12th International Conference on Computing and Control for the Water Industry, CCWI2013

Water quality-based real time control of integrated urban drainage systems: a preliminary study from Copenhagen, Denmark

L. Vezzaro[a,b]*, M.L. Christensen[c], C. Thirsing[d], M. Grum[b], P.S. Mikkelsen[a]

[a]*Department of Environmental Engineering, Technical University of Denmark, Miljøvej, Building 113, DK-2800 Kgs. Lyngby, Denmark*
[b]*Kruger A/S, Veolia Water Solutions & Technologies, Gladsaxevej 363, DK-2860 Søborg, Denmark*
[c]*Greater Copenhagen Utility (HOFOR),Ørestad Boulevard 35, DK-2300 København S, Denmark*
[d]*Lynettefællesskabet I/S, Refshalevej 250, , DK-1432 København K, Denmark*

Abstract

Global Real Time Control (RTC) of urban drainage systems is increasingly seen as cost-effective solution for responding to increasing performance demands. This study investigated the potential for including water-quality based RTC into the global control strategy which is under implementation in the Lynetten catchment (Copenhagen, Denmark). Two different strategies were simulated, considering: (i) water quality at the wastewater treatment plant (WWTP) inlet and (ii) pollution discharge to the bathing areas. These strategies were included in the Dynamic Overflow Risk Assessment (DORA) RTC strategy, which allows for prioritization of the discharge points in the systems according to their sensitivity. A conceptual hydrological model was used to assess the performance of the integrated control strategy over an entire year. The simulation results showed the benefits of the proposed approaches in reducing Combined Sewer Overflow (CSO) loads at the WWTP inlet and in an upstream location discharging to sensitive bathing waters for medium CSO events (i.e. those with greater potential for control). Furthermore, when looking at the overall performance across the entire catchment during the simulation period, no significant changes were observed. These preliminary results require further analysis by including detailed water quality measurements and simulations. Nevertheless, the potential for including water-quality RTC in global RTC schemes was unveiled, providing a further option to urban water managers to improve the performance of their systems.

Keywords: Global Real Time Control; Combined Sewer Overflows; on-line quality sensors; overflow risk; conceptual dynamic models

---

* Corresponding author.
  E-mail address: luve@env.dtu.dk

1. Introduction

Global Real Time Control (RTC) of urban drainage systems is increasingly implemented as a cost-efficient solution for improving the performance of these systems. Experience from full scale applications (e.g. Pleau et al., 2005; Puig et al., 2009), strengthened by several simulation studies (e.g. Dirckx et al., 2011), stress the importance of RTC in combination with other traditional structural solutions. As discussed in Schutze et al. (2004) and Campisano et al. (in press), development of sensors, improvement of their reliability, and new strategies for handling the increasing flow of available measurements pave the way to innovative approaches for controlling integrated urban wastewater and stormwater systems.

While the majority of RTC examples have focused on the hydraulics of the system (i.e. reduction of overflow volumes), only few examples of water-quality based RTC are presented in literature. However, on-line water quality sensors, which have widely been applied for control of wastewater treatment plants (WWTP), are increasingly installed in urban drainage systems, allowing a widespread development of water-quality based RTC strategies. Hoppe et al. (2011) and Lacour and Schuetze (2011), for example, showed the potential of using online sewer sensors (turbidity, UV) for RTC at the local scale (i.e. actuators are controlled based on information regarding only one site). Furthermore, the quality status of the recipient can be included in the control strategy, reducing the impact of Combined Sewer Overflows at the most sensitive point and at the most sensitive moment.

Global control strategies for reducing the impact of CSO events, based on advanced modelling tools and on the Dynamic Overflow Risk Assessment (DORA – Vezzaro and Grum (2012)) strategy, are currently under implementation in several urban catchments across Denmark. The DORA control strategy aims at the minimization of the global overflow risk across the catchment (quantified as the product of forecasted CSO cost and its probability), and it allows for a prioritization of the discharge points according to their sensitivity (e.g. avoiding overflow to bathing areas can have higher priority during the bathing season), but it does not consider dynamic variations in the quality of water in the sewer system or in the status of the recipient during a rain events.

