DIGITAL MAPPING TECHNIQUES 2013

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3D Sand Modeling for Characterizing Aquifer and Aggregate Resources

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Introduction

For about two-thirds of Minnesota, aquifers in unconsolidated glacigenic sediment are the predominant source of ground water. These aquifers may be at the land surface, where they commonly host lakes or rivers, and elsewhere they may be buried (covered by younger aquifer and non-aquifer sediments). Three-dimensional maps showing the arrangement of aquifer and non-aquifer materials make it possible to understand connections between wells, aquifers, and surface water features.

In glaciated terrain, multiple events of glacial deposition and erosion create uniquely complex distributions of materials that make it a considerable challenge to define discrete stratigraphic units at the county level (100k) scale of mapping. The modeling techniques we employ at the Minnesota Geological Survey (MGS) combine a variety of often limited data, geologic interpretation, and the data-handling capability of a geographic information system (GIS) to create three-dimensional depictions of sand and gravel bodies both at the surface and in the sub-surface (Figure 1). The models form the geologic framework that the MGS and other public and private entities use to identify and monitor aquifer as well as aggregate resources.

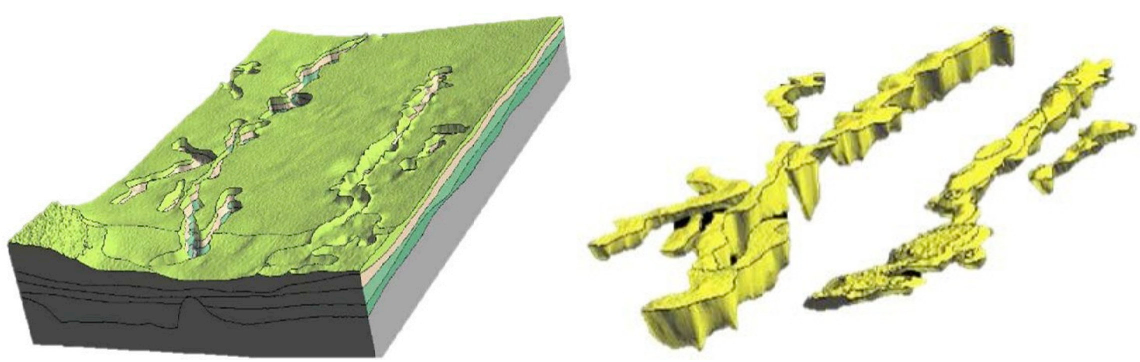

Figure 1. Example of modelling derived three-dimensional depiction of sand bodies with a complex geometry, resulting from deposition in a glaciated landscape. Subsurface extent of sand body is shown in right-hand figure.

Materials and methods

The creation of Minnesota's sand model stratigraphy is implemented through the functional/spatial analysis tools and scripting capability of ESRI's ArcGIS (*http://www.esri.com*). In order to model the subsurface, descriptions and samples from water well records, rotary-sonic core, scientific cutting sets, and auger borings (Figure 2a) are collected from the County Well Index (CWI) database. The collected data is then plotted on closely spaced cross section lines that are generated in a west–east direction (Figure 2b). The geologist provides an interpretation of materials that occur in the areas between wells or at depths not penetrated by wells, based primarily on an understanding of geologic processes (Figure 2c). The distribution of data greatly affects the resolution and accuracy of the models.

