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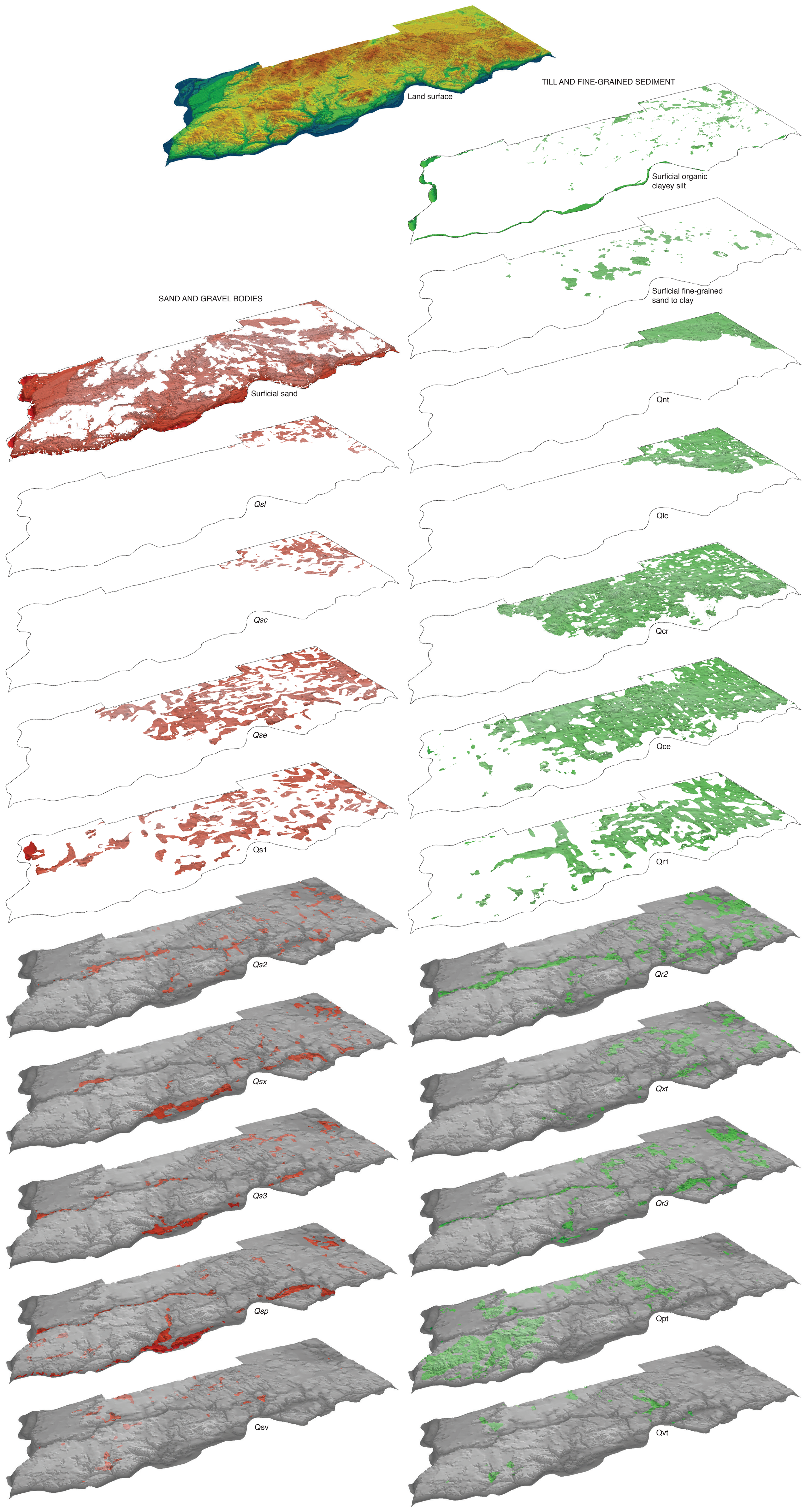
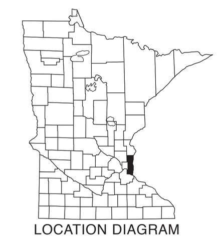


Figure 1. Stacked surfaces from the land surface to the bedrock surface. Major sand bodies underlying Washington County are on the left, with the intervening till and fine-grained bedded sediment layers on the right. Lighter shaded areas are where the surface of each unit (and the bedrock surface) is at higher elevations, and darker shaded areas are where each unit is at lower elevations. The lower units are each superimposed onto the bedrock surface to emphasize their preferential preservation in bedrock valleys.



SAND DISTRIBUTION MODEL

By

Gary N. Meyer and R.S. Lively

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INTRODUCTION

The Quaternary sand and gravel deposits of Minnesota are products of a complex history of multiple glacial events that makes mapping these potential aquifers difficult. However, establishing the location and characteristics of sand and gravel aquifers is an important step toward their wise use and protection. In Washington County, this project employed a process that combines the understanding of a geologist with the data-handling ability of a geographic information system (GIS) to create models showing the distribution in the subsurface of Quaternary sand and gravel deposits that may be aquifers. Although the models and interpretations are based on the best available data, they are unavoidably incomplete due to a lack of data in some areas.

