A Simulation Library for an Integrated Water Resources Management

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Introduction

The management of water resources often requires analyzing the behaviour of water systems like rivers, channels, reservoirs and their interactions. Usually, task-oriented simulation models are built to answer the management questions. If different tasks have to be solved, several different models are required.

The Fraunhofer Center for Applied Systems Technology has developed a simulation library for simulating water resources systems called ILM-River that is usable for miscellaneous questions. Up to now the library was successfully used in different projects, e.g. for optimal control of run-of-river reservoir cascades and water allocation simulation of large regions (Rauschenbach 1999), (Pfuetzenreuter and Rauschenbach 2005).

The simulation library consists of two modules, River-MOD and River-CON. The module River-MOD contains the simulation models for all important parts of a surface water system. The second module River-CON implements different control strategies, for instance for reservoirs. In addition to control concepts according to operating rules also optimal control methods were developed.

In the last two years the library has been extended with different simulation elements (e.g. interface to a groundwater simulation system, water quality simulation) that considerably extend its application area in water resources management.

Modeling library River-MOD

The simulation models for River-MOD rely on an analytical description of the hydrodynamic behaviour of rivers and reservoirs. Typically, it is sufficient to know the water level and the flow at gauges which are important for control. This reduces the effort for building the simulation model since the complete spatial behaviour of water flow along the river section isn't needed. The original simulation part of the library consists of the model elements that are required for simulating the behaviour of a run-of-river hydropower plant (Fig. 1). These elements rely on the discrete form of the Saint-Venant-equations and are used for the models of the Danube hydropower plants described in the examples chapter.

In the last years the library was extended with set of simulation models for complex surface water systems. Modelling a complex surface water system often results in a detailed simulation model with hundreds of parameters and long simulation durations. The new development for River-MOD reduces the modelling effort by using simplified simulation blocks. Using these blocks results in a fast, reliable simulation model, that is sufficient for control and optimization tasks (Rauschenbach and Gao 2005). Up to now models for the most important parts of surface water systems are implemented, e.g. water flow model for rivers and channels as well as models for water works, catchment areas, sluices and reservoirs (Fig. 2).

Coupling groundwater and surface water simulation

The current work focuses on extending the modelling library. In regions with water shortage all available resources have to be included in the allocation process. For instance, in areas with uneven rainfall during a year the

