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Demonstration of Integrated real time control of sanitation systems incl. early warning for WQ in receiving waters in Aarhus

Demonstration Report

SEVENTH FRAMEWORK PROGRAMME

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1 INTRODUCTION

The City of Aarhus, Denmark, has like many other coastal cities undertaken the task of restoring its old industrial harbour area into residential and recreational areas. Further, the city – as a coastal city – wants to use water as a recreational element in the old city center, and has therefore reopened a small cased river draining water from an upstream lake into the harbour – the lake already being a recreational area.

To support the opportunities for recreational use of the lake, river and harbour, the City of Aarhus in 2005 also decided to improve the hygienic water quality in the receiving waters. In more measurable terms this decision is driven by the European Water Framework Directive and the Bathing Water Directive, and the solution should in its design be adapted to the expected climate change scenario.

The preliminary planning work had already shown, that adaptation of the existing combined sewer systems in the old city center to a climate change driven increased intensity of rainfall, should include a more efficient transport and temporary storage of storm- and wastewater in order to protect the downstream wastewater treatment plants - leading to an overall reduced environmental impact from combined sewer overflows. Top three challenges were identified as:

- Sufficient storage tank volume (cost/space limitations in old city center)
- Sufficient water quality, (bathing water quality in Lake Brabrand, The Harbour of Aarhus and partly in the River of Aarhus)
- Climate change (rain intensity, sea level)

These challenges were assessed using an integrated model system for the resulting bathing water quality (based on the EU-directive classification) in the receiving waters – where compliance requires that criteria are met in 95% of the time over a 4 year period. Non-compliance caused by a rainfall intensity which occurs more seldom than every fourth year can be disregarded from the statistical calculation. The model consists of a hydraulic model super positioned with an advection/ dispersion model which describes the transport and dilution of E.Coli and Enterococci and a model describing the decay of E.Coli and Enterococci.

The modeling showed that a solution meeting the challenges and being compliant with the directives should be based on:

- Construction of 7 new storage tanks (incl. new trunk sewers where necessary) with a total volume of app. 67.000 m3
- Installation of extra hydraulic capacity at 3 wastewater treatment plants (secondary clarifiers and optimization/control of the treatment plants during rain)
- Disinfection of treated wastewater at 2 wastewater treatment plants discharging to the river
- Implementation of integrated RTC of sewer systems and wastewater treatment plants and a warning system for the bathing water quality in the harbour.

As a result of the planning work the City Council of Aarhus in 2007 approved the solution, which has a budget of approximately 50 mill. Euro.

2 FINDINGS

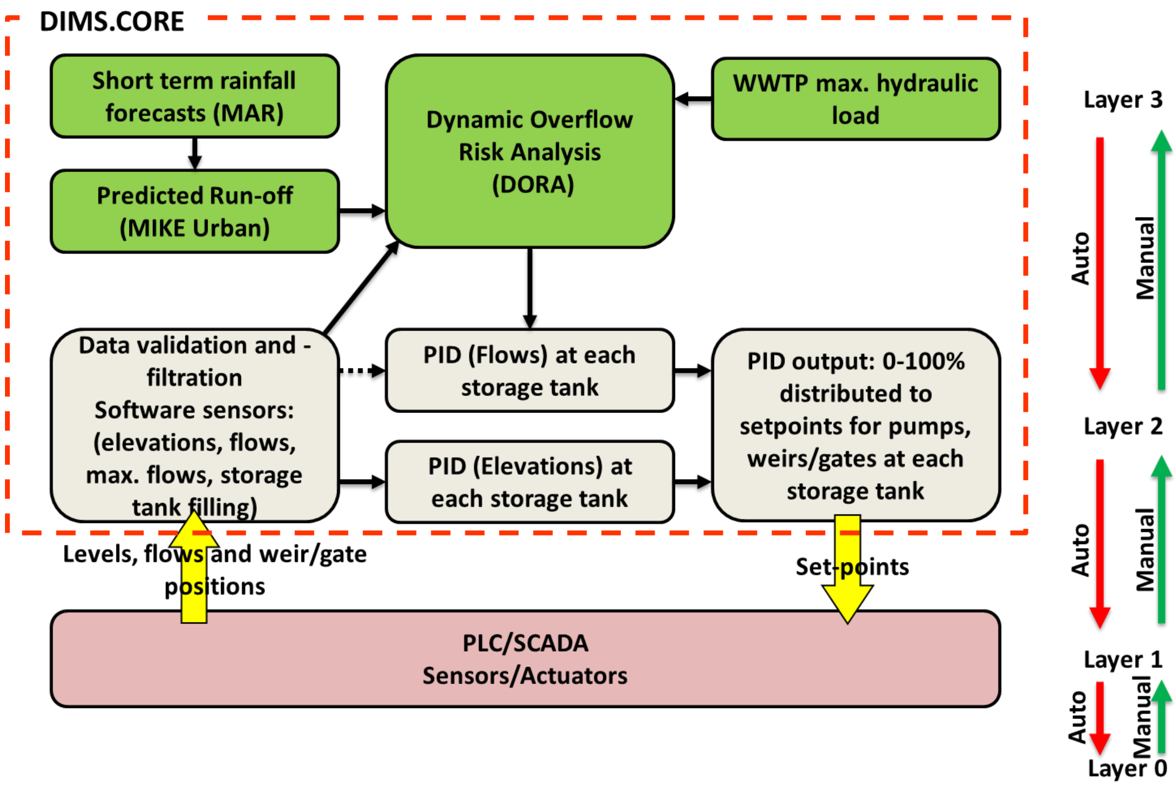
The construction work which started in 2007 was concluded in 2012 and the implementation of the real time integrated control system and the warning system was started in 2009 and PREPARED has contributed to several enhancements of the systems and the platform on which they are running (DIMS.CORE), which are briefly described below. The PREPARED Demonstration comprises the total system incl. operation of the infrastructure.

