Implementation and design of a RTC strategy in the sewage system in Kolding, Denmark

Elaboration et mise en œuvre d'une stratégie flexible de gestion en temps réel du réseau d'assainissement de la ville de Kolding, Danemark

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RÉSUMÉ

De nombreuses études et applications pratiques ont montré que l'introduction du contrôle en temps réel (CTR) dans un système d'assainissement peut améliorer les performances du système et réduire les coûts d'investissement et d'exploitation. L'utilisation d'un CTR permet l'optimisation des capacités de collecte et de stockage par l'exploitation et le lissage des effets induits par la variabilité de la distribution spatiale des évènements pluvieux. L'objectif de cette étude était de tester et de concevoir une stratégie CTR pour améliorer le système unitaire de la ville de Kolding au Danemark (pop. 86 000 h.). La partie centrale du bassin versant de la ville est surtout drainée par des déversoirs d'orage qui rejettent les effluents dans la rivière Kolding et son estuaire. Au cours d'évènements pluvieux extrêmes, les parties centrales de la ville sont inondées par les ruissellements et la surcharge du système d'assainissement. Une stratégie CTR globale a été envisagée pour l'ensemble du système, permettant d'associer chacun des éléments du système aux décisions de contrôle. Les performances du CTR ont été évaluées en calculant la réduction des volumes de surverse au moyen des évènements pluvieux des dix dernières années. Le CTR a été appliqué à un modèle hydrodynamique complet installé sur 9 stations de pompage ; de plus, des vannes ont été installées dans 7 bassins. Des fonctions de contrôle ont été mises en œuvre sur la base du débit entrant total dans l'usine de traitement des eaux, les niveaux d'eau dans les bassins et dans les parties critiques des systèmes. L'étude a révélé un potentiel de 40% de réduction des volumes de rejets dans la rivière Kolding.

ABSTRACT

Numerous studies and practical applications have shown that introducing Real Time Control (RTC) in a sewage system can improve the performance of the system and reduce capital and operational costs. The use of RTC focuses on the optimization of collection and storage capacities by exploiting and evening out the effects from varying spatial distribution of rain events. The objective of this study was to test and design a real time control (RTC) strategy for system improvements in the combined sewage system in the city of Kolding, Denmark (pop. approx. 86.000). The central part of the city catchment is predominantly drained by combined sewer systems with combined sewer overflows (CSO's) that cause substantial emissions to the Kolding River and estuary. During extreme rain events central parts of the city have been subject to flooding due to surface runoff and sewer surcharge. The entire system was considered for a global RTC strategy, thus allowing information from all parts of the system to be used for control decisions. The performance of the RTC system was evaluated by calculating the reduction in overflow volumes using rain events over the last 10 years. RTC was applied on a full hydrodynamic model setup on 9 pumping stations; furthermore gates were installed in 7 basins. Control functions were implemented based on total inflow to the wastewater treatment plant, water levels in the basins and in critical parts of the systems. The study showed a potential for up to 40 % reduction in discharge volumes to Kolding River.

KEYWORDS

RTC, design algorithm, reduction in CSOs, master planning, system setup, control structure, design tools

1 INTRODUCTION

While the sewer systems continue to meet requirements for protecting public health and the environment, some urgent problems need to be faced. Among those are old infrastructure, flooding, climate change and potential future changes in water quality regulations. Other factors include land-use change, population, water consumption, etc. In Denmark increased precipitation intensities are expected and it is important to access the actual performance of the sewer system and potential hazardous effects when system capacity is exceeded, IPPC (2007) and Arnbjerg et al. (2009). Addressing these problems will shape the improvements and alternatives developed through a master plan process. Based on the improvement needs and performance indicators, potential alternatives can be developed, screened, and ranked. This phase will lead to the development of a best apparent solution.

One method available for system improvements is introduction of Real Time Control (RTC). Numerous studies and practical applications have shown that introduction of RTC in a sewage system can improve system performance and reduce the capital and operational cost, e.g. Korte et al. (2009), Muschalla et al. (2009), Campisano et al. (2003). Use of RTC focuses on optimization of collection and storage capacities by exploiting and evening out the effects from varying spatial distribution of rain events. A review of the current use and state of the art of RTC of urban drainage system is given in Schütze et al. (2004).

