Modelling the sewer-treatment-urban river system in view of the EU Water Framework Directive

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Summary

The presented work lies within the context of the EU Water Framework Directive (WFD) adopted in 2000. It sets a number of deadlines to be met by Member States to reach good quantitative and qualitative status of water resources and introduces the concept of integrated river basin management. More particularly, it shifts the focus from a purely source emission approach to a combined approach with 'control of pollution at source through the setting of emission limit values and of environmental quality standards' (Article 40, WFD). It is widely accepted that modelling will play a major role within the WFD implementation, e.g. to fill information gaps around a river basin or to design monitoring and management plans.

This dissertation focuses on the integrated urban wastewater system (IUWS), i.e. the system consisting of urban runoff, sewer system, treatment plant and receiving river, which is, next to diffuse pollution, an important source of pollution to receiving waters. Within the immission-based approach of the WFD, the water quality of the river evaluates the performance of the IUWS in terms of hydraulic and pollution impacts. As a consequence, when exposed to the same urban catchment, a small creek would require different IUWS management practices than a larger river. Some of the possibilities and new directions for IUWS management are exposed in Chapter 2 and make clear that the large number of degrees of freedom to implement management schemes do not make it straightforward to find the 'right' solution for a considered urban catchment. It is also concluded that model-based scenario analysis represents one appropriate tool to test for the ‘best’ solution(s) according to given criteria.

The challenge to model the IUWS lies above all within the structural complexity of the system itself. Besides the system's large spatial extent, the complexity is also the result of its non-linear dynamics that are the result of a complex interplay of a wide diversity of processes. Hence, setting the level of detail of the representation of such a system in order to attain the set goals is a global challenge of such modelling exercise, and, in particular, for the here presented work.

The developed approach, based on the Driver-Pressure-State-Impact-Response framework, is also explained. The different steps to be accomplished are the collection of data, the identification of deficits and pressures, the construction and calibration of the model and the definition of scenarios that are expected to improve the system's performance. Once simulations are run, results can be evaluated according to well-defined criteria.

One major challenge for IUWS modelling is the connection of subsystem models. Through the fact that the subsystems sewer, WWTP and river are usually dealt with by different stakeholders and that they are subject to different problems (e.g. hydraulics in the sewer, biochemical processes in the WWTP, ecological indicators in the river), modelling softwares for subsystems most often differ and are difficult to link, making data transfer a necessity and a problem. The here used modelling software, called WEST® (MOSTforWATER, N.V., Kortrijk, Belgium), contains models for the simulation of the WWTP and river and Chapter 3 presents the newly implemented models for urban runoff and sewer transport. The idea behind this extensive additional implementation is to have all necessary modules to build the integrated model for sewer, WWTP and river available in one software. This arrangement will facilitate data transfer between models. The general concept of the implemented models has been taken from the KOSIM software (ITWH, 2000), which is widely used in Germany and Luxembourg.

The Chapter explains that the models are of appropriate complexity for application within an integrated context: not too complex to keep the data required for calibration reasonable and to keep the simulation times to a minimum, however detailed enough to contain all the necessary processes affecting the variables of interest. In addition, models for accumulation and wash-off of particulate matter on the surface and backwater effects were included as they were considered necessary for the required quality of simulation results. The developed model to approximate backflow is presented in more detail, and calibration of the model using hydrodynamic simulation results is illustrated on the integrated case study in Chapter 5.

KOSIM-WEST simulations are compared with the results obtained with the original KOSIM software in order to identify their respective fields of application. To test and gain experience with the new models in WEST®, they have been applied to a small catchment in Luxembourg City where data, both for hydraulics and water quality, were monitored in a storm water tank. Major outcomes of the evaluation are that first the local availability of incoming rain data determines the quality of the results to a large extent and that good dry weather flow calibration using online quality data is important before looking at wet weather results.

Towards the end, Chapter 3 briefly recalls the modelling approaches applied to the WWTP and river systems and gives principles for the connector models which are used to link variables among these submodels.

Chapter 4 contains the characteristics of the case study 'Bleesbruck' (Luxembourg), from population density to industry information in the catchment, to wastewater treatment plant layout and description and data on the 3 rivers of the considered urban catchment. Through two targeted measurement campaigns, water quality at the WWTP and the river were monitored in order to serve the subsequent model construction and calibration. The planning and set up of the campaigns are explained. Using the gained system information, deficits and pressures are identified as they are important to define alternate system configurations that can be used in the subsequent scenario analysis. It is concluded that one of the catchments' rivers brings high background pollution from upstream the Bleesbruck catchment, that the WWTP has poor nitrification capacity and that the sewer system is overflowing regularly.

Both existing and measurement campaign data were used to build and calibrate an integrated model of the case study in order to perform a scenario analysis using various system configurations. It is not a trivial task to build such an integrated model, first of all due to the complexity of the integrated urban wastewater system and therefore the related model itself, and secondly due to the difficulty for the user to choose the appropriate submodels for the integrated model out of a multitude of possible options. The choice depends on the level of data availability and the objectives of the study in question.

