DEPTH AND THICKNESS OF BURIED AQUIFERS

By

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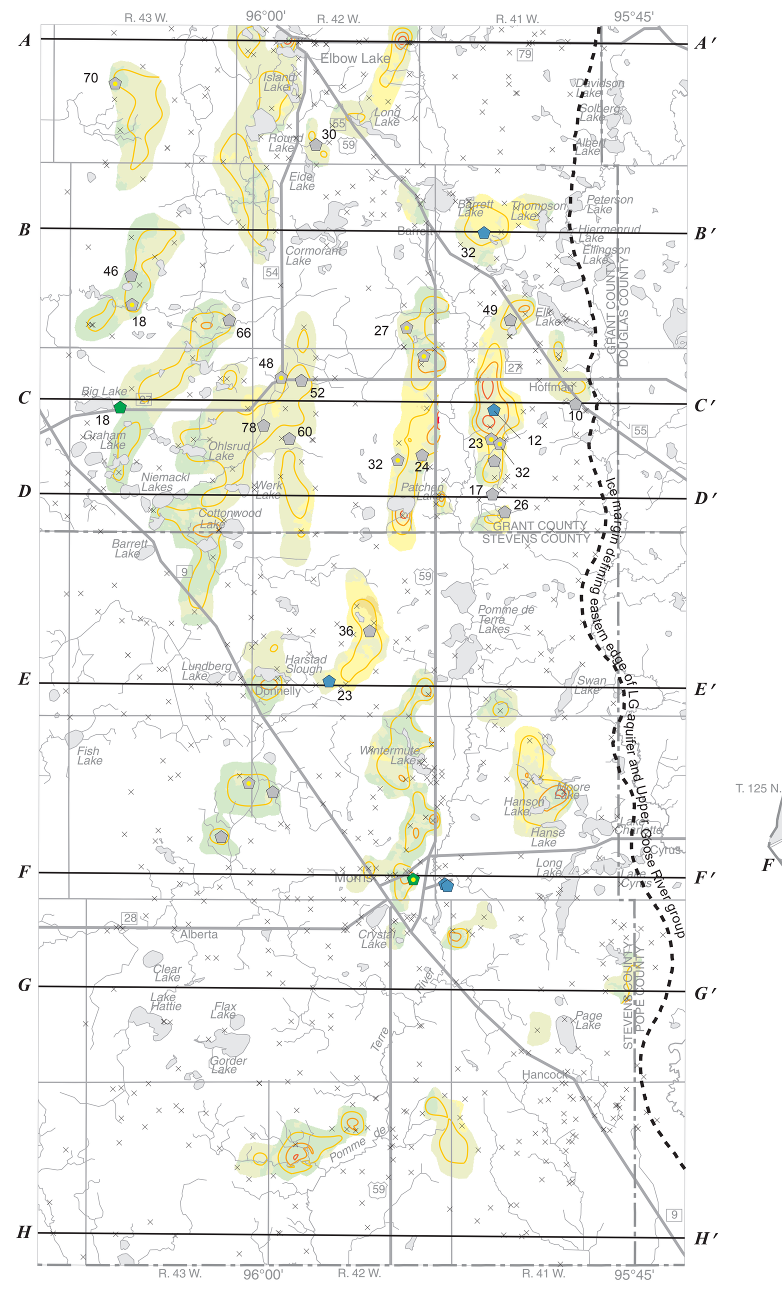

FIGURE 3. *Thickness and depth of sand and gravel deposits on top of the Lower Goose River group (LG aquifer).* *This is the youngest buried sand and gravel deposit in the study area. The extent of the deposit is defined by the extent of the overlying Upper Goose River group, which approximately coincides with ice margin 5 (Plate 1, Part A) to the east and an erosional edge of the Upper Goose River group to the west (not shown). The mostly north-south-oriented sand and gravel deposits typically have limited extent and moderate thickness (20 feet to 40 feet). Depths to the top of the deposit vary from 60 feet to 120 feet.*

