Model connectors for integrated simulations of urban wastewater systems

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Abstract In order to perform simulations of the integrated wastewater system, state variables of sub-system models (sewer, activated sludge, river) must be translated from one model to the other. A connector between ASM1 (Henze *et al.* 2000) and RWQM1 (Shanahan *et al.* 2001) is described in this paper to introduce the general approach developed to overcome this necessity. Inherent features of this connector are its closed elemental mass balances. The COD fractions of ASM1 have been split over the COD fractions of RWQM1, while balance terms were used to close elemental balances. Also the different environmental conditions in the systems (activated sludge, sewer and river) have been taken into account. An evaluation of the influence of several connector and model parameters on connector balance terms and outputs has been performed. Some results of a case study concerning the river Lambro (Italy) are described to show an application of such model connection approach.

Keywords ASM1, integrated modelling, mass balances, model connectors, RWQM1, urban wastewater system.

1 Introduction

In recent years the possibility of performing integrated simulations has largely improved due to the enhanced models described in literature and the continuous development of simulation software together with the increasing computational power at the desktop. Recently research on the integrated urban drainage system has received ever-increasing attention, especially after the approval by the European Union of the EU Water Framework Directive.

The integration of the different components of the urban drainage system in a single model allows the better understanding of (1) the working of the system as a whole, and (2) the mutual interaction between its components. This is clearly essential for the evaluation of the system performance as well as for the detection of the system's weak points, in the context of the development of environmentally and economically sustainable planning and management practices. It is also a necessary step for the implementation of Real Time Control (RTC) strategies for the urban drainage system (Meirlaen *et al.* 2001).

One of the main problems when developing an integrated model is the incompatibility between state variables, processes and parameters used in the different sub-models. An example of the difference between state variables is given by the treatment plant model and the river model, the former being typically based on COD and the latter on BOD, like QUAL2E (Brown and Barnwell 1987). (Maryns and Bauwens 1997) tried to avoid the problem by using the ASM1 model in riverine conditions but this approach did not give satisfactory results. To tackle this problem more fundamentally, the IWA task group on river water quality has developed a new COD based model, RWQM1 (Reichert *et al.* 2001). The

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states of this model are more like the ASM states, but some differences still remain. This is due to the fact that the full RWQM1 model has to describe more components than the ASM1 model (e.g. algae growth).

The environmental conditions in the sub-systems being rather different, the main processes will also differ due to the fact that the same group of organisms behaves differently depending on the environment. For instance, nitrifying bacteria in an activated sludge system are confronted with a high competition for oxygen due to the presence of heterotrophic organisms in high concentrations, while in the river system this competition is not that strong.

Therefore, when using two models with different state variables, a connector needs to be developed in order to ‘translate’ the state variables of the original model to the state variables of the destination model in a consistent way. This connector needs to contain all available knowledge about the different states in the two models, different environmental conditions in origin and destination, and requires closed elemental balances; in most cases the considered elements are C, N, P, O and H. This elemental balancing feature is one of the basic principles in all types of models, and it is hence important to adhere to these principles. This can also be seen from the evolution of activated sludge models, where ASM2 and ASM3 models (Henze *et al.* 2000) have closed elemental mass balances as well. Unlike a few years ago, when all in-sewer process models were BOD-based (Fronteau *et al.* 1997), recent models for this sub-system follow the same tendency and are COD-based as well, which makes integration and connection of models for the urban wastewater system easier (Huisman *et al.* 2003; Mourato *et al.* 2003).

In this paper, first a description is made of the connector between the state variables of ASM1 (as representative of sewer or WWTP process models) and the state variables of RWQM1. The approach adopted to create this connector can be used for any other coupling of similar models. Then some considerations follow on the influence of the state variables elemental compositions and connector parameters on elemental balances and connector output. A case study on integrated modelling of the effects of Combined Sewer Overflow (CSO) and WWTP effluent on the river water quality of the river Lambro (Italy) is presented to illustrate an application of such connector.

2 The model connector

The connector is a list of algebraic equations expressing concentration inputs in the river in terms of concentration outputs from the sewer or WWTP.