The objective of this study was to assess the potential for implementation of RTC to reduce emissions from combined sewer overflows (CSO's), and minimize the risk for flooding in the city of Kolding, Denmark (pop. approx 86.000). The central part of the city catchment is predominantly drained by combined sewer systems with CSO's that cause substantial emissions to Kolding River and estuary. During extreme rain events central parts of the city have been subject to flooding due to surface runoff and sewer surcharge. Due to large detention volumes and long flow times in the sewer system a potential for significant reduction of CSO volume was expected.

Initially the long-term goals for the project where formulated to ensure an optimized and sustainable development of the sewage system in Kolding (Vision 2020).

The goals are:

- Fulfilling the functional demands: Ensuring that new and newly renovated combined sewer systems do not surcharge more frequently than once every 10 years in average.
- Fulfilling the environmental demands: Reducing untreated emission from CSO's to the recipients.
- Fulfilling the economical demands: Improvements must be cost-efficient.
- Fulfilling the employees' whishes: Reduce direct contact with sewage.

The means to fulfill these goals are:

- Optimized Real Time Control of the existing system using rain forecast and state of the system.
- Improvement planning based on integrated modelling of surface runoff, sewage system, waste water treatment plant and receiving waters.
- Resilient flood management.
- Cost efficient management for all improvements.

In this paper the potential and model evaluation of a RTC strategy will be presented.

2 METHODS

2.1 Work method and status of the project

It was decided to use a flexible and adaptive work process as illustrated on Figure 1. The work process is made up as a series of modules, and after each module the impact of the current step will be measured - before new improvement are implemented. This ensures that the activities are constantly optimized and the objectives of Vision 2020 will be continuously evaluated. The method is well suited for the complex and constantly developing area of urban drainage. Each module is initiated with a workshop where the framework for the project is established and all relevant activities are described, including how to cooperate, roles in the project, etc. All participants are actively involved in the project and there is a mutual sharing of knowledge between partners. The goal is that the project is an ongoing process with new knowledge continuously included.

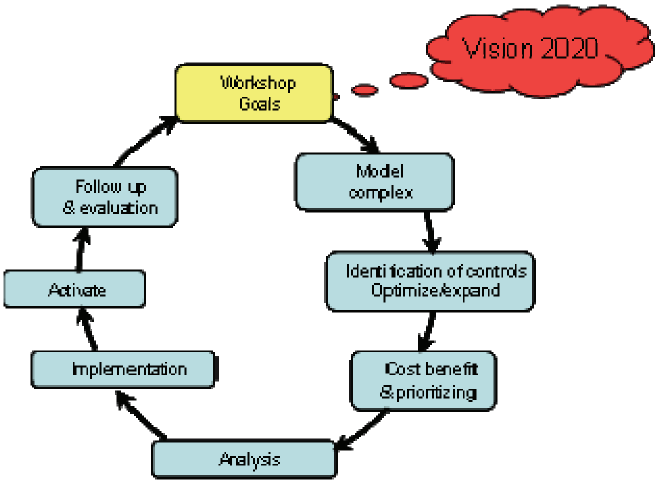


Figure 1: Iterative, adaptive method used for implementing the Vision for 2020.

Originally all steps in Figure 1 were intended to be completed before the next module was initiated. But it became clear in the early stages of the project that fundamental steps such as model building and validation of the model needed to be completed first.

The result of the work until now is:

- Significantly improved and detailed calibrated hydraulic model of the combined sewers in Kolding. The model is continually updated and is a fundamental basis to provide accurate control strategies. The project showed the importance of an overall tool to handle model setup and generation.
- Analysis of flood situations. The result of this analysis will be used for:
    - Optimize the utilization of the drainage system without the risk of flooding.
    - Give priority to areas at risk of flooding.
    - Overall planning.
    - Identification of risk areas in relation to the European Flood Directive.
- Specific examples and description of the optimization measures. This is described in a catalog to ensure a common platform for communication, control center and management components e.g. drum sieves, bending weirs, gates, controllers and management conditions.
- Established the basis for a fully integrated management of the wastewater treatment plant and drainage system via the control center platform.

2.2 Model overview

The model setup contains approx. 7300 nodes and pipes, 94 CSO's, 41 pumping stations and 21 storage basins.The total drainage area were calculated to approximately 1.300 ha (550 reduced ha) with additional sewage water coming from around 2.000 ha (separate system).