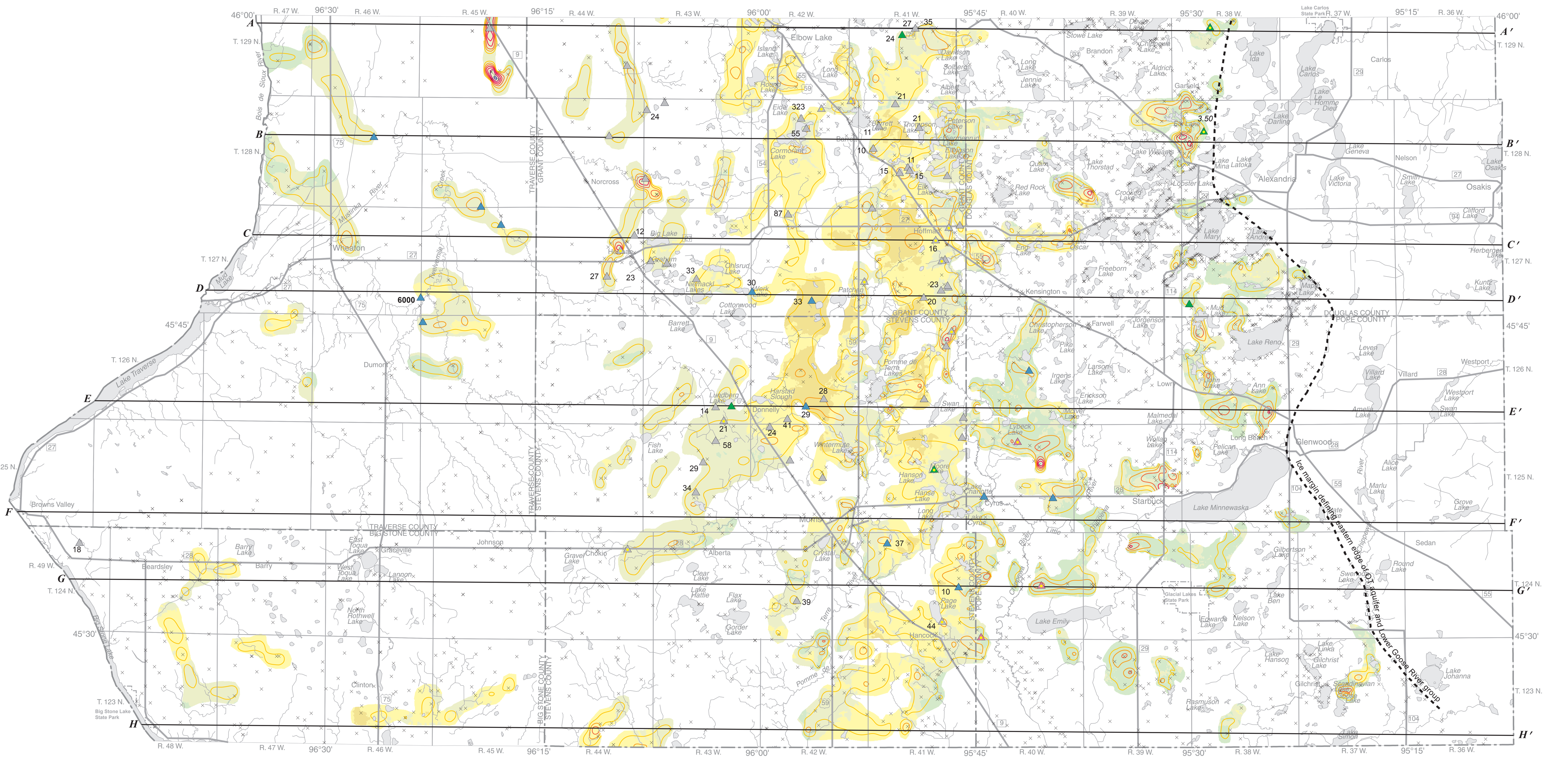

FIGURE 4. *Thickness and depth of sand and gravel deposits on top of the Otter Tail River group (OT aquifer).* *This is the youngest buried sand and gravel deposit in the study area, except where it is overlain by the deposit on top of the Lower Goose River group (LG aquifer) in the central portion of the study area. The extent of the deposit is defined by the extent of the overlying Lower Goose River group, which approximately coincides with ice margin 3 (Plate 1, Part A) to the east. The western edge is beyond the study area in the Dakotas. Typical sand and gravel deposits have limited extent, are laterally continuous, and are moderately thick (20 feet to 40 feet) and thicker (greater than 50 feet). The depths to the top of the deposit are highly variable, ranging from 20 feet to 150 feet.*

SCALE 1:250 000
COMPILATION SCALE 1:100 000
5 4 3 2 1 0 5 10 15 MILES
5 4 3 2 1 0 5 10 15 20 KILOMETERS

INTRODUCTION

Buried sand and gravel aquifers are an important ground-water resource throughout the study area for domestic, municipal, and industrial use. The locations of buried sand and gravel aquifers, however, are often difficult to map. Our knowledge of these aquifers primarily depends on drill hole information, and the reliability of the aquifer maps depends on the spatial density of that information. A mapping method using closely spaced cross sections was successfully used for some previously published geologic atlases (Berg, 2006; Tipping, 2006; Meyer and Lively, 2007; Petersen, 2007) and other reports (Thorleifson and others, 2005) and was also used to produce the maps on this plate. A brief description of the assumptions and methods used for this project is provided to help the user understand the strengths and limitations of these maps.

