GIS-based Three-dimensional Geologic and Hydrogeologic Modeling of the Milan, Ohio 1:24,000 Quadrangle







GIS-BASED THREE-DIMENSIONAL GEOLOGIC AND HYDROGEOLOGIC MODELING OF THE MILAN, OHIO 1:24,000 QUADRANGLE

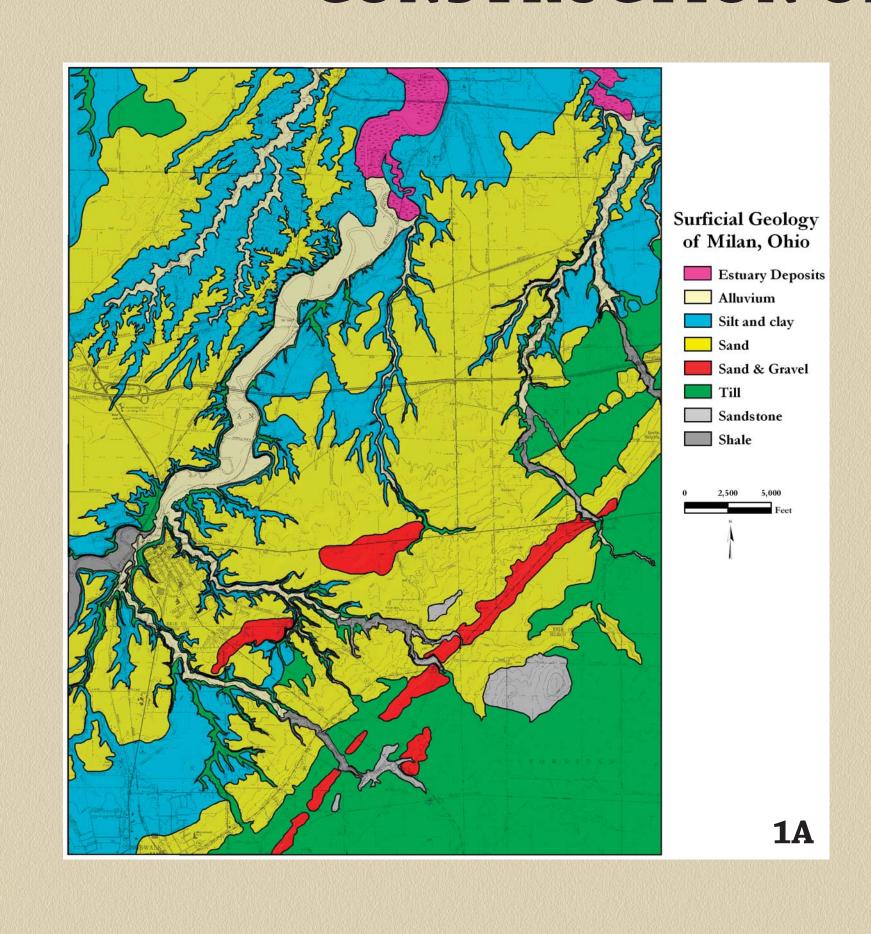
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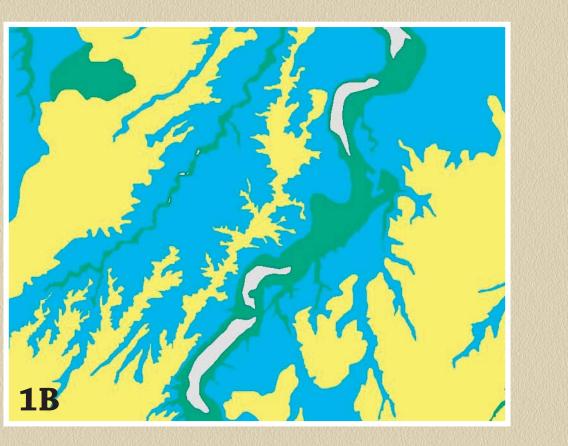
The Central Great Lakes Geologic Mapping Coalition (CGLGMC) is a partnership among the state geological surveys of Ohio, Indiana, Illinois, and Michigan, and the U.S. Geological Survey. The mission of the CGLGMC is to produce detailed three-dimensional geologic maps and information, along with related digital databases, that support informed decision-making involving ground water, mineral-resource availability and distribution, geological hazards, and environmental management. The initial Ohio project for the CGLGMC was the geologic and ground-water modeling of the Milan Quadrangle in north-central Ohio. This area was modeled as ten lithologic units, including alluvium, beach ridges, lacustrine sand and clayey silt units, Wisconsinan till, and a significant pre-Wisconsinan buried valley aquifer. Tools in ESRI ArcGIS, including the Spatial Analystextension, were used to analyze borehole and outcrop data, construct the bounding surfaces of each lithologic unit, and to produce raster data layers representing the three-dimensional framework of these units.

We used the detailed three-dimensional geologic model and merged it with an equally detailed groundwater-flow model to produce a more realistic understanding of the controls that glacial geology and geomorphology exert on shallow ground-water flow systems. The top of the geologic model was the surface topography (digital elevation model), which was also used to derive the drainage network that is an important boundary condition in the ground-water flow model. The bottom of the geologic model was the top surface of the Devonian Ohio Shale. Flow in the shallow saturated zone reflected strong control by surface topography and assumed hydraulic properties of the mapped sedimentary units. In contrast, the flow at depth was not strongly influenced by the topography of the Ohio Shale but did show some tendency for regional flow toward Lake Erie.