The distribution of sand (which in the following text implies sand and gravel) at the land surface was mapped by the geologist from exposures, shallow drill holes, soil maps, and landforms. In contrast, interpreting sand distribution in the subsurface relied primarily on well and soil boring records, augmented by scientific drill core and drill cuttings. Each well record or drill log describes the vertical sequence of earth materials at one location. It falls to the geologist to predict what materials occur in the areas between wells or at depths not penetrated by the wells. That prediction is based on an assessment of the available data and an understanding of the history and processes that created the sediment. The distribution of data greatly affects the resolution and accuracy of the mapped sand bodies. For example, if the wells are widely spaced, there will not be enough that intersect deposits of limited extent to support accurate mapping of those features. In a similar manner, bodies of sand and gravel that occur at greater depths are typically intersected by fewer wells because shallower bodies of sand and gravel are adequate to supply water and there is no need to continue drilling.

The unconsolidated Quaternary sediments that overlie the bedrock in Washington County vary greatly in character and thickness. These deposits are largely the result of at least ten distinct glacial ice advances during the Pleistocene Epoch (Plate 4, Fig. 2), and therefore most of the Quaternary aquifers within Washington County consist of sand and gravel beds laid down by meltwater that emanated from these glaciers. Layers of unsorted sediment (diamicton) composed of clay to boulder-sized particles deposited directly by the ice, termed "till," as well as fine-grained bedded sediment deposited in ponded meltwater in front of the glaciers, form confining layers (aquitards) that enclose the aquifers. The till layers left by each ice sheet tend to be more laterally persistent than the sand layers, because glacial ice usually spread across the county, whereas meltwater streams that deposited the sand and gravel were generally confined to drainages at the lower elevations of the evolving landscape (Fig. 1). Sand and gravel may be deposited by both an advancing glacier and a retreating glacier of the same cycle, thus till from an ice advance may bury its own sand and gravel as well as material deposited during a previous glacial event. In this report, the depicted sand and gravel bodies have been named after the underlying till or lake sediment (except for those at the land surface; Fig. 2).

Glacial ice and meltwater not only deposited sediments, but also eroded older, underlying sediments, creating a very disturbed "layer cake." A new layer of sand or till could fill a void eroded into an older layer or could completely take the place of an older layer, given sufficient erosion. The net effect of this depositional and erosional activity is that sand bodies which provide water to wells in Washington County tend to be discontinuous. Over relatively short distances in most directions, the extent and thickness of any given aquifer is difficult to predict. In order to address this problem, 63 closely-spaced (0.6 mile [1 kilometer]) cross section lines were generated in a west to east direction, along with one north to south cross section (see Plate 4, Fig. 1). Along these lines, water-well records, and records of scientific and engineering test holes where available (Plate 1, *Data-Base Map*), were used by the geologist to identify contacts between units in the subsurface. The results from the cross section analysis were compiled digitally into grids of top and bottom surfaces and grid thicknesses for each interpreted unit of till and sand. Final interpretations along six of these cross sections are shown on Plate 4.

Till is generally described as "clay" by well drillers. Where two clay (till) layers related to different depositional events were not separated by a sand layer, their contact was recognized by a change in the driller's description of the clay's texture (for example clay/sandy clay/clay and gravel), density, or color. Unfortunately, in Washington County, particularly in the southern portion where most wells were drilled to bedrock, well drillers commonly gave little detail in their logs of the Quaternary section. In general, the more detailed logs in any particular area were given more weight by the geologist in drawing unit boundaries. Using the available data, contact lines were drawn along each cross section, with each line representing the base of a unit of sand and gravel or till. GIS software was used to extract elevation values from vertices along each unit line and convert those into a gridded elevation surface representing the distribution of the unit over the county.

The till and sand surfaces were iteratively modified until the geologist was confident that they adequately represented the areal distribution and stratigraphic interpretation derived from the subsurface data. After the till and sand surface grids representing the base of each unit were final, they were processed through GIS raster calculations to create top and bottom surfaces and a thickness for each geologic unit. The result is a three-dimensional geologic model of tills and sands for the county. Due to the complexity of the glacial deposits, it was not possible to extrapolate all the detail from one cross section to the next, leading to the portrayal of the more widespread units as more continuous than they likely are. East-west oriented lines of small holes in the more extensive subsurface units illustrated in Figure 1 indicate that the mapped areas in between the lines should also have more small holes, and that the units are more discontinuous than portrayed.

Figures 3 and 4 depict fine-grained sediment that overlies the surficial sand and gravel. The more extensive sands portrayed by the geologic model are shown in Figures 5 through 14, ranging from the youngest sands at the land surface to buried, progressively older sands (Figs. 1 and 2). Where saturated, the sand bodies portrayed in Figures 5 through 14 are aquifers. Their capacities for water yield depend on their extent and thickness, as well as factors such as sediment coarseness, degree of sorting, and consolidation. In many places two or more of these sand units form a single aquifer where they are juxtaposed with no intervening till layer (see cross sections on Plate 4). Figure 16 illustrates that some areas in Washington County are underlain by numerous sand bodies, many of which are likely connected, whereas other areas within the county have no mapped sand units.