A system overview of downtown Kolding is shown is Figure 2. Total flow from the main pumping station (FORRENS) to the WWTP is controlled by pumps with a maximum capacity of 1500 l/s. Excess water is pumped to a detention basin with a capacity of 900 m^3. Overflow is going to Kolding River with a frequency of 30-35 events per year and a total volume of around 150.000 m^3. Three pipes are going into FORRENS and collecting water from the northern, southern and eastern parts of the city respectively and gates control the flow. The southern part of the city is giving highest priority due the risk of flooding in downtown Kolding.

Figure 2: System overview in central Kolding.

2.3 Rain data

One RIMCO tipping bucket rain gauge is located in the city area near the main pumping station (FORRENS). The rain gauge is used by the Danish Water Pollution Control Committee and connected to a national database (DMI, 2009).

3 RESULTS AND DISCUSSION

Between 15th June - 12th October 2009 level measurements where preformed at 11 locations and precipitation measurements at four locations in the catchment to FORRENS. The model is calibrated and validated against measured these water levels, flows going to FORRENS and CSO's in the system. Data is not shown in this paper.

In 2010 renovation of the basin at FORRENS is complete with a detention volume of 2700 m^3. This is expected to reduce the overflow events to 15 per year and reduce the overflow volume with 35 %. The aim is to get below 10 events a year using RTC. Kolding Municipality wants most of the discharges to Kolding River to occur at FORRENS. In this way the water undergoes a mechanical cleaning before discharge, and there is plan for expansion with further purification steps.

The catchments going to FORRENS is relatively optimal in terms of control opportunities. In Kolding water from several large catchments is collected in a limited area around downtown. This implies that small changes in the system in the city center will enable transport water to different catchments during rain. The main pipes are located close together and water is lead to FORRENS from virtually all directions. Thus, there is great potential to exploit the different distribution of rain events. When in addition to this there is a large unused capacity in the system, the possibilities for optimizing is large. Unfortunately, it is difficult to obtain an insight into the potential of transporting water between the various catchments. This will require long time series of distributed rain events. Therefore it is important to stress that the results obtained in this project is the absolute minimum for the control potential.

16 control locations were identified with detention capacities going up to 31 mm of rain and a total outlet capacity from all basins of approx. 1700 l/s. The performance of the RTC system was evaluated by calculating the reduction in overflow volumes for all rain events above 2 mm from 1999 to 2009.

The locations where the gates are implemented are connected to basins where the specific basin volume is large relative to basin size, going from 5.7 mm specific basins volume and up, see Table 1. An exception is SB0004 where the specific volume is small, but the outlet capacity is large, while it is close to FORRNES. Control wise, this will result in a net gain for system. An overview of the basins where gates will be installed and key parameters is shown in Table 1.

	Unit	SB0004	SB0803	SB0801	SB0202	SB0303	SB0302	SB0301
Imp. catchment area	Ha	23.2	13.6	4.2	3.5	10.4	10.3	11.0
Spec. basin volume	mm	5.7	6.5	10.9	16.3	19.5	23.8	31.0
Outlet capacity	l/s	500	100	35	60	150	150	100

Table 1: Parameters of the basic system for gates.

Control of pumps where implemented if a detention basin where in direct connection with the pumping station. The specific volumes ranges from 2.3 mm to 22.3 mm, see Table 2.

	Unit	SB0508	SB0701	SB0602	SB0601	SB1001	SB0509	PS0004	SB0401	SB0005
Imp. catchment area	Ha	8.0	23.9	5.6	10.3	11.8	10.0	7.6	10.6	2.3
Spec. basin volume	mm	2.3	2.4	3.8	3.9	4.0	5.1	9.0	13.5	22.3
Outlet capacity	l/s	20	80	20	20	70	230	75	38	30

Table 2: Parameters of the basic system for pumps.

The primary focus in terms of control is reducing CSO's from FORRENS. Control wise this is achieved by a simple rule based control strategy. All pumps in upstream storage basins are stopped when the storage basin at FORRENS starts to fill up. Pumping from individual basins is started again when the degree of filling in each storage basin reaches a certain level. This level is determined according to specific basin volume (mm basin) and type of recipient. It is ensured that CSO's is not increased compared to the status situation (no RTC). The control of gates is implemented in the same way. It is vital that there is established an overall (global) control strategy for the entire catchment to FORRENS in order to handle all parameters in the catchment.

