Geophysical Research Abstracts
Vol. 18, EGU2016-6694, 2016
EGU General Assembly 2016

The importance of spatial complexity in improving performance of groundwater-surface water models

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Recent studies of the importance of nested smaller-scale processes at larger reach and catchment scales have sparked exciting discussions on the level of simplifications made in groundwater-surface water (GW-SW) modelling that may influence the ability to simulate interface processes realistically. The inclusion of high-resolution spatial heterogeneity in subsurface composition can alter hydrodynamics, such as flow paths, and residence time, and detect important locations for ecohydrological processes. Furthermore, the presence of obstructions and spatial complexity, such as woody debris, low permeability structures, and microbial accumulations, influences the replicability with which fluid forcing properties in the environment can be incorporated into hydrodynamic models of the GW-SW interface. In this paper, we address a fundamental question: Does increasing spatial complexity improve the performance of groundwater-surface water models across the GW-SW interface?

A 3D model was developed to investigate groundwater flow paths and GW-SW exchange. The model was set up to test two comparative parameterisations: (1) homogeneous representation of the shallow subsurface and (2) heterogeneous subsurface geology utilising extensive core data and Ground Penetrating Radar (GPR) surveys of the area and in particular the streambed interface. Both the homogeneous and heterogeneous models were compared for residence time distributions and development of preferential flow paths. The two models were validated against continuous hydraulic head readings at piezometers and observation wells.

The heterogeneous model predicted increased lateral flow with more complex preferential flow paths around low conductivity structures and differences in residence times within the site that was controlled by the subsurface structure and infiltration. The differences presented in this paper between the homogeneous and heterogeneous subsurface models indicate that increased spatial complexity in model configuration produced more accurate representation of the site conditions. In comparison, the homogenous model with simplified subsurface conditions failed to adequately represent interface exchange flow patterns and residence time distributions in the subsurface. Importantly, quantified residence time distributions in the model including heterogeneity helped to identify biogeochemical hotspots. The ability for scientists to identify the characteristics of site specific biogeochemical hotspots and hot moments at larger management relevant scales in hydrodynamic models is an important advancement for replicating dynamic environmental conditions in GW-SW simulations.