The geologic model should be considered a guideline for the occurrence and approximate thickness of major sand bodies. The model does not guarantee sand and gravel will be found at all places shown, nor does it preclude them being found where they are not shown. In areas where numerous wells penetrated the shallower sands, so much data were available that much of the detail could not be shown at the map scale. Elsewhere, sands that were too thin or did not extend to neighboring cross sections commonly did not survive the processing that created the multiple surfaces. Because wells typically do not penetrate the complete thickness of sand layers, drillers' logs commonly underreport sand body thickness. As a result, some of the sands shown in cross section (but not necessarily on the final sand distribution map) may be thicker and more widespread than they are portrayed. At increasing depths in the stratigraphic section, data availability diminishes and delineated sand bodies could be more or less discontinuous than shown.

In some parts of Washington County water wells do not extend through the full thickness of the Quaternary deposits. The cross sections on Plate 4 indicate that the characteristics of deeper deposits cannot be differentiated in some places (Fig. 15). However, where deep drill holes occur locally, thicker sands are commonly present. Additional sand bodies, or extensions of those mapped, are undoubtedly present in these undifferentiated parts of the Quaternary section. In spite of these limitations, the geologic model provides a realistic interpretation of where and what kind of geologic units would be encountered in the subsurface of Washington County. However, given the limits of the data, as noted above, the model should be used as a guide and should not preclude further site-specific investigations or inspection of individual well logs.

REFERENCES

Meyer, G.N., and Lively, R.S., 2010, Sand distribution model, pl. 5 *of* Setterholm, D.R., project manager, Geologic atlas of Chisago County, Minnesota: Minnesota Geological Survey County Atlas C-22, scale 1:100,000, 6 pls.

Meyer, G.N., Tipping, R.G., and Lively, R.S., 2013, Sand distribution model, pl. 5 *of* Setterholm, D.R., project manager, Geologic atlas of Anoka County, Minnesota: Minnesota Geological Survey County Atlas C-27, scale 1:100,000, 6 pls.

CONTOURS FOR FIGURES 3 THROUGH 14

Thickness of a sand and gravel unit contoured at 20 foot (6 meter) intervals.

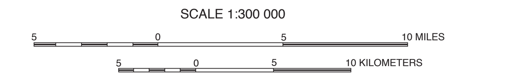
- 20
- 40
- 60
- 80
- 100
- 120
- 140 and greater

Note: Contour lines may not close at the edges of mapped areas. This is an artifact of the digital processing.

DEPTH FOR FIGURES 3 THROUGH 15

- 0–50
- 51–100
- 101–150
- 151–200
- 201–250
- 251–300
- 301–350
- 351–400

Depth in feet from the land surface to the top of a sand and gravel unit (depth from the land surface to the top of undifferentiated sediment is shown on Figure 15).



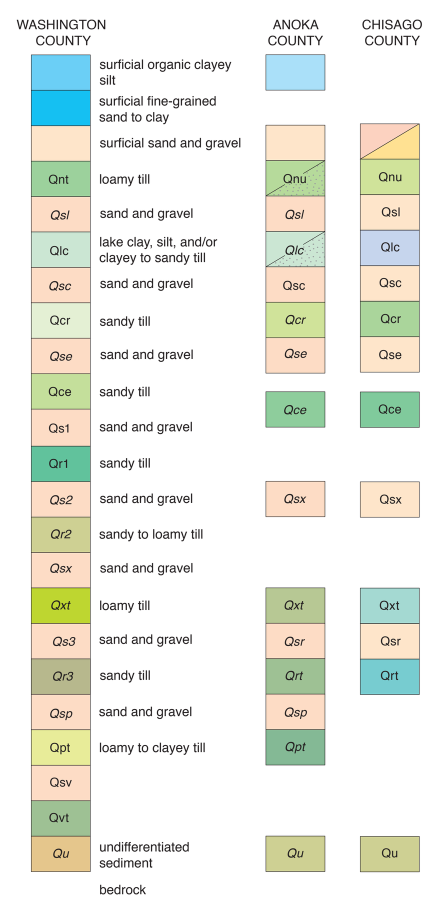


Figure 2. Stratigraphic position of sand and gravel bodies shown on the sand distribution diagrams (Figs. 5 through 14) compared with equivalent units mapped in Anoka (Meyer and others, 2013) and Chisago (Meyer and Lively, 2010) Counties. The patchy, complex, pre-Wisconsinan Episode deposits are divided into more units in Washington County than in Anoka and Chisago Counties, so like-named units are not completely equivalent. Sand units Qs1 and Qs2 are included in unit Qsx in Anoka and Chisago Counties, and till units Qr1 and Qr2 are included in unit Qce in the two counties, as well as in unit Qr1 in places where it is not overlain by unit Qxt.

