NUMERICAL MODELING INVESTIGATION OF FLUID FLOW ABOVE AND BELOW SEDIMENT-WATER INTERFACES

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This project focused on the interface between streams and underlying sediments, exploring fluid exchange in coupled stream water-pore water systems, and delineating the hyporheic zone configuration, depth, and residence times. Hyporheic zone exchange is important for biogeochemistry and aquatic life, both in freshwater streams and in estuaries and the coastal ocean. The spatial scale is one of meters, and the temporal scale is the residence time of fluids. Most previous studies of this issue have examined only the porous part of the system, including our own previous simulations of a Nebraska stream reach. Assuming a flat bottom, those studies typically apply a spatially periodic stream bottom pressure to mimic the effects of sedimentary ripple or bed forms. Our new non-linear coupled stream-porous sediment simulations, funded by this project, demonstrate that bed geometry plays an important role and shouldn't be ignored. We believe that it is the first coupled modeling of processes across this interface that addresses the full range of dynamics on both sides of the interface. It has been revealing.

The simulations employed sequential coupling, where flow in the stream is solved through the Navier-Stokes equations yielding bottom pressures which are used to drive porous flow in the bed below. Although we initially assumed that the streamflow is laminar, our later work focused on turbulent flow using a Reynold's average approach. Starting with preliminary simulations we relaxed assumptions, one by one, and incorporated additional processes like heat and solute transport. Strong coupling of the non-linear stream equations, particular turbulent flow models, with underlying porous flow is a computational challenge. The computational fluid dynamics (CFD) code and computer hardware support provided by the WRRI grant was essential.

Our most important findings focus on the configuration of the hyporheic zone. Here are a few. The zone is created by bottom pressure distributions caused by separation and formation of an eddy behind the bedform. As current in the stream increases, the eddy size, the normalized variation of bottom pressure, and the size of the hyporheic zone reach an asymptotic limit. The rate of exchange continues to increase "without limit," and residence times decrease, with faster currents, but the zone configuration stops changing. The depth of the zone is very sensitive to current in laminar flow, but less sensitive in turbulent flow. The zone never exceeds a depth equal to the wave length of the sedimentary beds. If the stream is gaining, it takes a minimum current to provide the pressure differences necessary to create a hyporheic zone in the presence of the groundwater discharge. For a current above this threshold, discharging groundwater shrinks the zone relative to the case of no net groundwater exchange. The discharging groundwater enters the stream at the bedform trough. It is here that the two waters, groundwater and shallow recirculating stream water, mix creating an intense biogeochemical "hot spot."

We have two journal articles that have just been published (and one comment), three in review, and two more in preparation (see attached list below). The work supported by the grant from NM WRRI appears in the articles still in review. We have given papers and posters at regional and national meetings, including national meetings of AGU, GSA, and ASLO, and perhaps a dozen invited seminars at universities ranging from Florida State University in the east, to University of Texas in Austin, to University of California Merced in the west.

Cardenas, M.B. and J.L. Wilson, *The Influence of Ambient Groundwater Discharge on Hyporheic Zones Induced by Current-Bedform Interactions*, J. of Hydrology. doi:10.1016/j.jlrydrol.2006.05.012. 2006.

Cardenas, M.B. and J.L. Wilson, *Hydrodynamics of Coupled Flow Above and Below a Sediment-Water Interface with Triangular Bedforms*, Advances in Water Resources, doi: 10.1016/i.advwatres.2006.06.009. 2006.

Cardenas, M. B, and J.L. Wilson, Comment on *Flow resistance and bed form geometry in a wide alluvial channel* by Shu-Qing Yang, Soon-Keat Tan, and Siow-Yong Lira, Water Resources Research. Vol. 42, W06601, doi:10.1029/2005WR004663, 2006.

Cardenas, M.B. and J.L. Wilson, *Dunes, Turbulent Eddies, and Interfacial Exchange with Permeable Sediments*, J. of Geophysical Research-Oceans, submitted, 2006.

Cardenas, M.B. and J.L. Wilson, *Exchange Across a Sediment-Water Interface with Ambient Groundwater Discharge*, J. of Geophysical Research-Oceans, submitted, 2006.

Cardenas, M.B. and J.L. Wilson, *Heat Transfer at the Sediment Water Interface*, Water Resources Research, submitted, 2006.