A Multi-Domain Solver for integrated modelling

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Highlights

- Different subsystems of urban water systems usually use different mathematical solvers (e.g. EPANET, SWMM, WWTP modelling).
- A novel modelling approach combines these solvers in a single modelling framework
- Integrated modelling of urban water systems becomes more use-friendly and more efficient.

Introduction

The integrated consideration of the different elements of urban water systems as one entity has been advocated already for some time (e.g. Beck, 1976). Their joint consideration in modelling, simulation, systems analysis and control allows to consider the water system in a holistic way in its entirety and, thus, supports integrated water management. Traditional approaches to cater for this in modelling range from sequential application of different simulators (e.g. output of a sewer model used as input of a WWTP model) (e.g. FWR, 1998) – this approach not being able to consider bidirectional interactions between the subsystems – over parallel (synchronous) simulations of different modules implemented either in different simulators or within the same simulation package (e.g., Schütze *et al.*, 2017) to the idea of a "super model" including "everything" and using the same set of state variables throughout the system (cf. Bach *et al.*, 2014).
Among the aspects usually neglected in the discussion and application of modelling approaches is the different nature of the mathematical equations describing the behaviour of the respective subsystems and the numerical solvers best used for their solution. For example, many sewer system simulation studies are based on hydrodynamic simulation programs for the solution of the full Saint Venant system of partial differential equations, using an efficient implicit solution algorithm (e.g. SWMM, Rossman, 2015). Combining this with a detailed dynamic simulation of a wastewater treatment plant (WWTP) requires combination with an efficient solver for complex systems of ordinary differential equations (e.g. the efficient ODE15s solver for stiff systems, Shampine, 1981). When adding additional components of the water system to the model (e.g. water supply or wastewater network with pressurised pipes), additional solvers are required (e.g. dedicated solvers for systems of algebraic equations, as, for example, in EPANET, Rossman, 1993) or discrete-time solvers for difference equations such as those used in rainfall-runoff and hydrologic sewer system modelling.

Methodology

Modelling applications implemented so far usually consist in linking the modules by (uni- or bidirectional) exchange of information between the subsystems and a time-step management ensuring that information exchanged refer to the same time instance. This leads to inefficiencies in performance (for example by synchronising fixed discrete time steps with variable time steps used in many continuous-time solvers).

Within the Simba# simulation system (ifak, 2021), the different solvers listed in Table 1 not only have been implemented, but also have been combined with each other and, thus, allow a simultaneous execution of multiple instances also of different solvers.

Table 1. Solvers implemented in the multi-solver simulation environment

1	Special solver for algebraic systems of equations (pressurised pipe network) (EPANET algorithm)
2	Special solver for solving the Saint Venant system of discretised partial differential equations (hydrodynamic simulation of sewer network) (SWMM solver)
3	As 2, second instance
4	Discrete-time difference equations (hydrologic modelling of rainfall-runoff processes and of flows within a sewer network).
5	ODE solver, selection of ODE solvers for solving complex differential equation systems, can also solve algebraic equations internally (wastewater treatment plant with activated sludge models) (ODE15s and others)
6	Control functions, using various modelling approaches: Function block-based description, using algebraic, difference and differential equation systems PLC language “Structured Text” according to IEC 61131-3 Petri nets, Finite Automata Model-based predictive control with arbitrary internal models

In order to implement this multi-solver modelling concept, the object-oriented modelling concept (based on C# classes) of the Simba# simulator (ifak, 2021) was extended by so-called Solver blocks. Each solver block is connected to a selected block of the simulation model. The solver block analyses the network of blocks connected to it, which are to be solved by this particular solver. These blocks are then removed from the global list of modelling blocks and are calculated using the associated solver block. This allows to define any number of instances of subsystems, each of which can be calcuated with their respective mathematical equation solver, within the same modelling project. The calculation order of the subsystems is integrated into the global calculation order. Using dedicated interface blocks, all subsystems can communicate with each other. Each solver defines its own time steps (e.g. constant or with its own control of dynamic time steps), whilst the integrated simulation environment schedules the data exchange between the subsystems and controls the calls of the solver instances.
Using this concept, also additional special solvers can be added; for example, for tasks related to logistics and simulation of communication networks, a solver for discrete-event systems, similar to OMNET (https://omnetpp.org/), is currently being integrated into the platform.
For the simulation of pollutant transport in drinking water networks, sewer systems and rivers, solution approaches based on advective-diffusive transport are included within the various solvers. Here, for all solvers a common approach was chosen which allows a spatial discretisation (i.e., cascade of continuously stirred tank reactors, or a Langrangian transport approach („water parcels“ with given dispersion to neighbouring water parcels)) to be selected for computation.