Quaternary Stratigraphy, Lithology Database, and Mapping Methods

"Quaternary" is the geologic age since the beginning of the ice age (Pleistocene) to the present. This is the period during which all the important aquifer sediments were deposited in the region by advancing and receding glaciers. Stratigraphy refers to the sequence of the various layers in these sediments. The stratigraphy of this region was developed during the Part A assessment from analysis of geologic materials from a limited number of surface exposures, shallow augered holes, and six deeper (150 feet to 200 feet) rotosonic core samples. This stratigraphic information was extrapolated across the region using lithology data from the County Well Index (CWI) database. A simplified regional cross section (Figure 1) shows the vertical and lateral relationships of fine-grained glacial sediments (glacial till) and sand and gravel deposits that are mapped. These deposits are also considered aquifers across most of the region. "Lithology" refers to descriptions by drillers and geologists about the types of geologic materials (sand, clay, and silt) that they have recorded from drill hole and outcrop samples. Sand and gravel layers and oxidized till samples (usually described as yellow or brown) were correlated and interpreted to create 66 closely spaced (1 kilometer), west-east cross sections with stratigraphic information extrapolated from the six core locations and the surface geology map on Plate 1 of Part A. This large set of cross sections was used to help create the aquifer maps shown in this report by employing a variety of three-dimensional geographic information system (GIS) methods.

Quaternary History and Sediment Depositional Models

The following geologic sequence of events summarizes the late glacial history of west-central Minnesota, as described in the Part A assessment, and focuses on the deposition of four of the five buried aquifers in this study area. Other aquifers are present beneath these mapped aquifers but could not be delineated across the study area because of a lack of data.

The late glacial history of west-central Minnesota is generally a story of sediment deposition from ice lobes that repeatedly moved into and retreated from the region. The two sources of the ice lobes were in Canada: the Keewatin dome, from which ice lobes flowed into Minnesota from the northwest, and the Labradoran dome, from which ice lobes entered from the northeast (Figure 2). Ice lobes from the northwest are referred to as Des Moines ice lobes. The depositional model for the LG and OT aquifers (aquifers above the Lower Goose River group and Otter Tail River group, respectively, Figures 3 and 4) is based on the assumption of sediment transport to the southwest and south. The ice lobes that created the LG and OT aquifers receded to the northwest and possibly acted as western barriers during sediment transport and deposition in some areas. In the eastern and central portions of the study area, the model for the CW aquifer (aquifer above the Crow Wing River group, Figure 5) is based on the assumption of southwestern movement of sand and gravel from ice lobes that were receding to the northeast. The depositional model for the earlier aquifer 1 (Figure 6) assumes sediment transport to the southwest and south similar to the later LG and OT aquifers. The stratigraphic associations of the western aquifer (Figure 7) in the western portion of the study area are mostly unknown.

THICKNESS AND DEPTH OF BURIED SAND AND GRAVEL DEPOSITS

The most common thickness values for all these buried sand and gravel deposits range from 20 feet to 40 feet. Locally, the deposits can be 80 feet thick or greater. Notably thick portions (greater than 50 feet) of the LG aquifer (Figure 3) in Grant County include an area west of Hoffman and east of the Pomme de Terre River (see also Plate 5, near the middle of cross-section C–C′). The most common depths from the land surface to the top of this aquifer range from 60 feet to 120 feet.

Thick (50 feet or more) portions of the OT aquifer (Figure 4) include the following areas by county: in Pope County, north of Starbuck and west of the Little Chippewa River; in Douglas County, south of Garfield; in northeastern Stevens County, between the Pomme de Terre and Chippewa rivers; in western Grant County, southeast of Norcross; and in northeastern Traverse County. The depth range of the OT aquifer is highly variable since the aquifer occurs across almost all of west-central Minnesota. The depths to the top of this aquifer tend to be shallower (20 feet to 80 feet) in the eastern and western portions of the study area, and deeper (100 feet to 150 feet) in the central portions of the study area.

The thickest portions of the CW aquifer (Figure 5) are in Pope County near Starbuck where the thickness can exceed 100 feet. Elsewhere in the study area, thick portions of the aquifer include the following areas by county: in Stevens County, west and southwest of Morris (greater than 40 feet) and southeast of Donnelly (60 feet); in Grant County, north of Hoffman (greater than 40 feet); and in Douglas County, southeast of Brandon (greater than 60 feet), northwest of Nelson (greater than 60 feet; see Plate 5, near right side of cross-section B–B′) and northeast of Kensington (50 feet). Depths to the top of this aquifer range from 20–40 feet in the eastern portion of the study area, where this aquifer is at the surface or is buried by only one layer of till and outwash, to 100–180 feet in the western portion of the study area, where the aquifer is buried by multiple layers.