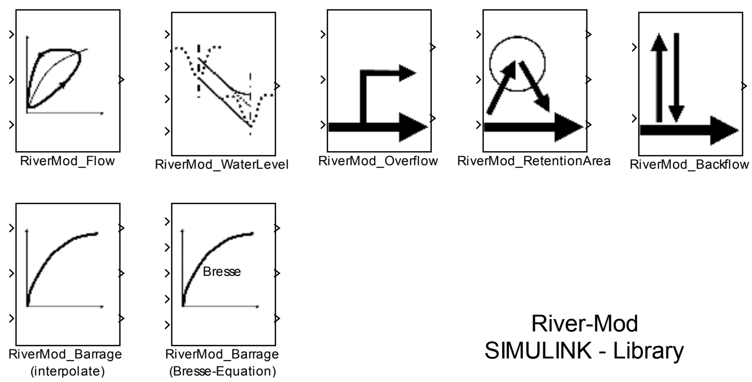

Fig. 1 The run-of-river simulation library

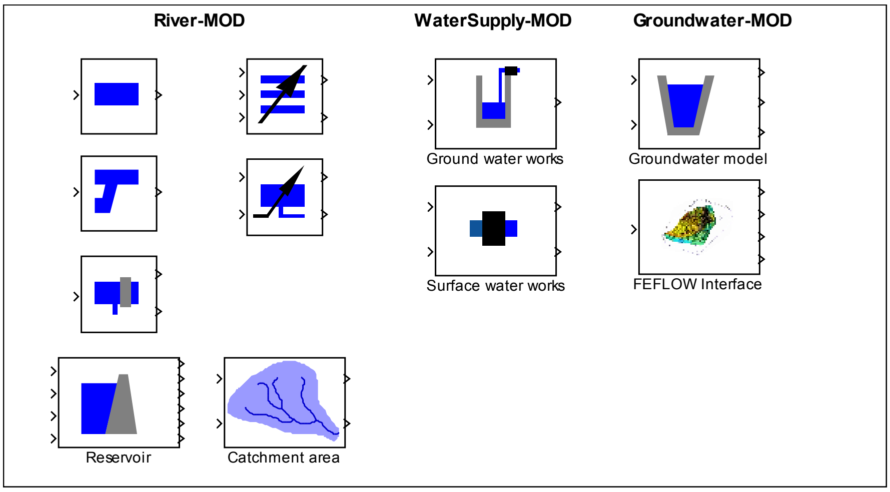

Fig. 2 New blocks of the River-MOD simulation library

groundwater plays an important role to satisfy the customer demand. Therefore an interface to the distributed groundwater simulation system FEFLOW was developed to integrate the groundwater resource into the water simulation system.

The physical coupling concentrates on the most important interchange processes:

- groundwater withdrawal (at well fields or as regional withdrawal)
- groundwater infiltration from water bodies, precipitation or irrigation,
- artificial recharge of groundwater at seepage fields.

The surface water simulation model computes all flow rates (withdrawal, infiltration, and recharge) from its internal states. These time-dependent rates are transmitted to FEFLOW und used for simulation of a predefined period. As output, FEFLOW sends the hydraulic heads at all locations the surface water simulator is interested in. During simulation, the surface water model is responsible for starting and controlling the groundwater simulator as well as for the coordination of data transfer. Two different types of coupling, the time-step coupling and the sequential coupling, were developed that are applicable to different scopes of application (Pfuetzenreuter et al. 2006). While the time-step coupling is suitable for simulating the bidirectional exchange between surface and ground water via the unsaturated zone, the sequential coupling assumes unidirectional flows from surface to ground water (infiltration).

Water pollution simulation

The second, important enhancement of the modelling library concerns the simulation of chemical concentrations. This allows assessing the water quality from the different sources and using this information for an optimal water allocation. The simulation uses one-dimensional, analytical models for the computation of chemical concentrations downstream of discharge locations.

The simulation blocks of the River-MOD library are able to simulate these processes and implement one-dimensional methods for simulation of two different scenarios:

- continuous pollution as consequence of natural and human life, industrial or agricultural production,
- one-time pollution, typically due to accidents or terrorist attacks.

The continuous pollution is modelled according to the methods developed by the GREAT-ER project as described in (Schowanek et al. 2001). The method assumes an instantaneous mixture of river and pollutant flows and a constant concentration along the cross section of the river. This leads to simple but efficient computation methods for the concentration down the river. The one-time pollution simulation was newly developed at Fraunhofer AST and takes into account the transport processes diffusion, dispersion and advection (Trapp and Matthies 1997). Both methods are designed with regard to a high computation speed. This allows a seamless integration of quality modelling aspects into existing simulation models.

Control library River-CON

The control library provides modules to compute the outflow of reservoirs. In a first stage PID and fuzzy controllers according to operational rules were developed. Especially in reservoir cascades the insulated control of single reservoirs is not optimal (for both flood protection and energy generation). Beside this the reservoirs in a cascade influence one another by hydraulic link-up. As a result, the natural flow behaviour is strongly affected by the control strategies of the reservoirs. This leads to an increasing demand of advanced control strategies for reservoir cascades.

Reservoir cascades have further tasks in addition to energy generation, e.g. to prevent overflows and to guarantee ship navigation. To avoid dangers for people and real values, the energy production has to subordinate to these tasks. Rules were created to support the operators in implementing the predefined strategies. Two modules of the model library River-CON realize a control according to such operating rules, a PID-controller with