Hence they are now accessible within the Simba# system; they can be combined in a user-friendly and convenient way within the same simulation environment. Also several instances of the modules (e.g. several sewer systems, each of them simulated by the SWMM solver, can be used. Furthermore, various automation functions are integrated, thus enabling to model, simulate and evaluate, with great flexibility, a wide range of control features: Function block-based description using algebraic equations, ODE models, discrete-time difference equations, lookup tables, PLC programming language “Structured Text” (IEC 61131-3), Petri nets, model-based predictive control, i.e. controllers applying a range of optimisation routines and containing an internal model. This internal model, in turn, can be also an arbitrary multi-solver model.

Figure 1 illustrates a typical setup of an integrated urban water system, modelled with the different modules and solvers within the same simulation environment.

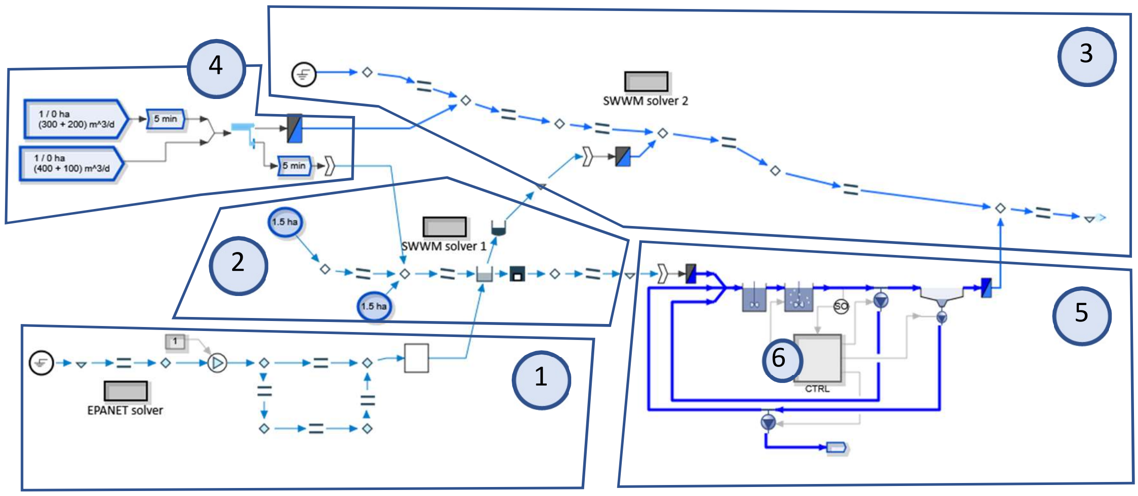

Figure 1. Multi-Solve simulator modelling different components of an urban water system using different solvers

Results and discussion

Besides the improved convenience and user-friendliness of having all component modules available in the same environment and, thus, being able, to combine them in an arbitrary way, also a significant performance gain (of around 30 %) could be achieved by this modelling architecture.

The conference contribution will illustrate and demonstrate these concepts on a case-study model in Germany.

Conclusions and future work

Different mathematical solvers, all of which being essential for a truly integrated simulation of water systems (e.g. mathematical approaches used in EPANET, SWMM, wastewater treatment simulation) have successfully been integrated into a single simulation framework. Future case study applications will benefit from this modelling approach integrating system components which traditionally have been modelled separately in different simulators.

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