7th International Conference on Hydroinformatics
HIC 2006, Nice, FRANCE

CONSTRUCTION AND CALIBRATION OF AN INTEGRATED MODEL FOR CATCHMENT, SEWER, TREATMENT PLANT AND RIVER

ANNE-MARIE SOLVI
BIOMATH, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium
Resource Centre for Environmental Technologies, CRP Henri Tudor, rue de Luxembourg 66, L-4002 Esch/Alzette, Luxembourg

BENEDETTI LORENZO, VANDENBERGHE VERONIQUE
BIOMATH, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium

GILLE SERGE
Laboratory for Industrial Technologies, CRP Henri Tudor, rue de Luxembourg 70, L-4002 Esch/Alzette, Luxembourg

SCHOSSELER PAUL
Resource Centre for Environmental Technologies, CRP Henri Tudor, rue de Luxembourg 66, L-4002 Esch/Alzette, Luxembourg

WEIDENHAUPT ANDRE
Administration de la Gestion de l'Eau, rue de Merl 51, L-2146 Luxembourg, Luxembourg

VANROLLEGHEM PETER
BIOMATH, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium
modelEAU, Département de Génie Civil, Pavillon Pouliot, Université Laval, Québec G1K 7P4, QC, Canada

Immission-based management of the urban wastewater requires a holistic consideration of sewer network, treatment plant and receiving water. Modelling and simulation of this integrated system allows for scenario testing and operation suggestions in function of the river status. This paper presents a general approach to such model construction and calibration. The used software WEST® contains all the model components needed: a hydrologic module for rainfall-runoff simulation, tank cascades for water flow, the activated sludge models ASM1, ASM2, ASM3 for the treatment plant and the RWQM1 for water quality in the river. The method is illustrated on a case study in Luxembourg.

INTRODUCTION

The EU Water Framework Directive (CEC [1]) requires that member states adopt measures to reach a 'good' chemical and ecological status for both surface and ground waters by 2015. Therefore, the currently applied emission-based regulations will have to be complemented with an immission-based approach. This implies an integrated assessment of the sewer - wastewater treatment plant (WWTP) - river system. In contrast to the single element based approach, an integrated view considers flows through the whole system, and makes the relation between rainfall-runoff and impacts on the WWTP or river explicit. It has the advantage of giving more possibilities to water managers and planners on how to operate sewers or treatment plants to prevent pollution of the receiving water (Fenz *et al.* [2]). Hence, model representation and simulation of an integrated system can then, for example, point to an overestimation of treatment capacities of a WWTP after construction of retention basins or predict the river buffer capacity when dealing with combined sewer overflows (CSOs) or WWTP effluents (Meirlaen *et al.* [3], Erbe *et al.* [4]).

Problems with building an integrated model often arise due to incompatibility between sub-model variables or connectivity problems of software used for the different subsystems (Erbe *et al.* [4], Rauch *et al.* [5], Benedetti *et al.* [6]). Also, the mere complexity of the entire system, the different temporal and spatial scales of processes, the many variables and parameters involved risk to overload the model so that overview is lost and simulation times become too long for efficient use of the model. Therefore, other examples have a very reduced and simplified model structure, and rely on statistical evaluation of a large number of simulated single events (Dempsey *et al.* [7]).

The here presented model has the advantage of being contained in one software and is a compromise between complexity of model structure and simulation time. Indeed, such integrated studies are very much related to the characteristics of the specific case study with well-defined objectives, and depend on availability of data, analysing tools and economic resources. A case study is presented below, which serves to illustrate the implementation of an integrated model. However the presented methodology should remain applicable to other case studies.

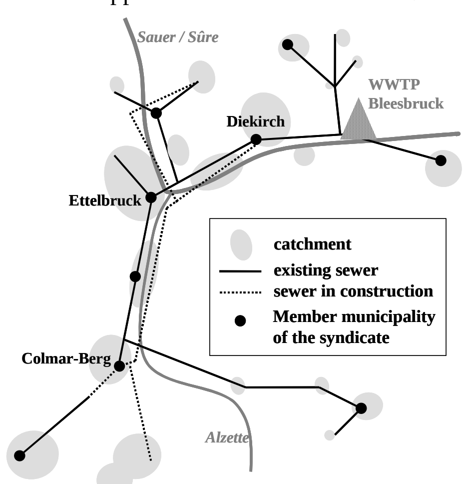

Figure 1. The Luxembourg case study.

