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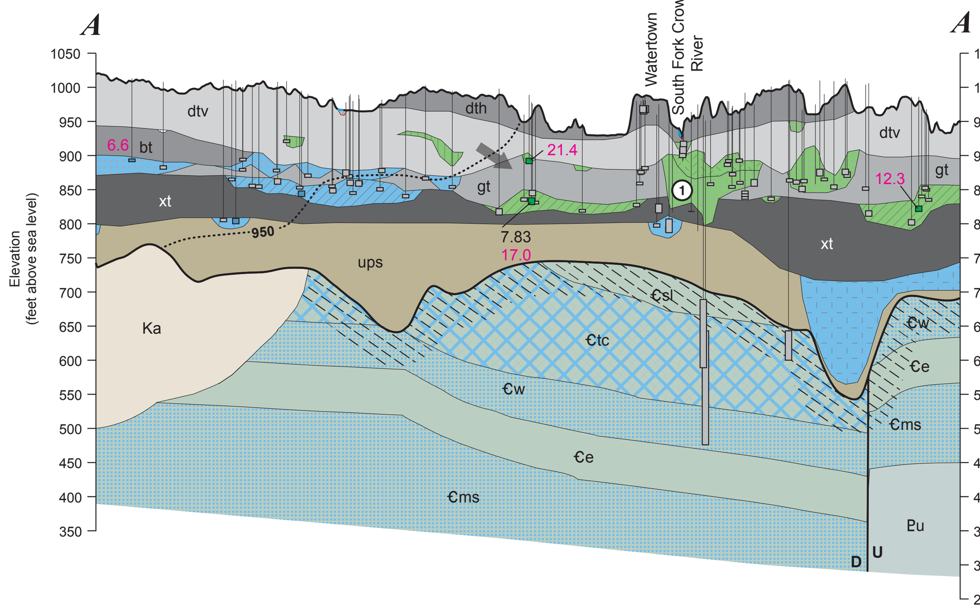

