Modelling of a combined sewer system to support planning decisions and initialise the application of a RTC System

Modélisation d'un réseau d'assainissement unitaire en tant qu'outil d'aide à la décision et à la mise en œuvre d'un système de gestion en temps réel (GTR)

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RESUME

La région de la Haute-Sûre située au cœur des Ardennes luxembourgeoises est une zone très sensible tant pour sa richesse écologique qu'économique. Pour y protéger sa grande ressource en eau de surface, des mesures draconiennes sont prises au niveau de l'assainissement des eaux usées communales. Afin d'en améliorer l'efficacité, la mise en oeuvre d'une méthode de gestion en temps réel est développée. Dans ce but, des stratégies sont programmées au niveau d'unités de contrôle via l'outil RTC dans le logiciel InfoWorks™ CS. Un exemple est choisi pour en démontrer l'impact positif sur la réduction des déversements et la durée de mise en charge des bassins déversoir d'orage.

ABSTRACT

The Haute-Sûre region, located in centre of the Luxembourgish Ardennes, is a very sensitive area as well as for its ecological richness as for its economic value. To protect its large surface water resources, drastic means are taken to transport and treat municipal waste waters. In order to improve their efficiency, a real time control system is under development. In this context, rule bases are developed for control units by using the RTC tool of the InfoWorks™ CS software. An example is shown to demonstrate their benefits regarding the reduction of overflow volumes and the loading duration of combined sewer overflow tanks.

KEYWORDS

Combined sewer network, Hydraulic and pollutant load modelling, Modular control unit, Real time control, Rural catchments

1 INTRODUCTION

1.1 The Haute-Sûre Catchment

The upper course of the river Sûre is located in the Ardennes, in the North-West of Luxembourg. This undulating rural area has a low population density and is highly frequented by tourists during the summer period. The villages in this region are predominantly drained by combined sewer systems. Their combined sewer overflows (CSOs) and effluents of waste water treatment plants (WWTPs) cause harmful emissions to the receiving waters. One of the most sensible ones is the artificial storage lake of the Haute-Sûre, which is also a drinking water reservoir with a volume of $60 \cdot 10^6$ m³ that satisfies 30% of Luxembourg's water demand. Moreover, parts of the lake are used as recreation areas and bathing waters or constitute an important ecological area (Kalmes and Berger, 2005). However, several studies analysing its water quality resulted in a very sensitive reaction of the lake to eutrophying pollutants (Salvia-Castellvi et al., 2001; Kalmes and Berger, 2005).

The existing sewage systems and decentralised treatment facilities are outdated, overloaded and do neither comply with the outflow quality requirements of the national regulations for the protection of the reservoir (JO du GDL, 2000) nor do they respect emission standards of the EU Urban Waste Water Directive (EEC, 1991).

To protect this resource of great national interest, it has been decided, after consideration of several possible construction scenarios (BLET and Hollinger AG, 1977) to drain waste water of the surrounding villages to a new WWTP, which will be put into operation in autumn 2007 (Holinger AG et al., 2002; JO du GDL, 2003). This measure should significantly reduce the pollution load discharged into the lake (Schmitt et al., 2003) and contribute to an improvement of the river water quality as required by the EU Water Framework Directive (EEC, 2000).

The characteristics of the new combined sewer system will be long interceptor sewers discharging low flows and pressure pipes of small diameters with high discharging heads subsequent to retention basins and pumping stations. Extensive measuring equipments observing quantity and quality of water flows as well as water levels in storage tanks, particularly during storm events, will send data to the centralised monitoring and management system at the downstream WWTP.

The Resource Centre for Environmental Technologies (CRTE) of the Public Research Centre Henri Tudor is in charge of a six year project (2002-2007) to accompany the construction works. It focuses on the modelling of the sewer network and the generation and validation of control strategies in order to reduce harmful CSO emissions. For this purpose, several measurement campaigns are performed. The project is conducted in close cooperation with the waste water syndicate "Syndicat Intercommunal de Dépollution des Eaux résiduaires du Nord" (SIDEN) and the involved consulting engineers. The results of load simulations based on a first model of the sewer network provide consultants with hints for an optimised planning and subsequent construction of the sewer system facilities. Compared to other projects dealing with real time control (RTC) in sewer systems (Weyand, 2002; Fuchs et al., 2004; Zawilski and Sakson, 2005) and due to the extraordinary boundary conditions, some of the outcomes of the project lead to uncommon results.