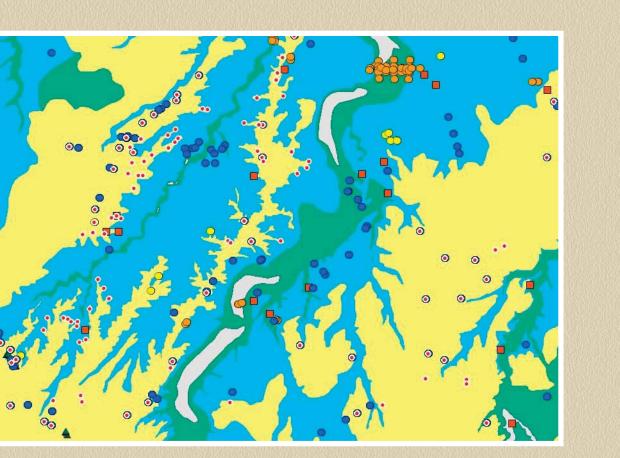
The resultant three-dimensional geologic model and companion ground-water modeling results can be used to produce a range of derivative products such as maps of recharge and discharge areas. Such products can be used to address the wide variety of water management, land use, environmental, and resource issues that are crucial to local, state, and federal agencies, private industry, and the

CONSTRUCTION OF THREE-DIMENSIONAL SURFACE ELEVATION RASTERS IN ARCGIS

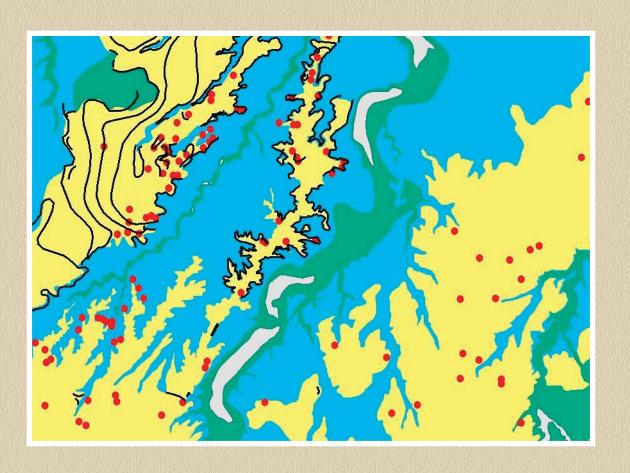




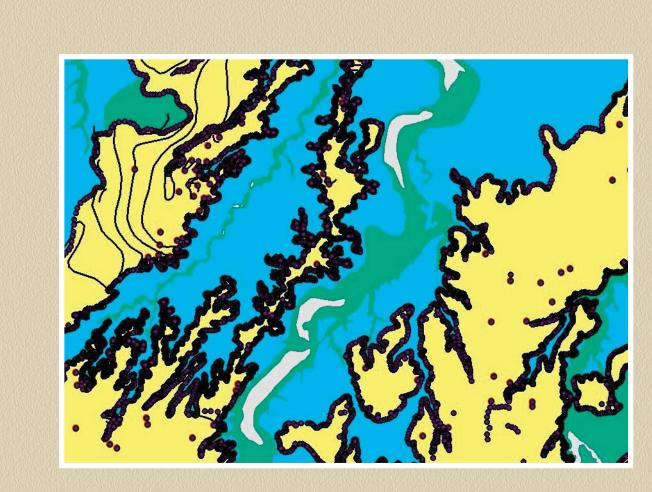
1. Polygons of all geologic units at the surface (1A) were constructed using outcrop, soils, borehole, and elevation data. The polygons for each geologic unit were then selected and exported as individual shapefiles. As the base of view also contains artificial sand base points tion. each unit was developed and merged into the that were added later as control for producing surface elevation raster and removed from the the desired raster. model, the unit polygons for the underlying unit were modified to include areas buried by higher units. In this example (1B) from the northwestern portion of the quadrangle, the estuary deposits, alluvium, and sand and gravel beach ridges have already been removed; the surface raster for the top of all remaining units [the sub_sg_all raster] became the starting raster for the top of sand raster. Shown here from top to bottom are sand [yellow], silt/clay [blue], till [green], and bedrock.



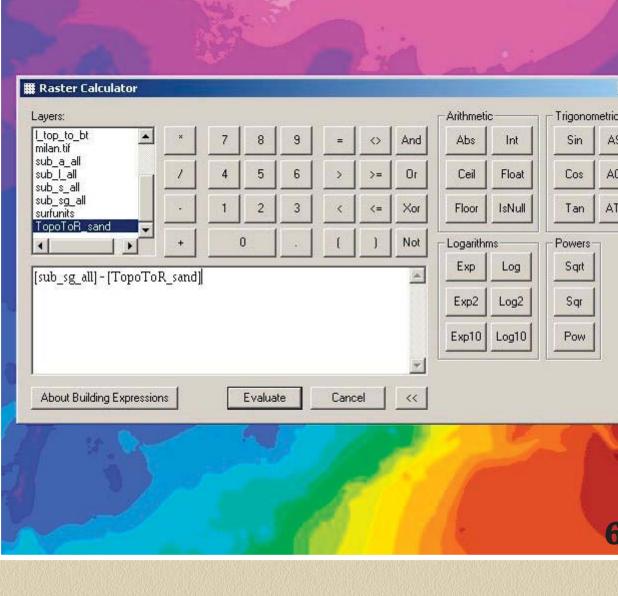
2. To begin construction of the base elevation raster of the sand unit, all outcrop and borehole data were analyzed and a shapefile of sand base points was developed [red dots]. This