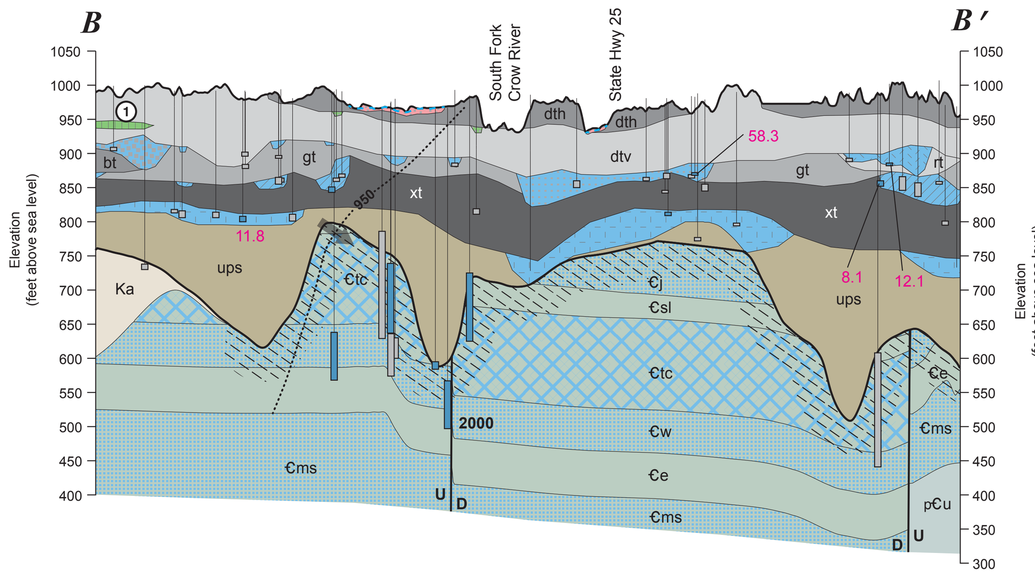

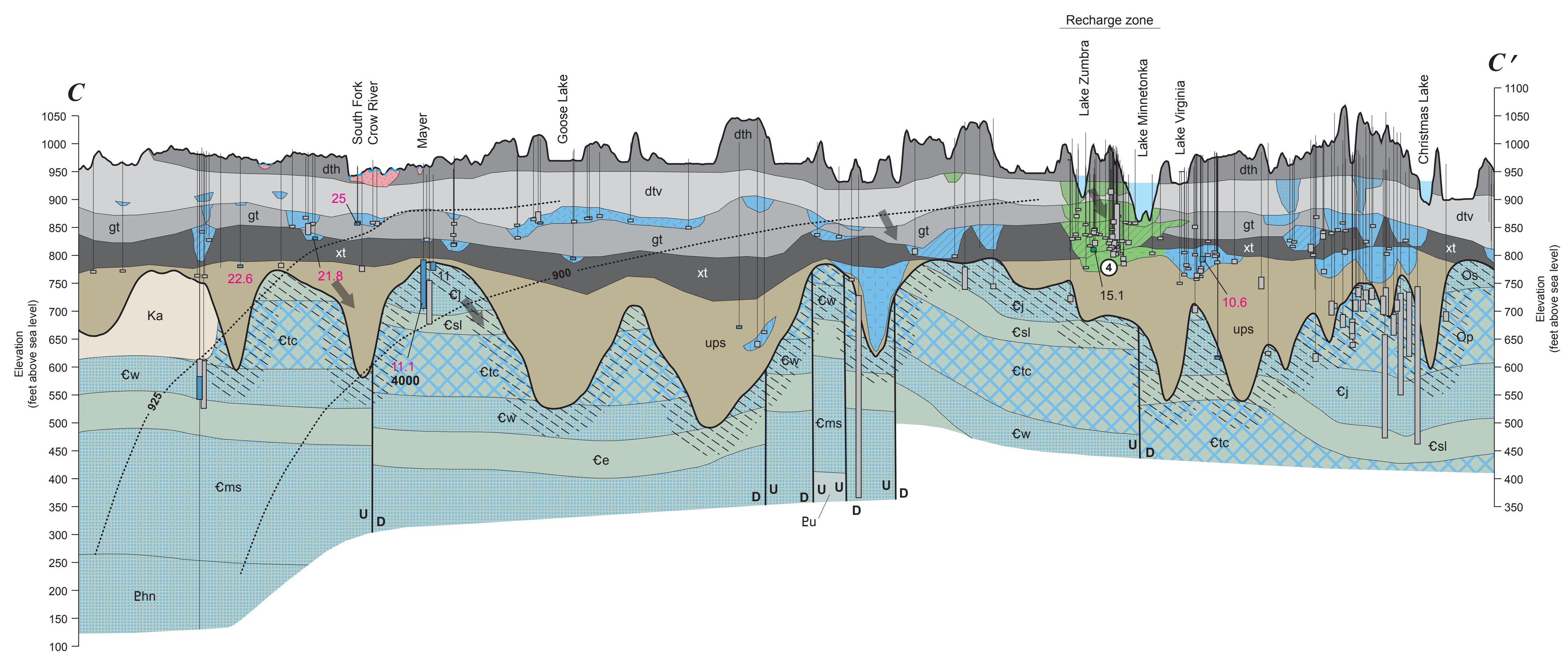

