SIMULATION OF THE INTEGRATED URBAN WASTEWATER SYSTEM USING MECHANISTIC SURROGATE MODELS

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KEYWORDS

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INTRODUCTION

The integrated urban wastewater system (sewers, treatment plants and receiving water) has a major impact on the quality of the receiving water, due to discharges of combined sewer overflows (CSO) during storms and due to effluents of the treatment plants. An integrated model, which takes into account the quality of the receiving water, is a useful tool to study these effects. Moreover, a parallel simulation of the integrated urban wastewater system has been asked for since the last few years (Rauch *et al.*, 1998; Schütze *et al.*, 1998).

A problem encountered when creating an integrated model is the fact the existing models are quite complex and require sophisticated integration algorithms to solve them. This results in long calculation times, making these models impractical to use, especially within optimisation problems where a lot of simulations need to be performed. These complex models need hence to be replaced by faster surrogate models. These surrogate models contain less knowledge in their physical concept, and this shortcoming has to be compensated by using more data when calibrating the model. However collecting data is an expensive and time consuming task (Vanrolleghem et al., 1999). In this work an alternative approach is proposed. Instead of collecting all data needed to calibrate the surrogate model, data are collected to calibrate the complex mechanistic model. Once this model is validated it may be used to generate virtual data, which can be used to calibrate the surrogate model. In other words, the knowledge of the complex model is transferred to the surrogate model by means of these virtual data.

Another problem in integrated modelling is that the state-of-the art models cannot be linked easily to each other due to differences in the respective state variables. This problem is partially addressed in this work by linking a treatment plant model (ASM1, Henze et al, 1987) with a river model (RM1, Reichert et al., 2000) in a consistent way. In this way, the effect of the effluent of the treatment plant on the resulting river water quality can be assessed. This will be illustrated for a case study on the river Lambro (Italy).

MECHANISTIC SURROGATE MODELS

Figure 1 shows the application of the concept of using complex mechanistic models to calibrate surrogate models on the urban wastewater system. Typical examples of complex mechanistic models of the different subsystems are given. In both sewer models (HYDROWORKS, MOUSE, ...) and river models (MIKE11, ISIS, DUFLOW-EUTROF1,...) flow propagation is described using the 'de Saint-Venant' equations. These partial differential equations can be simplified in certain cases, but they still require advanced numerical integration and, hence, a long calculation time. Therefore, alternatives for these models are suggested.

Fronteau (1999) compared the conceptual sewer model Kosim (Paulsen, 1986) with the complex mechanistic Hydroworks model and showed that long term results were comparable. Kosim is a conceptual run-off/sewer model and long-term simulations gave similar results. Since the Kosim model uses discrete time-steps, it could not be implemented as such in the WEST simulator (Hemmis NV, Kortrijk, Belgium) because this package is able to solve differential equations, but not discrete time equations. The corresponding differential equations have been worked out and implemented in the WEST simulator.

Flow routing in rivers can be approximated by a series of tanks with variable volume (Beck and Young,