1.2 The future sewer system of the Haute-Sûre Catchment

The planned combined sewer system will convey the sewage water of 24 villages as well as of several other small settlements located around the Haute-Sûre reservoir to the downstream WWTP “Heiderscheidergrund” (see Figure 1). Due to the rural character of the catchment, the sewer system will result in a wide system with interceptor sewers of about 60 km length. About 70% of those main sewers will consist of pressure pipes, whereas the rest will operate under free surface flow conditions. The WWTP is presently under construction and to compete against the population and tourism development its capacity will be of 12'000 population equivalents (PE). The total impervious area of the catchment is estimated to be about 170 ha. The average daily inflow load of the WWTP during the winter months is about 6'800 PE, which consists mainly of domestic and farm discharges. Tourism in summer months leads to an additional load of about 5'200 PE to be drained and treated in the WWTP. (Holinger AG et al., 2002).

Downstream of every subcatchment drained by a combined sewer system, combined sewer overflow tanks (CSOTs) will be built. Their dimensioning relies on the German Design Standards (ATV and DVWK, 1992; MU RLP, 1993). The flow times in the combined sewers of the subcatchments upstream the CSOTs do not exceed 18 minutes. This results in the construction of CSOTs retaining the first flush of combined sewage during storm events. The further flow to the WWTP is limited to the sum of twice the daily peak of the dry weather flow and the infiltration flow of the subcatchment. At present, there are 24 CSOTs planned or already under construction. They will provide a total storage volume of about 3'000 m³. Because of the undulating topographic structure of the catchment, 27 pumping stations will be integrated into the system. (Holinger AG et al., 2002).

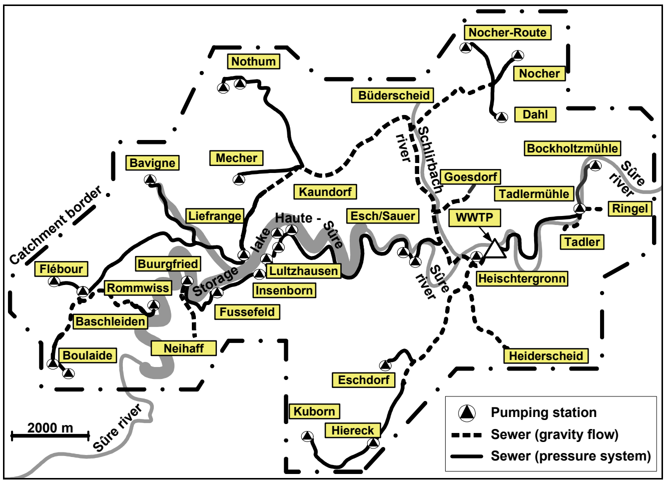

Figure 1 : Sewer system around the Haute-Sûre lake

2 METHODS

2.1 RTC in sewer systems

RTC systems in urban drainage networks are in common use (e.g. (Duong et al., 2005; Fuchs et al., 2005)). The baseflow of a CSOT to the WWTP, for example, can be adjusted as a function of the water level in the storage tank. Additionally, the hydraulic conditions at other significant points in a sewer system or at the waste water treatment plant can be considered. Therefore, control systems are based on numerous conditions and rules.