RWQM1 uses COD as a measure for organic pollution, which is in contrast with the more traditional river water quality models. This makes integration with the also COD-based ASM models easier. Moreover, RWQM1 has closed mass balances for COD, and closed elemental balances for C, N, P, O and H. Since these are important properties, the goal was to keep these in the new connector.

Due to the modelling approach used in RWQM1, some state variables can be very easily transformed from the activated sludge to the river conditions. Slowly and readily biodegradable substances will probably remain biodegradable when entering the river. One could also suppose that the active biomass coming from the sewer or activated sludge system would remain active biomass in the river. However, this is probably not completely true since the environmental conditions in the sewer or treatment plant and the river are usually very different in terms of temperature, food, light intensity, etc. (as a consequence these three variables may also vary with the period of the year), probably causing inactivity of at least part of the biomass. In the connector, biomass is split into a part that remains active and a part that is transformed into inert and slowly biodegradable organic matter. This fraction can be assumed to be bigger for biomass from sewage than from activated sludge.

Autotrophic biomass is modelled as first step and second step nitrifiers in RWQM1, but only as one group of organisms in the ASM1. In the connector the incoming autotrophic biomass is split into two active groups, first and second step nitrifiers (with respective surviving fractions f_{N1} and f_{N2}), while the remaining (dead) part is split into slowly biodegradable and inert particulate organic matter. Parameters for the fractions are to be found by calibration, since so far no values are available in literature, only the relationship $f_{N1} = 3 \cdot f_{N2}$ (Focht and Verstraete 1977) can be useful as a first approximation. Dead biomass is split in two particulate fractions, one biodegradable and one inert, calculated by means of the parameter f_I, that is likely to be similar to the parameter f_P present in ASM1, since the concept is exactly the same, even if it has to be considered that environmental conditions are different.

The way in which particulate matter and soluble components is transformed when going from the treatment plant to the river is shown in Figure 2.1.

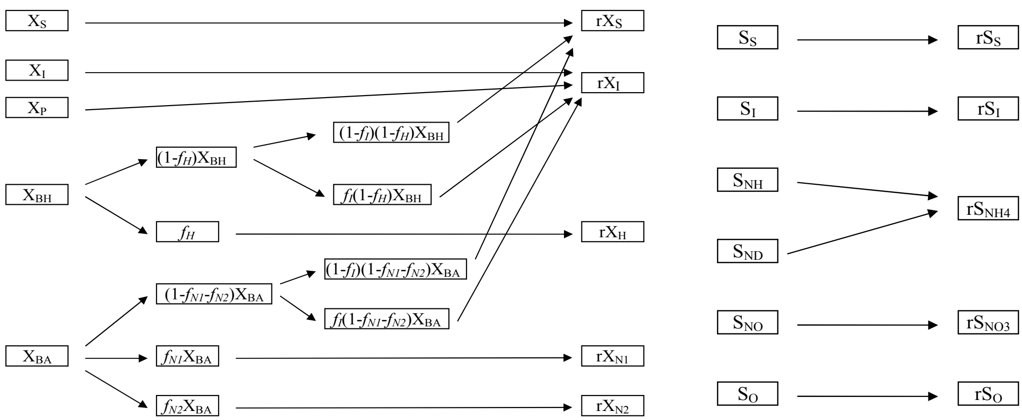

Figure 2.1 Fate of particulate biomass (left) and of soluble components (right) from state variables of ASM1 to RWQM1.

To calculate the output concentrations of the three species of carbonates (CO_2, HCO_3^- and CO_3^{2-}) in the river model, the carbonate equilibrium equations have been implemented, they are a function of incoming alkalinity (state variable in ASM1) and pH, which has been considered as a parameter of the connector.

Soluble organic nitrogen (S_{ND} in ASM1) is added to NH_4 in the output, since the ammonification process is usually fast, and no similar state is present in the river model.

Variables that are used in the RWQM1, but not in the ASM1, like nitrite, particulate phosphate or algae, are set by fixed parameters, which need to be estimated for the system under study.

