

A Coupled Geologic-Hydrologic Model of a Glacial-Lacustrine Aquifer System in Northwest Indiana: Model Development and Results of a Preliminary Simulation

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As part of the U.S. EPA Great Lakes initiative, we were contracted to develop hydrogeologic models of selected surficial aquifer systems in northwestern Indiana. Our most intensive effort, which included coupling of a variably saturated three-dimensional groundwater flow model with a geologic model of a glacial-lacustrine aquifer system, was conducted in the Trail Creek watershed. The headwaters of the Trail Creek watershed are on the northern edge of the Valpariaso Moraine and the creek discharges into Lake Michigan at the harbor of Michigan City, Indiana (Figure 1).

A total of 243 edited and georeferenced well logs (mostly from water-well driller's descriptions) were available for the Trail creek area. The unconsolidated materials described in the well logs were classified into six categories of apparent hydraulic conductivity magnitude (1 for gravel ... 6 for clay). A 5-foot interval was used except when a boundary was encountered. In the latter situation the length of the interval was determined by the location of the lithologic boundary. An example of a classified well log is provided in Figure 2. Those logs that contained information about the depth to bedrock were used to develop a digital elevation model (DEM) of the bedrock surface, which constituted the lower boundary of the aquifer system. A DEM of the surface topography was also obtained and was used as the upper boundary of the aquifer system. A three-dimensional representation of the aquifer system was derived by statistical kriging of the apparent conductivity logs.

A perspective view of the modeled apparent conductivity distribution indicates a highly heterogeneous aquifer system without uniform layering (Figure 3). Most of the upper surface consists of silty and clayey sediments (green to red colors), but some areas exist where sand and gravel are exposed at the surface. Those that occur in the upland areas at the head of the watershed are potential recharge areas for the main subsurface aquifer. A clearer image of the main aquifer was obtained by removing all the grid cells that had interpolated apparent conductivities greater than 2.0 (Figure 4). The sand and gravel deposits are thickest in the headwaters portion of the watershed and thin towards the watershed outlet. This distribution of aquifer materials is consistent with a fan-delta depositional system, which has been described by glacial geologists working in the area.

In an effort to simulate the flow of groundwater in this highly heterogeneous aquifer system, the interpolated apparent conductivity codes were converted into apparent conductivities (Figure 2) and output as a three dimensional array containing 49 rows (N-S dimension), 46 columns (E-W dimension), and 95 layers (vertical dimension). Since the model domain (Figure 3) is not a perfectly rectangular block, those cells that were not inside the watershed boundaries (including those that are above the ground surface in the lower watershed) were assigned a value of zero and excluded from the flow modeling exercise. The apparent conductivities were input to a numerical finite-difference model based on the three-dimensional, variably saturated model originally developed by Freeze (1971). To facilitate unsaturated flow calculations, typical values of the parameters in van Genuchten's (1980) characteristic equations for various sediment types (Schaap, et al., 2000) were input to the model. The later were used

along with the modeled apparent hydraulic conductivities (which were used as saturated conductivity values) to calculate the unsaturated hydraulic conductivities and moisture contents in the unsaturated zone.

The preliminary simulation consisted of first running the model in steady-state mode to generate a set of initial conditions, and then to running the model in transient mode subject to a uniform infiltration rate of 1cm/d.

Modeled flow vectors, produced by the transient simulation, are plotted in Figure 5. Although some elements of the flow field conform to conventional theory (downward flow in the upland recharge area, lateral flow towards streams), there are apparent local flow zones in the lower portion of the watershed where the flow at depth has a strong vertical component that is not always directed upward. Such non-uniform flow could be a result of inaccurate modeling, but according to Fogg (personal communication), decoupled and seemingly random flow patterns often occur as a result of heterogeneity in complex aquifer systems. Further work will be necessary to identify all the causes of complex flow patterns (both real and artificial) in heterogeneous aquifer systems like the one presented here. Regardless of the final answers to such difficult questions, this study has demonstrated the strong affect that aquifer heterogeneity can exert on the results of flow modeling exercises.

