International Conference on Hydroinformatics

2014

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11th International Conference on Hydroinformatics
HIC 2014, New York City, USA

DEVELOPMENT OF AN INFORMATION MAPPING FRAMEWORK TO COUPLE SURFACE FLOW AND SUBSURFACE HYDRAULIC MODELS

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Here we present the outline of an information mapping framework that allows coupling of existing surface and subsurface hydraulic modelling domains and can provide an alternate to specialized fully integrated coupled modelling codes. The flexibility of the framework intends to allow selecting solvers with assumptions and representations in-line with the requirements of the area being modelled as well as reusing the expertise that has gone into building the decoupled models as part of the respective surface flow or groundwater study. We focus on 2d representation of surface hydraulics and 3d representation of subsurface flow to form the basis of the generic information mapping framework and demonstrate its applicability.

INTROUCTION

Anthropogenic influences as well as river restoration projects have been a driver of interventions along river-reaches in many regions of the world. Studying the complex hydraulic interaction at these scales – among river, hyporheic zone, immediate aquifer and soil layers – has spurred the development of suitable modelling codes [1, 2]. Coupling of two dimensional surface hydrodynamics with subsurface hydraulics based on different assumptions and simplifications has been one strand of research [e.g. 3, 4 and 5].

However, one of the main challenges that have hindered wider usage of these coupled models is the inherent complexity of model setup. The spatial and temporal characteristic scales of surface and subsurface flow generally differ by a few orders of magnitude. Integrating them into a single solver to improve the mathematical accuracy and model representativeness can in turn, have a negative effect on computational and setup efficiency. Developing integrated models for these solvers can also be seen as redundant, especially in those cases, when separate surface and subsurface models already exist and have been developed, validated and calibrated individually over a period of number of years.

As an alternate approach, we have developed a generic coupling framework that may allow addressing some of the drawbacks of specialised integrated modelling codes noted above and extend the range of application of integrated surface and groundwater models to scales relevant for river restoration projects.

COUPLING FRAMEWORK AND APPLICATION

The coupling framework employs mapping of information on to an interface layer that acts as the central driver of the couple. This layer then closes the surface boundary requirements of the groundwater model while interacting with the surface water solver to ensure mass continuity with the shallow water system. The methodology is, in some respect, similar to the ghost-node layer method used in MODFLOW LGR [6] to couple coarse and fine scale groundwater models. Using an interface layer in this manner, allows isolating the coupling component and controlling its characteristics more effectively rather than extensively modifying the surface and sub-surface hydraulic modelling codes. By means of explicit coupling (which can be extended to iterative coupling), the interface is able to gather and transmit information to required components efficiently. In the proposed integrated model, the subsurface source term contributing the surface flow is resolved by means of partial differential equation splitting, to overcome some of the lag issues associated with explicit coupling [7].

The information mapping process can be clustered into three main components. The first, grid mapping, is a pre-processing stage that allows the interface layer to geo-locate the surface and subsurface cells based on size, orientation and geographical location. The next two mapping components, namely the forward and backward mapping of information, controls flow and information to and from the models via the interface layer at each coupling time-step.