After finishing all these logical transformations that maintain closed mass balances, elemental balances still need to be closed. This is done using compensation terms, which are used to compensate for a lack or surplus of elements. To this end, the elemental flux calculated in ASM1 state variables should be compared to the elemental flux calculated in RWQM1 state variables. The difference between these two fluxes (either negative or positive) is the compensation term, and needs to be added to the state chosen to serve as a balance term for the specific element. In an ideal set of models and connectors, compensation terms should always be zero. A balance term serves as a sink or source of elements in the organic compounds, e.g. if more nitrogen is present in the organic matter entering the river than is coming from the treatment plant, then the amount of ammonia going into the river is artificially decreased in order to close the nitrogen balance over the connector. The balance terms chosen in the river model are carbonates for carbon, NH_4^+ for nitrogen, HPO_4^{2-} for phosphorus, DO for oxygen and H^+ for hydrogen. To calculate the flux of the five elements coming from ASM1 one needs to fix the composition of the different model components. The nitrogen and phosphorus content were taken according to (Henze *et al.* 2000), while carbon, oxygen and hydrogen content were taken according to (Reichert *et al.* 2001). The following equation illustrates the use of a compensation term for nitrogen, which in the connector is added to the outgoing NH_4^+ balance term.

$$N\_comp = \begin{bmatrix} i_{N\_SS} \cdot S_S + i_{N\_SI} \cdot \mathrm{S_I} + i_{N\_XBH} \cdot \mathrm{X_{BH}} + i_{N\_XBA} \cdot \mathrm{X_{BA}} + i_{N\_XP} \cdot \mathrm{X_P} \\ -i_{N\_rSS} \cdot rS_S - i_{N\_rSI} \cdot \mathrm{rS_I} - i_{N\_rXH} \cdot \mathrm{rX_H} - i_{N\_rXN1} \cdot \mathrm{rX_{N1}} \\ -i_{N\_rXN2} \cdot \mathrm{rX_{N2}} - i_{N\_rXS} \cdot \mathrm{rX_S} - i_{N\_rXI} \cdot \mathrm{rX_I} \end{bmatrix}$$

or

$$N\_comp = \sum_{J}^{ASM1} i_{N\_J} \cdot J - \sum_{J}^{RWQM1} i_{N\_J} \cdot J$$

in which i_{N_J} is the nitrogen content of component J
S_i, X_i are components of the ASM1 model (gCOD/m^3)
rS_i, rX_i are components of RWQM1 (gCOD/m^3)

3 Results and discussion

The two process models and relative connector have been implemented in the WEST® modelling and simulation platform (Vanhooren *et al.* 2003), which allows to model the integrated urban wastewater system in a single platform, thus avoiding software communication and file transfer problems.

First, a number of simulations have been performed to test the influence of several factors on the connector performance. To represent the behaviour of a combined sewer overflow discharging directly in a river reach, the dry weather influent file for the 'benchmark' (Spanjers *et al.* 1998) has been used as input to the connector between the sewer system and a river stretch. The values of the adjustable parameters in the connector are specified in Table 3.1:

Table 3.1 Values for adjustable connector parameters

parameter	description	value
f_H	fraction of active heterotrophs	0.5
f_{N1}	fraction of active first step nitrifiers	0.15
f_{N2}	fraction of active second step nitrifiers	0.45
f_S	fraction of biomass that becomes inert particulate	0.08
pH		7

In Figure 3.1 the magnitude and evolution of the compensation terms is presented. It can be noticed that only carbon has a positive mass balance, while all other elements have a rather negative balance. This is due to the strong influence of the elemental composition of certain state variables on the elemental balances. A consequence is that, as evident in Figure

3.2, the concentration of some river components coming out of the connector is calculated to be negative, which is, of course, not acceptable.