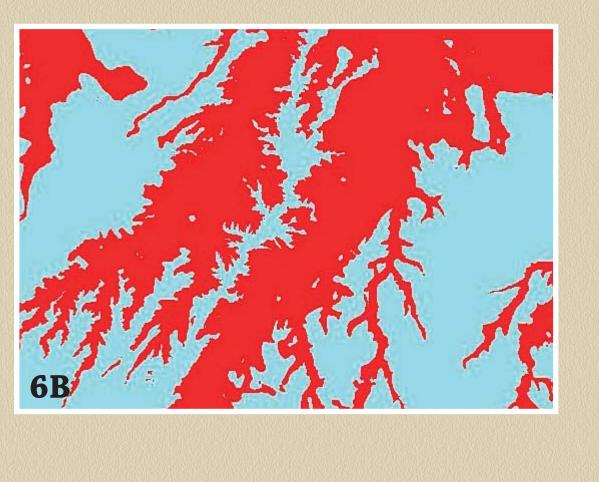


3. Contours were also developed for additional control. These do not need to cover the entire area of the sand or contain a regular interval; they may be assigned any useful eleva-

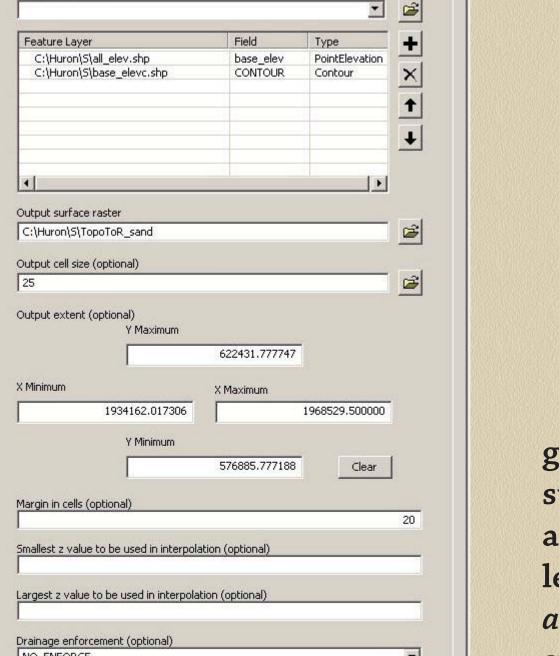


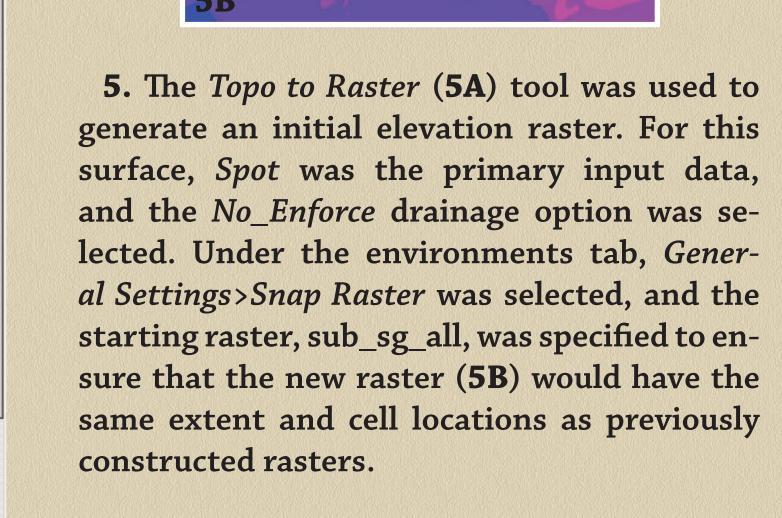
4. To ensure that the edges of the polygons reflect a zero thickness, the Feature Vertices to Points tool was used to create points at the edge of the sand. Elevations were assigned to these points using the Extract Values to Points tool (using the sub-sand and gravel surface as the input elevation raster). These points were merged with the base elevation points.

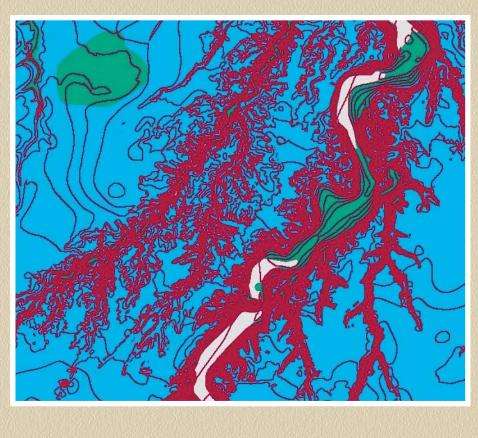




6. The Raster Calculator (6A) was used to subtract the new raster [T2R_sand] from the sub_sg_all raster. The resultant calculated thickness raster (6B) should have positive sand thicknesses in the sand areas [blue] and negative values in the areas where sand is absent [red]. If there were significant undesired results, additional control points and contours were added, and the process was repeated. Once the desired raster was produced, the Reclassify tool was used with the above thickness raster to produce a two-class raster that has an integer value of 1 for positive values and <NoData> for negative values. The resultant integer raster was input into the Raster to Polygon tool to produce a new sand polygon file. The Extract by Mask tool was used with these new polygons and the T2R_sand raster input to produce a raster [sand base] that only has elevation values for the base of the sand areas. The mask was also used to extract the top of the sand raster from the sub-sg-all raster.