The main objective of this study was to investigate the potential for including dynamic water-quality considerations into a global control strategy currently under implementation in the Lynetten catchment (Denmark), i.e. if it possible to improve the system performance by dynamically changing the prioritization of discharges at different CSO structures based on water quality considerations during a rain event. The proposed global water-quality based control strategy included dynamic cost functions reflecting that (i) the water quality at the WWTP inlet is affected by a significant "first flush" effect and that (ii) the status of the receiving water changes after overflow has started). A simplified conceptual model was used to evaluate the effect of the new control strategy on the performance of the system, and the evaluation focused both on the results for single rain events (enabling a better understanding of the behaviour of the proposed strategy) and on the effect on average yearly parameters (which are used by water utilities to evaluate system performance).

2. Material and methods

2.1. The Lynetten catchment

2.1.1. Catchment description

The Lynetten catchment includes the centre of Copenhagen (Denmark) and it has an area of approximately 76 km^2 (about 23 km^2 impermeable area). The system discharges to the Lynetten WWTP, which has a capacity of 750,000 PE and a maximum flow through the biological step of 23,000 m^3/h (in dry weather conditions this is limited to about 18,000 m^3/h) – more details about the catchment can be found in Breinholt and Sharma (2010). Two pressurized pipes (from the Kloevermarken and Strandvaenget pumping stations) constitute the main inlet to the WWTP, with a total volume of about 20,000 m^3. This configuration causes "first flush" effects at the beginning of rain events (see an example in Figure 2), when the wastewater stored in the pipes is pushed through the WWTP by the incoming increasing flow. When the capacity of the WWTP is exceeded, this can result in bypass of the biological treatment with discharge of untreated wastewater with high pollutant concentrations into the receiving waters.
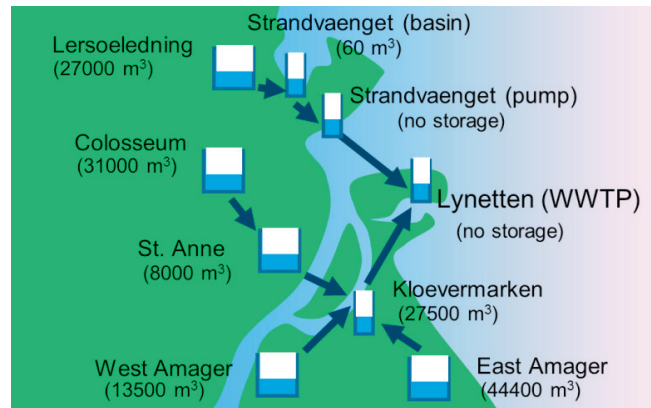
Fig. 1. Scheme of the Lynetten catchment with the controlled points (the approximate storage volume available for RTC is listed in brackets).

An integrated control of the catchment has been developed during the METSAM project (Vezzaro et al., 2012), connecting control of the WWTP and catchment in the same STAR$^{®}$ platform (Thomsen and Ônnerth, 2009). Eight structures (detention basins and pumping stations - Figure 1) are included in the global control strategy, which uses the Dynamic Overflow Risk Assessment (DORA) approach (see section 2.2) to minimize CSO volumes. The overflow structures discharge to different areas in the Copenhagen harbour, for which different protection targets are defined (Table 1). Bathing areas are classified as the most sensitive and therefore have a high overflow cost (25 €/m^3). The other areas are considered less sensitive; the main objective is here a general reduction of pollution loads discharged during CSO events and they therefore have a lower overflow cost (5 €/m^3).

A detailed hydrodynamic model of the catchment is available in MikeUrban (www.dhisoftware.com) and it is used by the local water utility to evaluate the performance of control strategies. To evaluate RTC over long time intervals, a simplified hydrological model of the catchment was implemented in the Wateraspects^{TM} (Grum et al., 2004) and calibrated against the MikeUrban model (similarly to the procedure followed by Borsanyi et al. (2008)). The Wateraspects^{TM} software can simulate water quality parameters only to a limited degree, as only advection is included in the model and other relevant processes (dispersion, settling and resuspension of sediments, biodegradation, etc.) are neglected. In this study Total Suspended Solids (TSS) and ammonia (NH4) were simulated. Due to the simplicity of the model, the simulated overflow loads were calculated only to provide an understanding of the performance of the proposed approach.