The objectives of this study are the elaboration of management strategies for a refurbished sewer system together with the WWTP through long-term simulation of scenarios, and their analysis in function of the water quality of the eutrophied receiving rivers.

THE CASE STUDY

The case study is situated in Luxembourg and the main collector stretches, the WWTP and the river are schematised in Figure 1 and the table below. More details can be found in (Solvi *et al.* [8]).

Drained catchment area:	~ 10km^2 (semi-rural)
Population equivalents (PE):	~ 52000 (domestic & industrial)
Sewer network:	± 60 km (mostly combined)
WWTP:	100 000 PE (hydraulics) Pre-treatment (screen, grit removal and grease separation, 2 activated sludge units in series, online sensor equipment for nutrients)
River 'Sûre', 'Alzette':	10 – 20 m^3/s (during dry weather)

THE INTEGRATED MODEL

The software used in this project is WEST® (Hemmis N.V, Kortrijk, Belgium) (Vanhooren *et al.* [9]). Due to size reasons it was not possible to show the case study model, but Figure 2 presents the main components that make up an integrated model in WEST®. Hence, the model structure is meant to present a homogeneous level of complexity so that we are facing one integrated model instead of 3 sub-models.

Flow in the receiving river(s) is modelled as a tank cascade, and water quality is represented by a simplified version of the IWA river water quality model RWQM1 (Reichert *et al.* [10]). It contains processes for oxygen, biodegradable organic matter, nitrogen and phosphorus cycles, pH and algae growth. The model can be reduced to adapt to local circumstances and was developed to be compatible with the IWA standard activated sludge models (ASM1, ASM2, ASM3 (Henze *et al.* [11])) for modelling WWTPs. For urban drainage and sewer transport, an adapted version of the German KOSIM model (ITWH [12]) was implemented into the WEST® modelbase (Meirlaen [13], Solvi *et al.* [8]). The 'catchment' icon includes dry weather flow (DWF) generation and runoff generation through wetting, depression, infiltration and evaporation losses. The transport of the wastewater in the collectors is modelled by means of linear reservoir cascades.

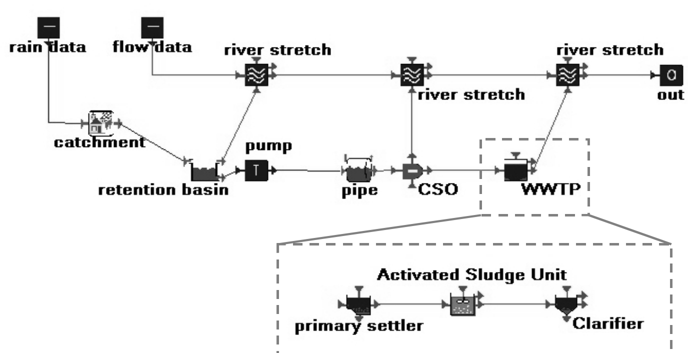

Figure 2. Typical model components for an integrated model in WEST®.

In the sewer part of the integrated model, no reactions are taking place for pollutants, but accumulation and wash-off, sedimentation in the basins and main collectors are modelled. The translation of state variables from one model to the other is done according to the principles of closed mass-balances (Vanrolleghem *et al.* [14], Benedetti *et al.* [6]).

For the case study, the river model was built and calibrated using 2 measurement campaigns in June and October 2005. The WWTP model was built and calibrated in a previous European Life project (Schosseler *et al.* [15]) and has now been translated into the WEST® software. A new one-year calibration of the WWTP is currently ongoing as on-line data on water quality is available from the WWTP. A one-year calibration is also being done on the conceptual urban drainage model and emphasis is put on this during the present paper.

CONCEPTUAL URBAN DRAINAGE MODEL

Data

The main data necessary for the conceptual urban drainage model are listed below:

Population equivalents (PE):	domestic, industrial, mean pollutant concentrations
S*urfaces:*	area, degree of imperviousness, surface characteristics, mean pollutant concentrations
Geometric data:	flow times, diameters, slopes, CSOs, basins
Other:	infiltration, evaporation

The data was compiled from demographic data, a WWTP extension study, aerial photographs, sewer maps from the operator, engineering offices and others, and in case there was no precise data available, parameters were taken from literature.