Particularly spatial variable rainfall intensities in big catchments lead to heterogeneous hydraulic load conditions and storage utilisations within wide ranging sewer systems. The control processes intend a better utilisation of available storage capacities in order to reduce the CSO volume and pollutant loads (Fuchs et al., 1999; Klepiszewski and Schmitt, 2002). Besides the optimised utilisation of storage tank capacities, certain control strategies provide the opportunity to activate storage capacity within large interceptors of urban drainage systems (Duong et al., 2005). Accordingly the future control system in the Haute-Sûre catchment will be based on the utilisation of the storage capacities of the 24 CSOTs spread all over the network (see Figure 2). Due to unavailability of large interceptors, it will furthermore take advantage of the long flow times in the interceptors between some of the subcatchments (e.g. Kaundorf to Buederscheid: 25 min.). Hence, control procedures can increase the base flow a CSOT to the nearby WWTP during a storm event until the combined sewage flow from upstream CSOTs arrives. This leads to a slower filling of the CSOT nearby the WWTP without exceeding the inflow rate the downstream treatment plant was dimensioned for. Furthermore, the control procedures should enable a faster emptying of the storage tanks after rain events to provide as much storage volume as possible for the next rain event.

The dimensioning of the CSOTs in the Haute-Sûre catchment was based on the particular attributes of the upstream subcatchments (e.g. impervious area, dry weather flow rate etc.). This leads to a specific volume and a specific continuous baseflow rate to WWTP during storm events for each CSOT. Therefore, it should be tested, if it is possible to reduce the CSO emissions by varying the continuous baseflow rates of the tanks. Contrary to the dimensioning procedure this takes into account the interaction of the CSOTs and the interceptors all over the catchment. Such static optimisation must not result in a hydraulic overloading of the WWTP.

Further information about the catchment, e.g. quantity of impervious areas or quantity and quality of flows in local subcatchments, is derived from planning data provided by involved consulting engineers, or result from monitoring campaigns.

The spatially variable rain intensities have a significant impact on the utilisation of storage capacities within the network. Therefore the development of the control system is based on rainfall time series of the last three years recorded by two rain gauges in the west and in the south of the Haute-Sûre catchment. Additionally radar rainfall data of high resolution will help to test and to optimise the performance of the control system.

Because of the additional loading of the sewer system due to tourism during summer months, the evaluation of the initial and the controlled sewer system is carried out for a summer scenario and a winter scenario.

2.2 Development of the RTC system

Development, test and optimisation of the control system are achieved by long term hydraulic and load simulations using the software tool InfoWorks™ CS (Wallingford Software). InfoWorks™ CS offers a wide range of possibilities to implement RTC procedures for flow control in sewer systems.

The required simulations are carried out in three steps:

1. Hydraulic load simulation for the initial sewer system
2. Static optimisation of the sewer system
3. Test and optimisation of the RTC system

The performance of the RTC system is evaluated by the amount of CSO emissions of the controlled system (result of 3rd step) compared with the CSO emissions of the initial system (result of 1st step) and the optimised initial system (result of 2nd step).

To keep the RTC system manageable for the future operator it is arranged in 8 control units (see Figure 2). Neighbouring control units share some input parameters to effect a cascade interaction of the units. The utilised storage capacities of the

CSOTs are the most important input parameters to the control procedures. Depending on the utilised capacities within a control unit, CSOTs baseflows to the WWTP are adjusted. This way the utilised capacity of a CSOT can serve as input parameter for several control units (see overlapping of control units in Figure 2), whereas the storage tanks baseflows are controlled by one unit only.

Moreover, performance indicators for the drainage system and the downstream sewage treatment plant are established to ensure a good operation of the facilities with respect to the ecological vulnerability of receiving waters (Vaes et al., 2005).

All possible control decisions within a control unit are consolidated in a rule base. This rule base should meet the following requirements:

- Simple global classification of input parameters:
  - utilised storage capacity ≤ 1% is equivalent to "empty" storage tank,
  - utilised storage capacity ≤ 50% is equivalent to "medium" utilisation,
  - utilised storage capacity >50% is equivalent to "high" utilisation
- Simple classification of local output parameters (see Table 1)
- Rules should be based on comprehensible logical interconnection of input and output parameters
- Pasting of additional rules, modification of existing rules and removal of unnecessary rules should be possible