2.1 Real Time Integrated Control

The real time control of the sewer system has been divided into several layers, where certain demands to the system status (measurements and control handles available) have to be fulfilled in order to maintain the control at a certain layer; otherwise control will fall back to a lower layer.

The control of levels and flows in the system, which is done by PLCs located at each storage tank, is a result of how the tank volumes are used. If the volumes can be used in a coordinated way according to the area distribution of rainfall and even better - where it will be raining the next hour – this will obviously be better than just measuring flows and levels in the system. However, being capable of measuring flow and levels across the system is obviously better than only being able to measure these locally at the single storage tank. Overview of layers lists as:

Layer 3: Global predictive control based on forecasts of rainfall
Layer 2: Global control based on level and flow measurements
Layer 1: Local control based on level measurements
Layer 0: Emergency control



The desired operation during rain fall events is the top layer 3 with global predictive control. This requires all implemented systems and devices in full and error free operation. The layer 2 is also considered as a good and robust operation which will be used for some periods. The lower layer 1 and layer 0 are fall back layers which automatically will be used in case of technical problems. These layers are also used by manual selection when repair work and inspections will be done - typically during dry weather periods.

Layer 0, the emergency control, is entered independently at each storage tank when no measurements are available to the PLC located at that tank. Gates, valves, weirs are set in default positions and pumps in the storage tanks are stopped – the catchment controlled from the storage tank PLC goes from an active state into a passive state. If power fails the same will happen as gates, valves, weirs are supplied with batteries with enough power to set them to default position.

Layer 1, the local control layer is entered if communication to DIMS.CORE fails or the global control for that storage tank is manually deselected. The PLC then maintains a certain level in the sewer system just downstream the storage tank, by operating gates and valves according to a simple step procedure driven by the difference of the level measured and a default set-point. Pumps emptying the tank are operated using the same procedure, but according to a level measured in the sewer where they deliver their water – if the level is too high pumps are shut off.

Layer 2, the global control layer is entered if rainfall forecasts are missing, or other necessary input measurements and calculations for the predictive control are missing. Global control can be exercised in two different modes – level or flow. Data are logged and validated every minute, and by the use of the DIMS.CORE software sensor concept, a PID-controller output for either a level or flow out of a catchment (at a storage tank position) is used to control one or more actuators (valves/gates, pumps) according to given set-points for either level or flow - a set of set-points comprises a control strategy. The PID output is distributed between the valves/gates (positions) and pumps (flows) and communicated to the PLCs.

Layer 3, the predictive control, is performing a coordinated usage of the storage tank volumes in order to minimize the combined sewer overflows. The control strategy is based on a dynamic risk assessment, where the risk of overflow is calculated for every storage tank every 5 minutes based on:

- actual storage tank filling and storage tank volume
- predicted runoff volume from the sewer system model to the storage tank from short term rainfall forecast from the local area weather radar
- the relative cost due to overflow (depending on i.e. recipient sensitivity)
- the maximum possible hydraulic load to the downstream storage tank
- the minimum possible runoff to the downstream catchment
- the actual hydraulic capacity of the downstream wastewater treatment plant