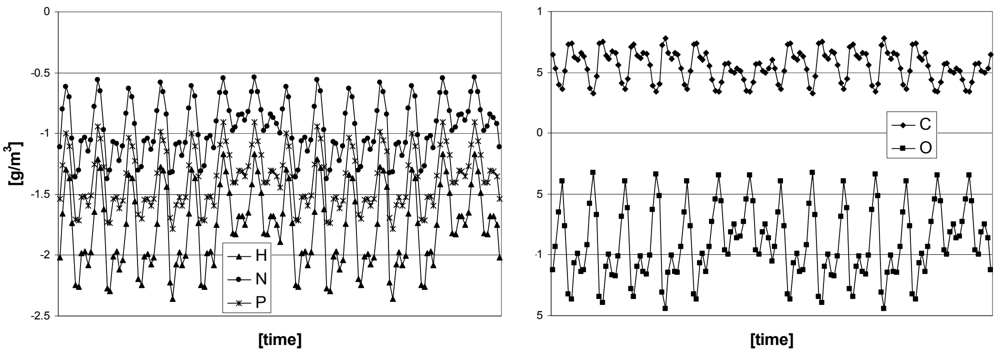

Figure 3.1 Dynamic profiles of compensation terms.

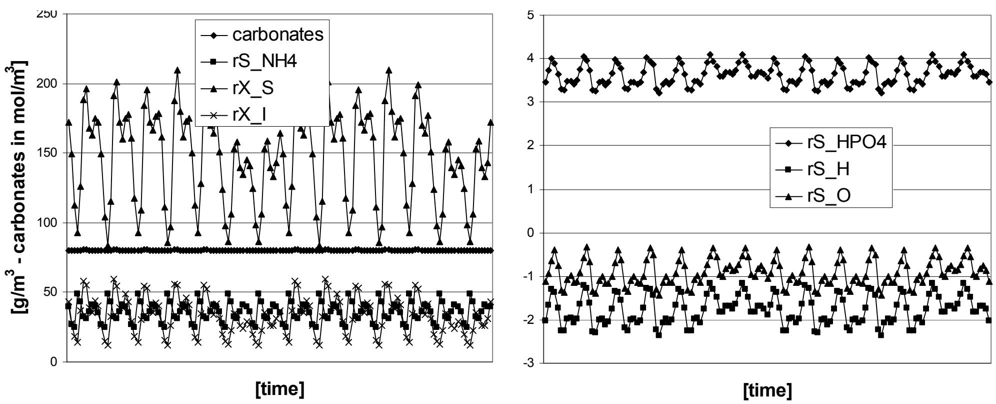

Figure 3.2 Dynamic profiles of relevant connector outputs.

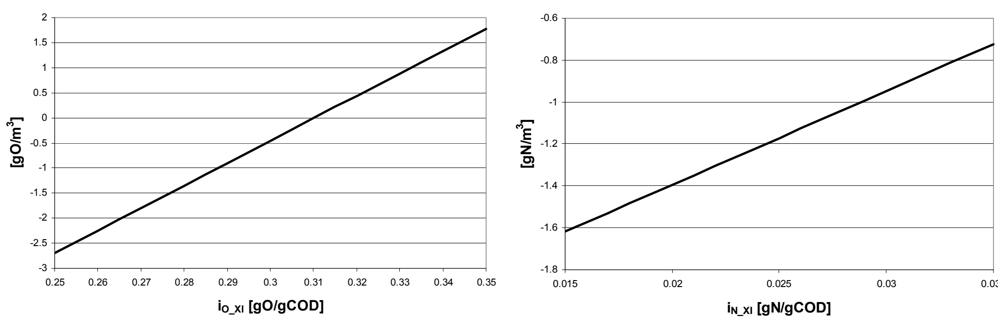

Figure 3.3 Influence of i_{O_XI} and i_{N_XI} on O (left) and N (right) balances.