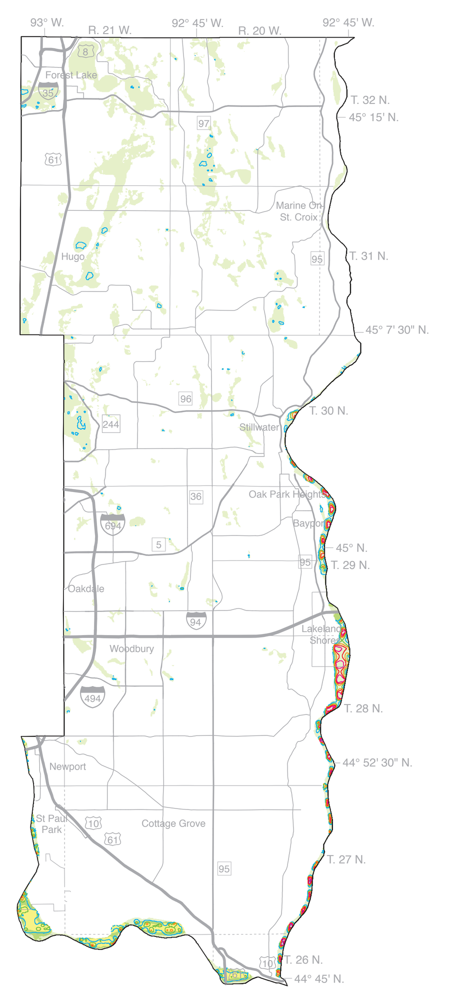


Figure 3. Surficial organic clayey silt—Model-generated map showing the extent and thickness of organic-rich, clayey silt (parts of units Ql and Qa [and units Qp and Ql where it overlies them] from Plate 3, *Surficial Geology*) generally occurring at or near the land surface. Due to its thickness (greater than 150 feet [46 meters]) and complexity, the sediment filling the Mississippi River channel is divided in the digital files into three layers each of organic clayey silt and sand. Only the deepest organic clayey silt layer in the channel is depicted in this figure. Because thick, organic clay and silt below Lake St. Croix is both overlain and underlain in places by sand, the sand is divided into two units in the digital files. The unit depicted on this figure is therefore deeply buried in places below both the Mississippi River and Lake St. Croix.

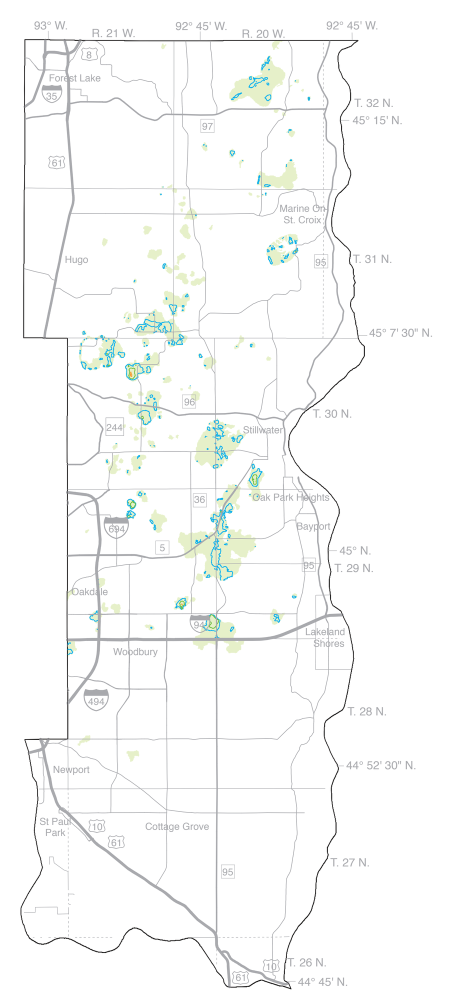


Figure 4. Surficial fine-grained sand to clay—Model-generated map showing the extent and thickness of laminated, fine-grained sand to clay (units Qrl and Qcl [and units Qp and Ql where they overlie them] from Plate 3, *Surficial Geology*) occurring at the land surface.

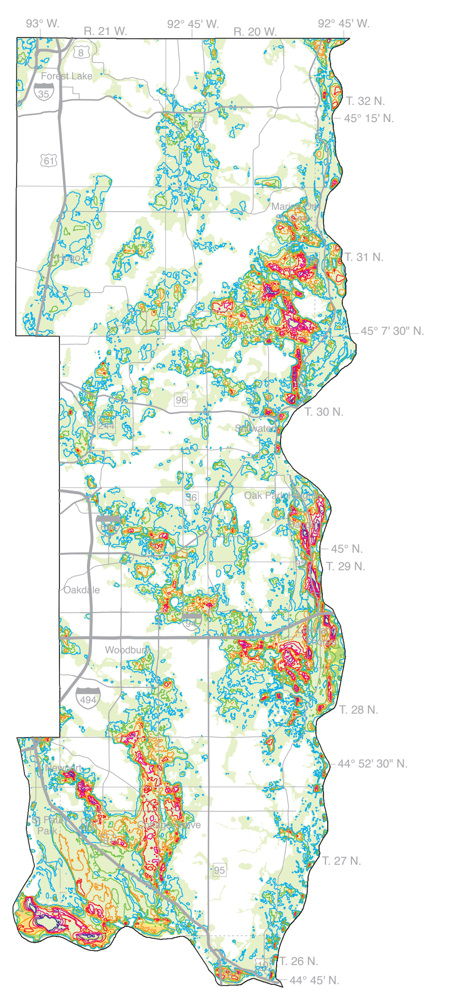


Figure 5. Surficial sand and gravel—Model-generated map showing the extent and thickness of sand and gravel bodies generally occurring at or near the land surface. Includes units Qf, Qbs, Qno, Qco, and Qpo, and parts of units Qa, Ql, and Qrc from Plate 3, *Surficial Geology*. Peat and loess (unit Qp and patterned area, Plate 3) are generally thin where over surficial sand and gravel, so are ignored in the subsurface model. The unit depicted on this figure is deeply buried in places below both the Mississippi River and Lake St. Croix due to their complex history (see the digital files). Where the surficial sand and gravel is below the water table and not overlain by more than 10 feet (3 meters) of fine-grained sediment (Figs. 3, 4, and digital files), it is the surficial aquifer in the area.

