COMSOL Modeling of Groundwater Flow and Pollutant Transport in a Two-Dimensional Geometry with Heterogeneities

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Abstract

The Delmarva Peninsula is located on the East Coast of the United States, between the Chesapeake Bay and Atlantic Ocean. The land is mostly flat with a network of streams that run from the central upland to either the Chesapeake Bay or the Atlantic Ocean. The region is primarily rural with roughly 50% of the land used for agriculture. Industrial farming in the Delmarva Peninsula leads to levels of nutrients, in particular nitrogen, which grossly exceed natural levels. Excess nitrogen reaches the freshwater streams of the peninsula via runoff water and groundwater, whichl then flows to the saltwater estuary of the Chesapeake Bay. The presence of extreme levels of nitrogen greatly impairs the health of the bay, and while runoff water may seem to be the main source of excess nitrogen in streams it has been shown that an average of 48% of a stream's nitrogen load has been discharged from groundwater [1].

The Delmarva Peninsula has an interesting underlying geologic structure. The aquifer geometry in this area is marked by two significant factors: a general sloping confined layer, angled toward the ocean with unconfined surface strata of sand and clay. The surface layer contains groundwater that flows to the streams of the peninsula. The clay strata are sloping banks three-to-four meters thick, through which groundwater flows much slower than the sand strata. It is generally supposed that the longer the flow path the longer the residence time of groundwater, so the difference in the flow speed through strata may change the length of flow paths on which groundwater carries nutrients.

We use COMSOL Multiphysics 4 to quantify how water residence times change due to heterogeneities within two-dimensional cross-sections [2]. In this way we can make inferences on the levels of excess nutrients from above ground agriculture that reach neighboring streams via groundwater. In COMSOL Multiphysics we implement a model representative of the region; the system consists of two rivers, a sloped impenetrable bottom and angled clay banks. We assume a steady state velocity flow, derived from Darcy's Law, to determine flow paths and an advection-dispersion equation to model nutrient movement through the system.

We find that variation in clay strata affects flow paths. A flow divide is the point on the surface that delineates the output river for rainfall. In the homogeneous case (no clay barriers - Figure 1), this divide occurs at 537 meters. Clay banks are placed on the left or right and terminate short of or extend beyond the homogeneous flow divide to examine how this changes the flow paths of nutrients reaching each stream. Clay banks from the left and short of the flow divide (Figure 2) and from the right and extended beyond the flow divide (Figure 3) shift the flow divide left and right, respectively. Furthermore the hydraulic pressure increases with the presence of clay strata due to shortening of the distance between the surface and clay barriers.

Reference

[1] Bruce D. Lindsey et al., Residence Times and Nitrate Transport in Ground Water Discharging to Streams in the Chesapeake Bay Watershed, USGS, Water-Resources Investigations Report 03-4035, 2003.

[2] Mattie Whitmore, Modeling of Groundwater Flow and Pollutant Transport in a Two-Dimensional Geometry With Heterogeneities, M.S. Thesis, Department of Mathematics and Statistics, University of Maryland, Baltimore County, 2011.

Figures used in the abstract

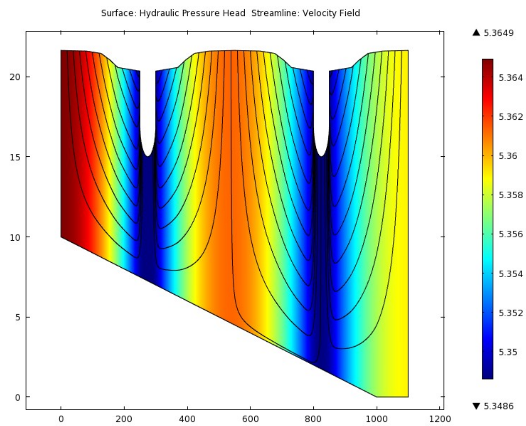

Figure 1: Homogeneous geometry solved for flow paths, and pressure head.

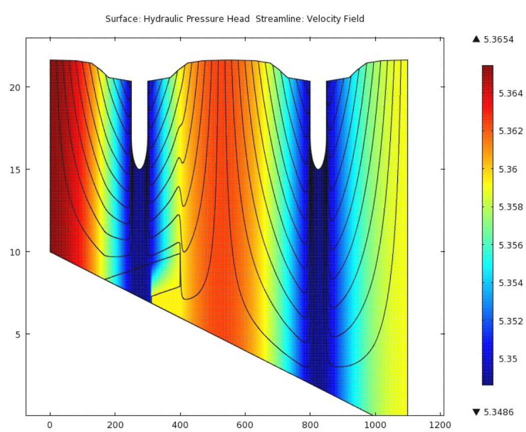

Figure 2: Heterogeneous geometry, with clay bank placed on the left and terminating before the flow divide. Solved for flow paths, and pressure head.

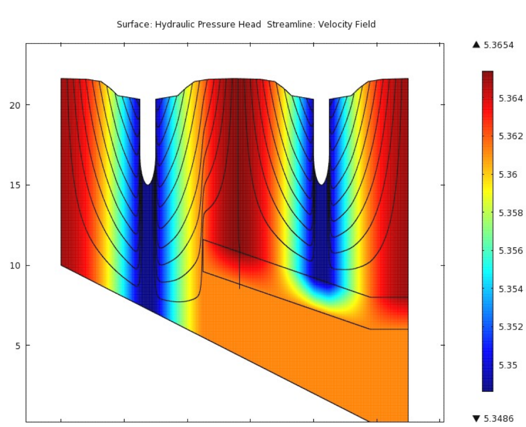

Figure 3: Heterogeneous geometry with clay bank placed on the right and terminating after the flow divide. Solved for flow paths, and pressure head.