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Following a drop of water from the cloud, throughout the sewer system, into the receiving water – Model predictive control of integrated sewer-wastewater treatment systems

P.S. Mikkelsen[1], L. Vezzaro[1,2], A.K. Sharma[1], B.G. Plósz[1], M. R. Rasmussen[3], S. Thorndahl[3], R. Gil[4], R. Löwe[5], H. Madsen[5], M. Grum[2], T.N. Gadegaard[2], M. Rungø[6], A. Lynggaard-Jensen[6], C. Thirsing[7], L. Bassø[8], J. Thyme[9], H. Petersen[10], D.E. Thornberg[11]

[1]Department of Environmental Engineering (DTU Environment), Technical University of Denmark, Building 113, 2800 Kgs. Lyngby, Denmark, luve@env.dtu.dk, akush@env.dtu.dk, beep@env.dtu.dk, psmi@env.dtu.dk
[2]Krüger A/S, Veolia Water Solutions&Technology, Gladsaxevej 363, 2860 Søborg, Denmark, lxv@kruger.dk, mg@kruger.dk, tng@kruger.dk
[3]Department of Civil Engineering, Aalborg University, Sohngårdsholmsvej 57, 9000 Aalborg, Denmark, mr@civil.aau.sk, st@civil.aau.sk
[4]Danish Meteorological Institute, Lyngbyvej 100, 2100 Copenhagen E, Denmark, rsg@dmi.dk
[5]Department of Applied Mathematics and Computer Science (DTU Compute), Technical University of Denmark, Richard Petersens Plads, Building 305, 2800 Kgs. Lyngby, Denmark, rolo@imm.dtu.dk, hm@imm.dtu.dk
[6]DHI, Agern Allé 5, 2970 Hørsholm, Denmark, mor@dhigroup.com, atj@dhigroup.com
[7]Lynettefælleskabet I/S, Refshalevej 250, 1432 København K, Denmark, ct@lyn-is.dk
[8]Aarhus Vand A/S, Bautavej 1, 8210 Aarhus, Denmark, lba@aarhusvand.dk
[9]Greater Copenhagen Utility (HOFOR), Ørestads Boulevard 35, 2300 København S, Denmark, jethy@ke.dk
[10]Avedøre Wastewater Services, Kanalholmen 28, 2650 Hvidovre, Denmark, hmp@spvand.dk
[11]Copenhagen Wastewater Innovation, c/o Lynettefælleskabet, Refshalevej 250, 1432 København K, Denmark, dt@spvand.dk

Abstract: This article presents selected examples of model-based prediction and control of integrated sewer-wastewater treatment systems, developed within the framework of the Storm- and Wastewater Informatics project (SWI). By exploiting all the available on-line information (e.g. radar based rainfall measurements, flow and water levels, operational parameters at treatment plants) it is possible to dynamically optimize the integrated storm- and wastewater systems according to different criteria (e.g. utilizing the system fully at all times and reducing volumes of combined sewer overflows, loads of pollutants discharged from treatment plants, etc.). The tools developed in the SWI project include (but are not limited to (i) rainfall nowcasting based on radar measurements, (ii) probabilistic flow forecasting based on data assimilation and stochastic models, (iii) prediction and optimization of wet-weather performance of wastewater treatment plants, and (iv) integrated control of the different elements of the integrated wastewater systems. Full-scale testing of these tools in different catchment located in Denmark ensure that the developed tools can represent an important step forwards for on-line operation of combined sewer networks and wastewater treatment plants.

Keywords: Integrated urban wastewater system; probabilistic forecasting; real time control

INTRODUCTION

New demands and stricter objectives are continuously defined for storm- and wastewater systems (e.g. improvement of quality of receiving waters, reduction of flood risk, energy optimization, etc.), posing new challenges to the management of these infrastructures. In this context, real time control (RTC) tools represent an important opportunity. RTC based on a combination of the information provided by on-line sensors and models is increasingly seen as a cost-effective tool to increase the performance of urban drainage networks (UDNs) and wastewater treatment plants

(WWTPs) during wet weather. While the basic concepts have already been established in the past decades, the developments in monitoring and modelling tools as well as methods for handling the uncertainty related to these tools have only recently paved the way for a widespread implementation of system wide RTC.