Table 1. Main characteristics of the point included in the global control strategy of the Lynetten catchment, along with environmental target for the receiving water body.

| Subcatchment	Impermeable area [ha]	Storage available for RTC [m^3]	Environmental target for recipient	CSO cost [€/m^3]
Lersoegroften (LER)	733	27,000	Bathing area	25
Strandvaenget – Basin (STB)	92	60	Bathing area	25
Strandvaenget – Pump (STP)	-	0	Pollution reduction	5
Kalkbraenderihavnsgade (KAL)	211	30,914	Pollution reduction	5
Skt. Annae (STA)	77	7,987	Pollution reduction	5
Amager Oest (AMO)	228	44,425	Bathing area	25
Amager Vest (AMV)	97	13,460	Pollution reduction	5
Kloevermarken (KLO)	777	27,500	Pollution reduction	5
Lynetten WWTP (LYN)	564	76	Pollution reduction	1
Total	2,279	151,432	-	
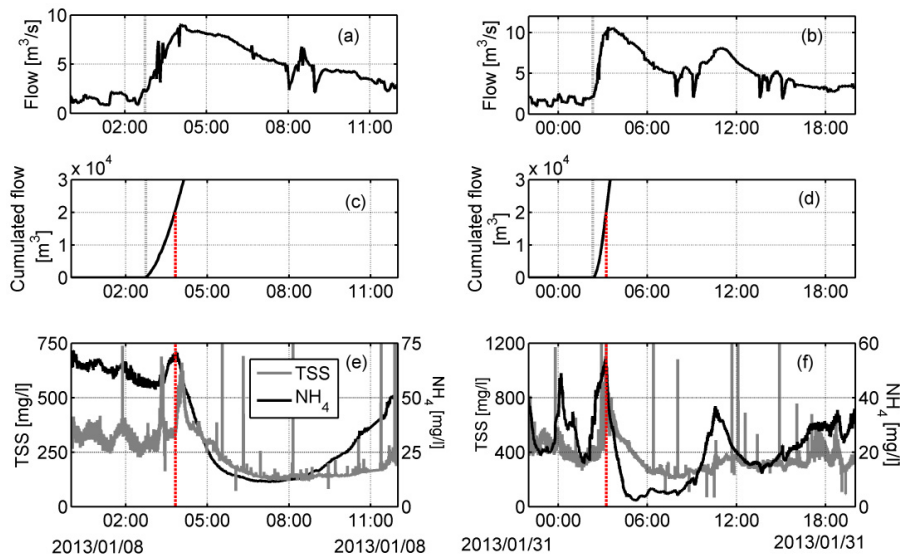
Fig. 2. Example of measurements at the Lynetten WWTP inlet (Sharma et al., 2013): (a,b) flow, (c,d) cumulated wet-weather runoff volume, (e,f) water quality parameters (TSS; NH$_4$). It is possible to note that the measured concentrations start to decrease after the total volume passed through the WWTP inlet exceeded 20,000 m^3 (corresponding to the volume of the two inlet pressurized pipes).

Water quality measurements (see Figure 2) with high temporal resolution (up to 5 seconds) were available at the WWTP inlet for the period from December 2012 to May 2013 (Sharma et al., 2013). Both particulate and dissolved water quality parameters were measured, allowing a detailed analysis of the variability taking place at the WWTP inlet. The measured parameters include, among others, turbidity and TSS, COD (total and dissolved), and ammonia.

2.2. Global control strategy (DORA)

The Dynamic Overflow Risk Assessment (DORA) strategy (see Vezzaro and Grum (2012) for further details) aims at reducing overflow risk in the system (quantified as the product of overflow cost and its probability) by minimizing a global cost function through an optimization routine. The global cost function considers:

- The current water volume stored in the entire system, allowing for a better usage of the storage capacity across the entire drainage network. This information is provided by online measurements from the system (water levels in the storage basins);
- The expected runoff volume in each subcatchment in the near future (2 hr), thus allocating greater storage in the system where needed. Radar-based runoff nowcasts (Thorndahl et al., 2012), which are updated every 10 minutes, are used for this purpose.
- The uncertainty in the runoff volume nowcasts, which is used to estimate the overflow risk at each controlled point. Currently, uncertainty is described by a fixed gamma distribution, but a dynamic description based on grey-box models is currently in the testing phase (see for example Vezzaro et al., 2013);
- The sensitivity of the receiving water body (Table 1), which is expressed for each *i-th* basin by the cost c_i [€/m3], which is linearly proportional to the overflow volume. Higher prices are assigned to sensitive points (such as bathing areas in summertime), while lower prices are used at less sensitive points, such as the WWTP inlet. The current control strategy uses static prices, i.e. the cost for overflow at an overflow structure is constant throughout a rain event and water quality is not considered in the control strategy.
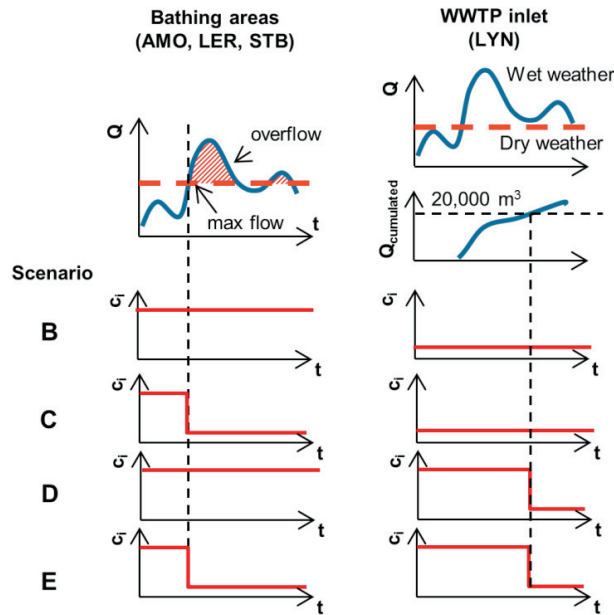
Fig. 3. Scheme of the cost functions used in the different scenarios.

The optimization routine is run every 2 minutes, i.e. every time new measurements from the drainage network are available. The algorithm thus estimates the optimal flows between the controlled points that ensure the minimum overflow risk across the entire catchment.

2.3. Consideration of water quality in the global control strategy

Water quality can be indirectly considered in DORA by dynamically varying the overflow prices c_i. The local utility identified two main objectives that can be addressed in this manner:

- Consideration of current bathing status in the global control strategy. After a CSO event has started, no swimming activities can be carried out for at least 2 days and it is no longer important to reduce overflow at this particular location at the expense of overflows elsewhere. The target for the recipient can therefore be switched to reduce pollution loads (corresponding to a lower CSO cost), and thus further minimizing the risk in other bathing areas (which maintain their high CSO price).
- Reduction of overflow volumes at the Lynetten inlet during "first flush", in order to reduce the pollution loads discharged into the environment;

These two objectives were included in the control strategy by introducing two dynamic cost functions (Figure 3): the first function decreases the CSO price from 25 €/m^3 (bathing area protection target) to 5 €/m^3 (general pollution reduction target) after an overflow event has started; the second decreases the CSO cost at the WWTP inlet during rain events from 5 to 1 €/m^3 after the first 20,000 m^3 of wastewater.

To evaluate the effect of the proposed dynamic cost functions, the simplified catchment model was used to run five different scenarios: (scenario A) baseline scenario, where the system is controlled only by local controls and no global optimization is operated; (scenario B) DORA with static prices (corresponding to the control strategy currently under implementation); (scenario C) DORA with dynamic price for bathing areas; (scenario D) DORA with dynamic price at the WWTP inlet; and (scenario E) DORA with dynamic prices both at WWTP inlet and bathing areas. The scenario comparison was carried out by simulating the rain events that caused overflows during

2012. To consider the effect of coupled rains, overflow events taking place within 8 hours from the previous overflow were lumped into a single event. After this analysis 88 events were identified and used for the scenario comparison.

3. Results and discussion

3.1. Global effect on the catchment

The overall results of the scenario comparison for the entire catchment are shown in Figure 4. The results for the baseline scenario (A) showed how the great majority of the CSO events and volume are located at the WWTP inlet (88 events) and at the Lersoeleding basin (15 events). Among the bathing areas, only Lersoeleding was affected by overflows: therefore scenarios C and E only affected this overflow structure. Figure 4 shows how the integrated water-quality based control strategies did not lead to great change in the overall yearly performance compared to the static-price scenarios (scenario B). When looking at the number of CSO events (Figure 4a), it can be noticed that the scenarios involving the WWTP protection (D,E) caused additional overflow in upstream points of the system (AMV, STA, and STP). This suggests that the control strategies stores more water in upstream basins compared to the scenarios where the WWTP was the less sensitive of the system (B,C).