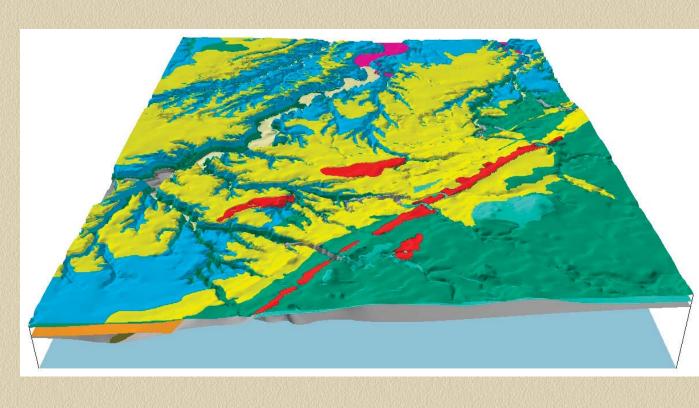




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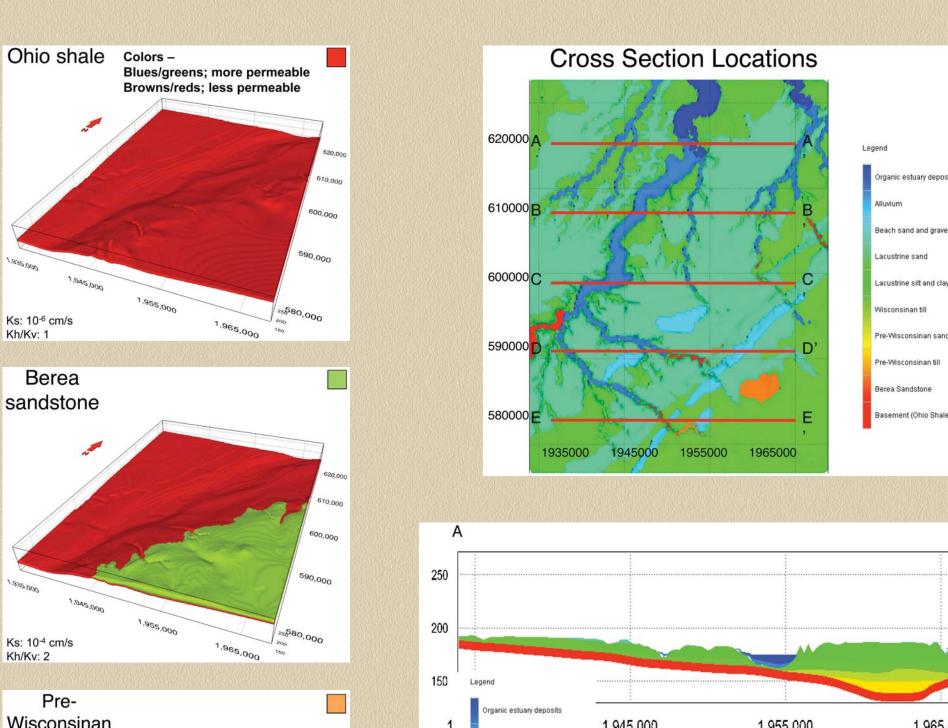
Maximum number of iterations (optional)

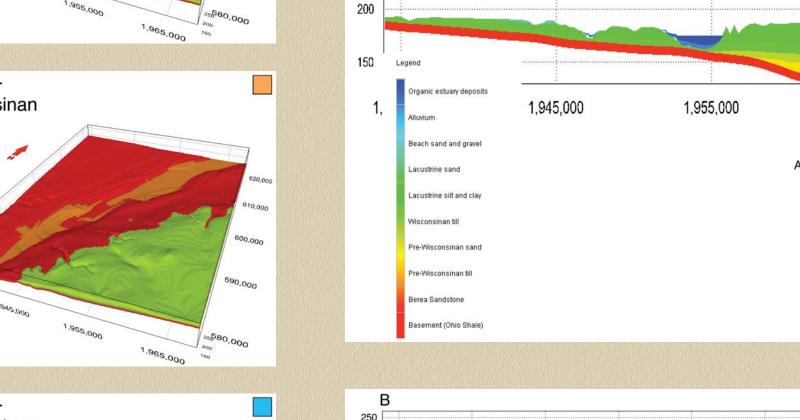
7. The Mosaic to New Raster tool was then used to construct the elevation raster to be used as the starting point for the next unit down, the lacustrine silt/clay [blue]. The sub-sg-all and sand_base rasters were used as input, and the Mosaic Method chosen was Minimum.