The overall control strategy, as it is planned, is always aiming to have the same buffer volume in all storage basins at the same time. The buffer volume is defined as the ratio of available volume in each basin, the reduced catchment area for each basin and sensitivity of the recipient. Control wise this achieved by keeping more buffer volume available for basin discharging to fragile recipients. If a rain prognosis were available this could be optimize further. Basins where this ratio is high will retain water, while basins with a low buffering capacity will begin or continue to release water from the catchment.

An interface based on a direct link between the modeling software (MOUSE) and excel was created. The interface is showing water levels, filling degree and overflows for each time step, see Figure 3. On the interface all basins are connected with links showing if the gate or pump is controlled by downstream water levels or flow.

The control interface was used to validate and test different control set points within the system. All control strategies were documented in a database tool thus allowing for reproduction and fast generation of different strategies. An optimizer updates all decision variables simultaneously based on the input and shows the calculated effect in the system. Each controlled pump and gate is included in the setup and it is shown on the interface whether a gate is closed or a pump is turned off. This provides a good overview for evaluation of system responses to different control strategies.

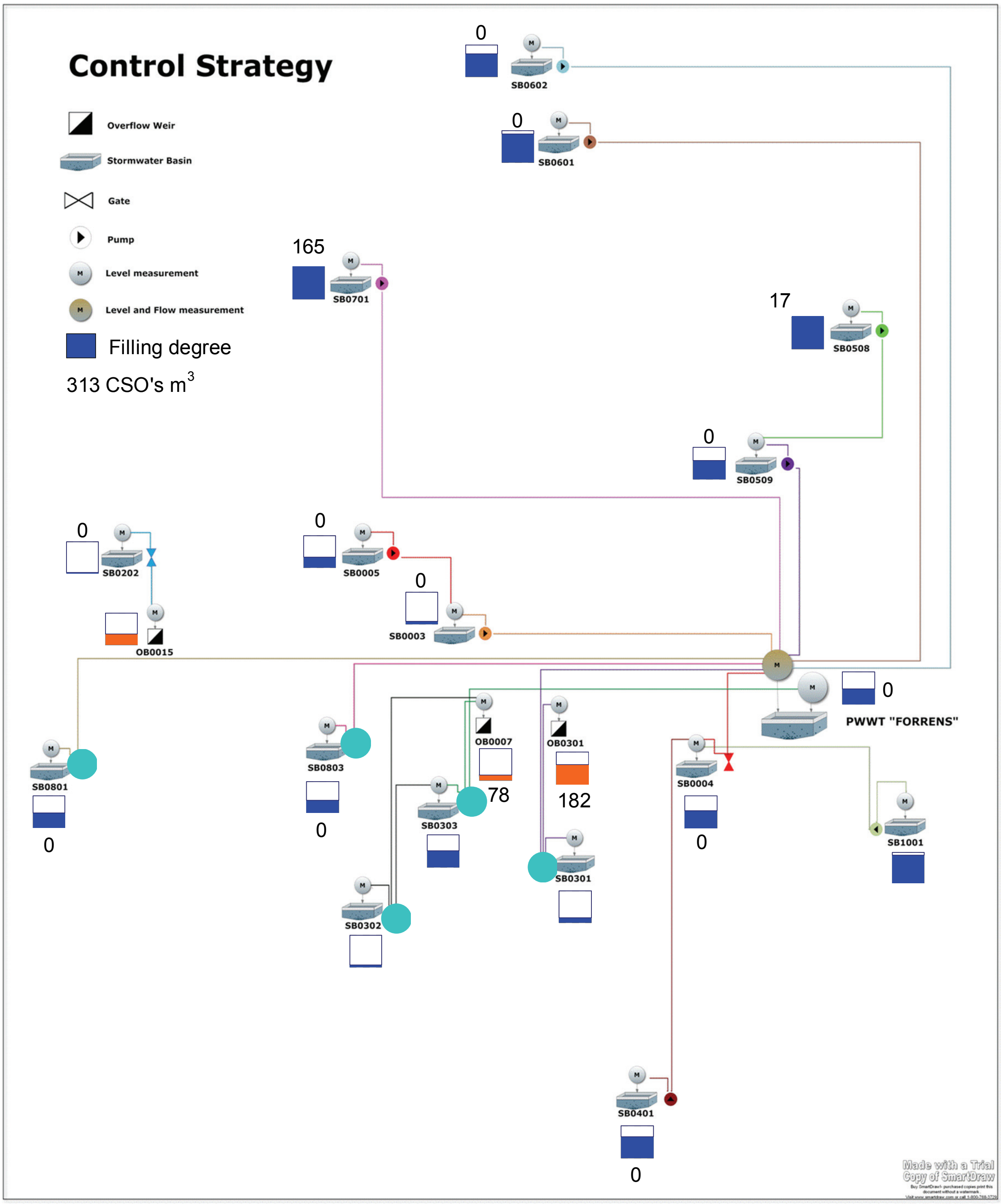
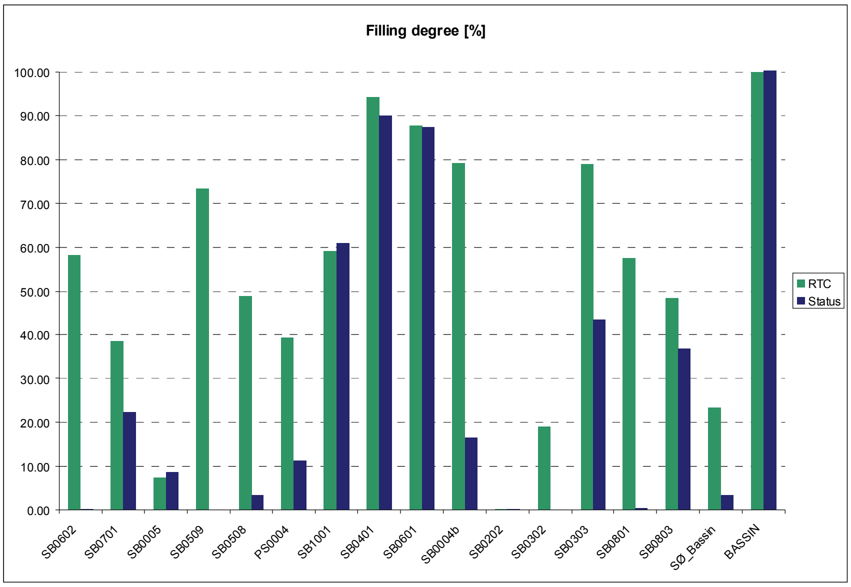