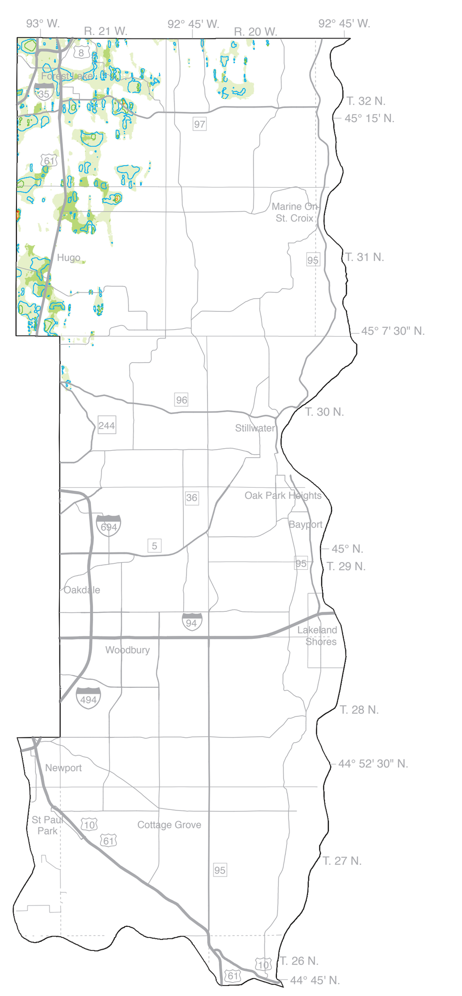


Figure 6. *Qsl* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above laminated silt and clay and/or till of unit Qlc. The broader bodies of sand in the northwest corner of the county consist mainly of reddish, fine- to medium-grained sand laid down in glacial Lake Lind. The narrower bodies to the east and southeast were laid down by streams draining from the retreating Automba phase of the Superior lobe, but also include some pro-glacial sediment from the advancing Grantsburg sublobe.

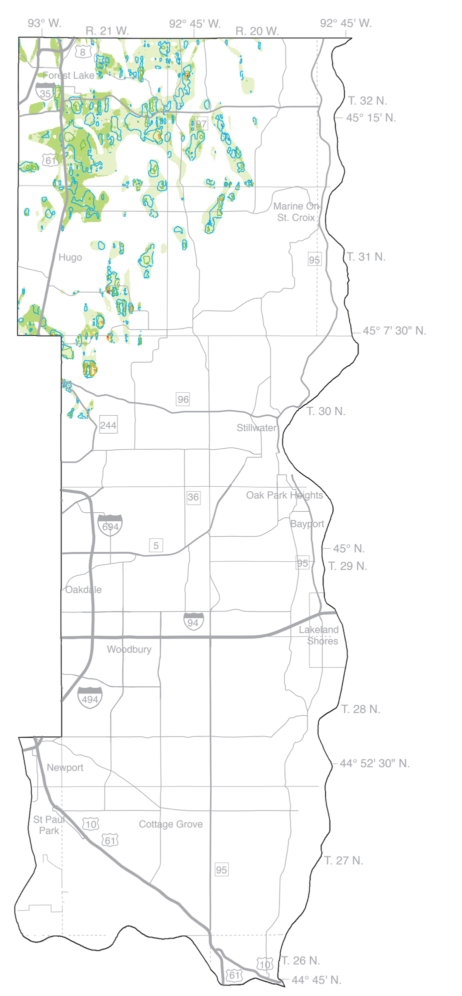


Figure 7. *Qsc* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above sandy till of unit Qcr. Mostly fluvial or deltaic sediment deposited by meltwater from the receding St. Croix phase and advancing Automba phase of the Superior lobe. The thicker deposits are fans laid down at the ice margin.