As an example, the influence of the parameters indicating oxygen and nitrogen contents in inert particulate matter (i_{O_XI} and i_{N_XI}) on oxygen and nitrogen balances has been simulated. Results are shown in Figure 3.3. It is to be noticed that assuming the reference value of i_{N_XI} in ASM2 (0.3 gN/gCOD) or in ASM2d (0.2 gN/gCOD; (Henze *et al.* 2000)) leads to a difference in the nitrogen balance of almost 0.5 gN/m^3. It is evident from the oxygen balance that small changes in this type of parameters have effects of paramount importance for the

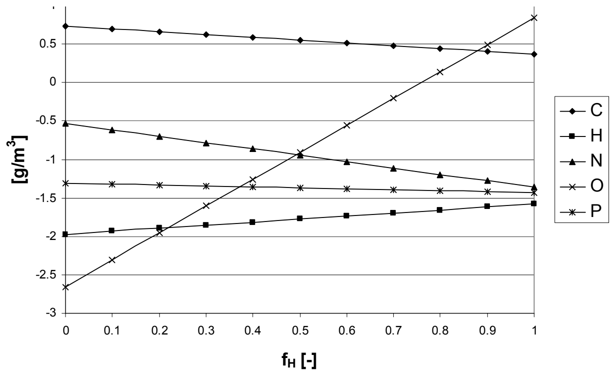

Figure 3.4 Influence of f_H on elemental mass balances.

elemental mass balances. A consequence is that the fractionation in model state variables of measurements of COD, BOD, TN, TP and similar data, coming from routine monitoring or special laboratory analyses, may also be considered from the point of view of elemental mass balances. This is especially true in the case of integrated modelling with conversion of state variables from one model to another.

The most influencing parameter in the connector is probably f_H (fraction of active heterotrophs), the effect of which on elemental balances and connector relevant outputs is shown in Figures 3.4 and 3.5 respectively. Since the oxygen content in the benchmark influent is close to zero, f_H is the only connector parameter responsible for the variations of oxygen in the connector output.

Some influence on elemental balances is also exerted by f_{N1} and f_{N2} (fractions of active autotrophs), but negligible compared to f_H since the concentration of autotrophs in sewage is usually very small.

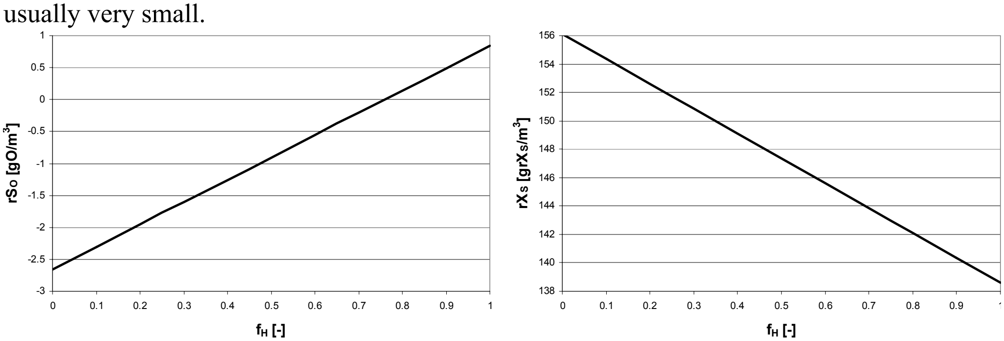

Figure 3.5 Influence of f_H on the most sensitive connector outputs, rS_O (left) and rX_S (right).

4 The river Lambro case study

An application of the connector has been made for the simulation of a 26 km long reach of the river Lambro, north of Milano, Italy. The most important pollution source in this stretch is the treatment plant of Merone. This treatment plant receives the wastewater of approximately 120.000 PE. Prior to an upgrade (+100% primary sedimentation and +50% biological treatment and secondary sedimentation volumes) the Merone WWTP was constantly working at its maximum hydraulic capacity (25.400 m^3/d), but this did not avoid the daily bypass of dry weather wastewater (approximately 40% was regularly discharged untreated into the river). The daily bypass of raw wastewater imposed a marked diurnal cycle in pollutant concentrations in the river for a considerable distance downstream of the plant.

The integrated system has been modelled with ASM1, a simplified version of RWQM1 (see (Vanrolleghem *et al.* 2001) for sub-model selection) and an *ad hoc* connector, all implemented in WEST®. Details on this case study can be found in (Benedetti *et al.* 2004).