Figure 3: System overview, control setup and interface for evaluation of single events.

Implementation of RTC on 9 pumping stations and introduction of 7 gates in the system resulted in a 40 % reduction on overflow volume from FORRENS and a reduction of 35 % in the frequency to less than 10 per year. Compared to the situation in 2008 a reduction in overflow volume from 150.000 m^3 to 60.000 m^3 was calculated with introduction RTC and the increase in detention volume at FORRENS.

Results from a single rain event are shown in Figure 4. The graphs are output from the control interface where different scenarios can be compared to each other. The figure illustrates the filling degree in basins and total CSO’s. It is clear that more water is retained in the basins using RTC and a reduction in total CSO’s is achieved. For this single event the total overflow volume is almost reduced by 50 %.



	RTC	Status
Weir	m^3	m^3
BASSIN	1624	3609
OB0007	78	382
OB0301	207	629
PS0004	0	0
SB0508	313	319
SB0004	0	0
SB0005	0	0
SB0202	0	0
SB0401	6	0
SB0509	0	0
SB0601	96	21
SB0602	0	0
SB0701	512	530
SB0801	0	0
SB0803	0	0
SB1001	169	203
Total	3006	5694

Figure 4: Filling degree and calculated overflow for a single rain event.

An example where RTC prevent overflow at FORRENS is shown in Figure 5. The figure illustrates the water level in the detention basin. The basin starts to fill later when RTC is used due to a greater retention of water in upstream basins. The total overflow for the entire system for this event (3rd of May 2005) is 9000 m^3 compared to 7000 m^3 with RTC.

