H2: Integral modelling approach for flow and reactive transport at surface water - groundwater interfaces

Doctoral candidate: Vahid Sobhi Gollo

Supervisors: Prof. Reinhard Hinkelmann, PD Dr. Jörg Lewandowski, Prof. Gunnar Nützmann

Introduction / Aims

The idea of the following research project is to further develop [following Broecker et al. 2018, project N7] an integral solver for high resolution modelling of hyporheic zone exchanges with groundwater and surface water. We are comparing this method to coupling methods in order to address its accuracy and functionality. We added the details of conservative transport into the solver and compared them to results of 1D and 2D analytical solutions. An actual test case (Fox et al. 2014) is being used to further test the transport model. In later stages, the idea is to test the integral solver for different cases, geometries and scales to check its range of application and validate it based on quantitative experimental approaches [e.g. Fox et al. 2014]. Finally, with the help of field data (collaboration with other UWI project H1) and parameterization, functionality of the solver will be examined for reactive transport.

Methods

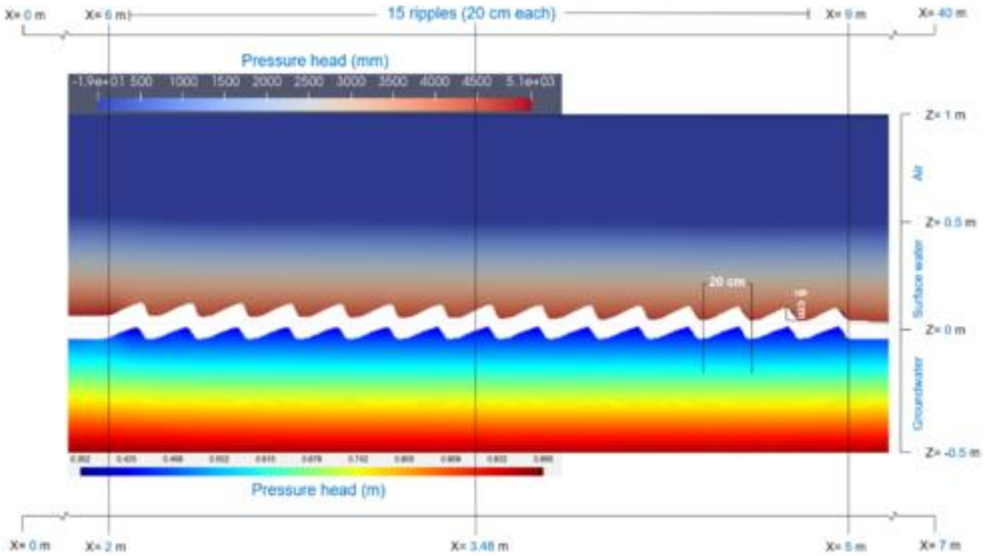
For surface water calculations, the free, open source computer fluid dynamics software "OpenFOAM" (Open Field Operation and Manipulation), version 2.4.0, is applied. For the investigation of groundwater and surface water interactions, an integral solver called „porousInter", developed by Oxtoby et al. (2013) was validated and is extended. The solver is based on the two-phase flow solver "interFoam" and extends the three-dimensional Navier-Stokes equations by the consideration of the porosity and an additional drag and inertia term.

For coupling with groundwater, PCSiWaPro® is used. It is a FEM 2D groundwater model developed by TU Dresden for vertical soil sections.