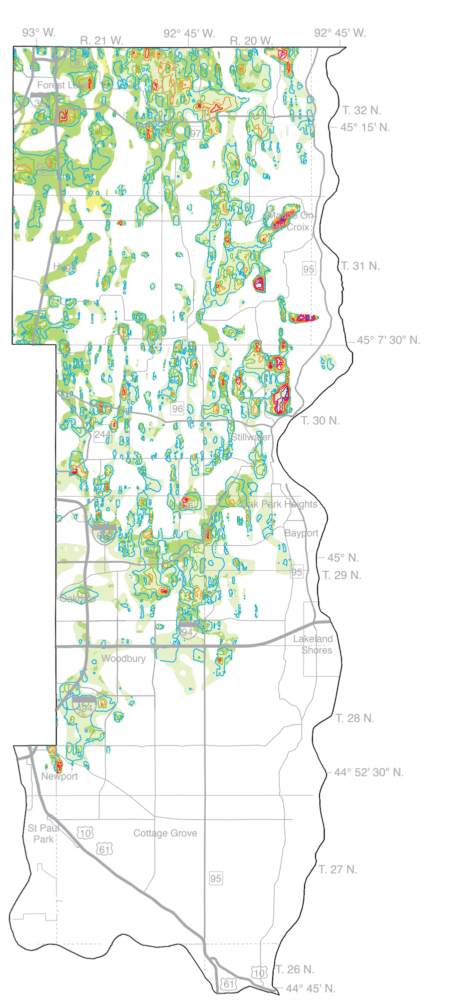


Figure 8. *Qse* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above sandy till of unit Qce. Mostly fluvial sediment deposited by meltwater from the receding Emerald phase and advancing St. Croix phase of the Superior lobe. The thicker deposits are commonly ice-marginal fans.

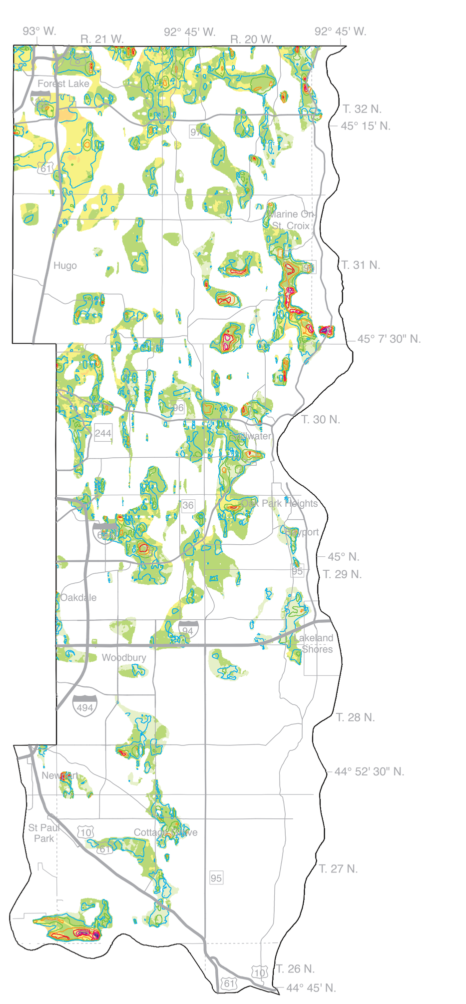


Figure 9. *Qs1* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above (mostly) sandy till of unit Qr1. Mostly pro-glacial outwash of the Emerald phase of the Superior lobe, but includes older deposits. The thicker, more linear deposits were laid down in bedrock valleys.

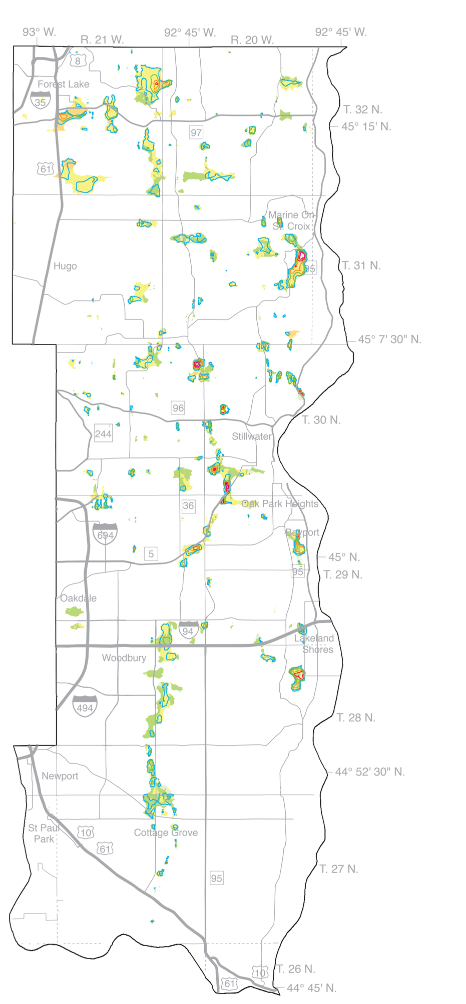


Figure 10. *Qs2* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above sandy to loamy till of unit Qr2. Primarily deposited by meltwater from pre-Wisconsinan Episode ice of Superior provenance. Chiefly preserved in bedrock valleys.

