Full-Scale Real Time Control Demonstration Project in Copenhagen's Largest Urban Drainage Catchments

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ABSTRACT
Real time control holds a potential for better exploitation of urban wastewater infrastructure reducing combined sewer overflows and thereby improving the environmental and recreational value of the surrounding waters. This has long been recognized and many local real time control systems have been implemented and are active today. System wide real time control strategies taking full advantage of today's forecasting and optimization technologies, integrating concerns of complete sewage networks and wastewater treatment plant have been limited largely to academic studies. This paper describes a full-scale real time control demonstration project for Copenhagen's two largest urban drainage catchments: a combined sewer network catchment and a primarily separate sewer catchment. The project involves full-scale implementation and testing of a new generalized real time control strategy combining radar based flow forecasts into a dynamic risk assessment. Also discussed are the main motivating factors for the project, it's highly compressed time line and it's context as a single step in an incremental approach, the expected benefits and an analysis that has been made of the critical factors for the project's success.

KEYWORDS
Urban drainage; integrated real time control; dynamic risk assessment; radar; flow forecast

INTRODUCTION
The Copenhagen communities have high ambitions with respect to the desired recreational value of their surface waters. Over the past years, large capital investments have been put into storage and treatment capacity in effort to reduce overflows. This has today transformed former polluted waters into attractive and highly popular bathing and water sporting areas including the old harbor in the center of Copenhagen city.

The Copenhagen utilities are looking to global integrated wastewater real time control for two main reasons. Firstly, out of a desire to optimize the exploitation of the existing wastewater infrastructure. Secondly, to minimize the required expansions to the wastewater system in meeting the required level of service. The wish to use urban surface waters for bathing presents one of the highest level of service requirements related to storage and treatment of wastewater.

To the Copenhagen communities and utilities real time control of the wastewater collection and treatment system is but one element of their general wastewater management strategy. There is a general wish to minimize the entry of rainfall-runoff and infiltration into sewer system and to encourage decentralized and eco-friendly approaches such as local filtration and infiltration zones. At the same time the Copenhagen utilities are well aware of the many physical limitations and the capital and operational expenses most often associated with decentralized eco-friendly approaches (Jeppesen et al. 2009). The Copenhagen utilities are well aware that for many decades to come combined sewer storage basins, increased wet weather treatment capacity, local overflow treatment and integrated real time control of these will be a part of the solution when seeking most recreational and environmental value for money.

The Project Context and Approach

This real time control demonstration project does not stand in isolation. In the Lynetten catchment it is part of a long term simulation study and implementation plan started in 2007 and stretching until the end of 2012. Prior to this project large investments have been put into creating, calibrating and validating an integrated model for both sewer network and treatment plants. In 2009 the Avedøre catchment launched an ambitious capital investment plan aimed at identifying and removing capacity bottlenecks in the integrated wastewater system. A part of this involves reducing combined sewer overflow the improved storage utilisation and higher utilisation of selected key transport conduits.

The implementation is part of an incremental approach to extending and optimising the real time operation of the wastewater system. Future steps could involve consideration of substance concentrations using continuous in-sewer sensors, improved control through dynamic consideration of forecast uncertainties, dynamic and non-linear combined sewer overflow cost functions, dynamic consideration recipient conditions and other yet unknown issues and opportunities. Progressing through short implementation projects with well-defined outputs provides agility and allows adaptation to changing priorities.