Thick portions (greater than 40 feet) of aquifer 1 (Figure 6) in Pope County include areas around Lake Reno, west of Farwell, and south of Lowry in the northern portion of the county (see Plate 5, right side of cross-section E–E′); McIver Lake area northwest of Starbuck in the western portion of the county; southeastern portion of the county west of Brooten; and southwestern areas of the county near the Chippewa River, including areas in adjacent southeastern Stevens County. Even thicker occurrences (50 feet to 70 feet) exist in other parts of the study area, such as locations in eastern Douglas County east of Chippewa Lake, the Osakis area, and the town of Carlos (see Plate 5, right side of cross-section A–A′); several areas all around Alexandria (see Plate 5, right side of cross-section B–B′); and an area east of Hoffman in the western part of the county (shown right of center on cross-section C–C′, Plate 5). In Grant County, thick occurrences of aquifer 1 exist east of Elbow Lake in the Pomme de Terre River area. Depths to the top of this aquifer range from 20–100 feet in the eastern portion of the study area to 100–180 feet in the central and western portions of the study area.

The extent of the western aquifer (Figure 7) is not well defined because few wells are completed in this aquifer. However, a few thick occurrences were identified, such as areas east (40 feet to 130 feet) and south (50 feet to 150 feet) of Beardsley in Big Stone County and areas west (greater than 50 feet) of Barret Lake in northwestern Stevens County. Depths to the top of this aquifer commonly range from 60 feet to 140 feet.

ARSENIC

A previous large-scale study (Minnesota Department of Health [MDH], 2001) found naturally occurring arsenic in well-water samples from a western Minnesota study area that overlaps approximately half of this study area. A high percentage of 900 private drinking water wells in this study area had arsenic concentrations that exceeded the federal drinking water standard of 10 parts per billion (ppb). The combined MDH and DNR dataset of 422 arsenic values for this study area showed 53 percent of water samples exceeded the federal drinking water standard (Figure 8). The elevated arsenic values are common in ground-water samples from wells in glacial sediment deposited by a sequence of ice lobes that moved into Minnesota from the northwest (Des Moines lobe till). The Des Moines lobe till contains approximately 20 percent to 40 percent shale (Table 1, Plate 1, Part A) as a proportion of the sand size fraction. This relatively abundant shale fragment component contains finely disseminated pyrite (an iron sulfide mineral), which may be the dominant source of arsenic and the reason for the association of Des Moines lobe till and elevated arsenic in well-water samples. Erickson and Barnes (2005) confirmed through statistical analysis that this spatial relationship is valid. They also conjectured that fine-grained material (clay and silt) and entrained carbon from wood and plant debris contribute to elevated arsenic in ground-water samples. In addition to this till composition factor, elevated arsenic values are only found in ground water that has little or no dissolved oxygen (reducing conditions).

REFERENCES CITED

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MAP EXPLANATION
Figures 3–7

Tritium age

Color indicates tritium age of water sampled in well.

- Recent—Water entered the ground since about 1953 (10 or more tritium units [TU]).
- Mixed—Water is a mixture of recent and vintage waters (greater than 1 TU to less than 10 TU).
- Vintage—Water entered the ground before 1953 (less than or equal to 1 TU).
- Well not sampled for tritium, but sampled for chloride and bromide.

Well and buried aquifer symbols

- LG aquifer
- OT aquifer
- CW aquifer
- Aquifer 1
- Western aquifer

Map symbols and labels

- 6.08 If shown, nitrate as nitrogen concentration equals or exceeds 3 parts per million.
- 23 If shown, arsenic concentration greater than or equal to 10 parts per billion.
- 2000 If shown, ground-water age in years, estimated by carbon-14 isotope analysis.
- If shown on well symbol, chloride to bromide ratio greater than 175.
- Well log used to map extent of aquifer.
- Ice margin.
- Body of water.
- F F′ Line of cross section.

Depth to aquifer (feet)

- 0–40
- 40–80
- 80–120
- 120–160
- 160–200
- Greater than 200

Aquifer thickness contours (feet)

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

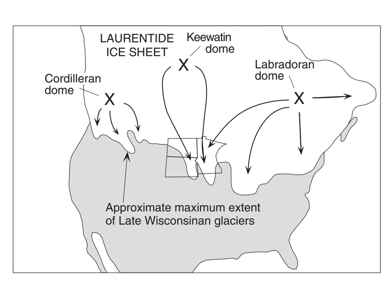


FIGURE 2. *Glacial ice sources.* *Approximate extent of a portion of the Laurentide ice sheet about 15,000 years ago. Arrows indicate possible ice lobe flow paths (modified from Plate 1, Part A).*