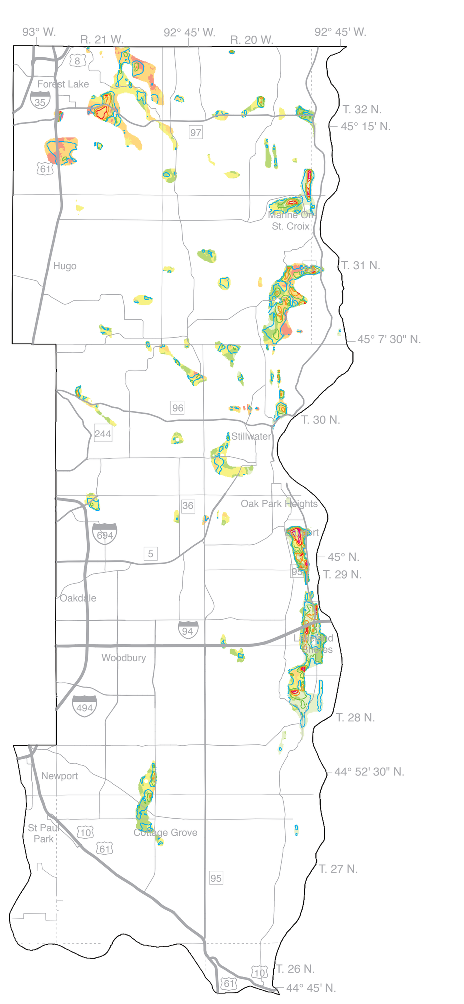


Figure 11. *Qsx* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above loamy till of unit Qxt. Deposited by meltwater from pre-Wisconsinan Episode ice of both Superior and Winnipeg provenance. Chiefly preserved in bedrock valleys.

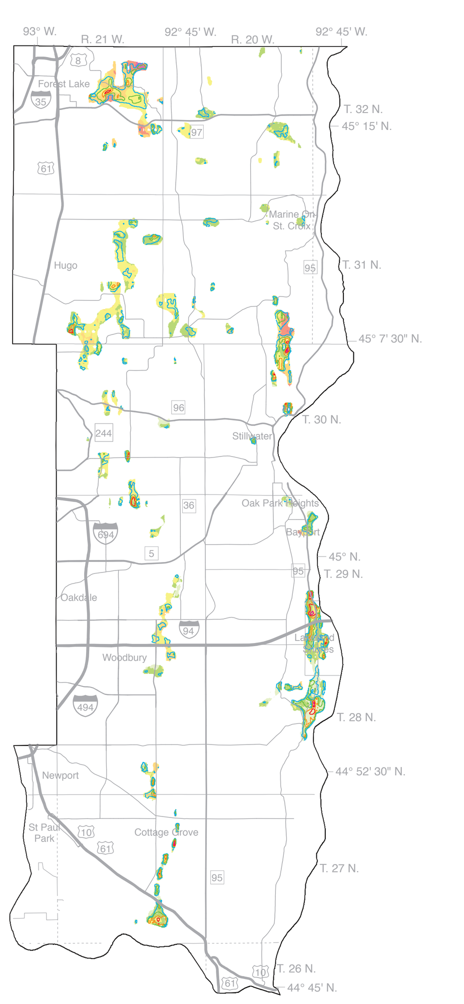


Figure 12. *Qs3* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above (mostly) sandy till of unit Qr3. Primarily deposited by meltwater from retreating, pre-Wisconsinan Episode ice of Superior provenance, but includes some sediment of Winnipeg provenance. Chiefly preserved in bedrock valleys.

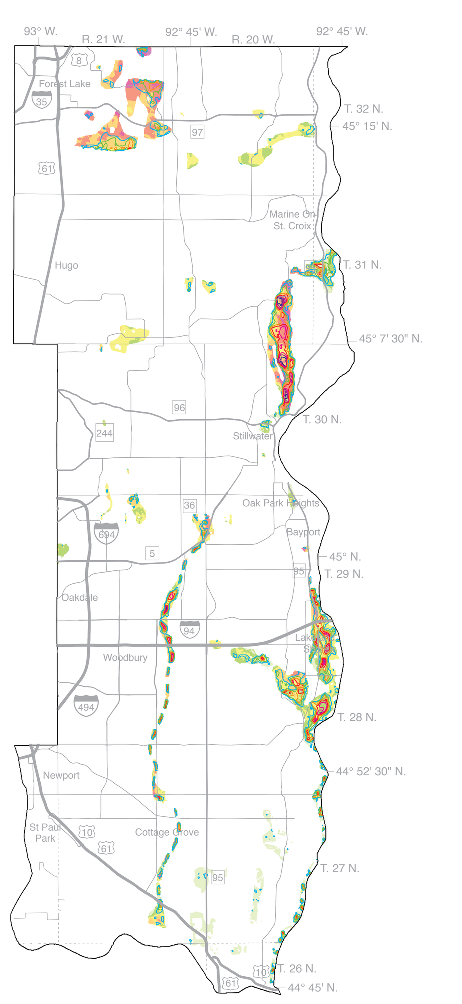


Figure 13. *Qsp* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above fine-textured till of unit Qpt. Primarily deposited by meltwater from advancing, pre-Wisconsinan Episode ice of Superior provenance, but includes some sediment of Winnipeg provenance. Chiefly preserved in bedrock valleys.