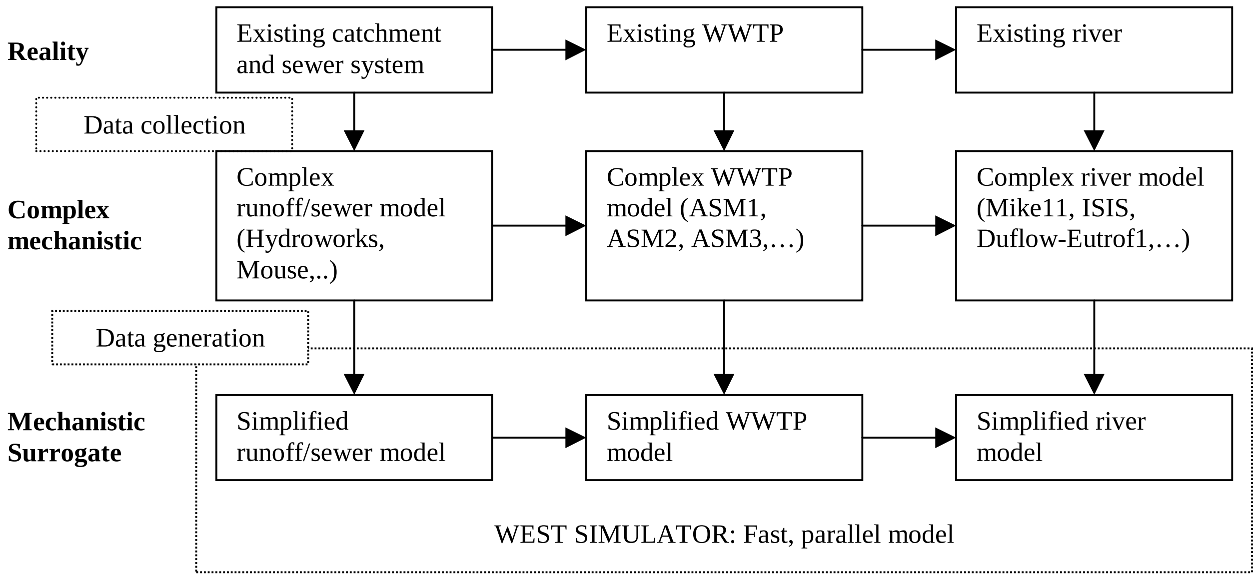

Figure 1: From reality to surrogate models using complex models

1975). Moreover, when these tanks are also used to describe the solutes in the river, the model is also able to describe dispersion in a reasonably accurate way (Reda, 1996). The procedure of calibrating a series of tanks on the basis of data generated by the 'de Saint-Venant' equations will be illustrated in a case study performed on the river Zwalm (Belgium). Figure 2 shows the validation results of a tanks in series model compared to the diffusive wave approximation of the 'de Saint-Venant equations'. Validation results (figure 2A) show a good correspondence between the simulation results of the tanks in series model and the 'de Saint-Venant' equations. However, when looking on a smaller time scale (fig. 2B) the peak flow is found 0.3 hour earlier than with the Saint-Venant equations.

Both the simplifications of the runoff/sewer model and the tanks in series model are implemented in the WEST simulator. Since this package was developed for simulation of wastewater treatment plants, the three

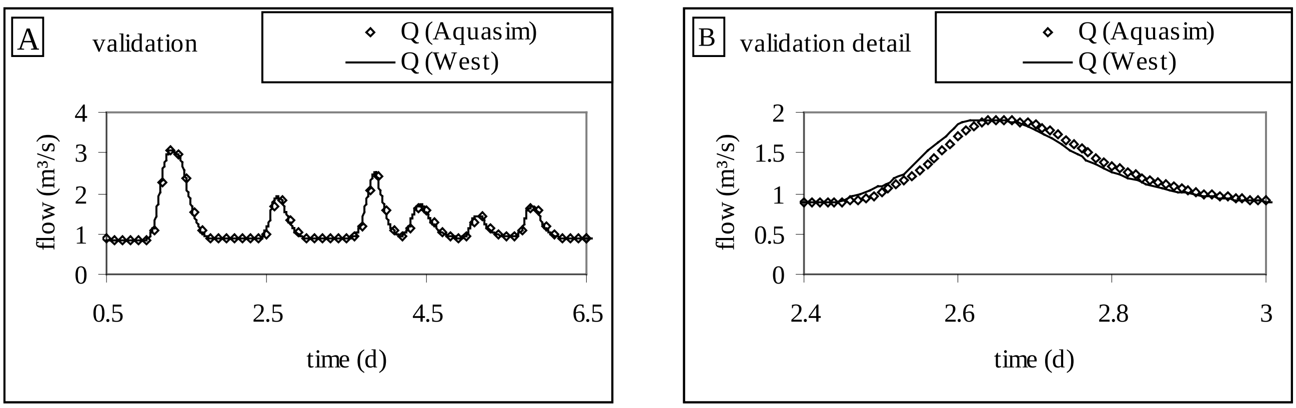

Figure 2: The validation results of the river Zwalm

parts of the integrated urban wastewater system (IUWS) are now available in one package, making linking of the submodels straightforward. Moreover, problems with file or data transfer between different simulators are avoided and a parallel simulation is possible.

INTEGRATED MODELLING

In order to simplify the connection between treatment plant models (typically COD based) and river water quality models (typically BOD based), a COD based river water quality model has been developed in which mass balances and elemental balances for C, N, O, P and H are closed (Reichert *et al.*, 2000; Shanahan *et al.*, 2000; Vanrolleghem *et al.*, 2000). In order to keep this important feature in the integrated model, the proposed connector between the states of the ASM1 and the RM1 also has closed mass and elemental balances.

The above connector and surrogate models have been used on a case study of the river Lambro. For a description of the catchment, see Whelan *et al.* (1999). The treatment plant in Merone has been focussed on in this study. Before June 1998, this treatment plants' capacity was insufficient to treat even the dry weather flow, with a daily bypass of raw wastewater as a consequence. Therefore the plant was extended in June 1998 (Details, see Meirlaen *et al.*, in preparation).

In this study the river Lambro has been modelled as a series of completely mixed tanks with variable volume. The available tracer data (Boron) were sufficient to determine the number of tanks needed to describe the behaviour of the river. By comparison with the field data (fig3a and b), it was concluded that 47 tanks yielded a good approximation of the Boron concentration in the last section of the river, for peak time, peak height and dispersion rate. Simulation results from the integrated model of the Lambro catchment, with both the former and the current plant layout are shown in fig 4. The extension of the treatment plant capacity has the L