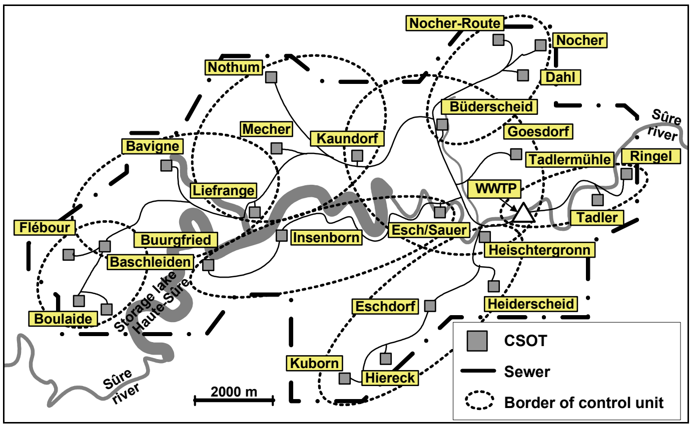

Figure 2 : Arrangement of control units in the Haute-Sûre sewer system

These attributes of the rule base will keep the RTC system comprehensible for the operating stuff and enables an adaptation of the rule base to changes in the catchment.

2.3 Structure and operation of the control unit Ringel/Tadler

The Structure and operation of the RTC system is exemplified by the control unit Ringel/Tadler. The CSO structures controlled by this unit are located to the east of the WWTP (see Figure 2). An Overview of the control unit with its in- and output parameters is illustrated in Figure 3.

Besides the global categories of storage utilisation, the classification of the baseflows of the CSOTs has to be defined for each tank individually (see Table 1). The baseflow category "normal" already represents the result of the static optimisation of the baseflow rate for the CSOTs in Ringel and Tadler.

The operation of the control unit is based on online measurements of the water levels inside the tanks and of the baseflow rate. The capacity of the pumping station

“Tadlermuehle” is adapted to the range of upstream baseflows. Therefore, it is not necessary to integrate the local control system of the pumping station into the rule base of the control unit.

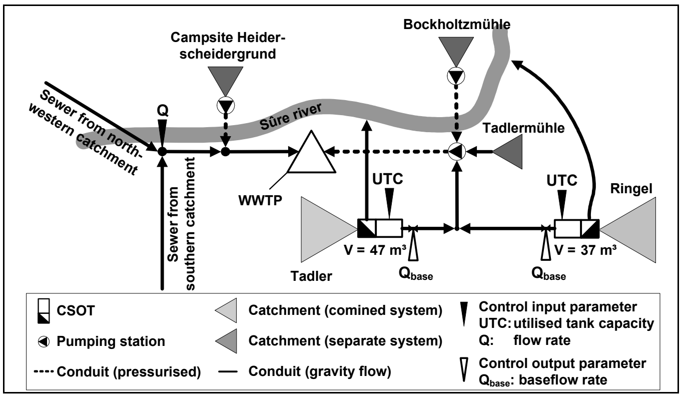

Figure 3 : Schema of the control unit Ringel/Tadler

	Baseflow [l/s]			
CSOT	normal	medium	high	very high
Tadler	1,0	5,0	8,0	15,0
Ringel	2,0	5,0	9,0	16,0

Table 1: Local classification of baseflows in control unit Ringel/Tadler (summer season)

Besides the activated storage capacities of the CSOTs Ringel and Tadler the flow rate after the confluence of the interceptors from the southern and the north-western parts of the catchment is an input parameter of the control unit (see Figure 3).

The rule base of the control unit Ringel/Tadler includes 19 rules (see Figure 4). The application of the control unit should increase the baseflows of the storage structures in Ringel and Tadler as long as there are low flow rates from the rest of the catchment. If the “normal” combined sewage flow rate arrives at the confluence structure the baseflow rates of the tanks is downgraded to “normal” flow rate (see rule no. 1, Figure 4). The utilised storage capacities of the structures in Ringel and Tadler do not interfere with this control decision (see grey areas for rule no. 1). Rule no. 13 represents the case of a local rainfall event in Ringel causing a high utilisation of the local CSOT (see Figure 4).