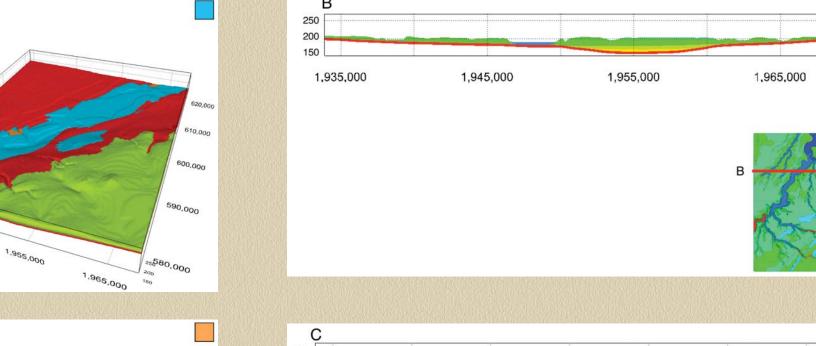


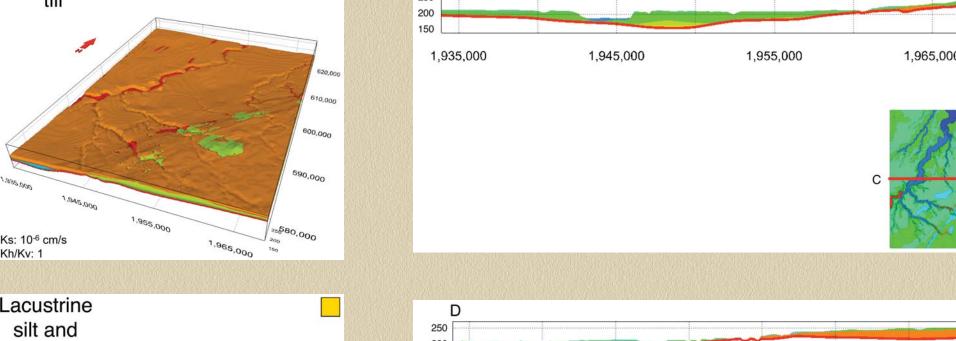
8. This view of the final three-dimension-I model, as displayed in ArcScene, consists f elevation rasters for the top of each unit. These rasters were imported into EVS for construction of a true three-dimensional voxel model, which was used for ground water flow