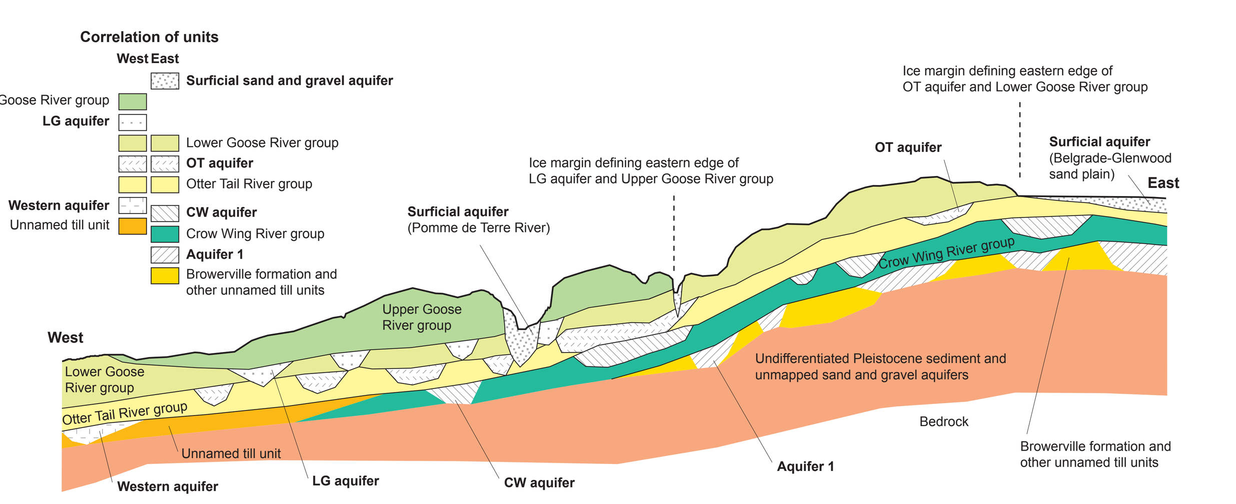


FIGURE 1. *Simplified cross section showing stratigraphy and distribution of aquifers and fine-grained glacial deposits.* *The six aquifers shown in this simplified cross-section diagram exist as complex overlapping layers across west-central Minnesota. Some of these aquifers, such as the OT aquifer, occur across most of the study area, and their boundaries are relatively well known. The extent of the deeper, buried aquifers, such as aquifer 1 and the western aquifer, is not as well known, and the mapped occurrences are limited to only a portion of the study area due to lack of data. The aquifers are interbedded with finer grained glacial sediments (glacial till) that are predominantly clay and silt with varying proportions of sand.*

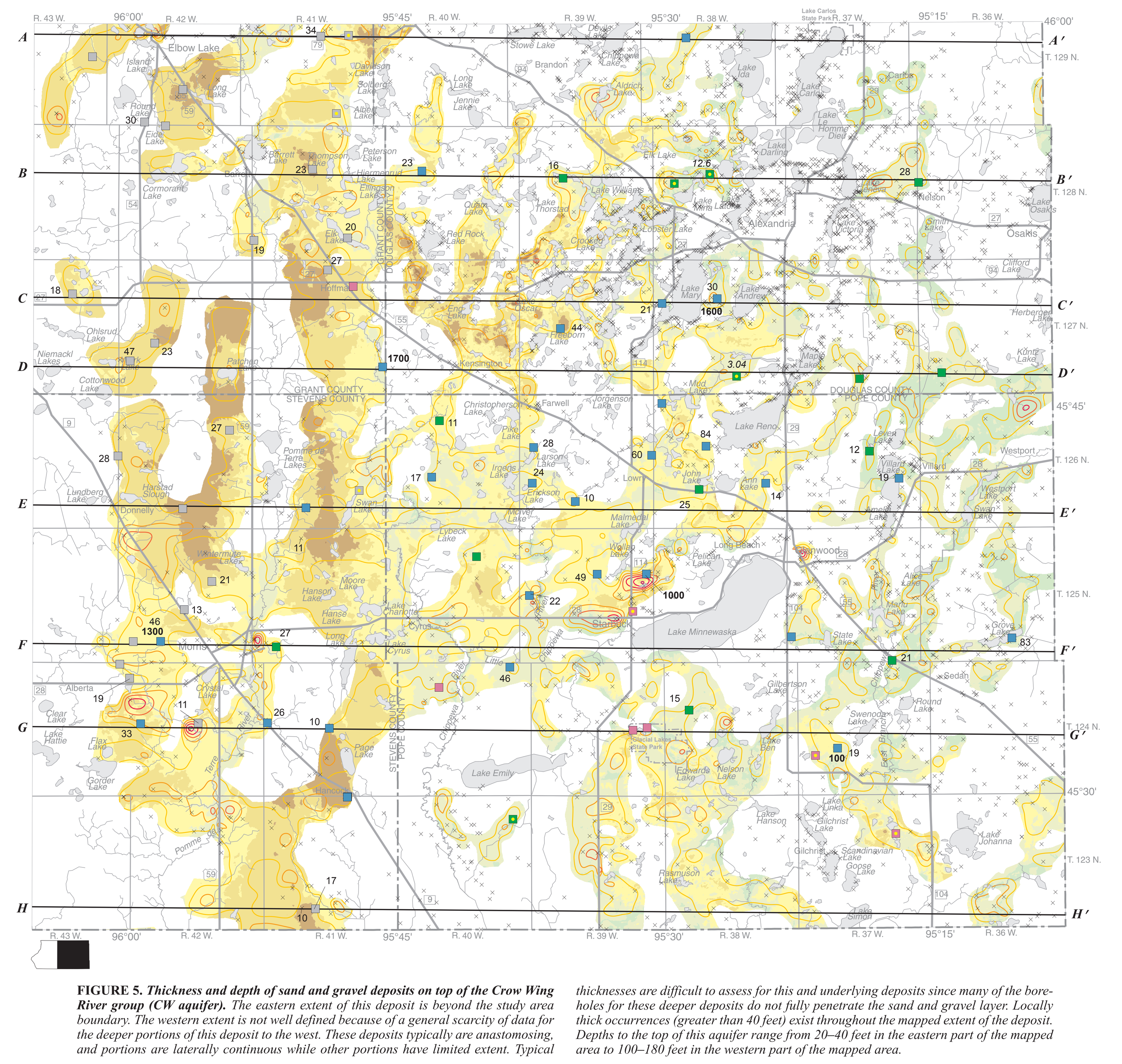
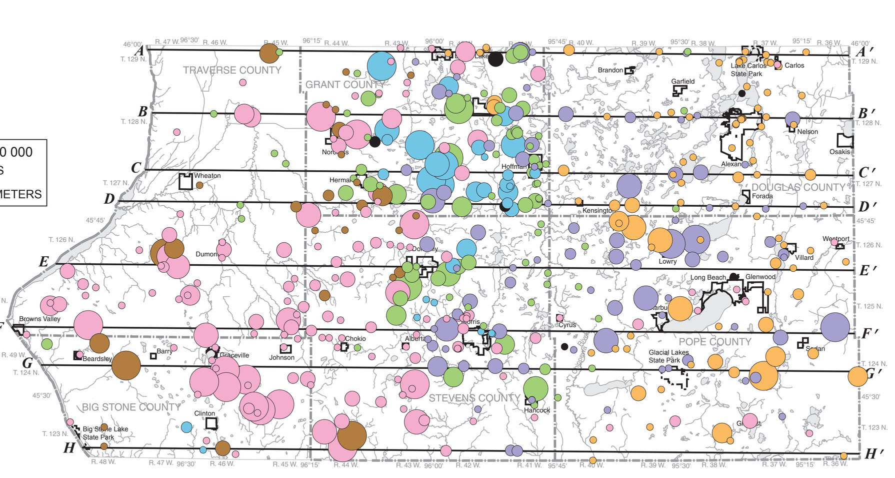