	Input			Output	
no.	Tadler	Ringel	Q	Tadler	Ringel
1			normal	normal	normal
2	empty	empty	low	normal	normal
3	empty	low	low	normal	high
4	empty	high	low	normal	high
5	low	empty	low	high	normal
6	low	low	low	medium	medium
7	low	high	low	normal	high
8	high	empty	low	high	normal
9	high	low	low	high	normal
10	high	high	low	medium	medium
11	empty	empty	very low	normal	normal
12	empty	low	very low	normal	very high
13	empty	high	very low	normal	very high
14	low	empty	very low	very high	normal
15	low	low	very low	high	high
16	low	high	very low	normal	very high
17	high	empty	very low	very high	normal
18	high	low	very low	very high	normal
19	high	high	very low	high	high

	Input			Output	
no.	Tadler	Ringel	Q	Tadler	Ringel
1			normal	normal	normal
			⋮		
13	empty	high	very low	normal	very high
			⋮		

Figure 4 : Extract of the rule base for control unit Ringel/Tadler

3 RESULTS AND DISCUSSION

First results of hydraulic simulations to analyse the effect of the control unit Ringel/Tadler are illustrated in Figure 5. Apparently the static optimisation leads to a slight decrease of the total CSO volume compared to the initial system.

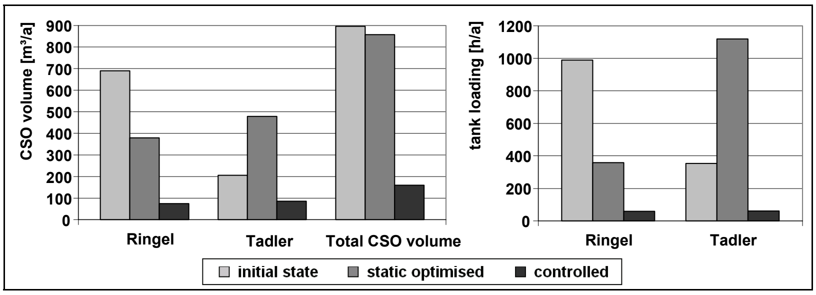

Figure 5 : Simulations for the different scenarios

The application of the RTC system results in a significant reduction of CSO volume at both CSOTs. Besides this the increased baseflows of the tanks in the RTC scenario cause a reduction of duration of tank loading. This is caused by a delayed filling and a advanced emptying of the tanks.

It has to be expected, that the introduction of the RTC units for the rest of the catchment results in extended periods of “normal” flow rate at the confluence structure western of the WWTP. Hence the impact of control unit Ringel/Tadler on local CSO emissions in the final RTC scenario might be less significant than in the RTC scenario shown here.

4 CONCLUSIONS

The Haute-Sûre storage lake is an important drinking water reservoir in Luxemburg. Therefore the lake and the surrounding water courses deserve to be protected.

A new combined sewer system, which connects the villages of the region to a centralised WWTP will significantly reduce emission of pollutants. A further reduction of emissions shall be achieved by implementing a RTC system in the sewer network.

RTC systems for flow control in sewer systems are in common use in urban drainage networks. They essentially rely on:

- Optimised utilisation of available storage capacities
- Activation of additional storage capacities (e.g. in large interceptors)

Because of the missing of large interceptors in the rural catchment under investigation, the RTC system presented here will profit of the long flow times in the interceptors.

The future RTC system will have a modular configuration and different control unit modules will be based on comprehensible modifiable rule bases. They will interact for further reduction of CSO emissions.

A rule base controlling a subsystem of two CSOTs has been tested in InfoWorks™ CS. The application of the RTC system reduces CSO emissions significantly. This shows that, as characteristics of the Haute-Sûre catchment are similar, this RTC strategy is extendable. Therefore, a RTC system might help to achieve a reduction of CSO emissions at the controlled CSO structures.

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LIST OF REFERENCES

ATV and DVWK (1992). ATV - A 128E : Standards for the Dimensioning and Design of Stormwater Structures in Combined Sewers. DVWK, Hennef, Germany, 119.

BLET and Hollinger AG (1977). Technischer Bericht über die Seesanierung Esch-Sauer - 1. Teil: Stellungnahme zu abwassertechnischen Sanierungsmöglichkeiten, Luxemburg, unveröffentlicht.