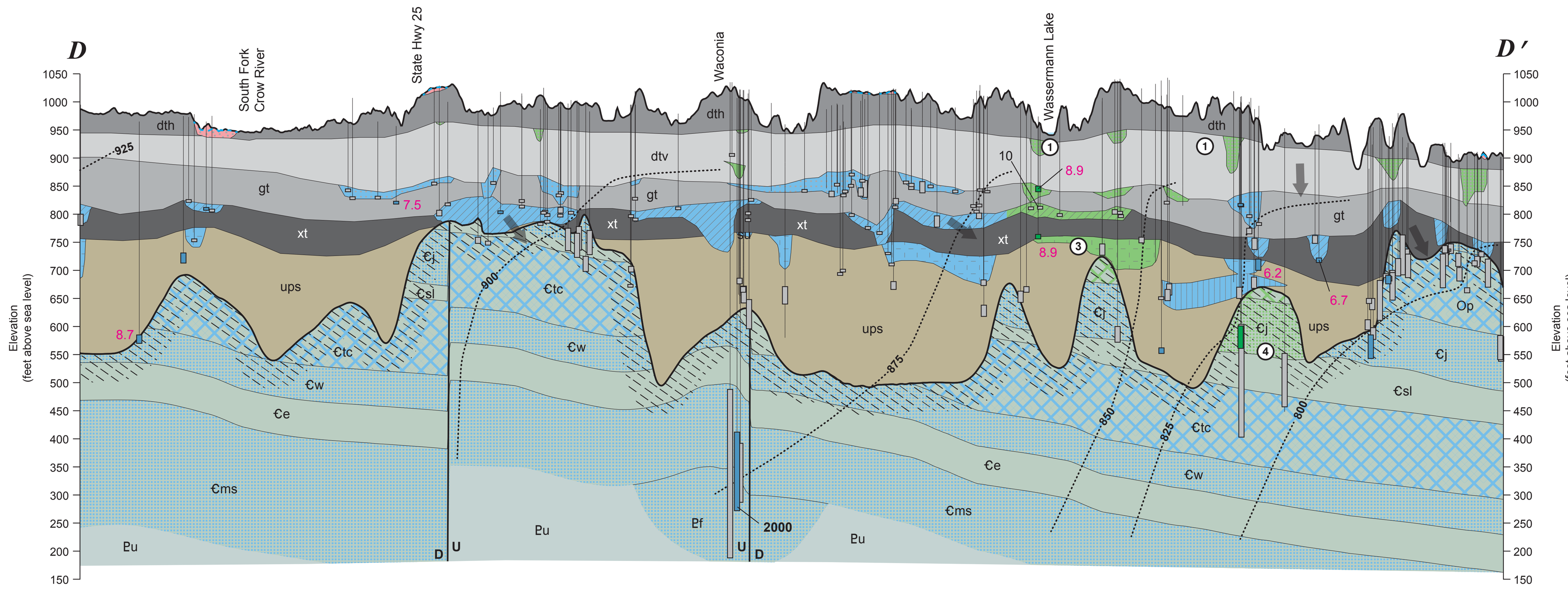

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