FIGURE 5. *Thickness and depth of sand and gravel deposits on top of the Crow Wing River group (CW aquifer).* *The eastern extent of this deposit is beyond the study area boundary. The western extent is not well defined because of a general scarcity of data for the deeper portions of this deposit to the west. These deposits typically are anastomosing, and portions are laterally continuous while other portions have limited extent. Typical thicknesses are difficult to assess for this and underlying deposits since many of the boreholes for these deeper deposits do not fully penetrate the sand and gravel layer. Locally thick occurrences (greater than 40 feet) exist throughout the mapped extent of the deposit. Depths to the top of this aquifer range from 20–40 feet in the eastern part of the mapped area to 100–180 feet in the western part of the mapped area.*



SCALE 1:750 000
0 2 6 MILES
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EXPLANATION

Aquifer symbols

- Surficial sand and gravel aquifer
- LG aquifer
- OT aquifer
- CW aquifer
- Aquifer 1
- Western aquifer
- Older, unmapped Pleistocene aquifers

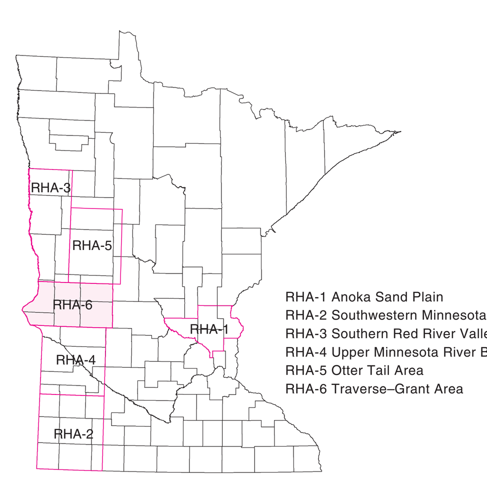
Arsenic concentration (parts per billion)

- 0–10
- 10–20
- 20–30
- 30–40
- 40–50
- Greater than 50

FIGURE 8. *Summary of naturally occurring arsenic values from ground-water samples.* *The arsenic data from ground-water samples from this project (146 values) were combined with 276 values collected by the Minnesota Department of Health (2001). In this figure, all these data are shown as symbol sizes proportional to arsenic concentration and are colored according to the aquifer designations of this project. Within the study area, 53 percent of ground-water samples analyzed for arsenic concentration exceeded the federal drinking water standard of 10 parts per billion (ppb). Although the distribution of these data is not uniform across the region, elevated values appear to dominate in northwestern Pope County, most of Grant County, central and southwestern Stevens County, northern Big Stone County, and southern Traverse County.*

Base modified from Minnesota Geological Survey, Traverse–Grant Area Regional Hydrogeologic Assessment, Part A, 2006.