While the effects of the different control scenarios are difficult to evaluate when looking at the entire year 2012, clearer differences can be identified when looking at the individual rain events (Figure 5). All the investigated control scenarios (including the baseline scenario) succeeded in eliminating CSO events smaller than about 5000 m^3 at the WWTP inlet, and all the scenarios achieved similar volume reduction for events with CSO volume above about 100,000 m^3 (as seen by the overlapping dots in Figure 5). Therefore, the evaluation of the different scenarios focused on the events where the differences between the control strategies were clearer, i.e. those events between 5,00 and 100,000 m^3 where the RTC had some degree of freedom to move water across the system.

Table 2. Details of the three analysed events. Rainfall depth is calculated as average value of the six rain gauges used as input to the model

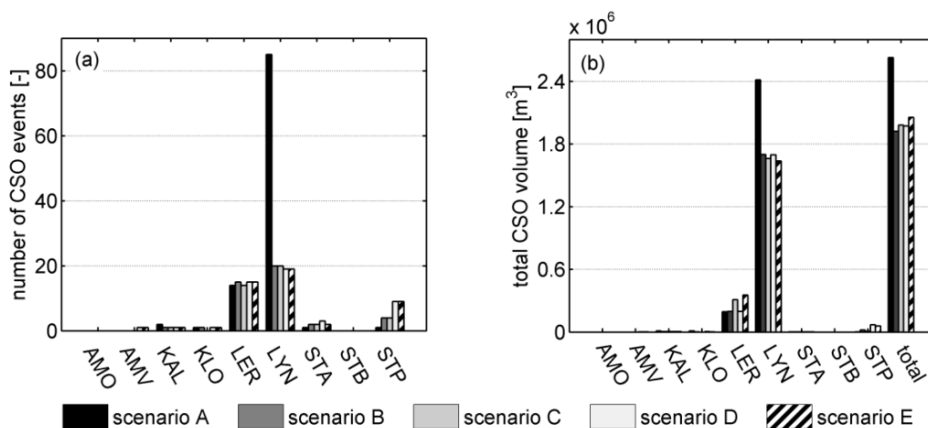| Event number	Simulation period		Average rainfall depth [mm]	Overflow volume (scenario A) [m^3]	
	start	end		LER	LYN
01	2012-01-01 03:15	2012-01-02 17:16	23.4	4,455	131,209
28	2012-06-01 08:52	2012-06-02 14:04	13.0	2,529	46,937
34	2012-06-24 03:14	2012-06-25 21:44	15.1	55,051	144,257

Fig. 4. Results of scenario comparison: (a) number of simulated CSO events during 2012; (b) simulated total overflow volume.
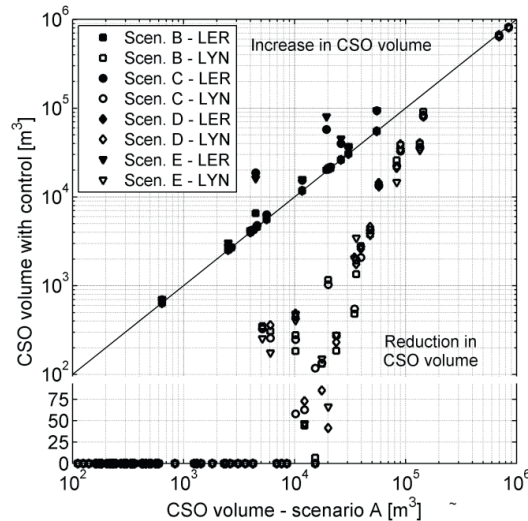
Fig. 5. Comparison between CSO event volumes for the baseline (scenario A – on the X-axis) and for different control scenarios at Lersoeledning and Lynetten (Note the different scale on the Y-axis).