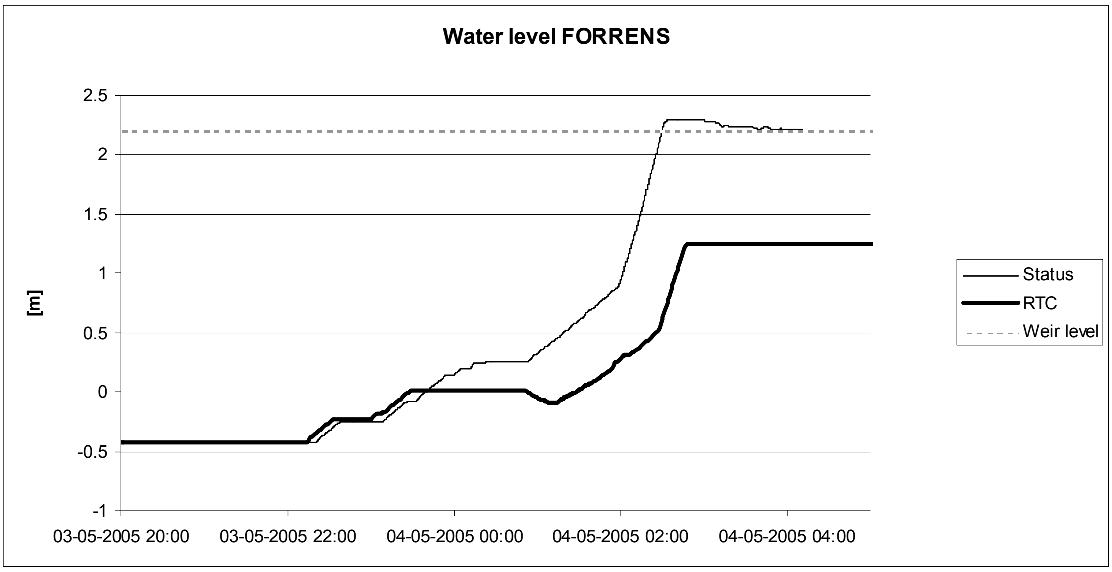


Figure 5: Filling degree at FORRENS.

During the measurement campaign and based on modeling result the two largest CSO structures in the system were identified, OB0007 and OB0301. The overflow pipes from these are located close together which give an opportunity to create a combined basin solution to reduce the overflow from both structures, see Figure 6.

Figure 6: Location of OB0007 and OB0301.

Since the new basin will receive water from two completely separate catchment the sewage system becomes more flexible. This in combination with a large pipe (D=1200 mm) replacing the southern collection pipe will ensure surcharging to Kolding River less than 10 times per year (results not shown). Use of RTC reduced the necessary detention volume with between 900 and 1500 m^3 depending on overflow frequency, see Table 3.

	No RTC		RTC	
Number of CSO's/yr	Detention volume [m^3]	Yearly overflow [m^3]	Detention volume [m^3]	Yearly overflow [m^3]
2	3800	5700	2300	4700
5	2400	10,300	1300	7900
10	1700	15,000	800	11,600

Tabel 3 : Calculated basin volume at OB0301+OB0007 and yearly discharge with and without RTC.

Critical parts with relation to flooding were identified and the proposed RTC strategy was analyzed in relation to flood frequency. It was shown that the flood frequency did not increase after introduction of RTC.

3.1 Further work

At all control locations online communication will be installed and the control strategy is being implemented and is expected to be finished 2010. It is the plan to establish a connection between the sewage system, SCADA system (System 2000) and the existing Star2® system at the wastewater treatment plant. This link will lead to the creation of a dynamic overview of the sewage system and the ability to integrate the management of both systems, see Figure 7. This opens a wide range of opportunities for optimal control of the wastewater treatment plant and sewage system. At the same time emptying of basins will be coordinated with the wastewater treatment plant and with forecasts of precipitation.