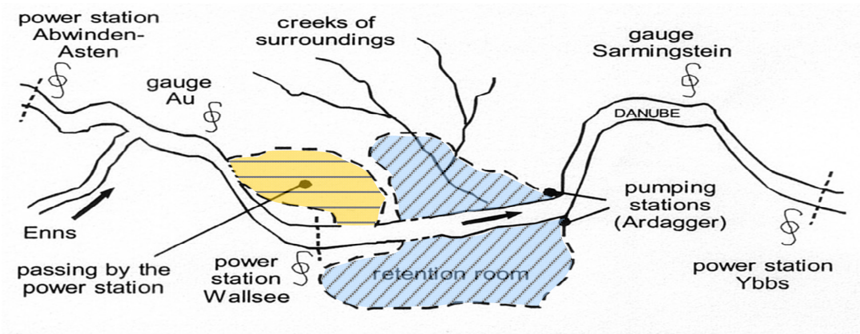

Fig. 3 River section between hydropower stations Abwinden and Ybbs

multiple parameter sets and a similar Fuzzy-concept. However, these concepts cannot optimally solve the mentioned multi-criterial tasks necessary for a coordinated operation of reservoir cascades. Instead, a newly developed concept called MEFURO is well suitable for such problems. Furthermore, a module for smoothing of discharge was integrated into RiverCON. For more information to the particular control strategies see (Pfuetzenreuter 2005].

Example: Simulation of run-of-river reservoirs

Using the ILM-River toolbox several simulation models for run-of-river river reservoirs have been developed. As an example, this paper presents the model for the Austrian Danube reservoir Ybbs (Fig. 3). Primary aim is to model the dynamic behaviour of the flow section between the two hydropower plants Wallsee and Ybbs. The model must describe the real inflow and discharge behaviour as well as the water level trajectories at all gauges.

The total length of the reservoir Ybbs is approx. 34 km, the width ranges from 150 m to 1.000 m. Downstream the gauge Au (in the middle of backwater storage) water bypasses the hydropower station Wallsee at flow rates higher than 6000 m³/s. Hence, the downstream gauge of station Wallsee does not register the total flow to the reservoir Ybbs. For this reason, it is necessary to consider the effect of bypassing in the model. The activation of the retention rooms shown in fig. 3 occurs by opening floodgates and using pumping stations at a flow rate of 4700 m³/s. Starting at a flow of 5400 m³/s, the water enters the retention rooms directly.

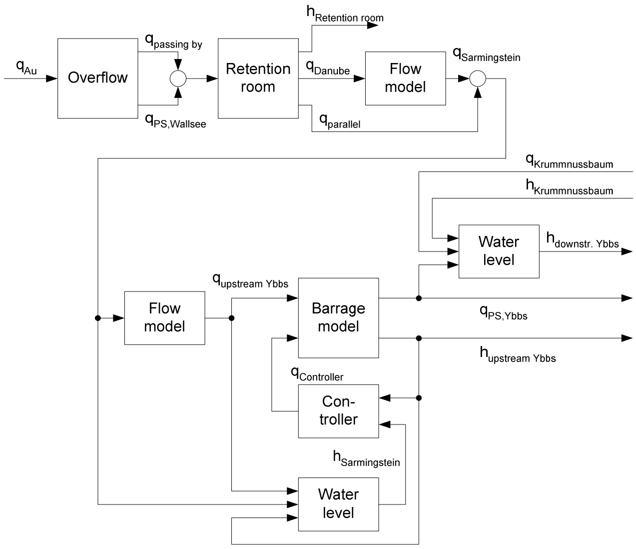

Fig. 4 Simulation model structure for reservoir Ybbs

Fig. 4 shows the rough simulation model of the reservoir Ybbs. With this model, good simulation results are achievable in all flow ranges. As an example, fig. 5 shows the simulated discharge of the hydropower station Ybbs during a moderate flood compared to the original data. Using a PID controller, the simulated behaviour is similar to the recorded time series. As the controller uses different water levels at the reservoir to control the outflow, the water levels are also reproduced very well.