3.2. Effect on single rain events

For illustration purpose, the graphs presented hereafter focus on three representative rain events (Table 2), but a similar behaviour in the simulated results was observed for other medium size events (CSO volume between 5000 m^3 and 100,000 m^3). Analysis of the overflows at Lersoeledning (some examples are presented in Figure 6) show the effects considering the quality status of the recipient in the global control strategy (scenarios C and E). Compared to the baseline scenario, the median increase of CSO volume at LER over the 88 events was 12% (with peaks of 186%) for scenario C, and 20% (with peaks of over 4000%) for scenario E (not shown). This shows how the global control strategy allowed the discharge of greater volumes through Lersoeledning as consequence of the deterioration of the quality of the recipient (i.e. loss of bathing water status). Consequently, the overflows in other points of the system was reduced. For example, the reduction of the overflow volume at the Lynetten inlet for scenario C had a median of 3%, with peaks up to 79% (not shown).
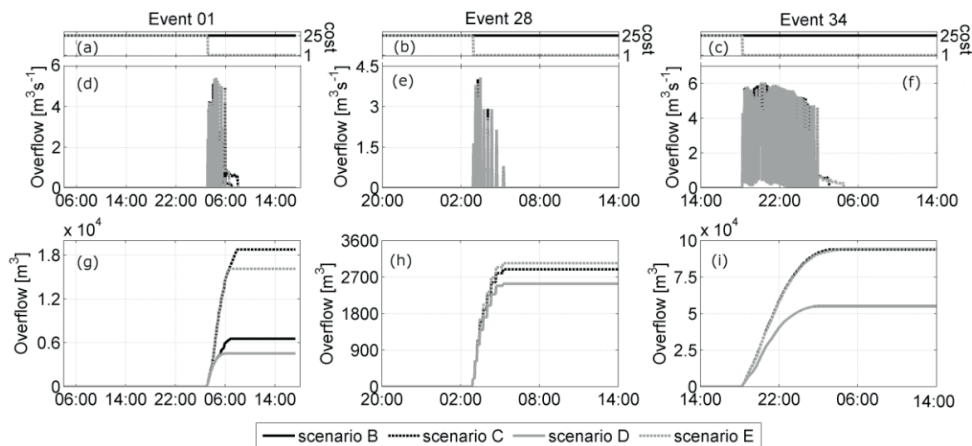

Fig. 6. Simulated CSO costs (a,b,c), overflows (d,e,f), and cumulated CSO volumes (g,h,i) at Lersoeledning for the three sample events.
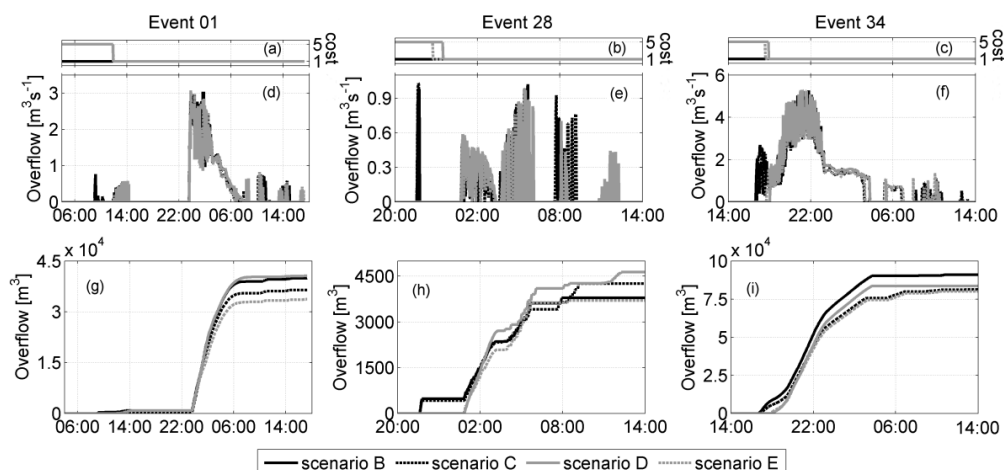
Fig. 7. Simulated CSO costs (a,b,c), overflows (d,e,f), and cumulated CSO volumes (g,h,i) at Lynetten for the three sample events.

Table 3. Comparison of simulated overflow events at the WWTP inlet (LYN) for different scenarios

Event	"First flush" Volume [m^3]				Total overflow volume [m^3]			
	Scenario. B	Scenario. C	Scenario. D	Scenario. E	Scenario. B	Scenario C	Scenario. D	Scenario. E
01	370	20	0	0	39,905	38,700	40,607	33,720
28	476	422	0	0	3,786	4,518	4,638	3,705
34	7,409	5667	0	0	90,860	79,734	83,622	80,098

The inclusion of a higher overflow cost in the beginning of events at the WWTP inlet into the global control strategy (scenarios D,E) led to the desired elimination of overflow during the "first flush" phase. As exemplified in Figure 7, overflows at the beginning of the rain event (when overflow cost was higher, reflecting the higher concentrations in wastewater) were eliminated. Subsequently, the overflow cost was lowered, and overflows were similar for all the scenarios. When looking at the total CSO volume discharged during the 88 events, Scenario D led to a median increase of 2% compared to Scenario B, while Scenario E achieved a median reduction of 4% (not shown).