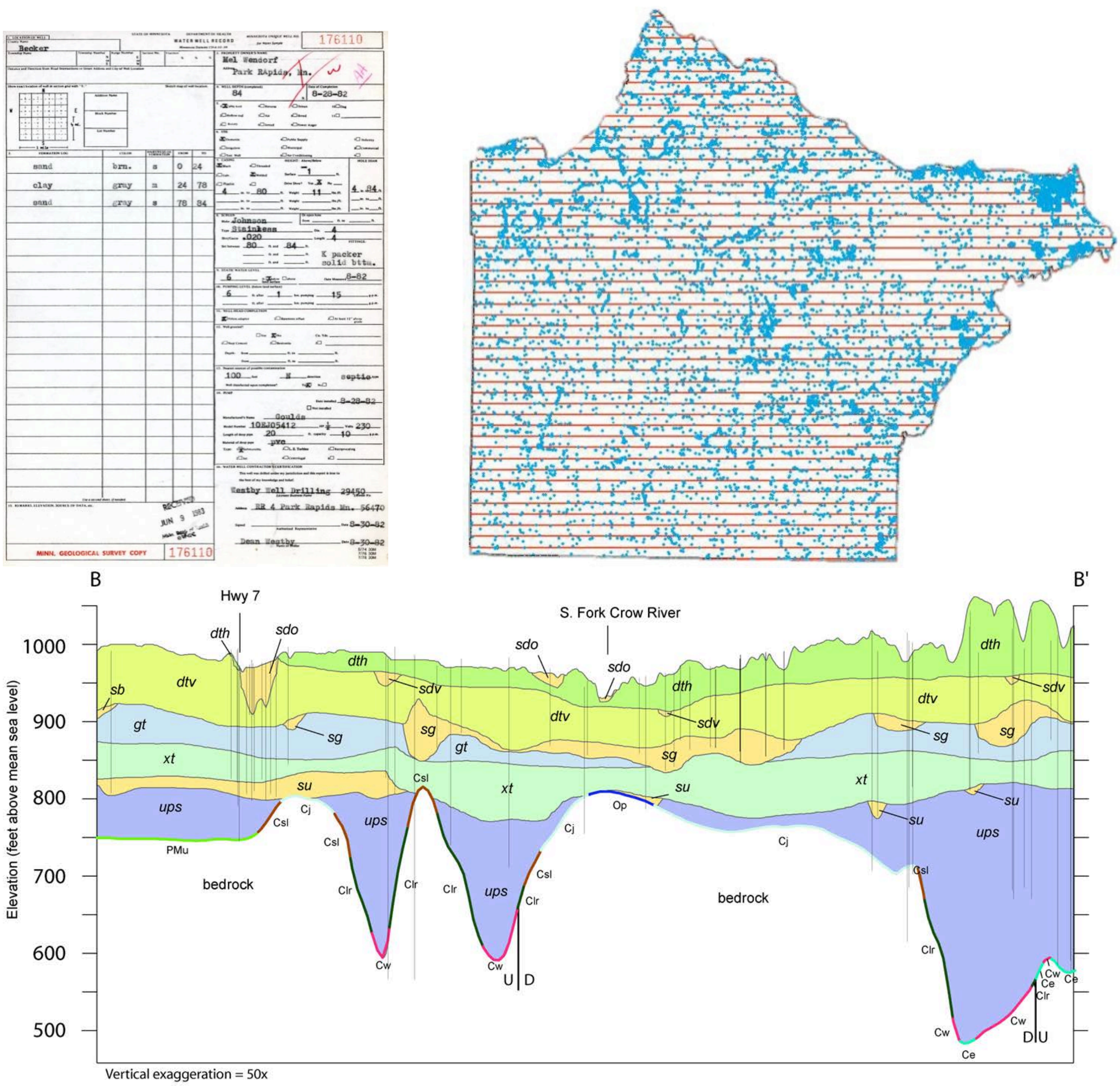

Figure 2. The existing CWI database in maintained by the Minnesota Geological Survey and the Minnesota Department of Health.

(a.) CWI Well Log. This database assists the geologists with creating cross sections across the country

(b.) CWI Well Locations & Cross Sections for Wright County, map view. Each cross section is spaced 1,000 meters apart.

(c.) Geologic Cross Sections. Each cross section traverses the county in an east-west direction.

As our 3D modeling processes have evolved we have tried to improve gridding efficiency and accuracy for the county geologic atlas program. The process used to map discontinuous sand and gravel bodies of variable thickness in Minnesota's Wright County exemplifies this process. The steps illustrated in Figure 3 improved gridding accuracy to more closely match geologists interpretation of the geologic structure of subsurface sand and gravel deposits.

In order to model the subsurface, approximately 10,868 borehole drilling records were used as the primary source of data to construct50 closely spaced cross sections for Wright County. Constructing individual stratigraphic units (Figs. 3a, b, c, d and e) is a tedious task that entails close communication and coordination between the geologist and GIS specialist. The addition of randomized points for each stratigraphic unit increases the grid accuracy and provides additional elevation data. Wright County contains approximately 28 Quaternary stratigraphic units, of which 14 are sand and gravel deposits. Figure 3e displays just one of the 14 units.