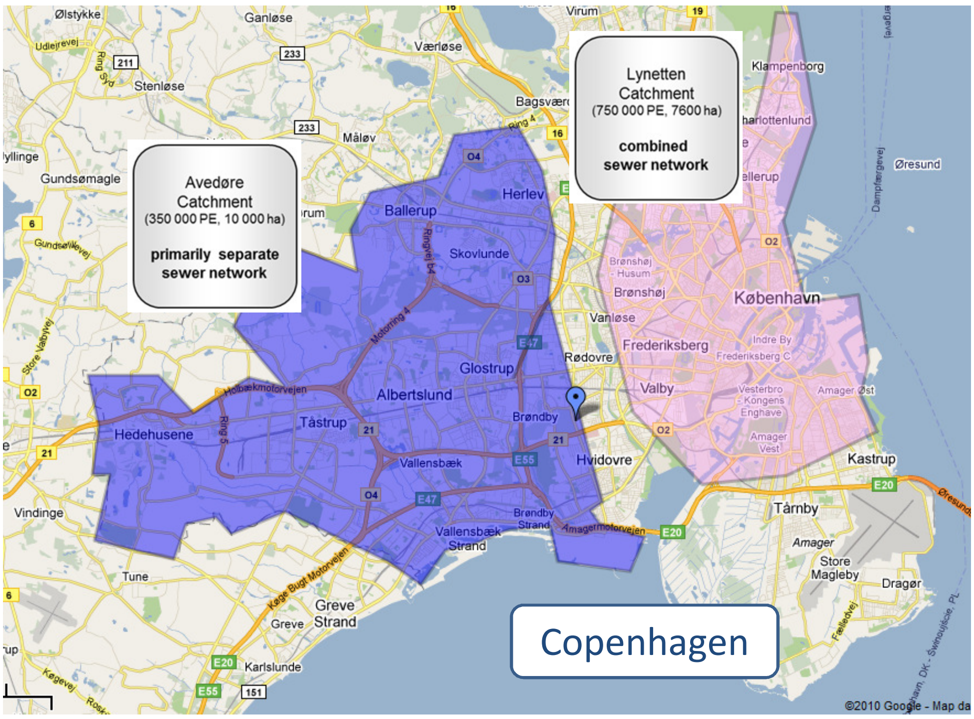

Figure 1. Location and key figures of the two demonstration catchments.

CATCHMENTS AND WASTEWATER SYSTEMS

The full-scale implementation and demonstration will take place in Copenhagen's two largest urban drainage catchments: the Lynetten catchment, a combined sewer network covering an area of 7 600 ha and a nominal treatment capacity of 750 000 PE; the Avedøre catchment, a primarily separate sewer network covering an area of 10 000 ha and a nominal treatment capacity of 350 000 PE. These catchments are shown on in Figure 1.

THE REAL TIME CONTROL STRATEGY

General Strategy

The real time control strategy is a system wide strategy sometimes called global control. The sewer network is divided into storage *sections* with *connections* between them in basically any pattern. Using a non-linear optimization routine the optimal flows in each connection are found (within the possible range) as those that minimize the total expected cost for the entire network. The total expected cost represents the product of risks and consequences for the entire wastewater system and is described in more detail in the following section. Actuators are signalled to accomplish the optimal flows and this process is repeated every two minutes.

The Radar Based Flow Forecast

Continuous radar based flow forecasts will be established to each *section*. This is done using a well-tested approach involving dynamic calibration of radar data against rain gauge measurements, radar forecasting, dynamic calibration of simple rainfall-runoff models and finally flow forecasting using the rainfall-runoff model with the forecasted radar data. The main principals of this approach are illustrated in Figure 2 below and have been described in detail in Thorndahl et al. (2009). Data from the C-band radar of the Danish Meteorological Institute (DMI) positioned at Stevns will be used for creating the flow forecasts in this project.