References

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- Schaap, M.G., Feike, J.L., and van Genuchten, M.Th., 2000. Estimation of the soil hydraulic properties. In, B.B. Looney and R.W. Falta (Editors), *Vadose Zone: Science and Technology Solutions*, Volume 1. Battelle Press, Richland, Washington, pp. 501-509.
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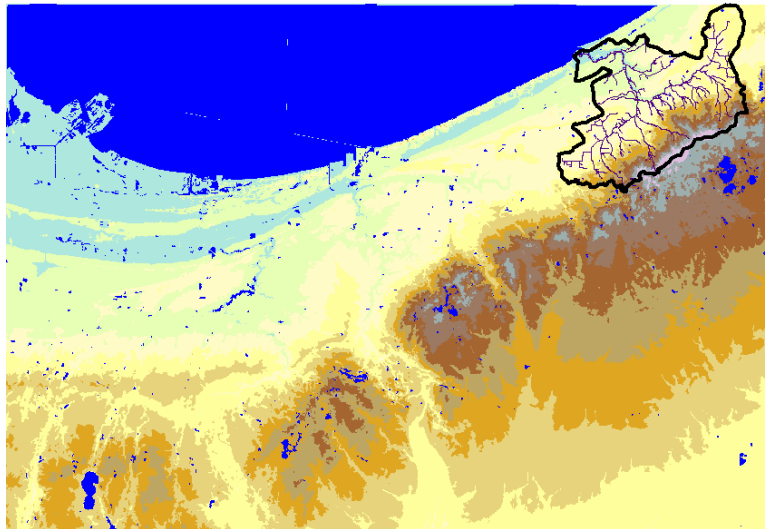


Figure 1. Shaded relief map of northwest Indiana showing the location of the Trail Creek Watershed. The watershed which drains an area of 142 km², has its headwaters in the Valparaiso Moraine and discharges into Lake Michigan.

	Descriptive Log	Apparent Hydraulic Conductivity	Category Magnitude	EVS Color Code
0 m	Soil	$K=10^{-4}$ cm/s	4	Yellow
2 m	Sand	$K=10^{-2}$ cm/s	2	Cyan
4 m	Gravel	$K=10^{-1}$ cm/s	1	Dark Blue
4 m	Mix	$K=10^{-5}$ cm/s	5	Orange
6 m	Silt	$K=10^{-4}$ cm/s	4	Yellow
8 m	Clay	$K=10^{-6}$ cm/s	6	Red
8 m				Red
10 m				Red

Figure 2. Example of how an edited water well log is translated into a numerical log for interpolation using statistical kriging. The material types are assigned apparent hydraulic conductivities based on look-up tables and published information about the study area. The category magnitude, which is the negative power of 10 associated with the apparent conductivity, is the variable that is input to the kriging procedure. The colors on the right are used to indicate conductivity distributions in three-dimensional visualizations of the aquifer system.

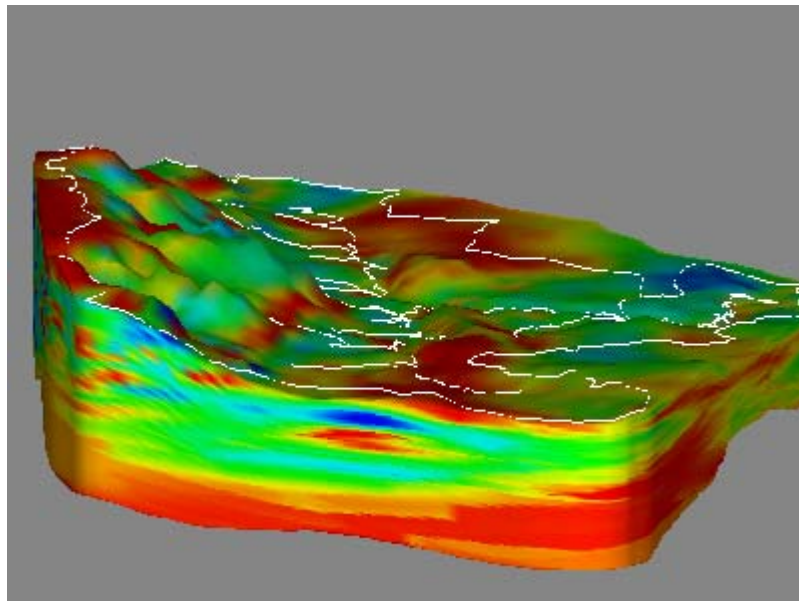


Figure 3. Perspective view of the modeled apparent conductivity distribution. Note the lack of uniform layering and the absence of a continuous capping (clay and silt) layer.