Infiltration into the sewer system was evaluated using inflow data into the WWTP. For 4 years of data, the 21-days moving minimum method was applied (Brombach *et al.* [16]). Figure 3 shows the daily average values of the 4 years of data set and a yearly infiltration pattern based on monthly averages (cf. Figure 1). This pattern was used for each of the sub-catchments, assuming that they represented the biggest contribution to infiltration into the network, i.e. the main collector is supposed to be free of infiltration inflow. The amount of infiltration flow that was deduced from this minimum flow analysis varies between 0.116 L/s/ha of total area in summer and 0.187 L/s/ha in winter. However, as was found out during subsequent simulations of the whole sewer catchment (described further down), this amount appears to include daily dry weather flow. This is due to retention and long travelling times of the water in the sewer, i.e. there is wastewater arriving at the WWTP anytime. Hence, after these corrections, the monthly mean infiltration was estimated to range from 0.044 L/s/ha to 0.116 L/s/ha.

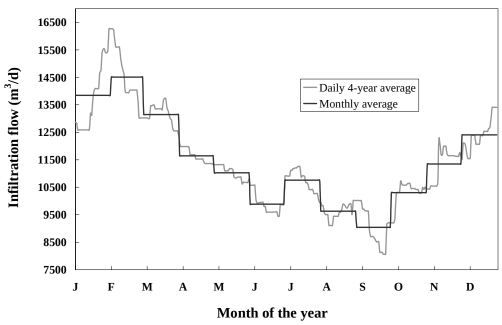

Figure 3. Sewer infiltration pattern for the studied catchment. The pattern was deduced from 4 years of hydraulic inflow data to the WWTP.

Model implementation

While gathering the data, it was realised that subcatchments often contained several CSOs and modelling all of them would certainly blow up model extensions and simulation times thereafter. Moreover, keeping every detail in the model does not necessarily improve the results. So, it was decided to keep the number of CSOs to a minimum, always leaving the possibility of refining the model according to future needs.

CSO reduction

To check whether a reduction of the number of CSOs to be modelled could be performed, the following analysis was done. It was noticed that some of the CSOs on the outskirts of a town, often new residential areas, had quite a high overflow limit with regard to the drained area. However, often the throttled base flow would enter an older sewer part, where the CSO had been designed for a much smaller area than it was confronted with now. Indeed these CSOs do overflow regularly. In order to simplify the model, a one-year simulation was performed for all the CSOs that were suspected to overflow rarely and in case of no overflows, the CSO was automatically omitted from the catchment model. In a second step, in-series connected CSOs were summarised into one CSO and this simplification was also tested with one-year simulations. Both mass balances and overflow peaks were compared and an example of the latter is depicted in Figure 4. It should be noted that this simplification was only considered in the case where it was sure that the concerned CSOs would be discharging into the same river model stretch.

It can be seen that the overlap in the shown example is very good considering the whole event. However, no real data were available to calibrate the original model, but ‘critical’ CSOs, i.e. often discharging CSOs, were identified and their frequent overflowing was confirmed by the system’s operator SIDEN.

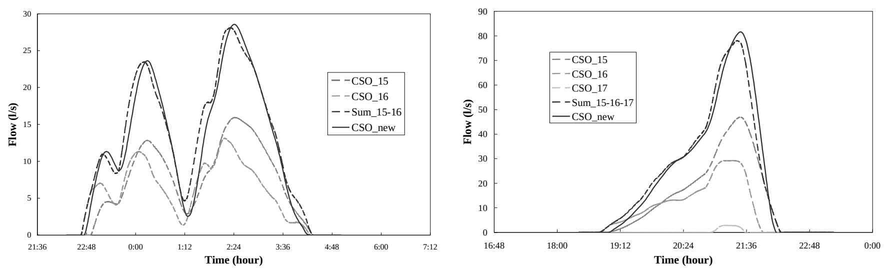

Figure 4. Model reduction example of multiple CSOs into one CSO. The figures contain two main overflows in that catchment during a year of simulation. They depict the simulated overflows from the individual CSOs as found in the sewer system, the sum of the latter and the simulation results of the new, calibrated CSO. Mass balance ratio of the calibrated CSO over the sum of the original CSOs is 0.998.