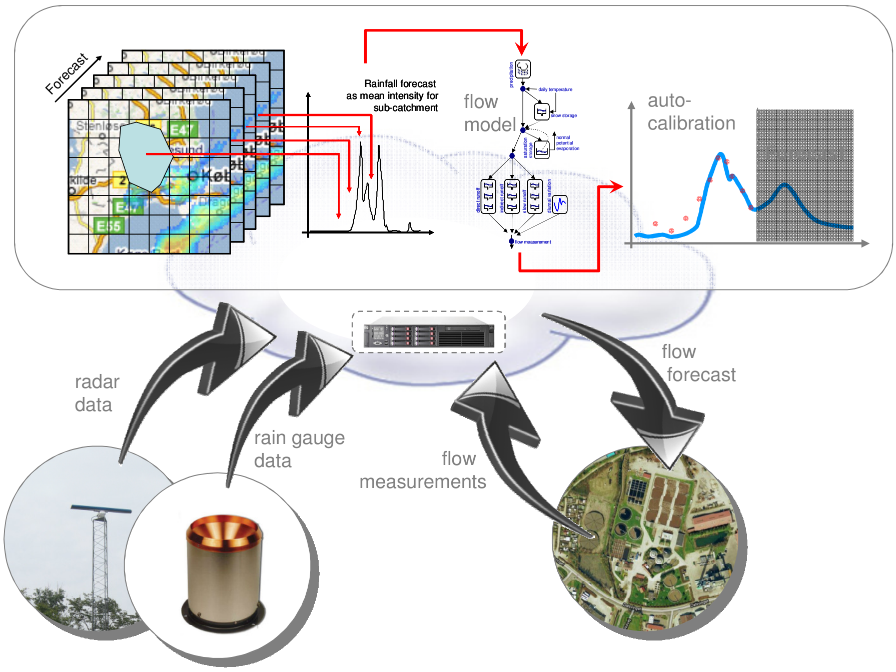

Figure 2. Illustration of the basic approach used to establish real time radar based flow forecasts will be established to 6-8 key points each of the two catchments. (See text and Thorndahl et al., 2009).

The Expected Cost

The expected cost is the core of the real time control strategy because its formulation ultimately dictates how the system will be operated. The expected cost can incorporate a wide variety of considerations such as the risk of overflow and flooding, risk of lost bathing water, pumping costs, risk of sludge loss at the treatment plant or risk of endured environmental taxes.

In this project the expected cost for each *section* has been defined as the cost of any given amount of overflow times its probability of occurrence. The endured cost for a given amount of overflow discharge has here been defined to be proportional to the volume of discharge. The expected cost for a section is thus expressed as the integration of the product of the cost of a given overflow volume (for a given runoff amount) and the probability of occurrence of that runoff amount. This is illustrated in Figure 3.

Critical Time. The total expected cost is evaluated at a point in time in the future. The vacant storage volume in each section at that point in time depends on the selected flows between network sections. The time until evaluation of the expected cost is called the *critical time* and represents the time available for minimising the expected costs. In this project the critical time has been selected as the length of time (given the current runoff forecasts) that it would take for the whole system to fill up if all volume and area were located at a single section.

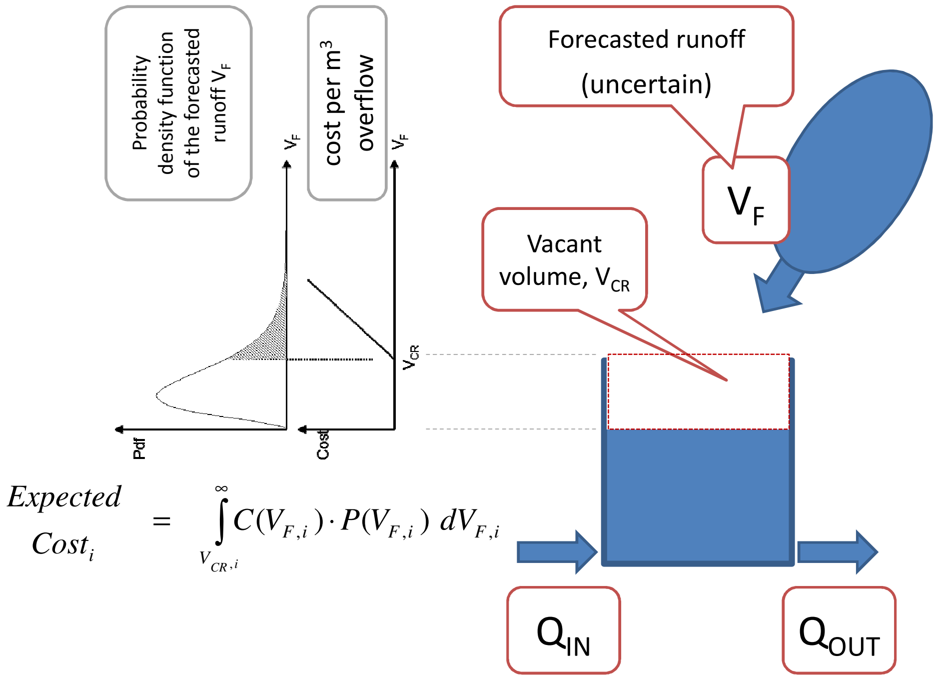

Figure 3. The expected cost is the integration over the forecasted runoff volume of the product of cost and probability and is evaluated at a point in time in the future (see text).