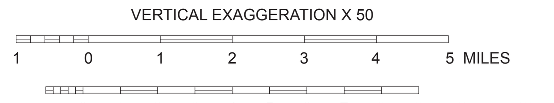
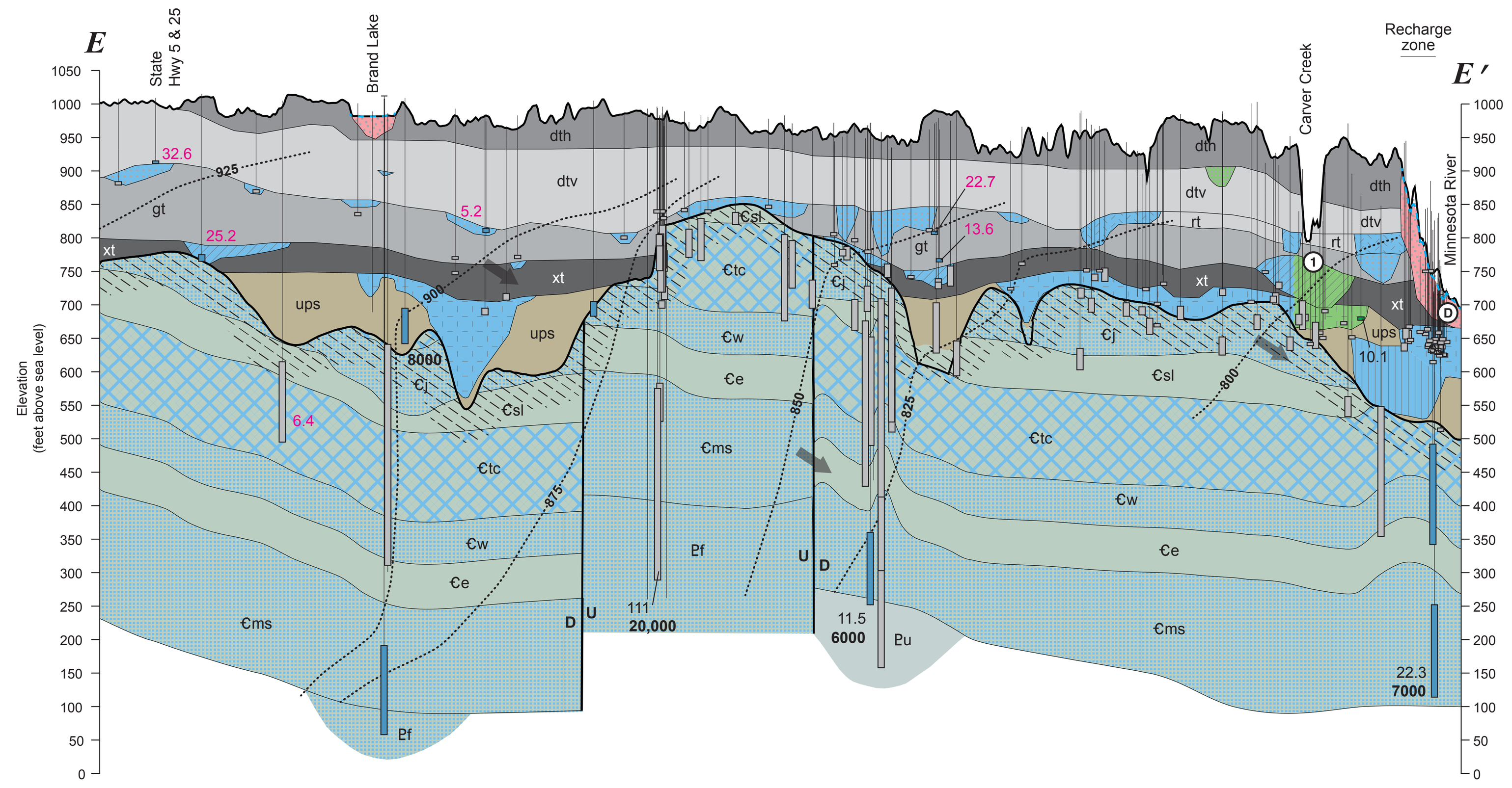