Simulations

After reduction of the model down to essential CSOs with their attached draining surface, simulations could be performed. As the impacts of individual operation scenarios will be analysed by integrated model simulations of yearly durations, it becomes important to do a one-year calibration on the catchment model, as is done for the WWTP, so as to include seasonal variations. The only data available in the sewer system apart from on/off data at the 4 pumps of the network, WWTP inflow data and COD, ammonium, nitrate and phosphorus data after the grit removal and grease separation.

Hence, a first DWF calibration is performed using the WWTP inflow data and Figure 5 shows first results over a summer period. Lower flows on weekends are not yet accounted for in the model (here: day 221 & 222 etc.). Also, simulation results in winter do not fit to measured data as well as in summer. Two reasons could be found: (1) the infiltration seems to have been a little higher during the simulation year than the infiltration pattern predicted and (2) more important, flow into the WWTP follows the level meter data of the river Sûre, so that we can assume that after a certain level is reached in the river, river water is intruding into the main collector. It was confirmed by the operator that water enters through CSOs until these are closed by hand, and this will have to be taken into account in the integrated model. Mass balance ratios of simulated and measured flow into the WWTP over one year give 10% discrepancy and in a next step pump operation data will be compared with pumping in the simulations. This will allow a more accurate calibration of smaller parts of the total catchment, especially through fine-tuning of values for drained surfaces and their imperviousness. In the case of frequent backwater effects in the system, hydraulic calibration of the collector with the hydrodynamic simulator InfoWorks™ CS is realised (cf. Solvi *et al.* [8]).

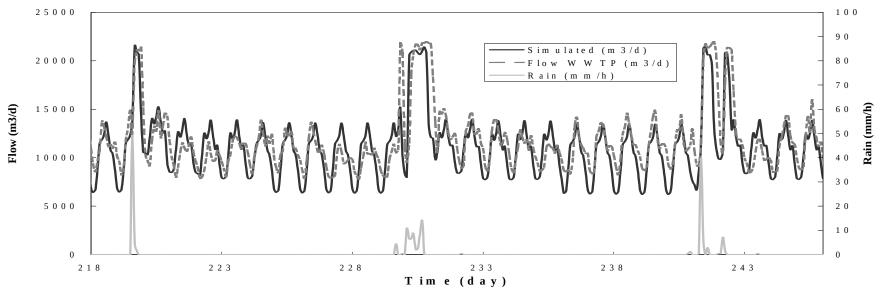

Figure 5: Simulation versus data for catchment outflow results over 30 days.

OUTLOOK AND CONCLUSIONS

After hydraulics are locally calibrated using pumping data, pollution will be calibrated at the WWTP. It seems important to perform one-year calibrations of the catchment model as seasonal variations play a major role in the system and different operation strategies may have to be considered in winter and summer for example. This model of the current system will then serve as a basis for the new and refurbished sewer system model, where no new reliable data will be available for some time.

When implementing an integrated model, working in one software (here WEST®) avoids switching between programs or data formats and guarantees a harmonised model structure. Next to the fact that model building alone creates a sort of data pool about the investigated system, first simulations provide more knowledge about the origin of water as well as first indications to the limits of the system. The simulated overloads at pumping stations, and high overflow volumes at some of the CSOs have shown that the refurbishments will bring a lot of benefits, and that optimal operating strategies for basins can be deduced and will be useful to the operator.

ACKNOWLEDGEMENT

The results presented in this article have been elaborated in the frame of the EU Project CD4WC, contract no. EVK1-CT-2002-00118. This project is organised within the Energy, Environment and Sustainable Development Programme in the 5th Framework Programme for Science Research and Technological Development of the European Commission. The first author is funded through a 'Bourse-Formation-Recherche' by the Luxembourg's Ministry of Culture, Higher Education and Research. The support of the SIDEN (Syndicat Intercommunal des Eaux Résiduaires du Nord) is gratefully acknowledged. Peter Vanrolleghem is Canada Research Chair in Water Quality Modelling.