Optimization Routine

A genetic algorithm is used to estimate the flows that minimise the expected cost as defined above. The optimization problem is a classical non-linear programing problem with discontinuities in the objective function with respect to the parameter values (the estimated flows). Therefore the faster gradient based methods often fail to find optimal parameter set. Similarly, wandering methods, such as downhill simplex, are fooled by the non-optimum flat points that real time control problems often encompass. Using a genetic algorithm also allows for a simple way of introducing constrains involving a number of parameters (flows).

Connecting to the Local Control Units

In establishing the connection between the system wide dynamic risk based real time control strategy and the local control units at gates and pumping stations, it is essential to understand the main responsibilities of the overall and local controls respectively. The overall control is primarily responsible for optimizing storage utilization whereas the local controls are typically responsible for avoiding local flooding and keeping water levels below combined sewer overflow weir levels.

In this project local control rules are generally not changed. The overall control merely modifies key setpoints in the local controls in order to achieve the desired flows between sections. “Watch-dog” signals sent to the PLCs are used to indicate whether or not the setpoints from the overall control should be used or whether the PLC should revert to the existing setpoints of the fallback strategy. Thus PLCs will automatically switch to their fallback strategy should the quality of the input data be too poor or should the operator for any reason choose to veto the overall real time control strategy.

Integration of Sewer Network and Wastewater Treatment Plant

In this project the integration of the real time control of sewer network and the wastewater treatment focuses on the following key points:

- The treatment plants will continuously report their current maximum capacity to the generalized real time control network optimization strategy described above.
- A radar based forecast of the flows to the treatment plant will be used to switch the wastewater treatment plant into wet weather operation.
- Bypass-flow and overflow at the treatment plant will be interpreted as sewer network overflows in the generalized real time control strategy with a cost corresponding to the relative severity of their discharge damages.

The total amount of combined sewer overflow from a wastewater system can be greatly reduced by sending more water through the treatment plant without jeopardizing treatment plant performance. This will happen in two ways: Firstly, with the radar based flow forecast it will be possible for the treatment plant to switch to wet weather performance before the flow to the treatment plant exceeds dry weather capacity (see pointer 1 in Figure 4). Secondly, by continuously sending the actual plant capacity to the overall real time control strategy more water will be sent to the treatment plants earlier in the event (see pointer 2 in Figure 4).

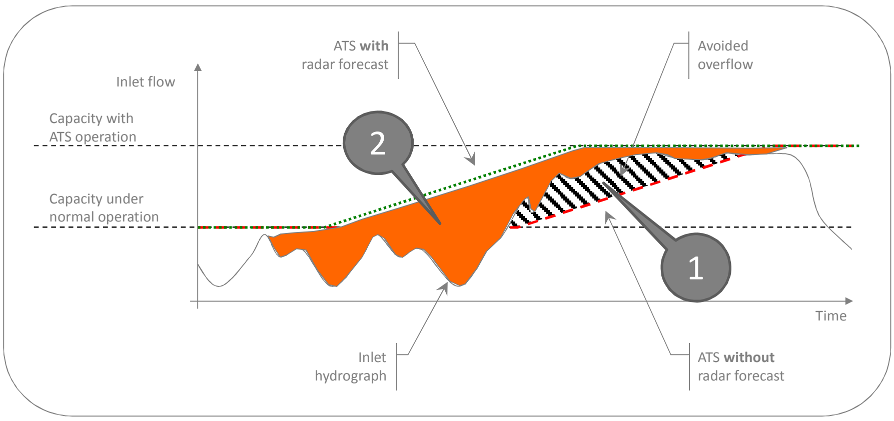

Figure 4. Wastewater treatment plant benefits of integrated real time control. See text.

IMPLEMENTATION AND EVALUATION

Implementation

The control strategy will be integrated into the existing wastewater treatment plant real time control platform, STAR, developed by Krüger. Through a web based user interface operators will be able to follow the current and near future status as well as animate past events in order better to understand the behavior of the network, the reasoning of the control strategy and the limiting constrains within their wastewater system.