For each of the 3 submodels, after all available data were gathered and analysed for quality, the model was constructed and calibrated. In the case no or few data were present for calibration, parameter values were either fixed at default values taken from literature, or estimations were done where possible. The adopted methodology and approaches to build the integrated model in order to achieve our goals are presented in Chapter 5.

For the development of the urban drainage model, several steps were followed. First, hydraulic calibration of the hydrologic model was performed on the basis of hydrodynamic simulation results of the main collector obtained in InfoWorks CS (Wallingford Software, UK). Second, water quantity and quality were calibrated for 8 months with online measurements at the WWTP influent. However, overflows at individual catchments could not be adjusted, as, apart from visual inspections and experience of the operator, no data was available regarding the activity of the overflow structures.

Using an already existing SIMBA model as a basis, the WWTP model was implemented in WEST® and has been calibrated and validated using 2 weekly measurement campaigns. Subsequently, the model was recalibrated over an 8 month period. This long-term calibration was a necessary step to allow using the model for the purpose of this long-term assessment of the system, i.e. to account for seasonal differences.

The main objective of the river model calibration is to get good water quality predictions as water quality will be the relevant criterion during scenario analysis. The used model is a simplified version of the IWA River Water Quality Model No. 1 (RWQM). pH has been omitted as monitoring showed it could be considered as constant and consumers are left out due to unavailability of data to state anything about their influence. The river model was calibrated using the data from the two measurement campaigns. The main components of importance in the study are nutrients and dissolved oxygen and this is where the calibration focused upon.

Although the three submodels differ with respect to the different processes that take place, it was ensured that all of the submodels were calibrated over the longest time period so as to make them consistent in that sense. The simulation results are extensively presented and the chosen calibration parameter sets are discussed.

With the calibrated integrated model and the information on the case study deficits, 15 scenarios were developed and described in the first part of Chapter 6. The scenarios include among others source control measures like load peak flattening or reduction of water masses through impervious surface reduction, construction measures like sewer retention tanks or WWTP nitrification volume increase, system operation modification like improved phosphorus control or measures taken directly in the river like aeration and shading. For each of them, an indicative cost analysis is performed to help stakeholders to choose optimal scenario(s) later on. The evaluation criteria were defined for emissions as well as immission concentrations, using mean, minima, maxima, duration and frequencies above/below thresholds. Variables of concern that were considered are chemical oxygen demand, dissolved oxygen, ammonia and nitrates, and orthophosphates.

The aim of the developed evaluation approach was to design a concept for easy interpretation of simulation results. Through the abundance of data, both in terms of the frequency over time and the variety of locations, the overview on essential, objective driven outcomes is quickly lost. The here developed evaluation matrix contains all the information for scenarios and criteria and gives a clear overview. Together with an analysis of selected events, the evaluation approach will show which variable is mostly affected by which scenario.

In this specific case, the scenario analysis illustrates that the impact of the different scenarios on the already eutrophied and polluted river in the Bleesbruck case study is small, due to the already high background pollution present. It could be concluded that investments for implementation of the WFD in this river basin need to be done in a first instance upstream of the Bleesbruck catchment, i.e. requiring emission-immission based upgrades of the treatment facilities of cities upstream. Taking into account the present background pollution, implementation of \emph{improved control algorithms} for nitrogen and phosphorus removal at the treatment plant presents good results at relatively low costs and can bring about positive changes with regard to reduction or even elimination of concentration peaks. Consequently, it can reduce the risk of ammonia fish intoxication and, as phosphorus is the limiting nutrient for algae growth, decrease algae mass in the vicinity of the WWTP.

In a second scenarios analysis, the same system configurations were tested, however, assuming that all receiving rivers are already WFD-compliant according to biochemical criteria. Results show that in such situation the receiving waters are much more vulnerable to urban pollution originating from the Bleesbruck catchment, as for example the capacity to cope with DO depleting discharges is gone with the state of supersaturation that existed with the presence of algae.

The conclusions highlight the usefulness of modelling both within WFD and IUWS management and presents prospects for further research in this area. The Driver-Pressure-State-Impact-Response (DPSIR) framework served as a basic structure to define the individual steps that constituted the system's analysis and it is repeated that the developed methodology from data collection to model construction to scenario analysis can be applied to other case studies. Within the WFD implementation context, modelling of the IUWS proved to be an essential ingredient supporting a more detailed analysis of an urban catchment where basin-wide models cannot give precise answers on how to operate or plan urban wastewater management that takes into account river water quality. The ability for zooming in on specific events gives the modeller the opportunity to understand what is happening on short time-scales and to verify whether simulated results are plausible.

Overall such model is expected to contribute to reported real integrated case studies, so that the investigation and implementation performed here can be used in a comparative study of the outcomes of model predictions from other studies. It allows to demonstrate the usefulness of an integrated approach and to bring forward discussion on when and where an integrated model is appropriate.