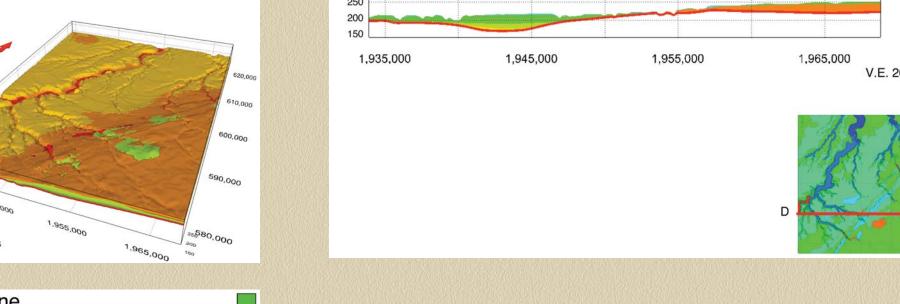
EVS MODEL VIEWS

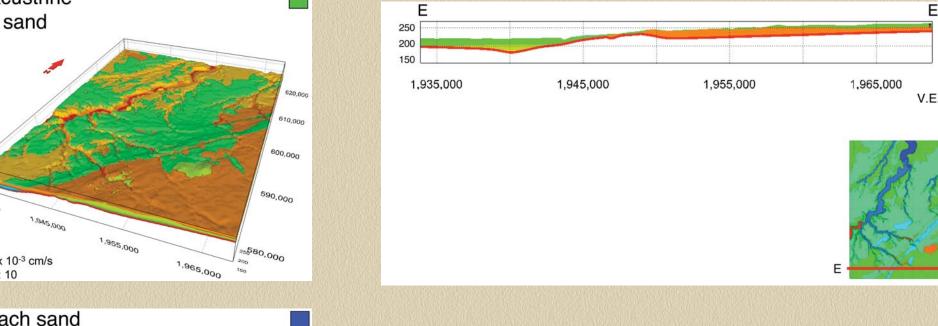


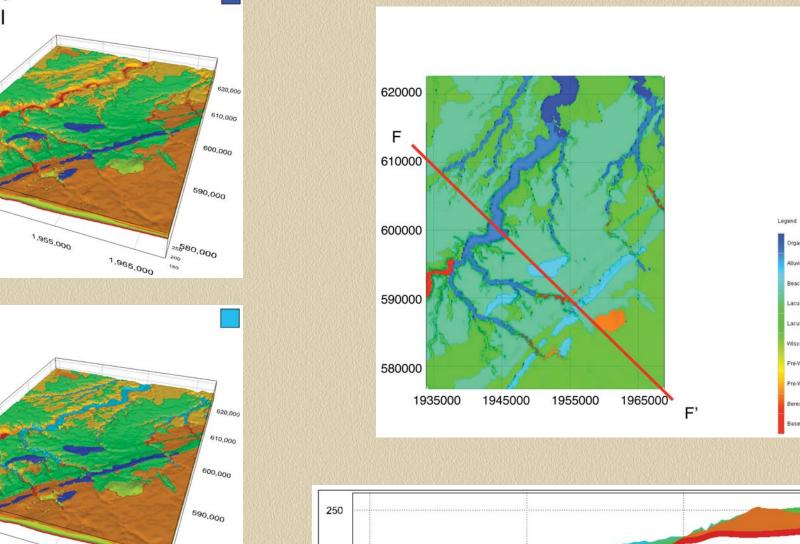


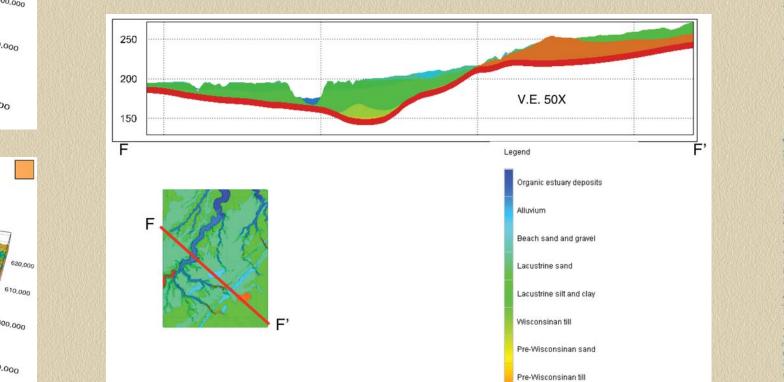








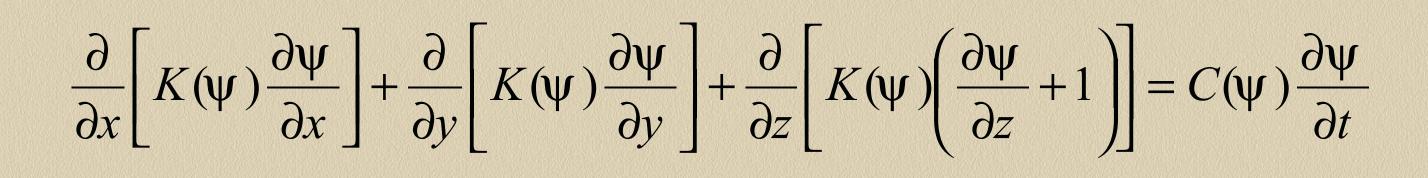




GROUNDWATER MODEL AND FINITE-DIFFERENCE GRID

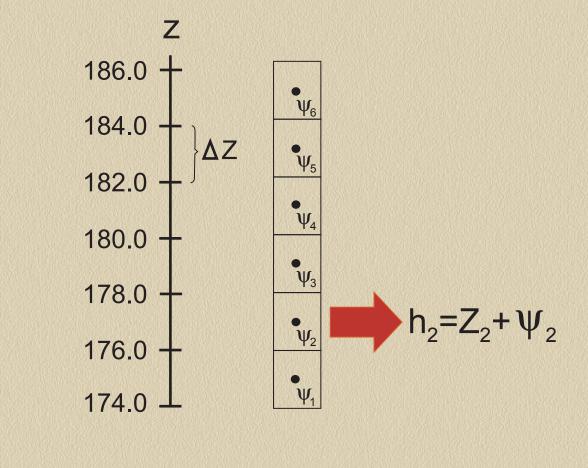
It is necessary to have a numerical model capable of handling variably-saturated flow subject to a heterogeneous distribution of hydraulic properties and non-uniform

GOVERNING EQUATION OF FLOW (FREEZE, 1971)

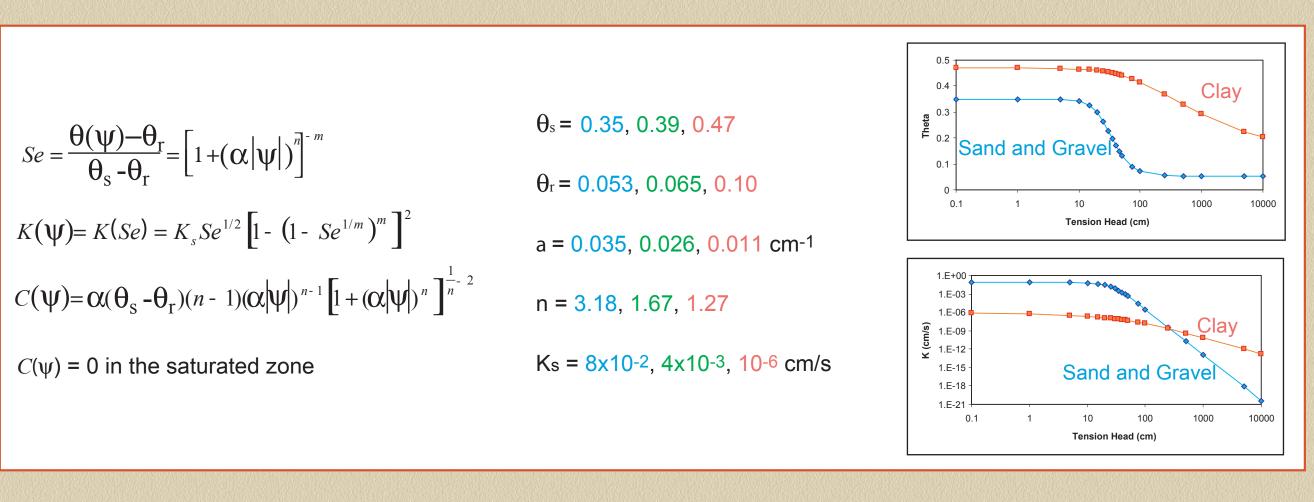


 $K(\Psi)$: hydraulic conductivity, pressure dependent in the unsaturated zone. $C(\Psi)=d\theta/d\Psi$: specific moisture capacity, pressure dependent in the unsaturated zone. Ψ: pressure head, negative in the unsaturated zone.

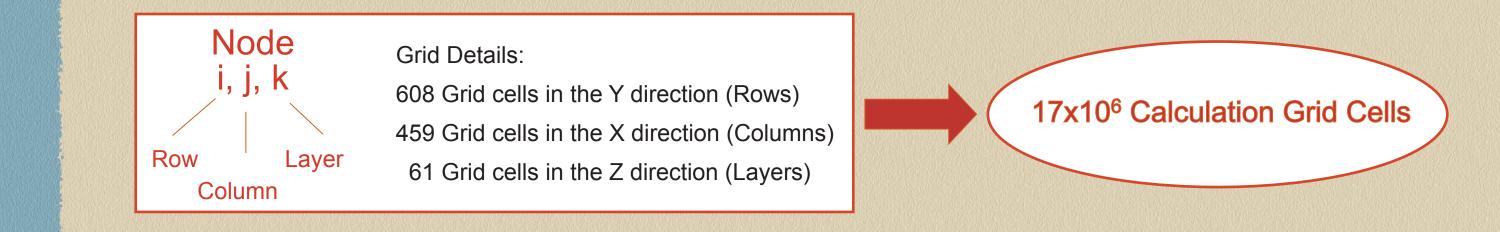
Solving for the pressure head (Y) allows to calculate the hydraulic head (h):