Results

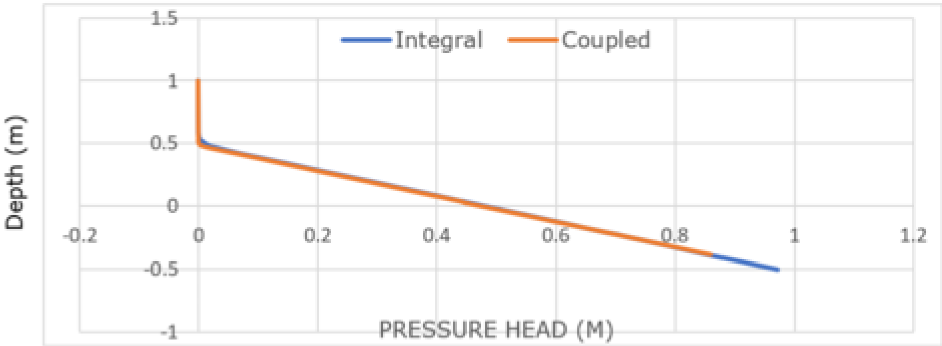
Integral approach – Coupled approach comparison

Using porousInter, we modelled the hydraulic exchanges between a rippled streambed and hyporheic zone (project N7). We then made a coupled groundwater – surface water model using the same geometry and parameters. Surface water modelling in this case is done by InterFoam solver included in OpenFoam and the groundwater model was built using 2D modelling tool PCSiWaPro®. We compared not only the results of both modelling approaches but also computational performances.



Ripple geometry and dimensions of coupled approach as well as pressure distributions in coupled approach above and within rippled streambed.

Preliminary results show that both models picture pressure head distributions identically.



Comparision of pressure head distribution of integral and coupled approach at section x = 3.48m (see figure above).

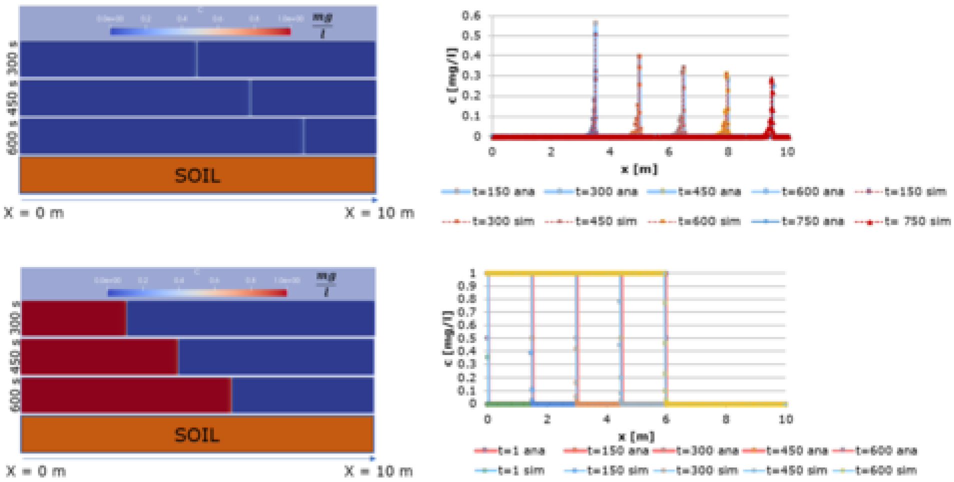
Velocity distributions on the other hand show some oscillations and cannot match perfectly. This has been discussed by Broecker et al. 2019 that assumption of a closed interface between surface water and groundwater can cause the negligence of flow and eddy accumulation and exchanges through the interfacial zones. Thus, a groundwater – surface water coupling without feedback on the interface will results in unprecise results. Further comparision of the integral approach to groundwater model with feedback is intended in the next steps of this project.

Other than these, it is worth mentioning that even a coupled approach without feedback effort requires more processing time in regards of more steps to feed the data between two models, matching the meshes, converting datasets and post-processing. This results in a higher computational performance for an integral approach, where the interface exchanges, as included in the model concept when compared to conventional coupled approach.