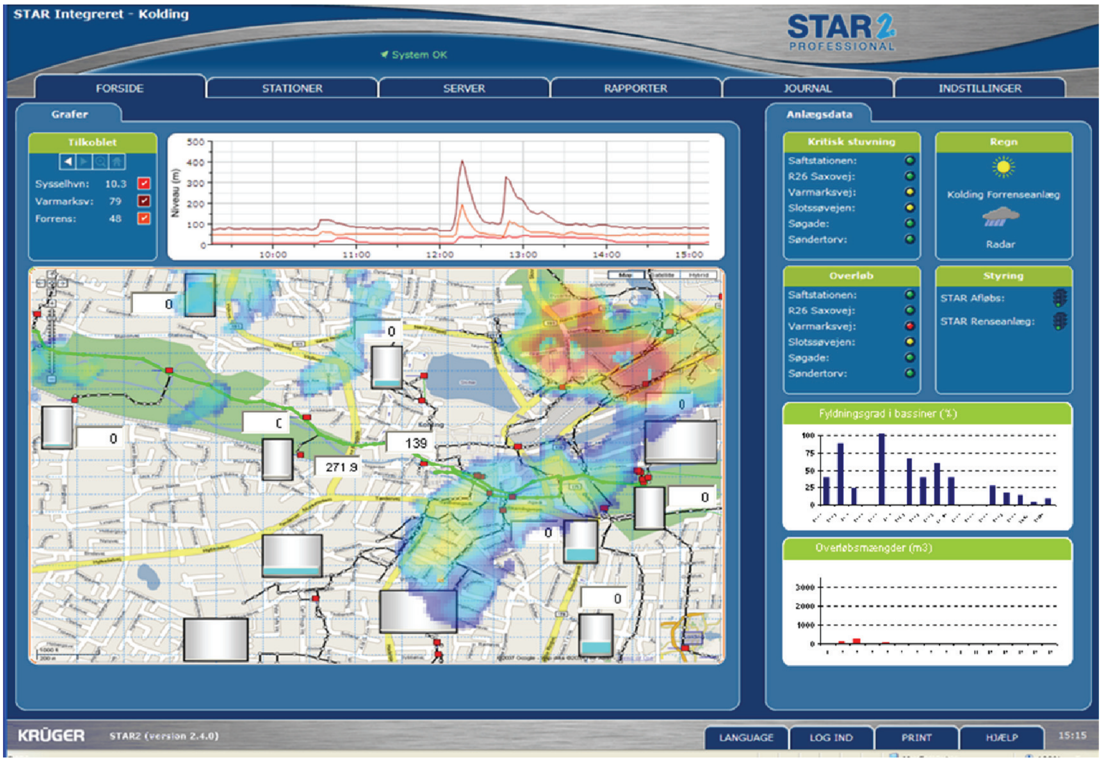


Figure 7: Control platform for integrated control of the sewage system and WWTP with a dynamic overview of the system. The platform is based on STAR2®.

Besides a monitoring program is established including 10 mobile level sensors and approx. 30 permanent level sensors and in 2010 eight rain gauges will be installed at strategic locations in Kolding. This will help with the evaluation and improvement of the RTC strategy in the future.

4 CONCLUSION

The Municipality of Kolding has taken the first steps towards implementing a RTC strategy in the sewage system. The work is part of the process towards fulfilling a long-term goal for optimized and sustainable development of the sewage system in Kolding (Vision 2020).

The work began with a workshop attended by the operating personnel, planning personnel and responsible leaders and resulted in a a wide range of ideas and concrete action. Notably a new basin of approx. 2700 m^3 at the main pumping station (FORRENS), directing the water to Kolding WWTP, to reduce overflows to Kolding River. This increase in detention capacity will make the sewage system more flexible and implementation of RTC willl enable further optimization of the system. Kolding Municipality wants most of the discharges to Kolding River to occur at FORRENS. In this way the water undergoes a mechanical cleaning before discharge, and there is plan for expansion with further purification steps.

A calibrated and validated hydraulic model was used to test and optimize the RTC strategy. The model is calibrated and validated on the basis of level measurement, sewer overflows and inlet flow to FORRENS. An interface based on a direct link between the model software (MOUSE) and excel, showing water levels, filling degree and overflows for each time step, was created. This provides a good overview for evaluation of system responses to different control strategies and is highly recommended. After the control strategies are implemented, focus will be on creating a common platform for managing data, modelling, management and optimization. The full effect of the proposed RTC strategy will be evaluated after this is implemented.

The main results from the study are:

- Control alone can reduce the number of CSO’s and volume at FORRENS with 30-35%
- Control alone can reduce the number of CSO’s and volume at key CSO structures by 35-40%.
- Control alone can reduce the necessary detention volume in the central part of Kolding significantly.

The study shows that implementation of a simple rule based RTC in a sewage system with large unused volumes and long transport times can reduce the overflows from the system significantly. The study also indicated that further optimization is possible when implementing prognoses for rain or the use of model predictive control.

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