steps in RTC in this field (Schütze et al., 2004), give a state of the art in the following years and a recent overview can be found in (García et al., 2015). At several locations RTC has been implemented and described in publications, see e.g. (Fradet et al., 2011; Fuchs and Beeneken, 2005; Seggelke et al., 2013). Such papers generally claim that the application of RTC improves the operation of the system; it leads for example to fewer combined sewer overflow (CSO) discharges. Overall, RTC is viewed as a viable method to reduce the impact on natural aquatic systems, to improve the operation of urban wastewater systems and to help adapt the systems to changing conditions.

Looking in more detail to the performance evaluation of RTC, most applied methods are deficient in two aspects: i) uncertainties are not accounted for, and ii) only a few events or short periods are applied. The first represents a lack of certainty on the significance of the outcome, whether the uncertainty arises from measurement uncertainty and model output uncertainty (originating from a combination of input, model structure or parameter uncertainty), see e.g. (Deletic et al., 2012). The second leads to an evaluation based on a limited range of conditions under which RTC in urban wastewater systems is operated. Knowing this, claims on the effectiveness of RTC in urban wastewater systems, without addressing the deficiencies outlined, can be viewed as just that.

This paper contributes to the discussion on the effectiveness of RTC in urban wastewater systems in practice and how to evaluate that. Questions on how to deal with ever changing conditions in real life situations and the need for and implications of including uncertainty analysis are addressed. It will focus on systems that at least encompass a combined sewer system. ‘Regular’ process control of wastewater treatment plants (WWTPs), such as aeration or return activated sludge control, is considered beyond the scope of this paper, as this topic is dealt with intensively in literature (Olsson, 2012; Olsson et al., 2014). On contrary, integrated control

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of urban wastewater systems is still considered to be at an early stage of development.

The paper is organised as follows: In the next section literature related to implemented RTC in urban wastewater systems is reviewed, resulting in the formulation of a more detailed problem statement. Section 3 proposes a methodology for the performance evaluation of RTC in practice. This is followed by a case study in section 4 to show the impact of the evaluation period and uncertainty analysis on the effectiveness of two RTC scenarios on a simple and easy to understand sewer network. Section 5 discusses the results from the case study and the methodology itself. Finally, conclusions are drawn and suggestions for further research are made.

2. Problem statement

RTC, hereby defined as changing the operation of an urban wastewater system based on real time measurements without changing its infrastructure, is claimed to be an effective and efficient manner of optimising a systems functioning with respect to a certain goal, see e.g. (Erbe et al., 2002; Fuchs and Beeneken, 2005; Nelen, 1992; Puig et al., 2009). Changes in the system objectives over time, e.g. from minimising the CSO volume towards minimising the overall impact on the receiving water body, are important drivers for RTC. Apart from this, imbalances in the system due to a faulty design, improper adaptation, uneven loading, or changes in design principles in an organically grown system, can cause unwanted effects that may also enhance the need for RTC.

Many developments in RTC in urban wastewater systems have taken place based on modelling exercises, for both hypothetical systems and 'real-world' case studies. For example (Schilling et al., 1996) describe an early application of RTC on a sewer system and wastewater treatment plant combined (Einfalt et al., 2001). introduce the central basin approach, that to date in German speaking countries is viewed as the method to define the optimum controlled state of a system (Erbe and Schütze, 2005). further integrate the modelling environment and take a quality approach (Vanrolleghem et al., 2005). deal with the difficulties of preparing an integrated model for RTC application. An investigation into the effect of rainfall forecasting on the runoff and its potential for RTC are described by (Krämer et al., 2007) (Schütze et al., 2008). introduce the German M180 guideline document for the planning or RTC systems in urban drainage catchments. Equipment needed for the implementation of RTC is reviewed by (Campisano et al., 2013) and the effort needed is described by (Beeneken et al., 2013) (García et al., 2015). give an overview of and references for different implementation levels, optimisation strategies and software tools for RTC in urban wastewater systems. Recently (Garbanini Marcantini et al., 2016), claim intermittent operation of RTC can help determine the impact of RTC more easily and (Löwe et al., 2016) looked into the influence of rainfall forecasting and its uncertainties on RTC strategies. For WWTPs, a benchmark for control strategies has been developed, allowing to test strategies in a general sense in a controlled model environment (Alex et al., 1999). This procedure is very promising for mutually comparing the effectiveness of control strategies at WWTPs, but not to quantify the added value of the control in urban wastewater systems in reality. This is due to for example the propagation of errors between subsystems, the difference between model results and reality and the influence of operational issues.