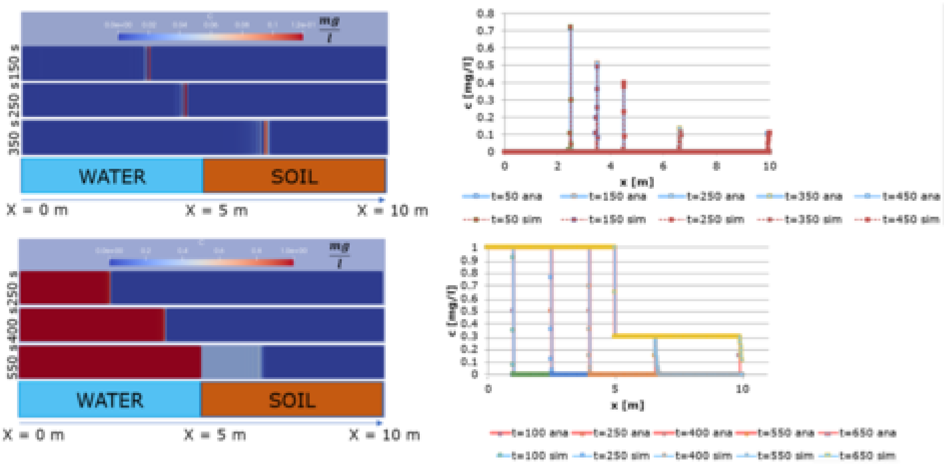
Transport model verification

We have implemented a transport equation into porousInter solver (project N7). 1D and 2D verification is done using analytical solutions to prove that the numerical results are correct. We investigated, for both pulse injection and constant tracer boundary conditions, the convergence between our model and analytical solution results. 1D comparison results for diffusive-advective cases ($D_{mol}=10^{-9}$ m^2/s) show a very good match. Therefore, we can conclude that the model, for diffusion and advection, is mathematically correct.

For calibration, results of Fox et al. 2014 experiments are currently being investigated (project N7).

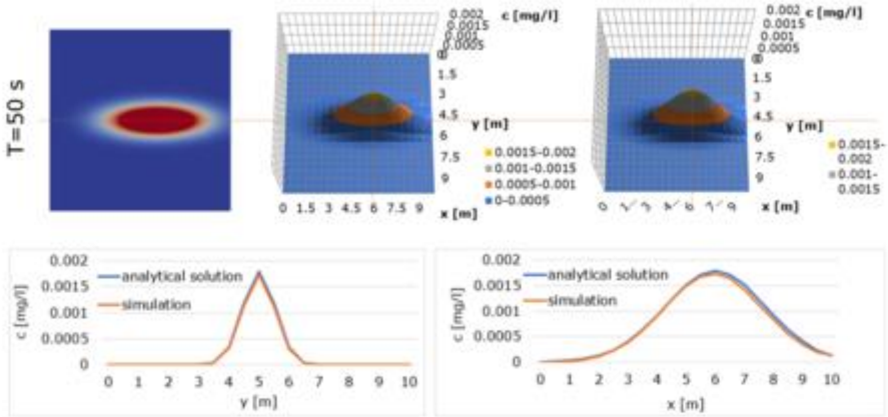


Verification, pulse (top) and constant (bottom) injections, only soil, Left: Soil system and tracer concentrations for different time steps (simulation), Right: Comparison of tracer concentrations for different time steps (simulation (sim) <> analytical solution (ana)).



Verification, pulse (top) and constant (bottom) injection, water + soil, Left: Water-Soil system and tracer concentrations for different time steps (simulation), Right: Comparison of tracer concentrations for different time steps (simulation (sim) <> analytical solution (ana)).

We then implemented a 2D scenario where a pulse tracer is injected in a square of 10mx10m and we compared the flow triggered movement of the tracer with the analytical solutions considering an advective-dispersive behavior. Results show a perfect match compared to analytical solutions.



Top: Concentration distribution in x and y directions for t=50 s after injecting a pulse tracer at the mid left boundary of the model– simulation (left), analytical solution (right), Bottom: Cross-sectional view of analytical solution compared to simulation. Vertical section (left), Horizontal section (right).

References

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Collaborations

Other UWI projects:

- H1: TrOCs samples for calibration of transport model
- N7, S2, T3: modelling with OpenFOAM
- F2, F3, W2: water quality modelling

Common topic: Interface urban hyporheic zones