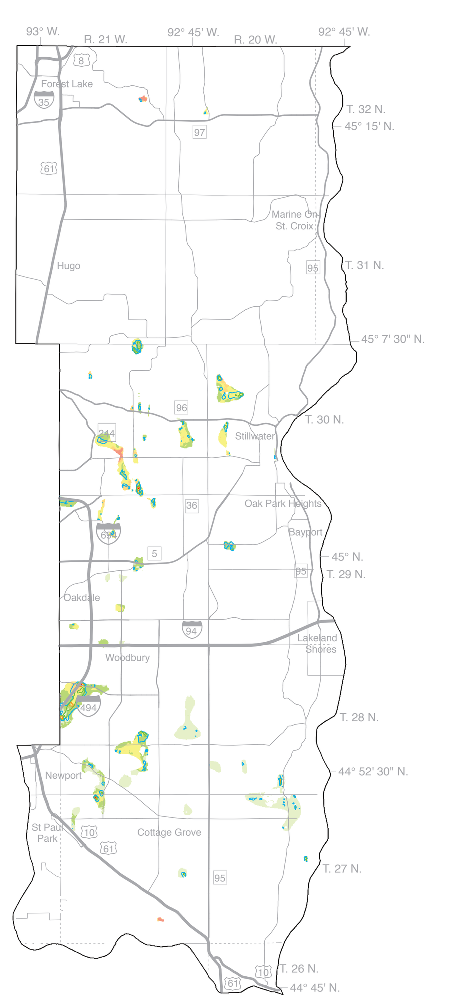


Figure 14. *Qsv* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above (mostly) sandy till of unit Qvt. Deposited by meltwater from pre-Wisconsinan Episode ice of Superior, Winnipeg, and possibly Rainy provenance.

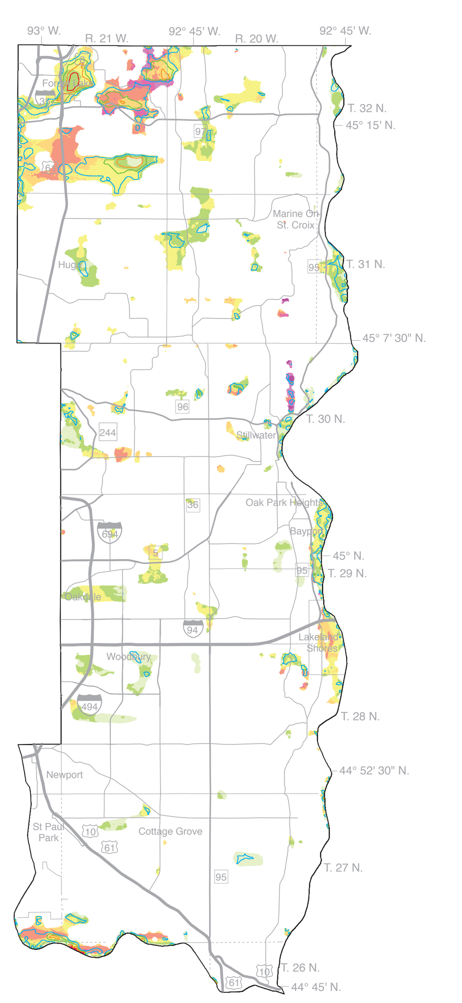


Figure 15. Undifferentiated sediment—Model-generated map of the extent, depth from the surface, and thickness of Quaternary sediment for which little or no descriptive data are available, contoured at 50-foot (15 meter) intervals.

CONTOURS FOR FIGURE 15

- 50
- 100
- 150
- 200
- 250

Thickness of undifferentiated sediment.

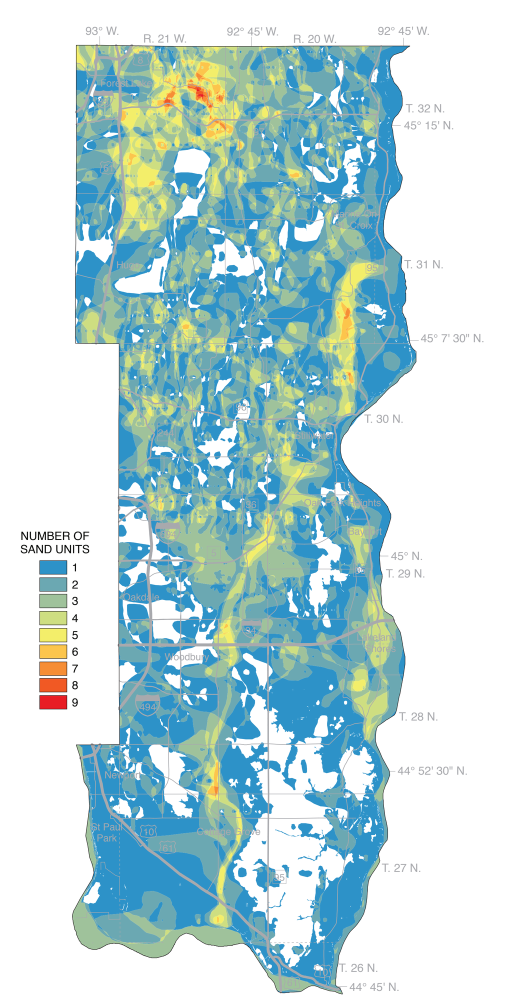


Figure 16. Number of sands below a given point—Model-generated map of the number of sand bodies underlying Washington County. The sand bodies are not necessarily interconnected. Uncolored areas have no mapped sand units.