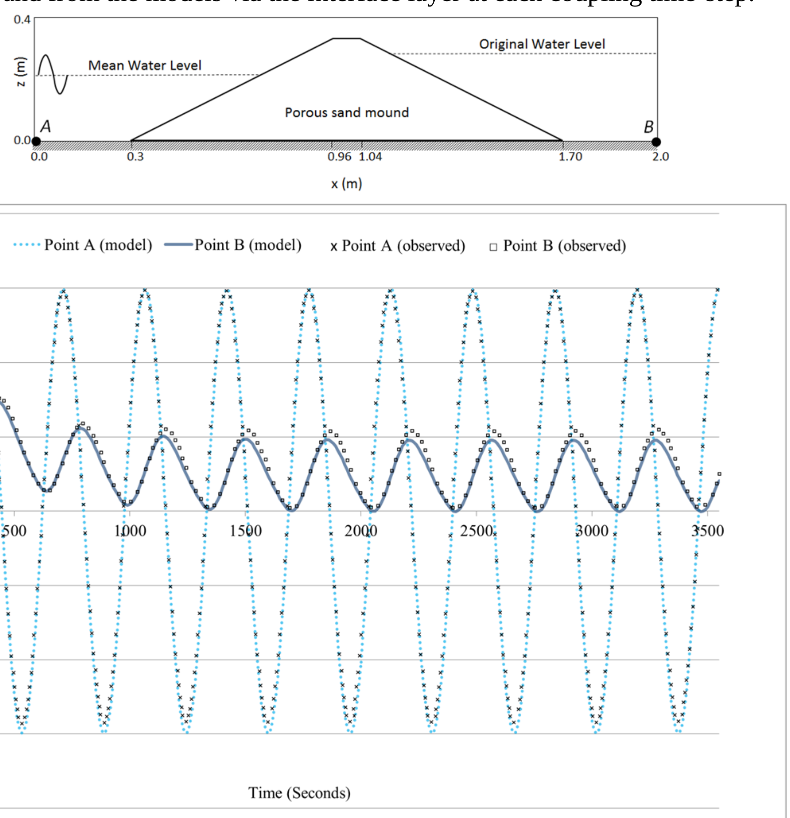

Figure 1 – Application of the copuled 2dMb-MODFLOW

The framework has been applied to couple a full shallow water equation hydrodynamic model for the surface, 2dMb [8,9], with MODFLOW-2005 [10] and MODFLOW-VSF [11] for saturated and unsaturated subsurface conditions, respectively. The results from the successful

2dMb-MODFLOW coupling over a water surface variation through a porous sand-embankment based on lab experiment conducted by Ebrahimi et al. [12] can be seen in Figure 1.

CONCLUSION

The proposed coupling framework builds in a flexibility that may allow faster testing of merits of coupling surface-water with groundwater models and possible adoption to approach real world problems. The process allows for direct usage of many of the utilities, post processors and other related software developed for the original decoupled codes – for example [13] for MODFLOW. Further improvements in components also directly impact and improve adaptation of the framework to the computing resources available. For instance, the development of versions of 2dMb that utilise OpenMP[14] and MPI[15] parallelisation protocols allows utilisation of HPC (High Performance Computing) resources by the framework. This improves the model performance and allows extending application to larger spatial scales (thus, covering longer river reaches).

At the current stage of development, the main components of the framework are nested within the surface water solver. However, it is structured in a manner which would allow formulation of the interface layer such that it becomes part of a third-party system similar to the Open Modelling Interface [16].

REFERENCES

[1] Furman A, "Modeling coupled surface–subsurface flow processes: a review."*Vadose Zone Journal* 7.2 (2008), pp 741-756.

[2] Morita M and Yen B C, "Modeling of conjunctive two-dimensional surface-three-dimensional subsurface flows." *Journal of Hydraulic Engineering*128.2 (2002), pp 184-200.

[3] Brunner P and Simmons C T, "HydroGeoSphere: A fully integrated, physically based hydrological model." *Ground water* 50.2 (2012), pp 170-176.

[4] Liang D, Falconer R A, and Lin B, "Coupling surface and subsurface flows in a depth averaged flood wave model." *Journal of Hydrology*337.1 (2007), pp 147-158.

[5] Swain E D., and Decker J, "*Development, Testing, and Application of a Coupled Hydrodynamic Surface-water/groundwater Model (FTLOADDS) with Heat and Salinity Transport in the Ten Thousand Islands/Picayune Strand Restoration Project Area, Florida*." US Department of the Interior, USGS, (2009).

[6] Mehl S W and Hill M C, "*MODFLOW-2005, the US Geological Survey Modular Ground-Water Model: Documentation of shared node local grid refinement (LGR) and the boundary flow and head (BFH) package*." US Department of the Interior, USGS, (2005).

[7] Shaad K and Burlando P, "Investigating grid-size dependency in coupled surface-subsurface hydraulics", *Proc. International conference on fluvial Hydraulics*. Lausanne. Taylor & Francis Group, CRC Press. (under review)

[8] Faeh R. "Numerical modeling of breach erosion of river embankments."*Journal of Hydraulic Engineering* 133.9 (2007), pp 1000-1009.

[9] Shaad K and Burlando P, "Flood Modelling Sensitivity To DTM Processing In Densely Settled River Corridors" , *Proc. Conference on Hydraulics, Water resources, Coastal and Environmental Engineering* , CD ROM (2013)

[10] Harbaugh A W. "*MODFLOW-2005, the US Geological Survey modular ground-water model: The ground-water flow process*." US Department of the Interior, USGS (2005).

[11] Thoms R. B, Johnson R L, and Healy R W. “*User's Guide to the Variably Saturated Flow (VSF) Process for MODFLOW [electronic resource]*.” US Department of the Interior, USGS, (2006).

[12] Ebrahimi K, Falconer R A, and Lin B. "Flow and solute fluxes in integrated wetland and coastal systems." *Environmental Modelling & Software* 22.9 (2007), pp 1337-1348.

[13] MOFLOW and Related Programs. http://water.usgs.gov/ogw/modflow/ (March 2014)

[14] OpenMP Specification. Version 4.0. http://www.openmp.org/wp/openmp-specifications/ (March 2014)

[15] MPI Forum."MPI: A message passing interface standard." *International Journal of Supercomputer Application* 8.3 (1994), pp 165-416

[16] Gregersen J., Gijsbers P, and Westen S. "OpenMI: Open modelling interface." *Journal of Hydroinformatics* 9.3 (2007), pp 175-191.