Project data compiled from 2004 to 2007 at a scale of 1:100,000. Universal Transverse Mercator projection, grid zone 15, 1983 North American datum. Vertical datum is mean sea level. GIS and cartography by Jim Berg and Greg Massaro. Edited by Nick Kroska.



INDEX OF REGIONAL HYDROGEOLOGIC ASSESSMENTS IN MINNESOTA

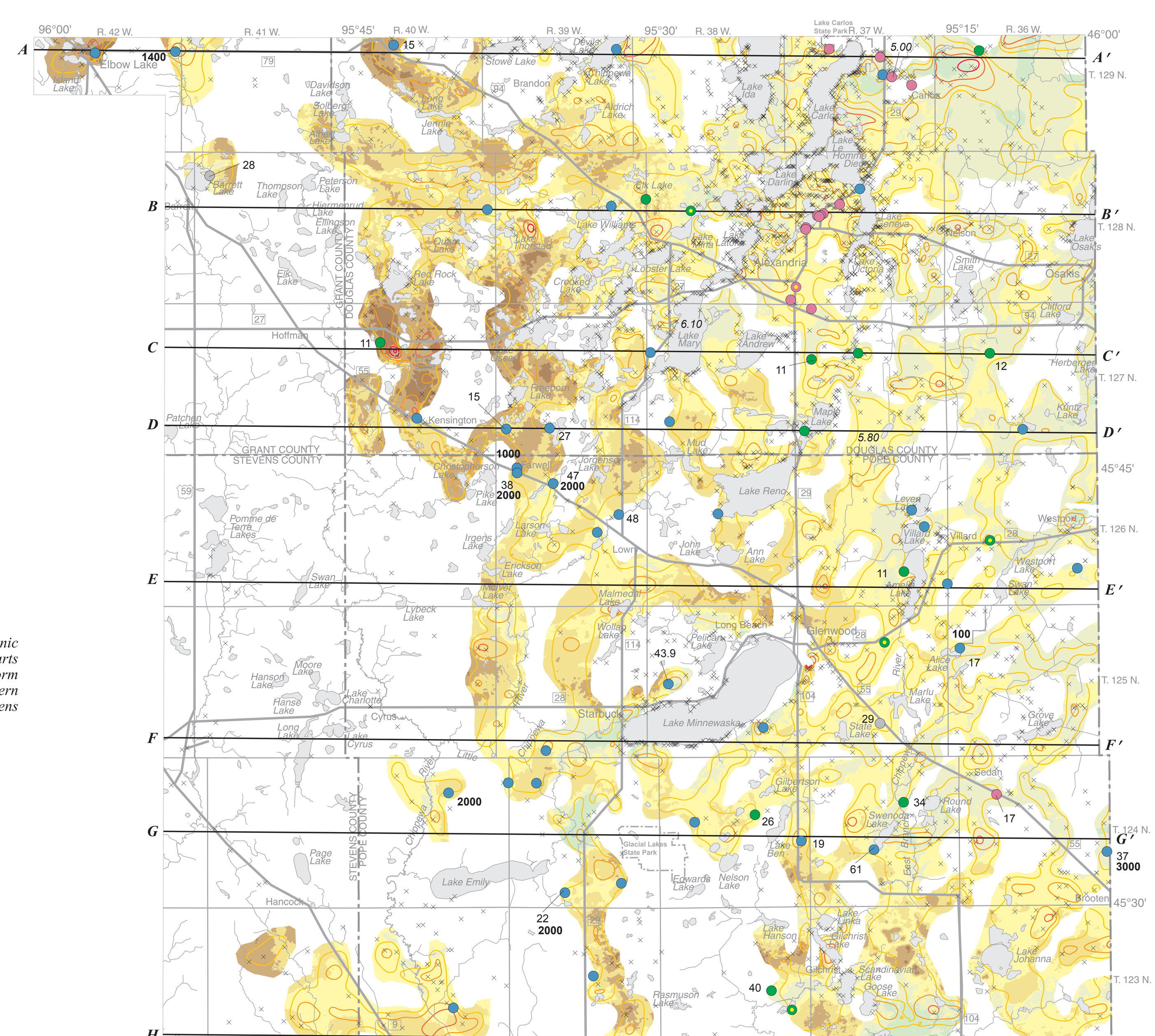


FIGURE 6. *Thickness and depth of sand and gravel deposits on top of the Browerville formation and other unnamed till units (aquifer 1).* *The extent of this deposit is not well defined because of a general scarcity of data. These deposits typically are anastomosing, and portions are laterally continuous while other portions have limited extent. Typical thicknesses are difficult to assess for this and underlying deposits since many of the boreholes for these deeper deposits do not fully penetrate the sand and gravel layer. Locally thick occurrences (greater than 40 feet) exist throughout the mapped extent. Depths range from 20–100 feet in the eastern part of the mapped area to 100–180 feet in the western portion of the mapped area.*