Evaluation

The project also involves testing and evaluation of the real time control strategy against hydraulic models of the sewer networks. Note that hydrodynamic network models are not part of the real time control solution described above but they are used to evaluate the performance of the strategy and its configuration. The exact same software code and configuration files will be used to control actuators in the catchments hydraulic models as the actuators in real system. The testing and evaluation with take place in three phases/levels:

- Off-Line Tests. Off-line simulations with sewer network models without and with the system-wide real time control strategy. On office PC.
- On-Line Tests. Real time control strategy will run in real time in parallel with the real wastewater system with measurement data from the wastewater system but no setpoints will be sent to the local control units. Hydraulic sewer models receiving real time input data will run in parallel with real system both with and without the overall control strategy. There will be no model update.
- Full-Scale Demonstration. Here the calculated setpoints be sent to the local controls.

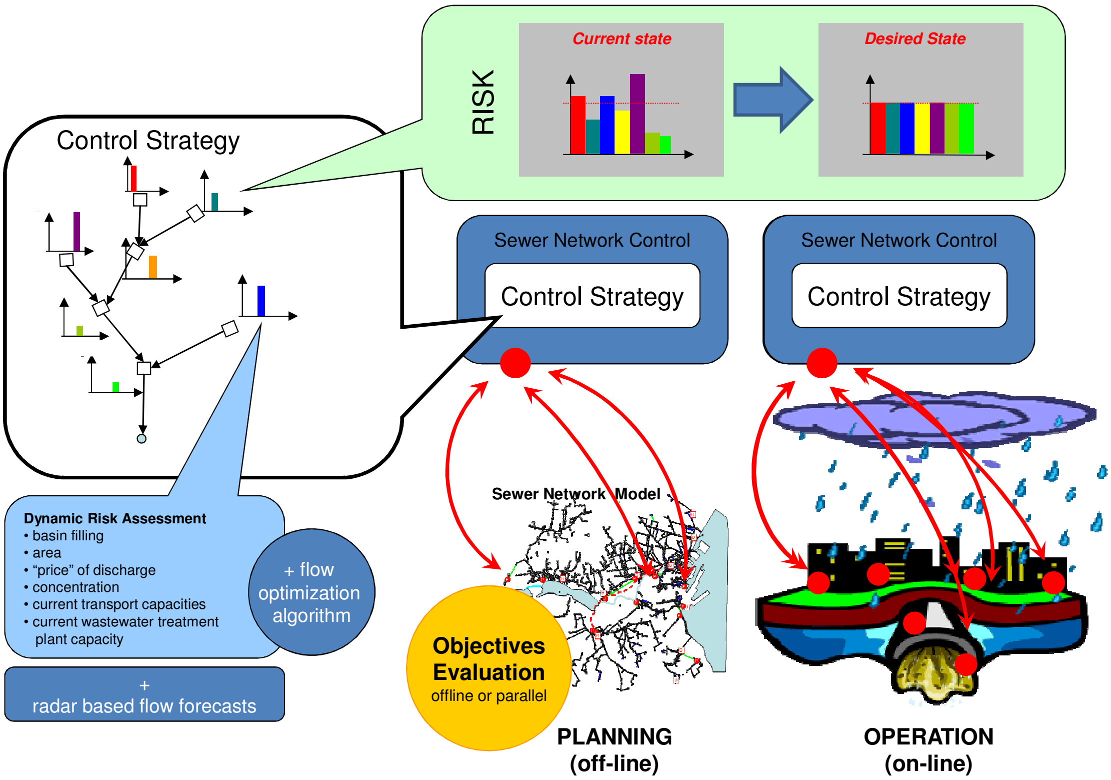

Figure 5. Illustration of the dynamic risk based network storage real time control strategy, its evaluation against models in the planning phase and its use in operation.

Performance of the integrated wastewater system will be on the basis of a weighted sum of overflows discharges where weighting is based on the relative costs of overflow that have been defined for the generalized real time control strategy.

CONCLUSIONS

This paper has presented a full-scale real time control demonstration project in Copenhagen's largest urban drainage catchments. Some of the aspects that make this project unique are:

- its cutting-edge generalized dynamic risk assessment approach
- the combination of radar based flow forecasts input into a cutting-edge generalized dynamic risk assessment
- the agile approach and its compressed and ambitious development and execution time

ACKNOWLEDGEMENT

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