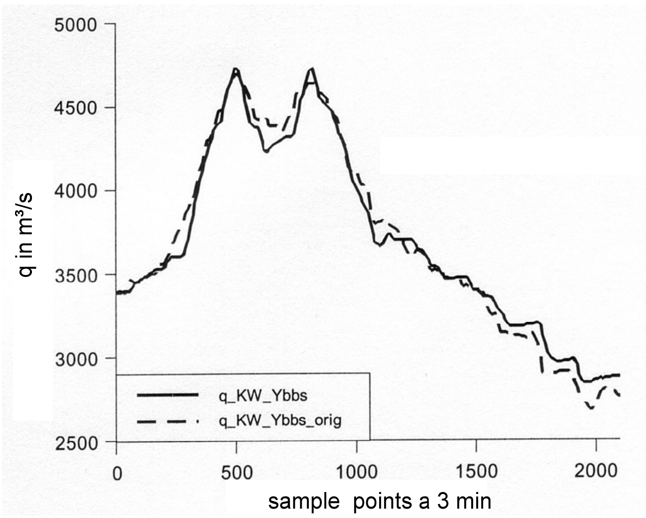

Fig. 5 Simulation results for a flood

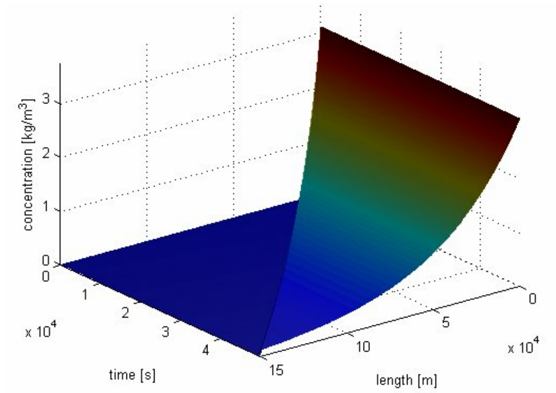

Fig. 6 Continuous pollution simulation in a river section

Water quality modelling

Using the simulation blocks of the complex surface water system library, many different tests were performed. For example, the simulation results of a river's continuous pollution with benzene are shown in fig. 6. At the location of the entry, the concentration of benzene is given by the ratio of the flow rates of river and pollutant. Downstream the concentration reduces by elimination processes like sedimentation, degradation and volatilization. If the whole river section is polluted, the concentration becomes stationary because of the continuous pollution with benzene.

Another scenario assumes that a one-time pollution with benzene has occurred. Using the newly developed propagation method described earlier, the results shown in fig. 7 were obtained. The propagation wave changes its shape while it spreads through the river section. Therefore, the concentration of benzene is lower but prolonged due to the simulated dif-

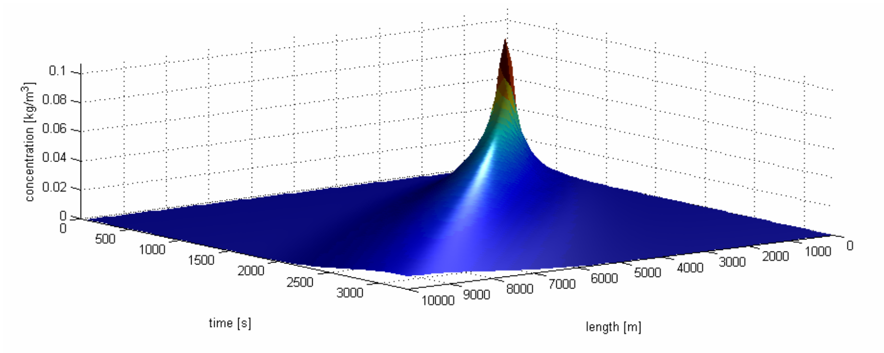

Fig. 7 Simulation of on-time pollution along a river section

fusion and dispersion processes (Thibodeaux 1996).

Summary

This paper presented the latest additions to the MATLAB / Simulink toolbox ILM-River. The library consists of two modules for simulation and control of surface water systems and allows an integrated management of surface and ground water resources using the interface to the finite element groundwater simulator FEFLOW. The chemical exposure modelling assists in estimating risks if pollutants enter a surface water system. The example of modelling a run-of-river reservoir in the Austrian Danube shows the practical usability of the simulation blocks.

The further development of the library is an ongoing work. Especially the pollution simulation methods have to be tested intensively. In addition, the models for the water supply network like pumping stations and waterworks as well as models for wastewater treatment are actively under investigation.

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