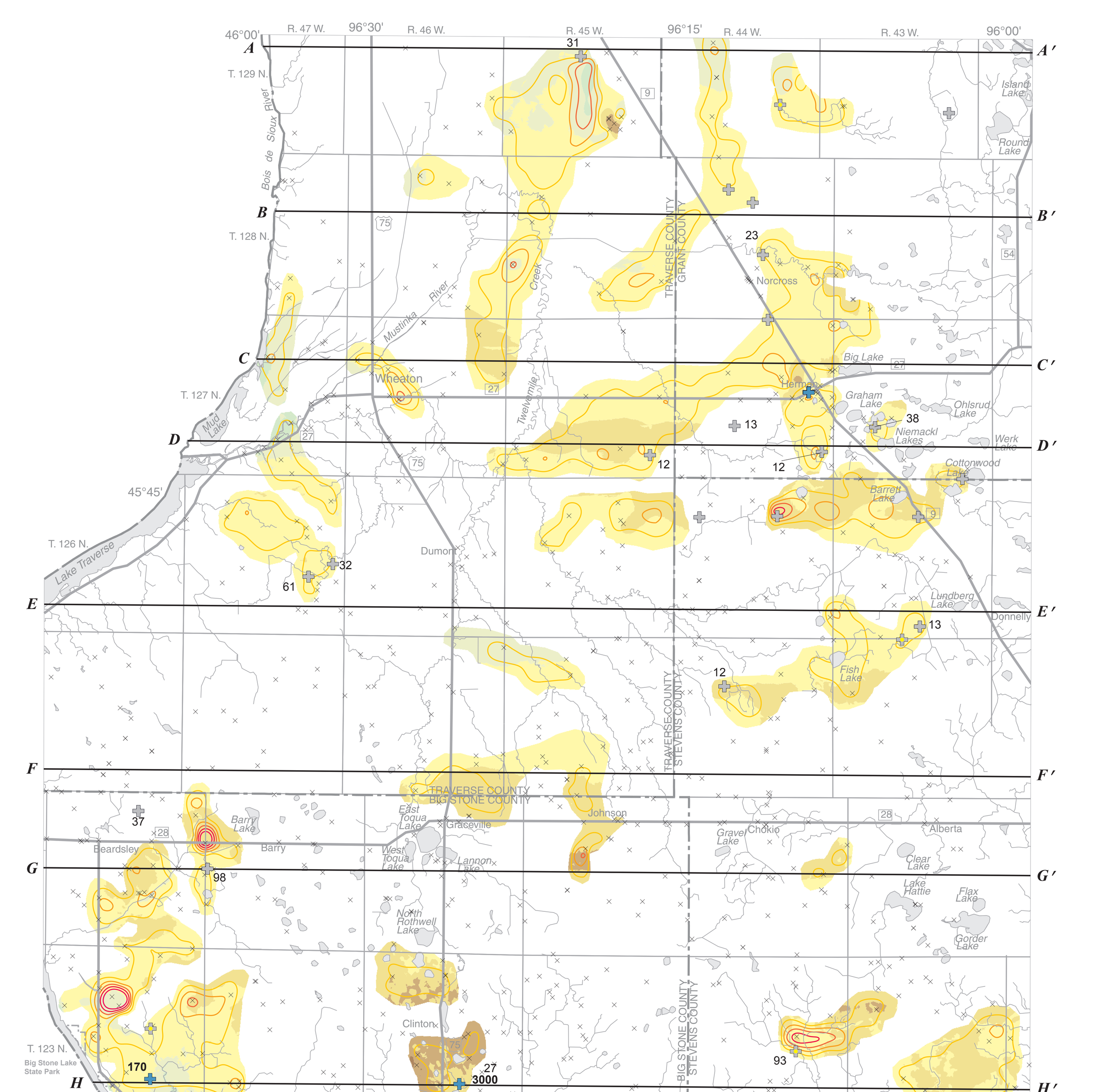


FIGURE 7. *Thickness and depth of sand and gravel deposits on top of an unnamed glacial till unit but below the Otter Tail River group in the western portion of the region (western aquifer).* *Very limited data were available to map this sand and gravel deposit in the western portion of the study area. Occurrences of the western aquifer are limited in extent. Typical thicknesses are difficult to evaluate since many of the boreholes do not fully penetrate the deposit. Some thick (greater than 40 feet) occurrences have been found in northern Big Stone and Stevens counties. Depths to the top of this aquifer are commonly 60 feet to 140 feet.*

REGIONAL HYDROGEOLOGIC ASSESSMENT
TRAVERSE–GRANT AREA, WEST-CENTRAL MINNESOTA