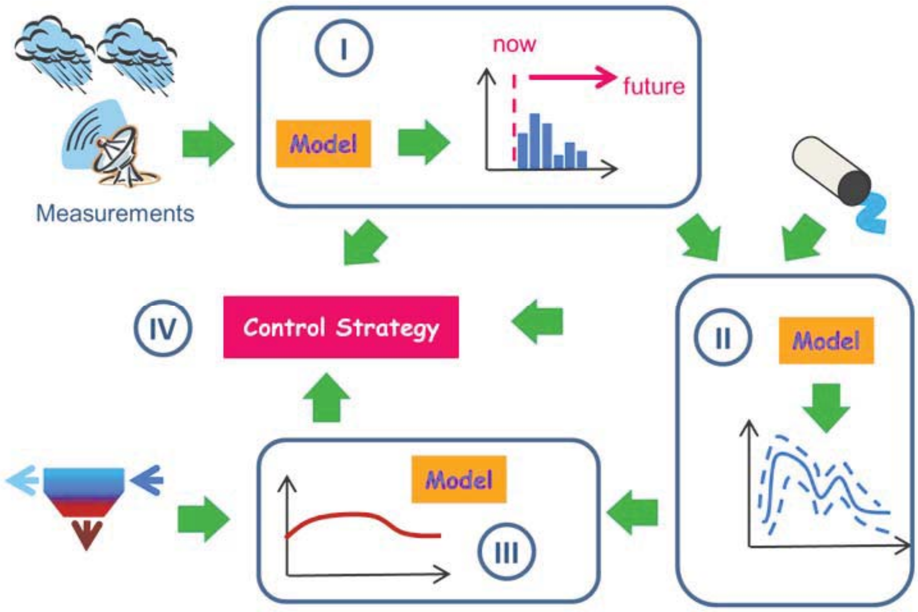

Figure 1 Schematic representation of the SWI framework for model-based control of integrated urban storm- and wastewater systems. Number I, II, II and IV are explained in the text below.

The knowledge gaps which hinder an immediate full-scale implementation of system wide RTC of urban drainage and wastewater treatment systems (e.g. handling of the uncertainty in the different parts of the system) have been investigated in the Storm- and Wastewater Informatics (SWI, 2008-13, http://www.swi.env.dtu.dk/) project. The framework for RTC developed by using the SWI tools (see Figure 1) can be schematized into the following elements:

I. Rainfall nowcast methods based on radar measurements are developed to estimate the precipitation expected in the catchment within a short time horizon (e.g. 2 hours ahead). These tools provide the input for rainfall-runoff models, which are used to predict the expected runoff volumes in the different part of the controlled system. An example is presented by Thorndal et al. (2013).

II. Rainfall-runoff models, along with hydraulic UDN models, taking rainfall nowcasts as input and assimilating system measurements (e.g. flows and water levels) in real-time are developed to improve the predictions, using e.g. maximum a posteori estimation to update parameters (Poulsen et al., 2013) or stochastic grey box models to update system states (Breinholt et al., 2012).

III. Models which mimic the behaviour of WWTPs are developed to estimate the wastewater flows that can be treated during wet weather without worsening the WWTP performance (e.g. protecting the secondary clarifies from overload). These models will thus provide dynamic boundary conditions for integrated system wide control of urban drainage and wastewater treatment systems.

IV. Overall integrated control strategies are developed that utilize all available measurements as well as probabilistic model predictions to optimize the system operation. The Dynamic Overflow Risk Analysis method (DORA, cf.Vezzaro and Grum (2012) constitutes the backbone of the control strategy developed within the SWI project. DORA is currently under implementation in three catchments: the Lynetten and Avedøre catchments (located in the Copenhagen area) and the Marselisborg catchment (located in the central Aarhus).

This contribution presents some selected examples of application of the tools developed within the SWI project. Thanks to triple-helix collaboration between research organisations, industry and water utilities these tools are tested in real systems during the project. This ensures a quick implementation of the developed technology in real systems.

CHALLENGES

The project to a large extent uses and further develops tools that are known from other fields (e.g. radar rainfall measurements, data assimilation techniques, model predictive control). Direct transfer is however not possible, and some of the major challenges are:

1. The fast dynamics of the processes taking place in the system. Rainfall represents the input to the system, and it is intrinsically characterized by a high temporal and spatial variability, which is difficult to predict at the urban scale.
2. The high complexity of the urban drainage networks, which calls for a compromise between fast conceptual models (suitable for the most widely applied data assimilation techniques) and detailed (but slow) physically based models, which are needed to obtain accurate information about the state of the system (e.g. water levels in pipes).
3. The high uncertainty affecting the available measurements, which strongly affects the performance of the models using this information and calls for the use of stochastic methods for modelling and optimisation.

The tools developed within the SWI project address these challenges from different angles. For example, flow forecast can be generated either by using deterministic models where states (or parameters) are updated based on measurements, or by using stochastic models which provide a dynamic estimation of the uncertainty in the predicted flows.

