2026 Geological Society of America Hydrogeology Division Birdsall-Dreiss/LaMoreaux Lecture 2

The Enigmatic Biscayne Aquifer: Field, Laboratory, and Computational Approaches

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The Biscayne Aquifer of southeastern Florida supplies water to approximately 6 million people. It is a Pleistocene eogenetic carbonate karst unconfined aquifer characterized by meter-thick strata of dense networks of 2-cm burrow ichnofossil touching vugs and bedding plane conduits. The porosity of the burrowed zones can be 50% or more and the rock can be difficult or impossible to core. The large pores and high porosity likely result in non-Darcian flow under quite low gradients ($>10^{-5}$) and contribute to extremely high hydraulic conductivities (*K*s) that are challenging to quantify. While numerous arguments can be made against efforts to quantify a hydraulic conductivity of karstic rocks, enhanced understanding of the operative processes has fundamental value and may ultimately enable higher fidelity flow and transport modeling.

Multiple independent lines of investigation have been followed to address these challenges, and some consistent results are emerging. Standard petrophysical laboratory measurements yield exceptionally low *K*s ($\sim 10^{-5}$ m s^{-1}) probably due to intrinsic limits of the tests. The *K* of similar intensely burrowed zone rocks has been shown to be ~15 m s^{-1} through high viscosity glycerol laboratory measurements on a 0.1 m diameter 3-D printed epoxy core created from computed tomography data collected from an outcrop sample. This is consistent with analytical Poiseuille flow solutions for a 2-cm pipe yielding $K \sim 10^2$ m s^{-1}. Lattice Boltzmann flow modeling corroborates the experimental results. Other Lattice Boltzmann results on smaller samples yield *K* estimates approaching 50 m s^{-1}. The Lattice Boltzmann simulations of flow in the 0.1 m core were extended to a Reynolds number of approximately 100 and reductions in the apparent hydraulic conductivity were used to fit a Forcheimer model. Subsequent laboratory measurements using water and flows with Reynolds numbers in the range of 1,000 to to 10,000 were exceptionally well predicted by the Forcheimer model.

Lattice Boltzmann modeling of flow was applied to an atypically large 0.4 x 0.4 x 17-m block of the aquifer that was simulated geostatistically and conditioned on high resolution borehole imaging data. The estimated *K* was 50 m s^{-1}. Slug tests in the Biscayne Aquifer frequently show underdamped oscillatory responses indicative of inertial flow conditions. A literature search shows that the results of analyses of any underdamped slug tests never exceed *K* values of ~0.1 m s^{-1}. Careful aquifer tests on the Biscayne Aquifer conducted and published in the 1950s and 1990s yielded minimum estimates of the high end of the *K* range of the Biscayne Aquifer of 0.1 to 0.2 m s^{-1}.

These disparate results demand explanation. The agreement of laboratory and Lattice Boltzmann results at the 0.1 m scale suggests that the *K* of the burrowed zones is well constrained in the 10-50 m s^{-1} range. Simple thickness-weighted averaging of these *K*s for a number of 1 and 2 m thick burrow zones observed in a 16 m thick portion of the aquifer suggests that the overall K would be about 5-25 m s^{-1}. The older aquifer tests are inconclusive and new aquifer tests are prohibitive if not impossible to conduct conclusively. The slug test analyses yield unexpectedly low *K*s; further examination of the standard approaches for analysis of oscillatory slug tests seems needed. Standard petrophysical laboratory measurements are not appropriate for these rocks.