Modelling the interaction of surface-water and groundwater flow by linking Duflow to MicroFem

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Abstract Duflow is a computer program for one-dimensional hydraulic modelling of surface water. MicroFem is a finite-element model that simulates saturated groundwater flow in multiple-aquifer systems. Both model codes simulate steady-state as well as transient flow. A method is presented to couple the flow systems in Duflow and MicroFem. The results of both models are exchanged to bring the flow systems in equilibrium with each other in an iterative way. The coupling software is verified with several analytical solutions. To demonstrate its use a regional coupled model is build of a water-supply well field with induced surface-water infiltration. Compared to individual surface-water and groundwater flow models, coupled models have a surplus value in all situations where the flow systems have a significant mutual interaction.

Key words saturated groundwater; surface-water; finite-element groundwater modelling; one-dimensional surface-water modelling; surface-water/groundwater interaction modelling

INTRODUCTION

When groundwater flow is modelled, the exchange with the surface-water system is based on assumed boundary conditions. The same applies to the groundwater system when surface-water flow is modelled or a simple empirical rainfall-runoff model is used. In most cases this simplification is a defendable choice. In certain situations, when the interaction between the surface-water system and the groundwater system plays an important role, it can be an advantage to combine the surface-water model and the groundwater model for an integrated calculation.

In this paper a method is presented to couple a surface-water-model built with Duflow, and a groundwater-model built with MicroFem. The coupling software brings the results of both models in equilibrium with each other in an iterative way.

DUFLOW

Duflow is a computer program to model steady-state and transient surface-water systems (EDS, 1995; STOWA, 2000). The surface-water flow is modelled in a one-dimensional network of nodes connected by sections with a certain length and hydraulic resistance. For each section the bottom height and the dimensions of the cross-section have to be specified. Within the network several types of hydraulic structures, like weirs, culverts and pumps can be modelled.

Duflow solves the Saint-Venant equations for conservation of mass and momentum, using the initial and boundary conditions, such as an incoming flow at the upstream part of the model and a measured downstream water level. Duflow calculates for each section and for each time step the discharge, water level and mean velocity.

MICROFEM

MicroFem is a finite-element model code for multiple-aquifer saturated groundwater modelling (Hemker & Nijsten, 1996; Diodato, 2000; Hemker, 2004). Within MicroFem there are several options to model the top boundary condition. The river-type of condition is used for the link with Duflow. The drainage or infiltration flux depends on the resistance of the bottom of the watercourse, and the difference between the surface-water level and the calculated hydraulic head in the top aquifer.

COUPLING IN SPACE

The surface-water and groundwater models are built in Duflow and MicroFem respectively. Some initialisation-routines help to collect the needed data for a coupled calculation and to place MicroFem nodes right below the sections of the Duflow-model. The number of MicroFem nodes that are coupled with each Duflow-section can be chosen freely. The example shown in Fig. 1 couples three MicroFem nodes to a single Duflow-section.

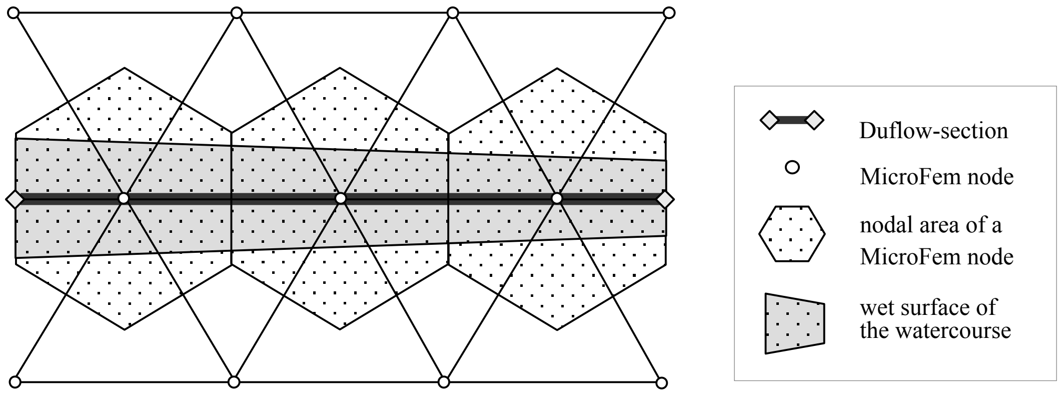

Fig. 1 Coupling in space; three MicroFem nodes coupled to one Duflow section.

The coupling software interpolates for each coupled MicroFem node the bottom height and the dimensions of the coupled Duflow cross-section.

COUPLING IN TIME

The modelled period is usually divided in several time-intervals. The lengths of these intervals can be chosen freely. The number of Duflow and MicroFem time steps within each interval can be chosen independently. However, the length of an interval should be a multiple of the time step length in Duflow as well as in MicroFem.

SOME CHARACTERISTIC DETAILS

A section in Duflow can run dry, for instance if the upstream inflow stops. In such a case the coupling software stops any infiltration from this section. Watercourses are allowed to repeatedly run dry and be refilled again.