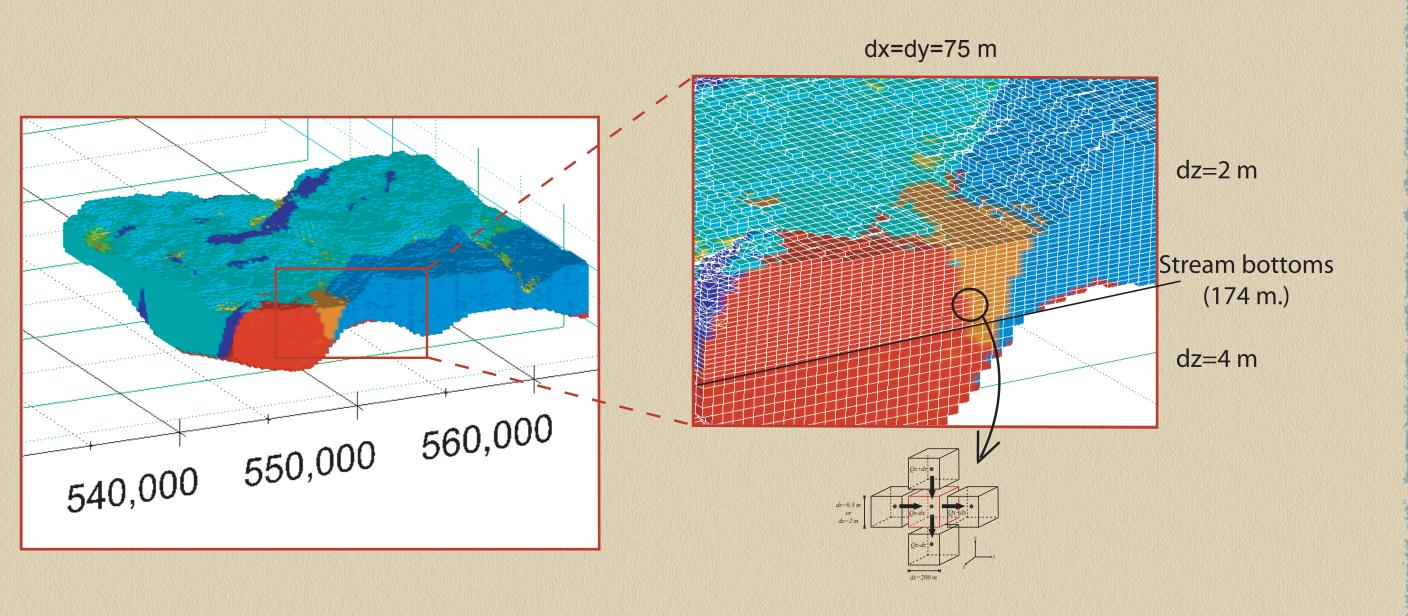
van Genuchten Characteristic Equations:



We created 3-D arrays, where each grid cell node is characterized by: i (row), j (column), k (layer), an ID for van Genuchten characteristic equation parameters as well as saturated hydraulic conductivity and Kh/Kv ratio.



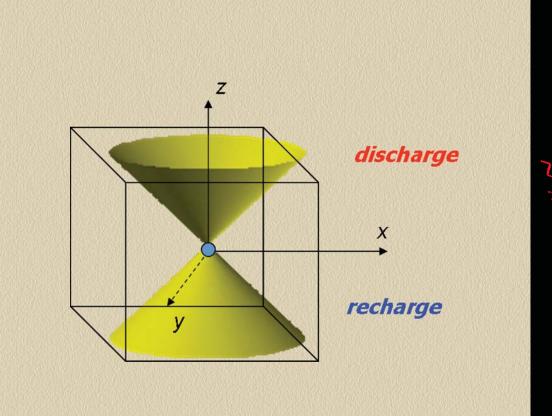
The colors in the figures below represent the 3-D finite-difference grid ("brickpile") at its current resolution. The brickpile was generated from the virtual wells using a custom computer program and is visualized here using 3DIVS.

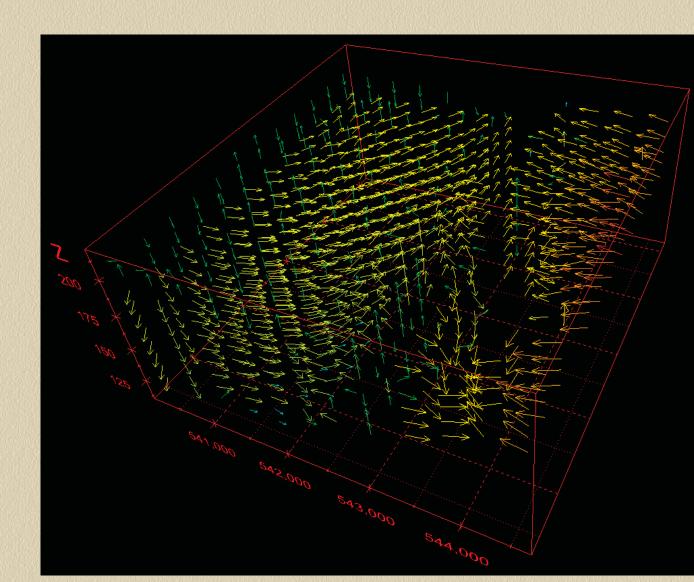


RECHARGE AREA MAPPING

The results of the ground-water flow modeling were used in recharge/discharge area mapping for the Milan Quadrangle. Three-dimensional flow vectors were used to calculate the direction and rate of flow of water from the surface through the unsaturated zone. The results were classified into low, moderate, or high rates of recharge or discharge.