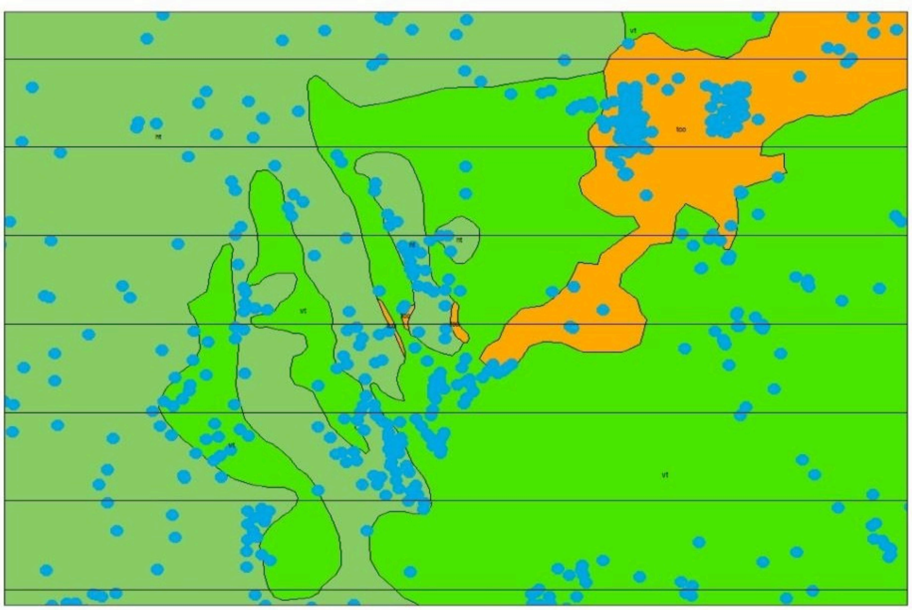

Figure 3a.

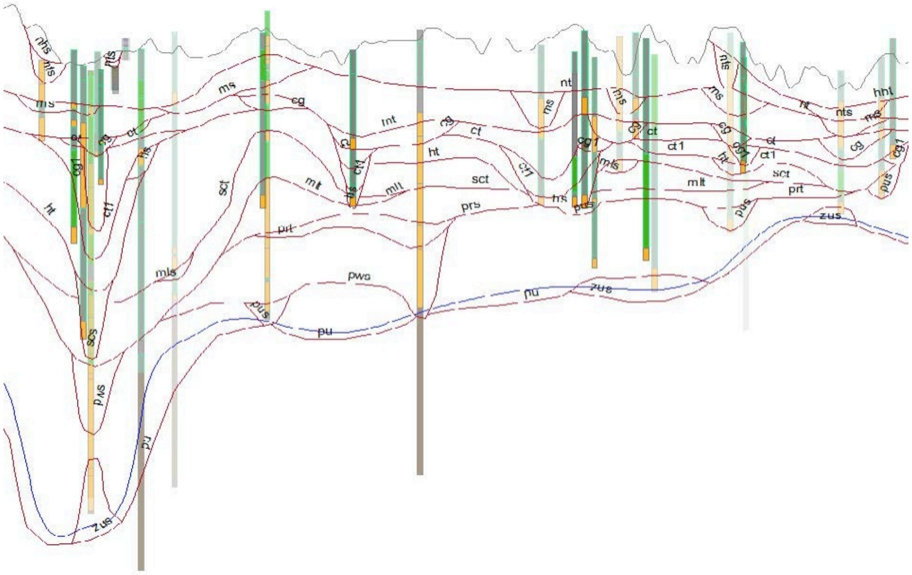

Figure 3b.