When focusing on the sample events listed in Table 3, the "first flush" fraction of the overflow represented a minor part of the total CSO volume (ranging from 1% for event 01 to 13% for event 28). However, as can be seen from the measurements shown in Figure 2, concentrations at the WWTP inlet during "first flush" are usually 2-3 times higher than during the remaining part of the rain event. Therefore, the reduction of the pollutant loads discharged by overflow can be expected to be greater than the volume reduction.

3.3. Future outlook

The results obtained in this study were based on hydraulic considerations and therefore more detailed investigations, based on detailed water quality models, are needed. The quantification of pollutant loads discharged during CSO events is essential to better quantify the potential of including water quality into the global control strategy of the Lynetten catchment. In fact, all the scenarios taking water quality into account (C,D,E) resulted in an increase of the total yearly CSO volumes (Figure 4) compared to the scenario which considered only water quantity (B). However, concentrations in CSO are not expected to be constant in space and time, i.e. an increase in CSO volume might not result in an increase of pollutant loads.

The CSO volume increase was mainly caused by greater overflow in the upstream part of the system (where concentrations are expected to be lower) and lower discharge at the WWTP inlet (where concentrations are expected to be higher). To ensure a throughout analysis of the proposed control strategies a simplified catchment water quality model, such as the one presented by Prat et al. (2012), could be used for scenario analysis.

When analysing the proposed control strategies, more complex approaches can be developed thanks to a better estimation of the pollutant concentrations at the WWTP inlet. Scenario D and E, in fact, were based on mere hydraulic estimation (i.e. the volume of wastewater stored in the pressurized pipes leading to the WWTP), while the CSO cost c_i at Lynetten inlet could be directly correlated to the current concentrations. These can be determined by direct on-line measurements (as those obtained by Sharma et al (2013)) or by software sensors (based, for example, on simple stochastic quality models such as the one presented by Bechmann et al. (1999)), or by using the existing measurement that are currently available at different points within the WWTP plant.

Similar approaches could be applied for each discharge point by using simple water quality models which are capable of estimating real-time concentrations at the CSO point. These models would benefit from a wider application of in-sewer on-line sensors, which provide a solid background for development of these models (see for example, the data collected by Metadier and Bertrand-Krajewski (2012)). Also, connection with dynamic on-line recipient quality models, such as those currently used by the Copenhagen water utility to inform the population on the current status of bathing waters (kbh.badevand.dk), could represent a further development of the proposed control strategies.

4. Conclusions

This study investigated the potential of global water-quality based RTC strategies in the Lynetten catchment (Denmark). The evaluation was based on a simple hydrological model, but water quality considerations were indirectly included by using dynamic costs functions allowing to change the prioritization different discharge locations during events. Some preliminary conclusions can be drawn:

- When looking at the total number of CSO events and discharged volumes across the entire catchment over the simulated year, the inclusion of water quality considerations into the existing global scheme control did not show significant variations compared to the current global strategy, which considers only water quantity;
- The effect of the investigated strategies was more evident for selected CSO structures and for CSO events of a medium magnitude, i.e. those where the RTC had the potential to optimize the storage in the system;
- The control considering the status of the recipient succeeded in allowing greater overflow discharges after the bathing quality was degraded, thus reducing the overflow in other more sensitive parts of the system;
- The control based on the quality at the WWTP inlet succeeded in eliminating the overflow of highly polluted "first flush" waters, thus contributing to reduce the CSO loads discharged at the WWTP inlet;
- Overall, inclusion of water quality-based control strategies managed to modify the behavior of the global RTC approach, highlighting the potential for a further development of these approaches for full scale applications.

The preliminary results obtained in this study show how water-quality based RTC of urban drainage networks can represent an important option for urban water managers who have to respond to the increasing performance demands their systems are subject to.

References

Bechmann,H., Nielsen,M.K., Madsen,H., Kjølstad Poulsen,N., 1999. Grey-box modelling of pollutant loads from a sewer system. Urban Water, 1, 71-78.

Borsanyi,P., Benedetti,L., Dirckx,G., De Keyser,W., Muschalla,D., Solvi,A.M., Vandenberghe,V., Weyand,M., Vanrolleghem,P.A., 2008. Modelling real-time control options on virtual sewer systems. Journal of Environmental Engineering and Science 7, 395-410.