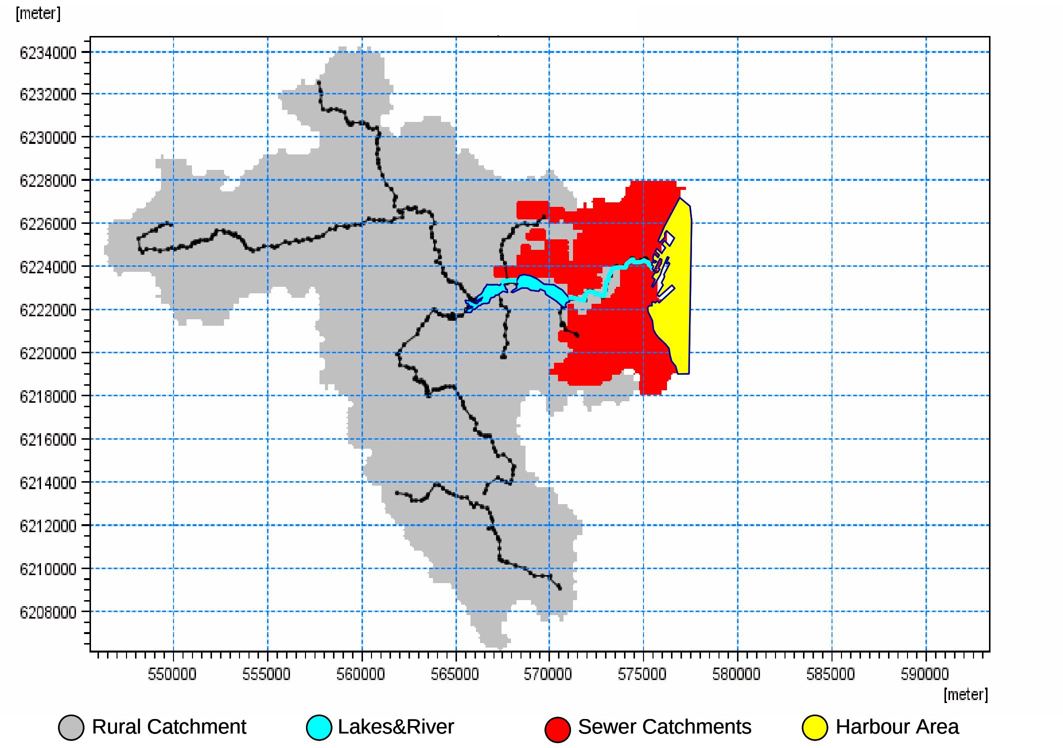
and using a simplified model of the sewer system together with an optimization procedure, the total overflow risk (all storage tanks combined), is minimized. The output is calculated set-points for the flow out of each catchment, and these are used as a set of flow set-points for the global control.

2.2 Warning System

The warning system, which can forecast the start and end of a non-compliant event in the harbour, is implemented because the Bathing Water Directive allows one non-compliant event per year – if properly warned – instead of one non-compliant event every four years. Obviously, this has a quite significant influence on the necessary volume of the designed storage tanks – calculated as a saving on the investment in infrastructure of approx. 25 mill. Euro.

The warning system is built on the top of the control system and uses the same integrated modeling tool as for the planning. This model complex for hydrology, hydraulic and water quality modeling is divided into four coupled parts

- Rural catchment model driven by rainfall calculating the run off from the rural area as an input for the Lake&River model
- Sewer catchments models driven by rainfall and dry weather flows calculating flows, run-off, CSOs and E.Coli/Enterococci transport (wastewater treatment plants as a part of these for E.Coli) as input to the Lake&River model.
- Lake&River model: flow and E.Coli/Enterococci transport as input to the Harbour model
- Harbour model: flow pattern and E.Coli/Enterococci transport. Downstream boundary from national marine model including the Bay of Aarhus.



After the planning period the model systems has been transferred to live operation based on real time measured data. The process has also included a dividing of the modeling systems between three system operators. Exchange of data is done via the Internet. Technically it would be possible to execute all model systems from the DIMS.CORE installation at Aarhus Water. However, after considerations concerning efficiency, cost and not least model maintenance it was decided to distribute the modeling between three operators.

The most upstream and rural part of the modeling is operated by the Environmental Section of the Municipality of Aarhus. The modeling system for the rural area is here in operation mainly for prediction of flooding risk in the low land areas around the lake Brabrand and along the river. The rural area modeling represents mainly slow response processes. The model system is run on a daily basis and the system produces a forecast for several days. The computed inflow to the upstream end of the lake Brabrand is delivered over the Internet to the DIMS.CORE system at Aarhus Water where this result is used as the upstream boundary condition for the modeling of the River Aarhus.