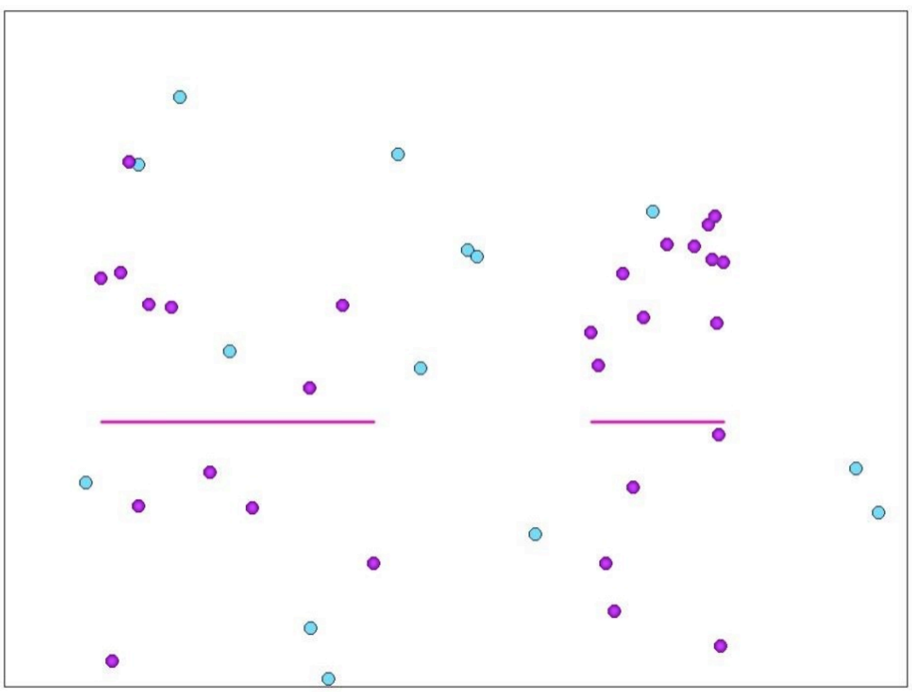

Figure 3c.

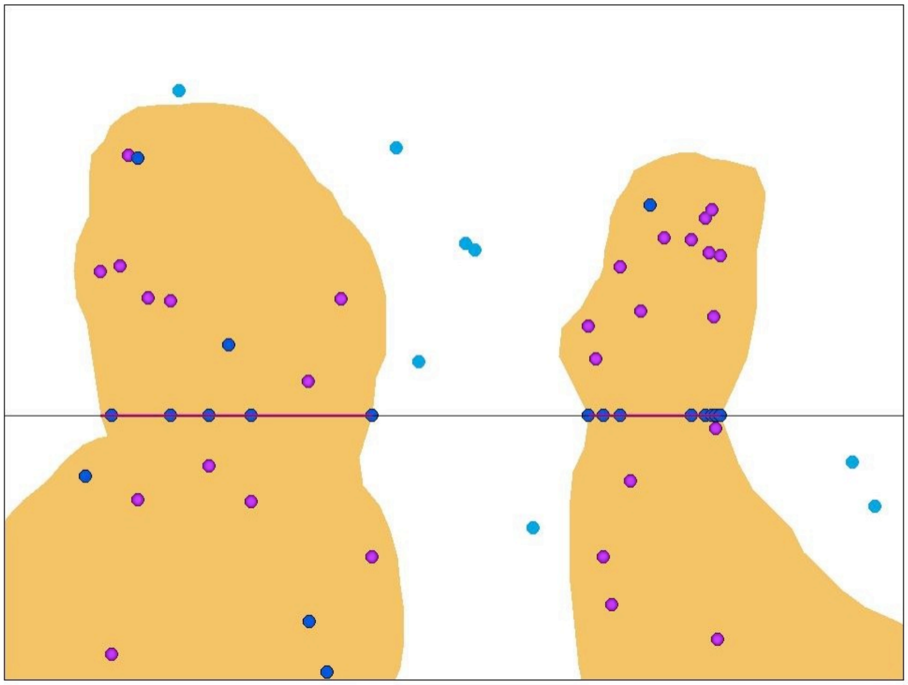

Figure 3d.