EXAMPLE OF APPLICATIONS

Pilot implementation and testing of different elements of the SWI control framework is currently progressing. Two examples are briefly mentioned below and more will be detailed at the conference.

Radar forecast for WWTP wet weather control

Flow forecasts at the WWTP inlet can be used to modify the plant operations and to increase the plant capacity (Figure 2). This allows for a reduction of the volume of untreated wastewater that is bypassing the WWTP at the beginning of rain events. An implementation of this approach is operational at the Aalborg West WWTP since summer 2012 (further details can be found in Poulsen et al. (2013)).

Stochastic flow forecast models for control of drainage systems

Given the high uncertainty in the inputs (radar-based rainfall nowcast) and of the available observations (flows and water levels), stochastic models can represent a useful tool to predict runoff in drainage systems. These so-called grey-box models (based on stochastic differential equations) can predict runoff and simultaneously provide a dynamic estimation of the uncertainty affecting these predictions (Breinholt et al., 2012). Vezzaro et al. (2013) present a first application of these models in combination with DORA for controlling the Lynetten catchment in Copenhagen.

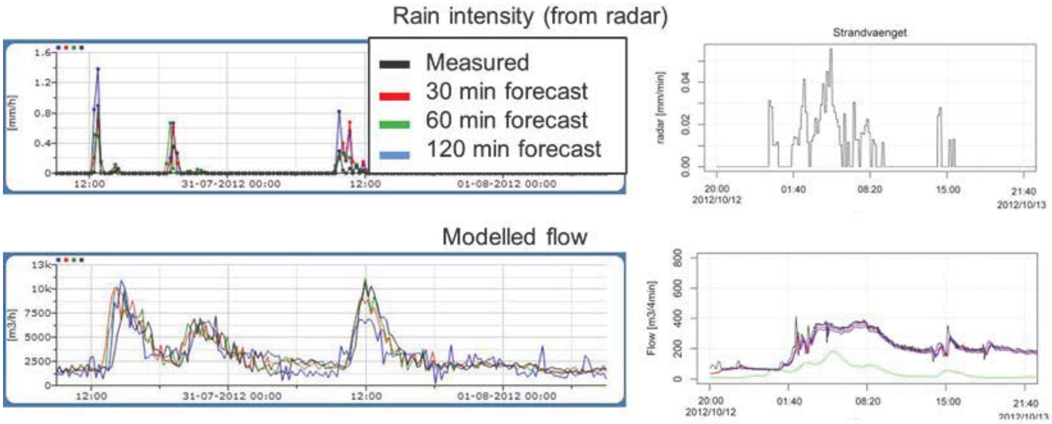

Figure 2 Left: Example of radar based forecast for inlet flow at the Aalborg West treatment plant (from Poulsen et al., 2013). Right: Example of flow forecasts along with 90% uncertainty bounds for a pumping station in the Lynetten catchment (from Vezzaro et al. 2013).

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REFERENCES

Breinholt, A., Møller, J.K., Madsen, H., Mikkelsen, P.S. (2012): A formal statistical approach to representing uncertainty in rainfall-runoff modelling with focus on residual analysis and probabilistic output evaluation - distinguishing simulation and prediction. *Journal of Hydrology*, ***472-473***, 36-52.

Poulsen, T.S., Öennert, T.B., Rasmussen, M.R., Pedersen, J.S., Thirsing, C. (2013): Weather radars used in online control of wastewater systems. Submitted to 11th IWA conference on instrumentation control and automation, Narbonne, France, 18th-20th September 2013.

Thorndahl, S., Poulsen, T.S., Bøvith, T., Borup, M., Ahm, M., Nielsen, J.E., Grum, M., Rasmussen, M.R., Gill, R. & Mikkelsen, P.S. (2013): Comparison of short term rainfall forecasts for model based flow prediction in urban drainage systems. *Water Science & Technology*, ***68***(2), 472-478.

Vezzaro, L., Grum, M. (2012): A generalized Dynamic Overflow Risk Assessment (DORA) for urban drainage RTC. In Proceedings of the 9th International Conference on Urban Drainage Modelling, Belgrade, Serbia, 4th-6th September 2012.

Vezzaro, L., Löwe, R., Madsen, H., Grum, M., Mikkelsen, P. S. (2013): Investigating the use of stochastic forecast in Real Time Control of urban drainage systems. Proc.8th NOVATECH Conf.- Planning and technologies for sustainable urban water management, Lyon, France, 23rd-27th June 2013.