When the water level in a watercourse rises, the wet surface and thus the infiltration area increases. The coupling software takes this effect into account.

In practice it appears that the infiltration rate reaches a maximum value when the hydraulic head drops below the river bed and direct hydraulic contact between surface-water and saturated groundwater is lost. For this reason a maximum infiltration rate can be defined for each coupled MicroFem node.

In most cases only the main watercourses will be modelled in Duflow. The effect of the minor watercourses can be taken into account by one of the top boundary conditions in MicroFEM, such as the drainage system. All MicroFem nodes in some area can be grouped and their total flux to drains can be directed to a single node in the Duflow model. In this way sub-catchments can be attached to Duflow-nodes, which allows to also build regional coupled models.

A COUPLED CALCULATION

The coupling software starts by running the Duflow model for the first interval. For each coupled node the calculated mean waterlevel (*h*) and the calculated mean wet surface (*LW*) are transferred to the MicroFem model. The coupling software then runs the MicroFem model for the first interval with *h* and *LW* as boundary condition parameters of the river system. MicroFem calculates for each coupled node the flux between the surface-water and the groundwater system. The mean calculated flux is transferred for each coupled section to the Duflow-model. With these mean fluxes as boundary conditions the coupling software runs the Duflow model again for the same interval. The Duflow and MicroFem model runs are repeated for the same interval until the calculated water level in every Duflow section remains within a user-specified range. In this way the results of both models are balanced. Subsequently the next intervals are dealt with one by one until the full model period is computed (Fig. 2).

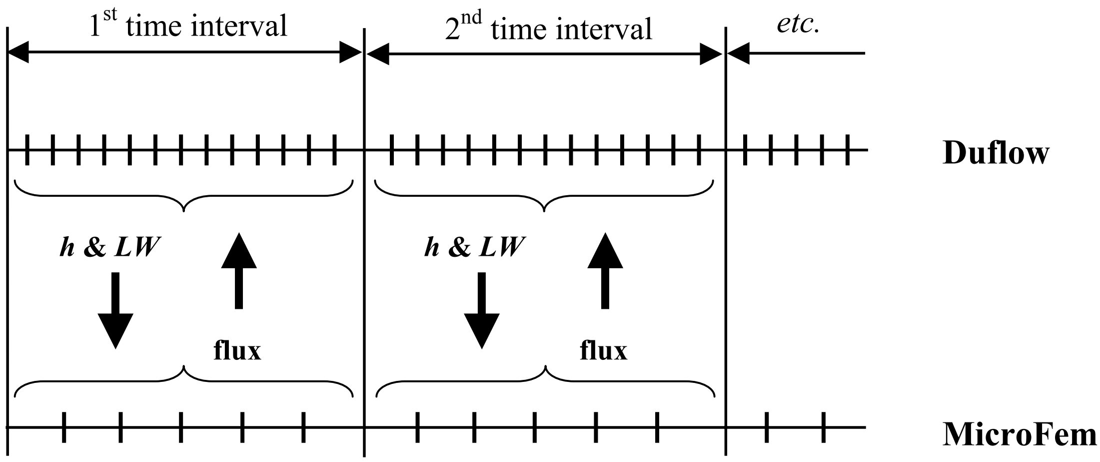

Fig. 2 Coupling in time showing the parameters that are brought in equilibrium for each interval. Vertical lines represent time steps.

VERIFICATION AND APPLICATION

A number of simple coupled models were set up for code verification. Some of these models used the transient water balance as a check, while others were compared with analytical solutions (e.g. De Ridder & Zijlstra, 1994). The coupling produced sound results in all of these cases.

Next the coupling software was used to build a regional model of an infiltration system around a water-supply pumping station in the eastern part of the Netherlands. The watercourses in this region may drain, infiltrate and run dry depending on the season and the availability of discharge from upstream areas. Preliminary tests with simple boundary conditions show that the coupled model produces the expected heads and fluxes for this complex system, both in time and in place. Further investigations will include the real boundary conditions, as obtained from measured water table levels and river flow.

CONCLUSIONS

Compared to individual surface-water and groundwater flow models, coupled models have a surplus value in all situations where the flow systems have a significant mutual interaction.

The presented method couples the model codes Duflow and MicroFem. It uses the river-type top boundary condition in MicroFem. One or more MicroFem nodes can be coupled with each Duflow section. For each time interval the coupling software brings the results of both models in equilibrium in an iterative way. The length of the intervals as well as the Duflow and MicroFem time steps within an interval can be chosen freely. Within a coupled model watercourses may run dry temporarily, a limit can be set to the infiltration rate and the drainage of sub-catchments can be directed to the main watercourses in Duflow.

The coupling software was verified with simple models and analytical solutions. A coupled regional model was built of a water-supply well field with a complex surface-water infiltration system and produced proper results for the tested boundary conditions.

For further information one is referred to the full-extent paper on the conference CD-ROM.

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