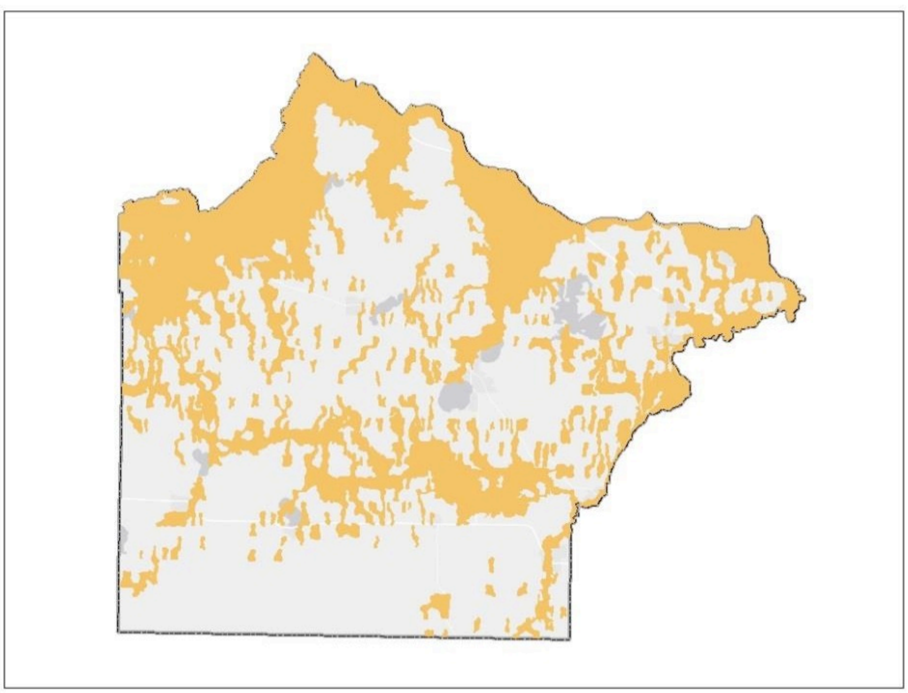

Figure 3e.

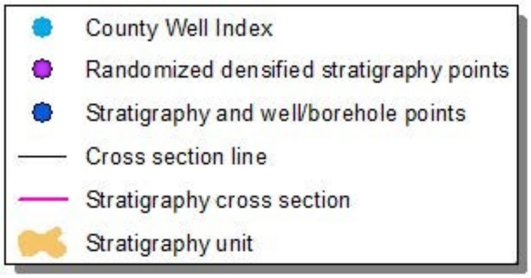

Figure 3. The process of creating 3D stratigraphic units within a county between the land surface and bedrock surfaces.

(a.) This displays the initial data (CWI locations and cross section location) that the geologist uses for the interpretation of the stratigraphic units.

(b.) The geologist digitizes each unit based upon the CWI data. Locations, either boreholes or wells, are included if they fall within 500 meters of each cross section line. The CWI locations fade the further away they are from the cross section.

(c.) Stratigraphic layers are created by a geologist along each cross section. Python scripts are used to extract the layers and plot their projections into a mapview. Additional elevation points from each cross section layer are then randomly distributed north and south of the cross section line to provide additional elevations for the gridding process.

(d.) A geologists then draws a boundary (mask) around the points defining the extent of the stratigraphic unit.

(e.) The final results show a single stratigraphic unit extent within the county.

Using ESRI's Spatial Analyst and MGS Python scripts we create grids for each individual stratigraphic unit. Figure 4 shows the step-by-step process for establishing the top, bottom and unit thickness grids for the stratigraphic units. A digital elevation model (DEM) establishes the initial elevation and then the base of each unit is subtracted from the unit above in the sequence from youngest to oldest (i.e., Malolepszy, 2006). This creates the top, bottom and unit thickness grids for each stratigraphic unit. An example (Figure 5) of Wright County's model shows the surface elevation grid (including well data), two individual sand unit grids and the bedrock elevation grid. During and after processing, the grids are checked against the geologists' original cross sections (Figure 6) for accuracy.