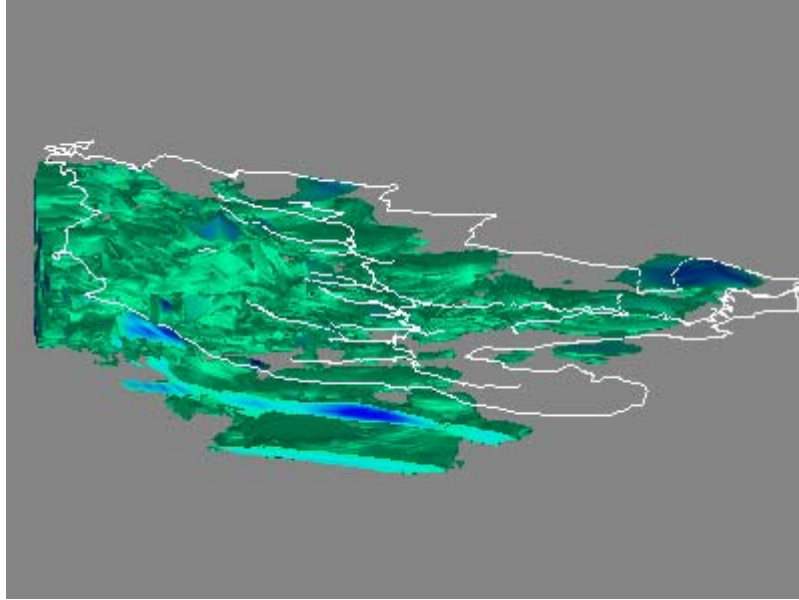


Figure 4. Perspective view of the modeled aquifer system with all cells having a category magnitude greater than 2.0 excluded from the image. The main aquifer thins toward the watershed outlet and exhibits several zones that are partially or completely isolated from the core region.

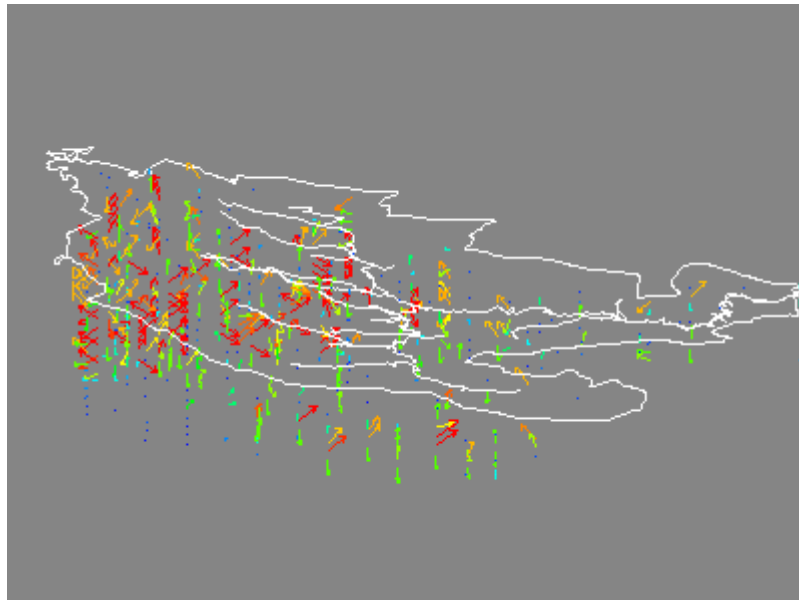


Figure 5. Flow vectors calculated using the numerical finite-difference model. Red arrows indicate areas and directions of highest flow rate and blue arrows areas and directions of lowest flow rate. To facilitate viewing, vectors were plotted for every fourth cell in the grid. Also, flow vectors in clay-rich cells do not show in the image because they are so small. Note that the main locus of flow corresponds to the recharge area and headwaters portion of the main aquifer.