Simultaneous to these developments, at several locations RTC has been implemented in practice, for which a non-exhaustive and concise overview will be presented. Unless stated otherwise the main objective of the applied RTC is reduction of CSO activity, possibly at specific sites. As early as 1994 a model predictive control strategy was prepared for implementation in Seattle (Gelormino and Ricker, 1994) (Fuchs and Beeneken, 2005). describe the process of implementing a rule-based control that includes rainfall forecasts in Vienna. In Quebec, a model predictive control RTC system based on rain forecasts is executed in a stepwise manner. The first phase is presented in detail in (Pleau et al., 2005), while (Fradet et al., 2011) describe the later phases and the project in a wider scope. The applied model and global control development for Berlin is described in detail in (Pawlowsky-Reusing, 2006). In Copenhagen RTC is implemented as described in (Grum et al., 2011). It includes risk assessment and flow forecasting (Hoppe et al., 2011). describe the development of a pollution based RTC strategy for the separate sewer system of Wuppertal. In Wilhelmshaven the aim of the implemented RTC is twofold: CSO reduction and WWTP influent limitation in case of critical situations (Seggelke et al., 2013). describe the effectiveness based on one year of operation. For Kessel-Lo (Dirckx et al., 2014), provide details on construction and cost aspects regarding the implemented RTC. A recent application of RTC in the sewer system of Bordeaux is described in (Robitaille et al., 2016), including an evaluation over a period of three years.

A table, summarising the system type, control type, objectives and evaluation characteristics (period and whether uncertainty analysis was performed) of the papers dealing with RTC performance evaluation referred to in the previous paragraphs, is presented in the supplementary material.

From the papers that deal with implemented RTC systems, the current practice for a performance evaluation of implemented RTC systems in the field of urban wastewater management was extracted. First of all, a performance evaluation is not always carried out (or reported). When it is executed, there is no consensus on the procedure. It is generally (with a few exceptions) based on either less than ten storm events or over a period of maximum a few months only. Comparisons are made between the systems functioning with and without RTC based on measurements or modelling results or a mixture of both. Only two publications were found that describe the effectiveness or functioning of existing RTC over periods longer than 1 year. Second, none of the publications cited report on uncertainties in parameters used for the performance evaluation, leaving the question on the significance of the effect open. Only (Hoppe and Gruening, 2007) and (Breinholt et al., 2008) make a point for including uncertainty analysis in RTC evaluation, but their call has remained unheard so far. Even (Löwe et al., 2016), who in a modelling exercise do apply uncertainties in the rainfall estimation and use many events from a three year period, still refrain to include uncertainties in the final performance evaluation.

Current practice is thought to originate from the reality of working with actual systems, for customers in a commercial setting along with an unfounded trust in our ability to understand and describe reality in models (Harremoës, 2003). Urban wastewater systems are normally not operated for the purpose of research and therefore changes in set points, operation strategy and even infrastructural adaptations are continuously made. In other words, in practical situations one is never certain about the structure and geometry of the whole considered system, although this is desired from a scientific point of view. High quality measurements are hard to obtain in real working conditions, especially simultaneously and for extended periods of time. Generating a data set for a performance evaluation for a prolonged period is therefore an organisational feat. Uncertainty analysis is believed to be omitted because in actual systems uncertainties are often not known, it is deemed complicated and time consuming, and the results become more difficult to communicate. Customers add to this by expecting (fast) results and preferring their money well spent, at least on paper.