The modeling of hydraulics and water quality for Aarhus Harbour is depending on external boundary conditions for the Bay of Aarhus and further out into the sea. These conditions are continuously being modeled by a Danish national wide system modeling conditions and forecasts for the sea around Denmark extending to both the Baltic Sea and the North Sea.

For a local model execution of the harbour area, it would be required to exchange data along the boundary between the local model and the national sea model. It was however found more efficient and convenient to include the detailed modeling of the harbour area in the larger Danish Sea area modeling complex. In addition to the water quality in the harbour, the system also delivers forecast for bathing water quality along the coast line both north and south of the city of Aarhus. This model complex is operated as part of the Water Forecast - a service operated by DHI.

The exchange of data with the Water Forecast system is two way. The Water Forecast delivers a prognosis for the water level in the harbour. This water level forecast time series is used as the downstream boundary condition for the river model. The modeling system at Aarhus Water delivers flow and water quality (E.Coli and Enterococci) computed for the river outlet and CSO overflows to the harbour

The implemented solution at Aarhus Water includes exchange of data with the two above mentioned external modeling systems and a local modeling system of the city area hydrology, sewer network hydraulics and river flow and water quality modeling. All is operated and managed from the DIMS.CORE system at Aarhus Water.

The final solution avoids duplicated modeling effort by utilizing already existing external modeling systems or extending these to cover the specific needs for Aarhus Water. Instead exchange of data between the systems is done via Internet. This approach also assures that the applied models are optimally operated and maintained.

In addition to the inputs described above, inputs to the warning system also include some CSO and Storm Water outlets to the north and south of the city and the discharges from wastewater treatment plants. These inputs are also delivered by DIMS.CORE via the internet to the already existing warning system for the beaches along the coast line around the Bay of Aarhus – this warning system now being extended with a detailed part for the harbour area.

The warning system is designed to comply with the Bathing Water Directive by issuing a warning for the general public. Besides the public warning is the operational personnel on duty also warned by SMS and visual indicators change status on the DIMS.CORE user interface. The warning system delivers public warning on both a public website and an app for smart phones.

3 CONCLUSIONS AND RECOMMENDATIONS

In early 2013 the system has been operated and tested without forecasting of rain and in the autumn of 2013 tests with forecasting of rain and prediction of flows started. By spring 2014 the first official bathing season will commence. The hygienic water quality in Lake Brabrand, River Aarhus and in the harbor has already been remarkable improved and it is expected that compliance with the EU Bathing Directive will be the result by the end of the 2014 bathing season.

Based on five years of design, development and implementation of the system in a joint cooperation between DHI, Krüger and Aarhus Water (PREPARED Research partner, technology provider and utility) a few important recommendations should be passed on:

- It is essential that the operating staff from the utility is working actively on development and implementation. This secures ownership and insight and avoids a “black box”-system. The internal IT-organization at the water company must be engaged in development and operation of critical parts of the system, i.e. IT-architecture, operation and maintenance of servers.
- A suitable number of measurements in the sewer network are needed. These shall be continuously validated and supplemented with several software sensors, i.e. flow calculations based on level measurements. Calibration of software sensors is essential.
- A suitable number of control handles are needed. For example enough storage tank volumes at several locations around the city, together with controllable valves, gates and pumps. Major investments in infrastructure might be needed up front, if not already done.
- SCADA/PLC-system must cover all the actual components participating in the system. On-line data connections are an absolute must. A secure fall back strategy shall be implemented and components on the lowest level shall be hard wired and the most critical be equipped with uninterruptible power supply (UPS). Standards for numbering of components and signals must be implemented and the actual functioning of components must be controlled in the field.
- Organizational responsibility must be clear for all operational tasks, with focus on how to obtain 24/7 operation of the system. This may not be necessary for layer 3 control, but always for layer 0 and 1. Backup of system components, servers and communication lines. Alignment of service contracts for externally operated system components, i.e. communication lines. The system should automatically send alarm messages to internal or external staff responsible for the actual part of the system which is failing.
- Implementation of an early warning system, which can forecast the start and end of a non-compliant event as defined in the Bathing Water Directive should always be considered before design and implementation of an infrastructure update as described here. Although a warning system might be complex in nature, the development and implementation of such a system is only a fraction of the investment in infrastructure it replaces.
- Finally it is important to realize that combined sewer overflows will happen once in a while making bathing in the harbour an unpleasant event. Therefore, despite the fact that the system complies with the Bathing Water Directive, a communicative preparedness at the utility regarding the press, politicians and citizens of the city is essential.

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