One of the aims of the study was to estimate the impact of a plant upgrade on the receiving water quality. Simulation results concerning concentrations of ammonia and nitrates in the river in dry weather conditions can be seen in Figures 4.1 and 4.2 respectively, showing the plant impact before and after the upgrade. As expected from a nitrifying but not denitrifying plant, the nitrates concentration in the river increases and the ammonia concentration decreases.

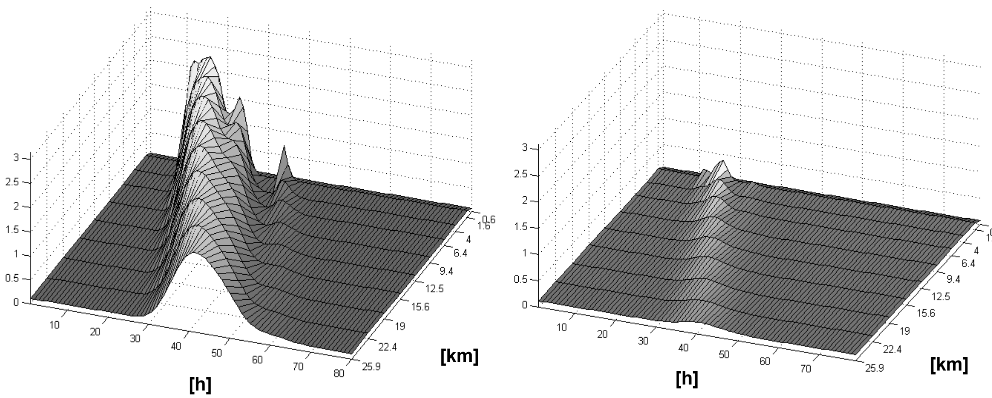

Figure 4.1 Ammonia concentration in the river in dry weather conditions before (left) and after (right) WWTP upgrade.

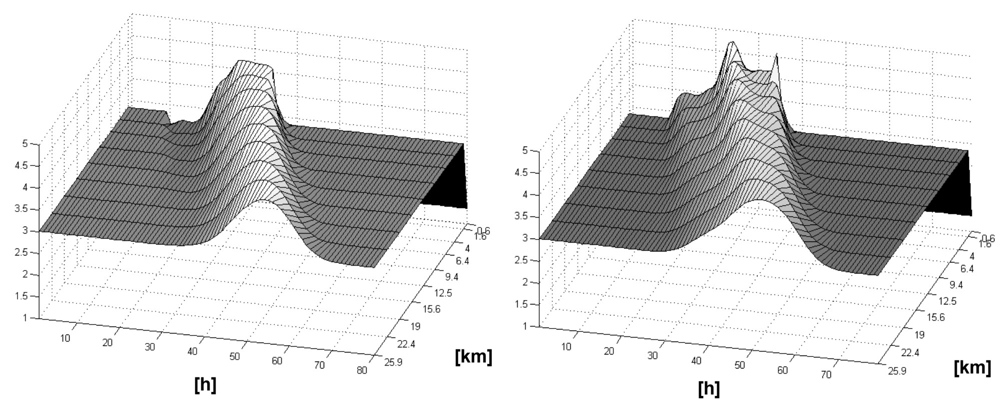

Figure 4.2 Nitrates concentration in the river in dry weather conditions before (left) and after (right) WWTP upgrade.

5 Conclusions

A connector between ASM1 and RWQM1 has been described in this paper. It should be considered as an example to introduce the approach to translate state variables from one model to another for integrated wastewater system modelling. Inherent features of this connector are its closed mass and elemental balances. The COD fractions of ASM1 have been split over the COD fractions of RWQM1, while compensation terms were used to close elemental balances. Also the different environmental conditions in the systems (activated sludge, sewer and river) have been taken into account to correct for inactivation of organisms when changing from one system to another. An evaluation of the influence of several connector and models parameters on connector compensation terms and outputs has been performed, showing that great importance lies in the elemental composition of the state variables, for which only scarce data can be found in literature. Some results of a case study have been described to show an application of such model connection approach, which is general and can be applied to any coupling of ASM-like models.

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