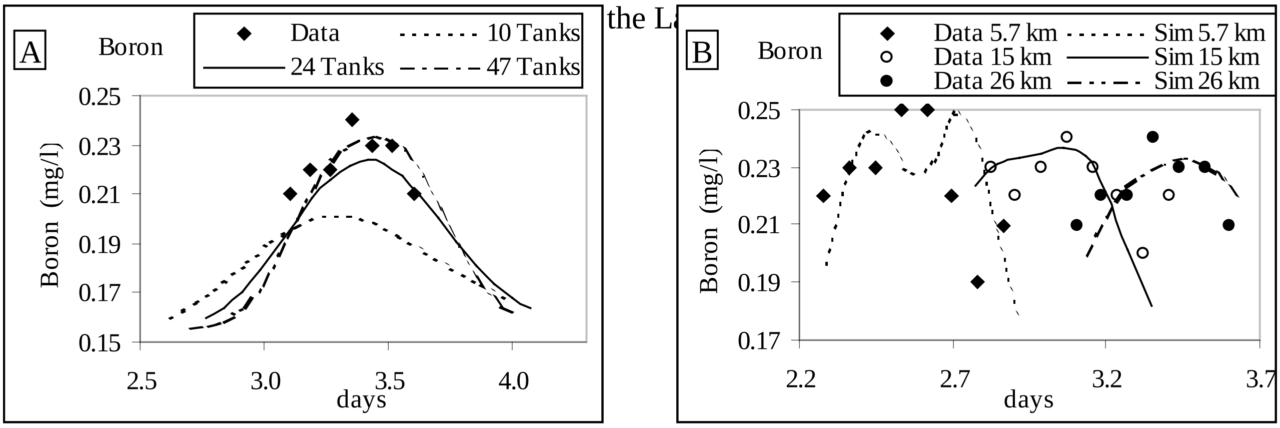

Figure 3: Effect of the number of tanks on dispersion after 26 km (A), longitudinal propagation of pollution wave (B).

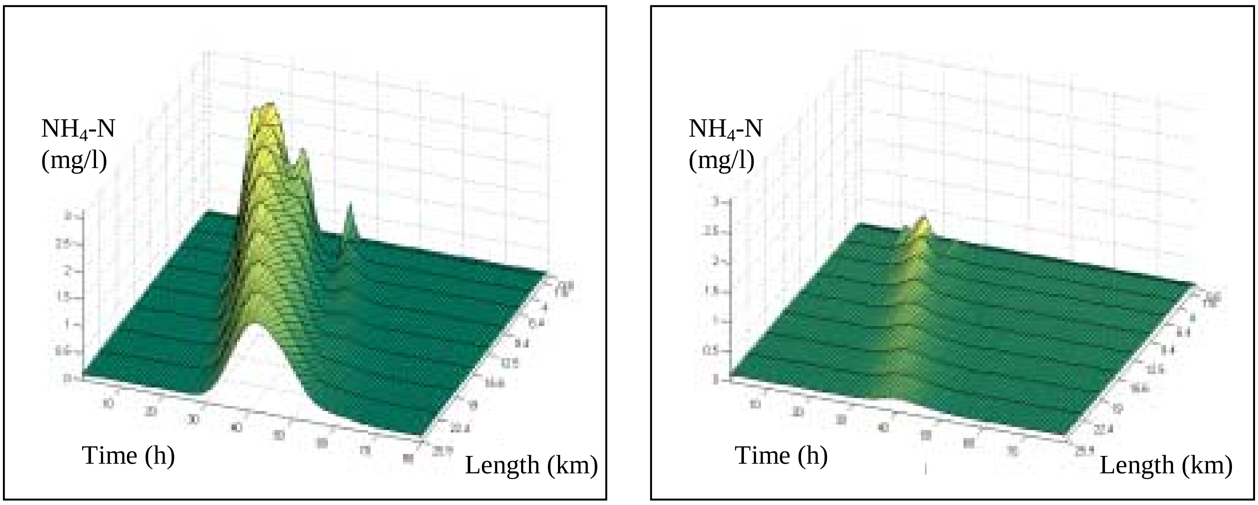

Figure 4: Ammonia concentrations in the Lambro during a storm, with old (A) and upgraded (B) plant capacity

CONCLUSIONS

A new procedure to calibrate surrogate models with the aid of complex models has been outlined. This procedure solves the problems of the long calculation times of the complex mechanistic models and of the amount of data required to calibrate models. A calibrated complex mechanistic model is used to generate virtual data, which are used to calibrate a fast surrogate model. This approach was illustrated on the river Zwalm, where flood wave propagation could be approximated by a series of tanks with variable volume. This surrogate model to predict the hydraulic behaviour is easier to implement and can be used in combination with a biological conversion model. Moreover, it was three times faster than the complex mechanistic model. Hence, the use of surrogate models within optimisation problems seems to be promising.

A mass and elements conserving connector has been developed between the ASM1 and the RM1 models. This connector has been used in a case study on the river Lambro. The hydraulics of the Lambro could be approximated by a series of tanks with variable. Because both the treatment plant and the river model could be implemented within the WEST modelling and simulation software, linking of the two models is straightforward. Simulation results clearly show the detrimental effect of the pollution load of both overflow and treatment plant on the river. The integrated model predicts a substantial reduction in pollution load and an increase in the river water quality by the extension of the hydraulic capacity of the treatment plant. The simulation results for the upgraded plant still need validation by field data.

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