Duong, D. D. T., Charron, A., Colas, H. and Lamarre, J. (2005). Optimizing the operation of large interceptor systems. 10th International Conference on Urban Drainage, Copenhagen, Denmark, 1-8.

EEC (1991). Council directive 91/271/EEC of 21 May 1991 concerning urban waste water treatment. Council of the European Communities.

EEC (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Community, L 327, 1-73.

Fuchs, L., Beeneken, T., Pfannhauser, G. and Steinwender, A. (2005). Experience with the implementation of a real-time control strategy for the sewer system of the Vienna city. 10th International Conference on Urban Drainage, Copenhagen, Denmark, 1-8.

Fuchs, L., Günther, H. and Lindenberg, M. (2004). Minimizing the Water Pollution Load by means of Real-Time Control (RTC) - The Dresden exemple. 6th International Conference on Urban Drainage Modelling 2004, Technische Universität Dresden, Dresden, Germany, 317-325.

Fuchs, L., Günther, H. and Scheffer, C. (1999). Comparison of Quantity and Quality Oriented Real Time Control of a Sewer System. 8th Intern. Conf. on Urban Storm Drainage, Sydney, Australia, 432-440.

Holinger AG, Schroeder & Associés S.A. and Best Ingénieurs Conseils (2002). Abwassertechnische Sanierung der Gemeinden rund um den Stausee Obersauer - Globales Projekt - Etude de faisabilité, Luxembourg, unveröffentlicht.

JO du GDL (2000). Règlement grand-ducal du 14 décembre 2000 tendant à assurer la protection sanitaire du barrage d'Esch-sur-Sûre. Mémorial Journal Officiel du Grand-Duché de Luxembourg, Luxembourg. A, 133, 2957-2959.

JO du GDL (2003). Loi du 12 août 2003 autorisant l'Etat à participer au financement des travaux nécessaires à l'évacuation et à l'épuration des eaux usées générées par les localités regroupées autour du lac de la Haute-Sûre. Mémorial Journal Officiel du Grand-Duché de Luxembourg, Luxembourg. Mémorial A-N°117, 2468-2469.

Kalmes, P. and Berger, M. (2005). Einschätzung der ökologischen Empfindlichkeit am Stausee Obersauer und mögliche Nutzungskonflikte mit Freizeit- und Tourismusnutzung. EFOR Ingénieur-Conseils, Luxemburg, unveröffentlicht.

Klepiszewski, K. and Schmitt, T. G. (2002). Comparision of conventional rule based flow control with control processes based on fuzzy logic in a combined sewer system. Water Science & Technology, 46(6-7), 77-84.

MU RLP (1993). Richtlinien für die Bemessung und Gestaltung von Regenentlastungsanlagen in Mischwasserkanälen, Verwaltungsvorschrift des Ministeriums für Umwelt Rheinland-Pfalz. Ministerialblatt der Landesregierung von Rheinland-Pfalz, Bundesrepublik Deutschland, 15, 535.

Salvia-Castellvi, M., Dohet, A., Vander Borght, P. and Hoffmann, L. (2001). Control of eutrophication of the reservoir of Esch-sur-Sûre: Evaluation of phosphorus removal by predams. Hydrobiologia, 459(1-3), 61-71.

Schmitt, T. G., Hansen, J., Wiese, J. and Schuchardt, L. (2003). Studie zur Abschätzung der Wasserqualität der Sauer nach Bau der Kläranlage Heiderscheidergrund. Tectraa - Zentrum für Innovative AbWassertechnologie an der Universität Kaiserslautern, Bundesrepublik Deutschland, unveröffentlicht.

Vaes, G., Swartenbroekx, P., Provost, F., Van den Broeck, S. and Bourgoing, L. (2005). Performance indicators for waste water treatment and urban drainage system. 10th International Conference on Urban Drainage, Copenhagen, Denmark, 1-8.

Weyand, M. (2002). Real-time control in combined sewer systems in Germany - some case studies. Urban Water, 4, 347-354.

Zawilski, M. and Sakson, G. (2005). Optimal control strategies for stormwater detention tanks. 10th International Conference on Urban Drainage, Copenhagen, Denmark, 1-8.