Breinholt,A., Sharma, A. K., 2010. Case Area Baseline Report - Copenhagen Energy and Lynetten Fælleskabet. Report, Technical University od Denmark, Department of Environmental Engineering (available at www.swi.env.dtu.dk; accessed on 12/06/13).

Campisano,A., Cabot Ple,J., Muschalla,D., Pleau,M., Vanrolleghem,P.A., in press. Potential and limitations of modern equipment for real time control of urban wastewater systems. Urban Water Journal, doi:10.1080/1573062X.2013.763996.

Dirckx,G., Schutze,M., Kroll,S., Thoeye,C., De Gueldre,G., Van De Steene,B., 2011. Cost-efficiency of RTC for CSO impact mitigation. Urban Water Journal 8, 367-377.

Grum, M., Longin, E., Linde, J. J, 2004. A Flexible and Extensible Open Source Tool for Urban Drainage Modelling: www.WaterAspects.org. 6th International Conference on Urban Drainage Modelling, Dresden, Germany, 15-17 Sept. 2004.

Hoppe,H., Messmann,S., Giga,A., Gruening,H., 2011. A real-time control strategy for separation of highly polluted storm water based on UV-Vis online measurements - from theory to operation. Water Science and Technology 63, 2287-2293.

Jørgensen,H.K., Rosenørn,S., Madsen,H., Mikkelsen,P.S., 1998. Quality control of rain data used for urban runoff systems. Water Science and Technology 37, 113-120.

Lacour,C., Schuetze,M., 2011. Real-time control of sewer systems using turbidity measurements. Water Science and Technology 63, 2628-2632.

Metadier,M., Bertrand-Krajewski,J.L., 2012. The use of long-term on-line turbidity measurements for the calculation of urban stormwater pollutant concentrations, loads, pollutographs and intra-event fluxes. Water Research 46, 6836-6856.

Pleau,M., Colas,H., Lavallée,P., Pelletier,G., Bonin,R., 2005. Global optimal real-time control of the Quebec urban drainage system. Environmental Modelling and Software 20, 401-413.

Prat,P., Benedetti,L., Corominas,L., Comas,J., Poch,M., 2012. Model-based knowledge acquisition in environmental decision support system for wastewater integrated management. Water Science and Technology 65, 1123-1129.

Puig,V., Cembrano,G., Romera,J., Quevedo,J., Aznar,B., Ramon,G., Cabot,J., 2009. Predictive optimal control of sewer networks using CORAL tool: application to Riera Blanca catchment in Barcelona. Water Science and Technology 60, 869-878.

Schutze,M., Campisano,A., Colas,H., Schilling,W., Vanrolleghem,P.A., 2004. Real time control of urban wastewater systems - where do we stand today? Journal of Hydrology 299, 335-348.

Sharma, A. K., Alferes, J., Vezzaro, L., Lamaire-Chad, C., Thirsing, C., Vanrolleghem, P. A., Mikkelsen, P. S., 2013. Effect of on/off pumping strategy on sewer sediment behaviour elucidated by high frequency monitoring at the treatment plant inlet. 7th International Conference on Sewer Processes & Networks, Sheffield, England United Kingdom, 28-30 August 2013.

Thomsen, H. R., Ônnerth, T. B., 2009. Results and benefits from practical application of ICA on more than 50 wastewater systems over a period of 15 years. 10th IWA Instrumentation, Control and Automation conference, Cairns, Queensland, Australia, 14-17 June 2009. 2009. Keynote paper.

Thorndahl, S., Poulsen, T. S., Bøvith, T., Borup, M., Ahm, M., Nielsen, J. E., Grum, M., Rasmussen, M. R., Gill, R., Mikkelsen, P. S., 2012 Comparison of short term rainfall forecasts for model based flow prediction in urban drainage systems. 9th International Conference on Urban Drainage Modelling, Belgrade, Serbia, 4-6 September 2012.

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

Vezzaro, L., Kunnerup, T., Christensen, T. L., Grum, M., 2012. A new risk based approach to Real Time Control of urban drainage networks. 10th International Conference on Hydroinformatics, Hamburg, Germany, 14-18 July 2012

Vezzaro, L., Löwe, R., Madsen, H., Grum, M., Mikkelsen, P.S., 2013. Investigating the use of stochastic forecast for RTC of urban drainage systems. 8th Novatech 2013 - Sustainable techniques and strategies in urban water management, Lyon, France, 23-27 June . 2013.