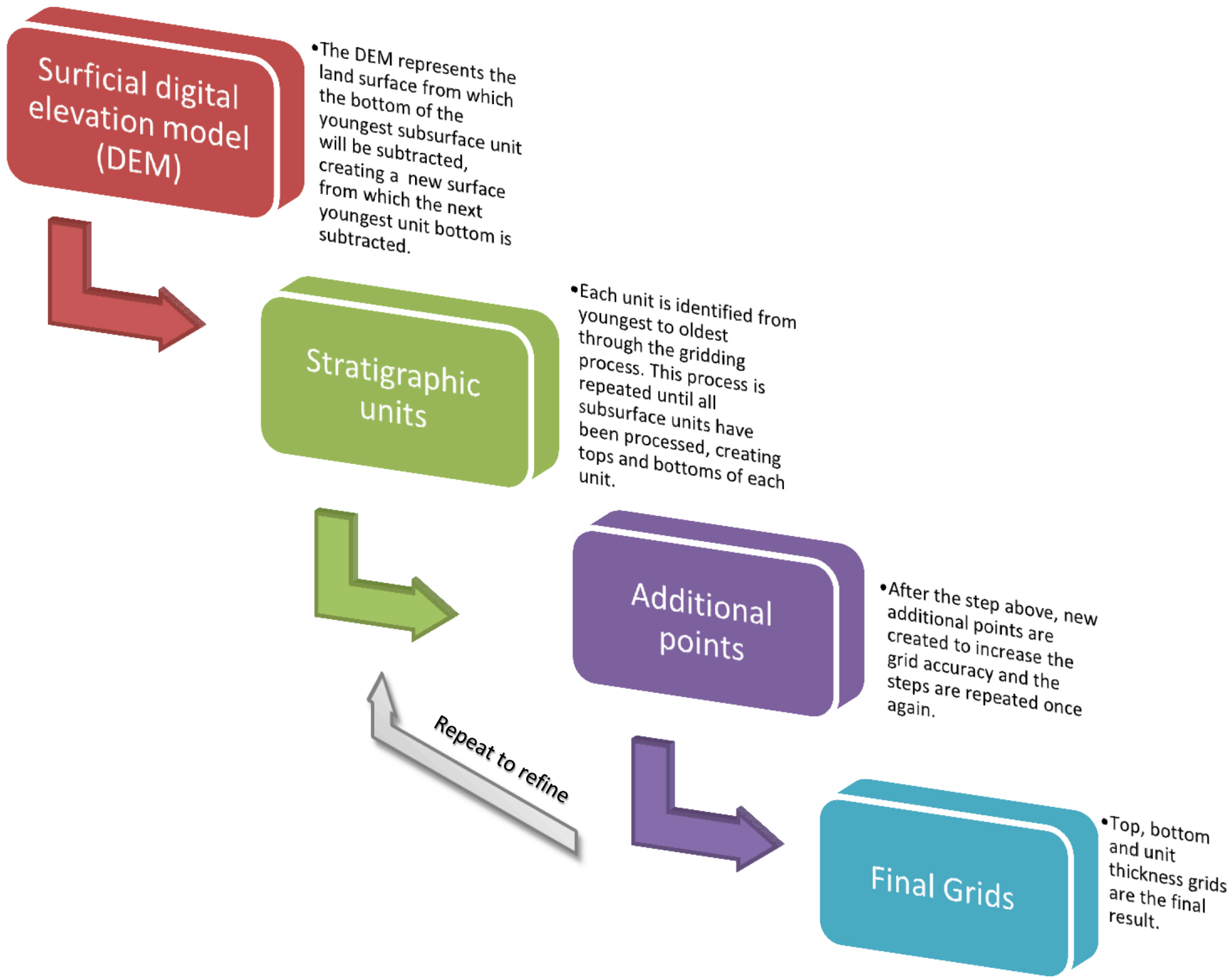

Figure 4---A digital elevation model (DEM) establishes the initial elevation and then the base of each unit is subtracted from the unit above in the sequence from youngest to oldest (i.e. Malolepszy, 2006). This creates the top, bottom and unit thickness grids for each stratigraphic unit.