The preliminary results suggest that the vertical spacing of the layers in the unsaturated zone should be reduced to capture details of ground-water discharge.

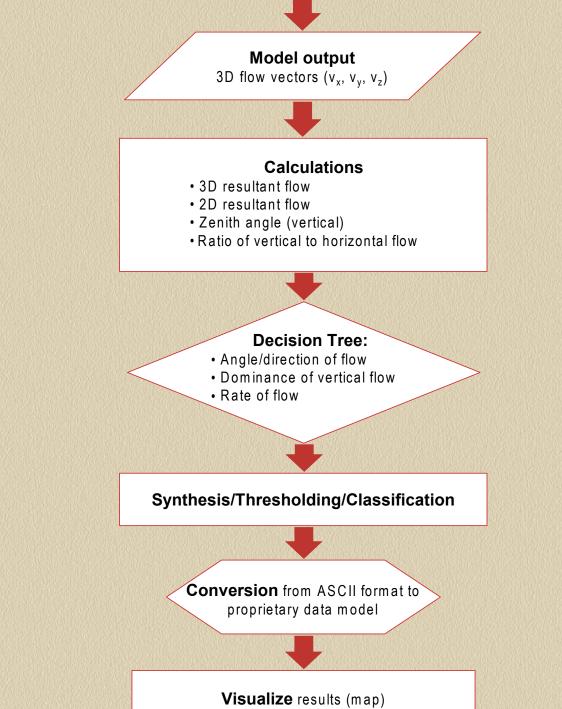


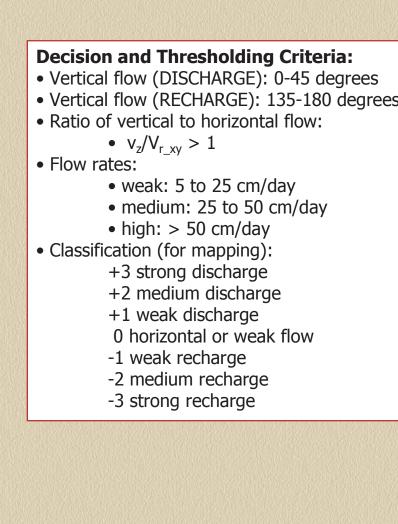


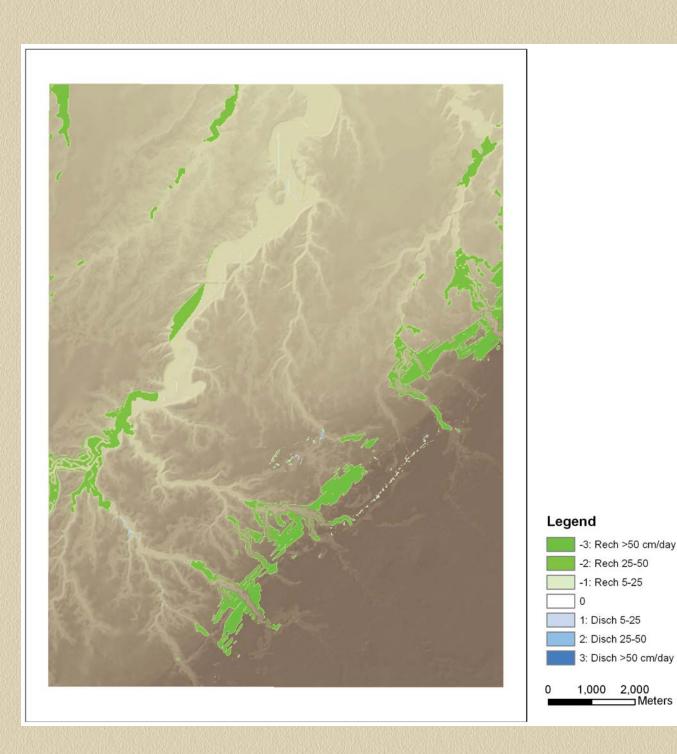
3-D flow at a contact between high andlow conductivity sediments

Investigation of recharge and discharge areas has implications for water supply (if impervious surfaces prevent recharge) and water quality (if urban or industrial areas supply contaminants that migrate directly to the ground-water table). Understanding the hydrologic controls on wetlands can provide guidance in restoring wetlands, or establishing successful wetlands in alternative locations.

THREE-DIMENSIONAL GROUND-WATER MODELING:







Freeze, R. A. 1971. Three-dimensional, transient, saturated-unsaturated flow in a groundwater basin. Water Resources Res., 7, pp. 347-366. Stone, B.D., K.A. Kincare and D.W. O'Leary. 2002. Glacial geology mapping in Berrien County, Michigan: Resolving the third dimension for increasing the actone, B.D., J.R. Stone, J.P. Masterson, and D.W. O'Leary, 2004. Integrating 3-D Facies Analysis of Glacial Aquifer Systems with Ground-water Flow Models: Examples from New England and the Great Lakes Region, USA, in Berg, Richard C., Russell, Hazen and Thorleifson, L. Harvey, (eds): Three-Dimensional

Geological Mapping For Groundwater Applications: 49th annual Meeting Geological Association of Canada, Mineralogical Association of Canada, St. Catherines Ontario, Canada, Workshop Extended Abstracts. Illinois State Geological Survey, Open File Series 2004-8, 100p. Schaap, M. G., Feike, J. L., and van Genuchten, M. Th. (2000). Estimation of the Soil Hydraulic Properties. in Vadose Zone Science and Technology Solutions, Vol. 1, edited by B. B. Looney and R. W. Falta, pp. 501-509, Battelle Press, Columbus, OH.

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