REFERENCES

[1] CEC (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.

[2] Fenz, R. and W. Rauch (2003). Mischwasserbehandlung - Anforderungen und Ermittlung der erforderlichen Massnahmen mit Hilfe der Modellierung. *Wiener Mitteilungen*, Institut für Wassergüte, TU Wien. **Band 183:** 119-148.

[3] Meirlaen, J., J. Van Assel and P. A. Vanrolleghem (2002). "Real Time Control of the integrated urban wastewater system using simultaneously simulating surrogate models." *Wat.Sci.Tech.* **45**(3): 109-116.

[4] Erbe, V., T. Frehmann, W. F. Geiger, P. Krebs, J. Londong, K.-H. Rosenwinkel and K. Seggelke (2002). "Integrated modelling as an analytical and optimisation tool for urban watershed management." *Wat.Sci.Tech.* **46**(6-7): 141-150.

[5] Rauch, W., J.-L. Bertrand-Krajewski, P. Krebs, O. Mark, W. Schilling, M. Schütze and P. A. Vanrolleghem (2002). "Deterministic modelling of integrated urban drainage systems." *Wat.Sci.Tech.* **45**(3): 81-94.

[6] Benedetti, L., J. Meirlaen and P. A. Vanrolleghem (2004). Model connectors for integrated simulations of urban wastewater systems. *Sewer Networks and Processes within Urban Water Systems.* J.-L. Bertrand-Krajewski, M. Almeida, J. Matos and S. Abdul-Talib, IWA Publishing**:** 13-21.

[7] Dempsey, P., K. Murrell, W. Williams, B. Crabtree and R. Walwyn (2003). Simplified integrated modelling of a large conurbation - the river Tame catchment. In: *Proc. IMUG Conference*, 23-25 April 2003, Tilburg, The Netherlands.

[8] Solvi, A.-M., L. Benedetti, S. Gillé, P. M. Schosseler, A. Weidenhaupt and P. A. Vanrolleghem (2005). Integrated urban catchment modelling for a sewer-treatment-river system. In: *Proc. 10th International Conference on Urban Drainage*, 21-26 August 2005, Copenhagen, Denmark.

[9] Vanhooren, H., J. Meirlaen, Y. Amerlinck, F. Claeys, H. Vangheluwe and P. A. Vanrolleghem (2003). "WEST: Modelling biological wastewater treatment." *J. Hydroinformatics* **5**: 27-50.

[10] Reichert, P., D. Borchardt, M. Henze, W. Rauch, P. Shanahan, L. Somlyódy and P. A. Vanrolleghem (2001). *River Water Quality Model No.1*. *Scientific and Technical Report No.12*, IWA Publishing, London, UK.

[11] Henze, M., W. Gujer, T. Mino and M. van Loosdrecht (2000). *Activated Sludge Models ASM1, ASM2, ASM2d and ASM3*. *Scientific and Technical Report No.9*, IWA Publishing, London (UK).

[12] ITWH (2000). *KOSIM 6.2: Anwenderhandbuch*. Institut für technisch-wissenschaftliche Hydrologie GmbH, Darmstadt, Germany, Hannover.

[13] Meirlaen, J. (2002). *Immission based real-time control of the integrated urban wastewater system*. PhD Thesis. BIOMATH, Ghent University, Belgium,

[14] Vanrolleghem, P., C. Rosen, U. Zaher, J. Copp, L. Benedetti, E. Ayesa and U. Jeppsson (2005). "Continuity-based interfacing of models for wastewater systems described by Peterson matrices." *Wat.Sci.Tech.* **52**(1-2): 493-500.

[15] Schosseler, P. M., E. Boudinet, D. Fiorelli, S. Gillé and M. Oldenburg (2003). Modellgestützte Optimierung und Steuerung der Abwasserreinigung in Bleesbruck (L). In: *Proc. 10. Simba Anwendertreffen*, May 14-15, 2003, Freyburg/Unstrut, Germany.

[16] Brombach, H., G. Weiss and S. Lucas (2002). Temporal variation of infiltration inflow in combined sewer systems. In: *Proc. 9th International Conference on Urban Drainage*, 8-13 September 2002, Portland (USA).