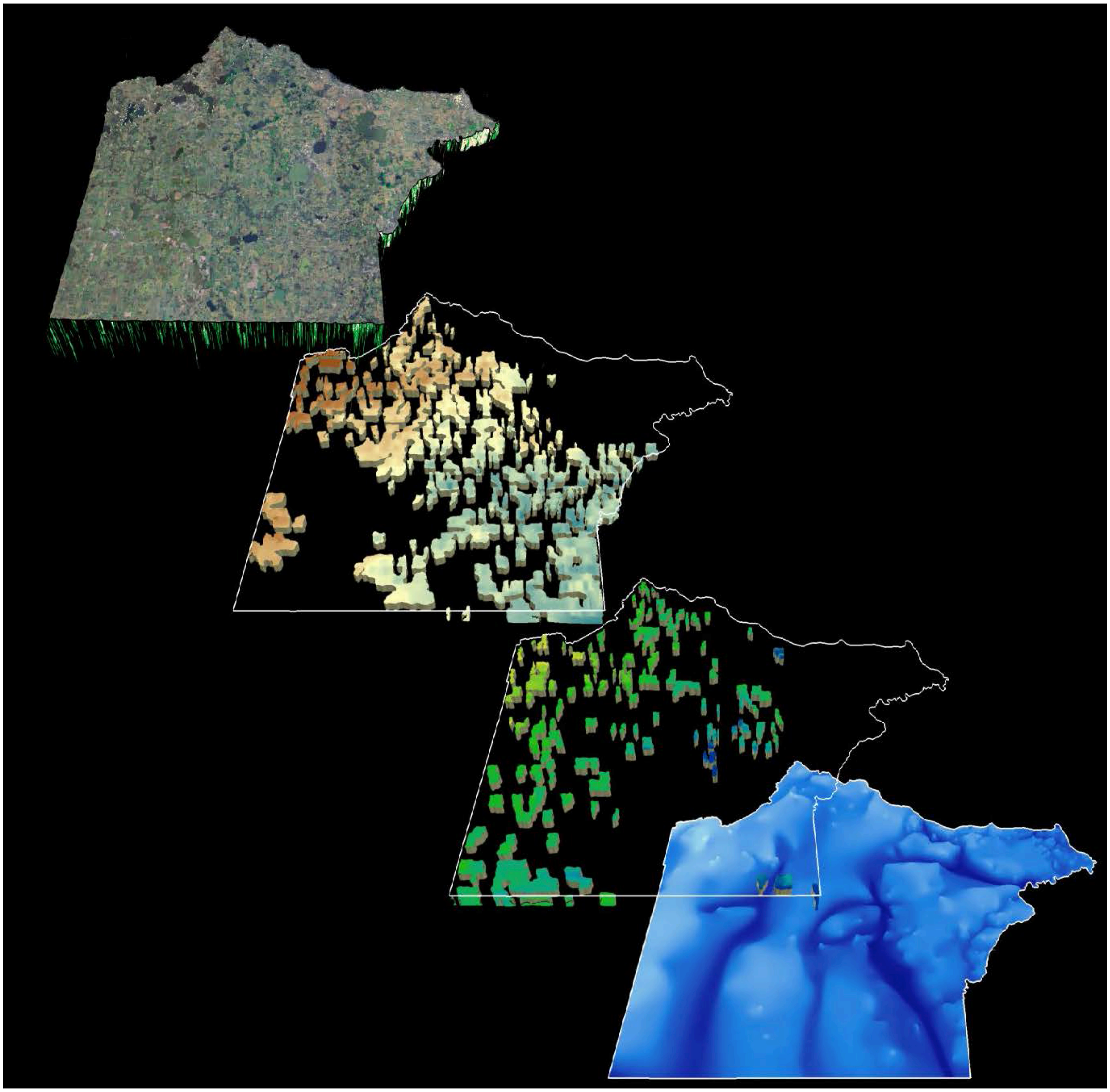

Figure 5. Four grids representing the surface elevation with wells, two (out of 14) stratigraphic sand unit grids and the bedrock elevation grid.

Figure 6. Final grid elevation for a bottom unit (shown in green hatched line) along with the original geologic cross section (shown in red). Profiles of the final grid tops and bottoms of each unit can be checked against the original geologic cross section. This is used to identify any gridding errors and pin point specific locations for making corrections.

Conclusions

Minnesota is one of many states with a glaciated terrain that presents a unique set of problems and complexities for mapping individual stratigraphic units. The use of 3D maps is on the rise, and improvements in technological efficiency and cost effectiveness have aided the mapping process. Many of the mapping technologies today allow the geologist to frame 3D models to closely match their geologic interpretation of the subsurface.

The MGS has been using ESRI's ArcMap software to model glacial deposits at 1:100,000 scale as part of our County Geological Atlas mapping program. Individual stratigraphic units can be modeled separately. The addition of randomized points, as well as additional points along the mask outlines for each stratigraphic unit, increases the accuracy and look of the grid for each unit. The modeling results in turn yield an improved depiction of the distribution of important sands and gravel units, both at the surface and in the sub-surface. These refined 3D models form the geologic framework that the MGS and other public and private entities use to identify and monitor important aquifer and aggregate resources.

Acknowledgments

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