WATER FLOW AND SOLUTE TRANSPORT ACROSS THE SURFACE-SUBSURFACE INTERFACE IN FULLY INTEGRATED HYDROLOGICAL MODELS

Submitted by:

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Summary

Modelling studies often separate surface water and groundwater, despite the known connection between the two. Physically based, fully integrated hydrological codes that simulate both surface and subsurface processes have proved useful for capturing the complex dynamics of entire catchments in a single model. While the coupling of surface and subsurface hydrologic processes in these codes is a major advantage, few studies address the impacts of the coupling method on dynamic catchment processes such as overland flow, streamflow generation and solute transport. This thesis examines the implementation of surface-subsurface coupling approaches in fully integrated codes, evaluates their controls on simulating integrated flow and solute transport, and provides guidance for model users.

The influence of a commonly used approach to couple surface and subsurface flows (first-order exchange coefficient; FOEC) is systematically explored in the first half of this thesis using different hydrological scenarios of overland flow generation, infiltration, and exfiltration. In a mesh-centred code (HydroGeoShpere), results converge on the more accurate, but more computationally intensive, continuity of pressure coupling approach as the coupling length parameter (l_e) within the FOEC is decreased. Lower l_e values are required for infiltration under Hortonian conditions, in lower permeability soils, and to capture the initiation of overland flow. A threshold value of l_e is found to be equal to rill storage, above which inaccurate simulations can occur.

The FOEC approach is explored further with an analysis of its numerical implementation in a block-centred code (MODHMS), where a half-cell distance

separates the surface and uppermost subsurface nodes. Defining the FOEC based on the uppermost grid size inhibits accurate prediction of infiltration and the time to initiate overland flow under Hortonian conditions. Increasing the FOEC independently of the grid allows for accurate simulation of infiltration, but not the timing of overland flow. The addition of a thin layer at the surface improves model accuracy substantially.

In the second half of the thesis, the effects of solute dispersion across the surface-subsurface interface, versus within the subsurface, on integrated solute transport and tracer hydrograph separation are evaluated. In 2D hypothetical hillslopes, the pre-event water contribution from the tracer-based separation agrees well with the hydraulically determined value of pre-event water, despite dispersion occurring in the subsurface. In this case, subsurface dispersion parameters have little impact on the tracer-based separation results. The pre-event water contribution from the tracer-based separation is larger when dispersion across the surface-subsurface interface is considered. In a 3D catchment model, solute discharge is compared to field measurements during a rainfall event. Adding solute transport into a fully integrated 3D flow model can improve the assessment of internal model dynamics, but transport results are highly sensitive to model parameters and must be interpreted with caution.

The results of this thesis show that although fully integrated codes do not require an explicit boundary condition between the surface and subsurface, the coupling parameters can highly influence both the integrated and distributed response of flow and solute transport. As such, it is important that these parameters are carefully chosen and sensitivity analyses be performed to ensure robust model performance.

Declaration

I certify that this thesis does not incorporate, without acknowledgment, any material previously submitted for a degree or diploma in any other university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Jessica E. Liggett

Co-Authorship

Jessica E. Liggett is the primary author of this thesis, including the published documents. Co-supervisors Assoc. Prof. Adrian Werner and Prof. Craig Simmons provided intellectual supervision and editorial comments on this thesis and the associated published manuscripts. Preliminary work for Chapter 3 was undertaken by Matthew Knowling for his B.Sc. Honours thesis "Partitioning Infiltration and Overland Flow Using a Block-Centred Coupled Surface-Subsurface Code (MODHMS)" (2010, Flinders University, School of the Environment), under supervision from Ms. Liggett and Assoc. Prof. Werner. This work was subsequently re-modelled, re-interpreted, and re-written by Ms. Liggett for this thesis. Dr. Brian Smerdon provided intellectual discussion and editorial help with Chapter 4. Dr. Dan Partington provided code support and intellectual discussion for Chapters 4 and 5. And finally, Dr. Sven Frei provided intellectual discussion and background data for Chapter 5.

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