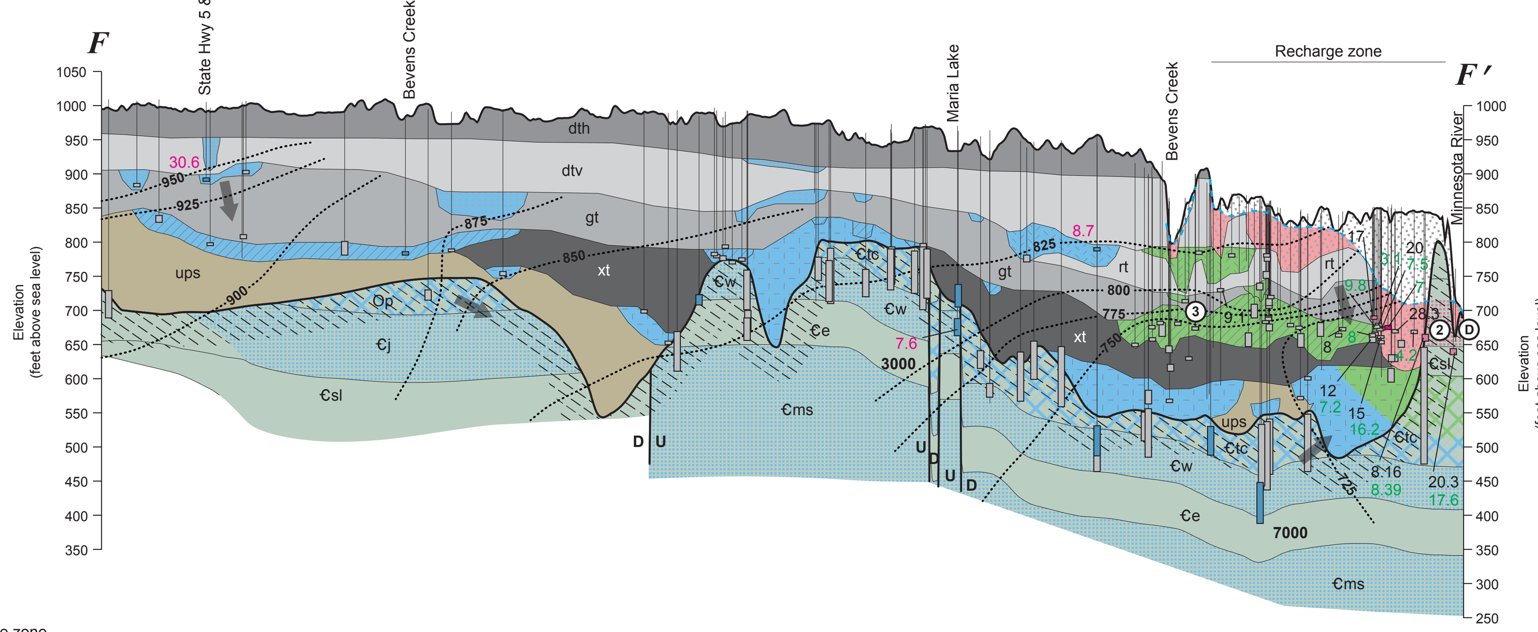
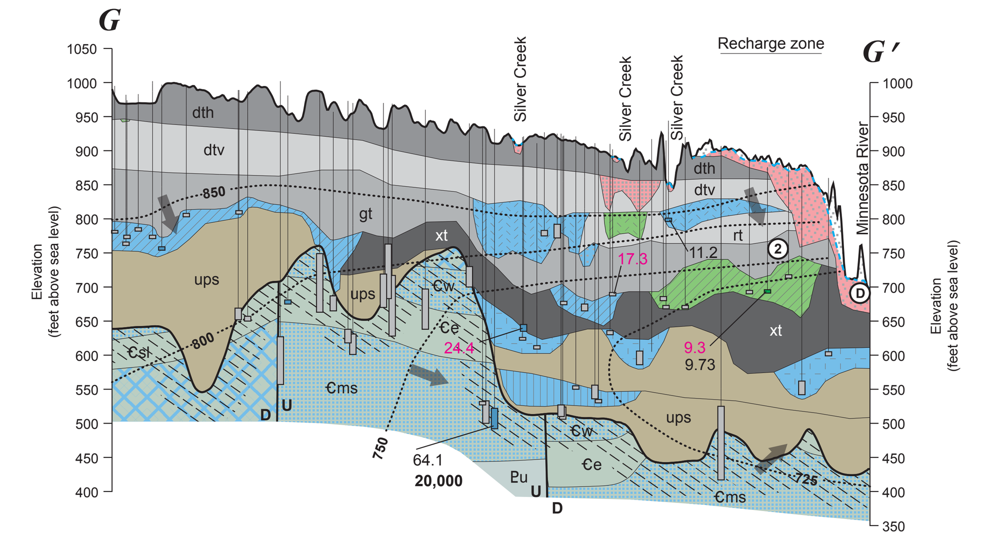








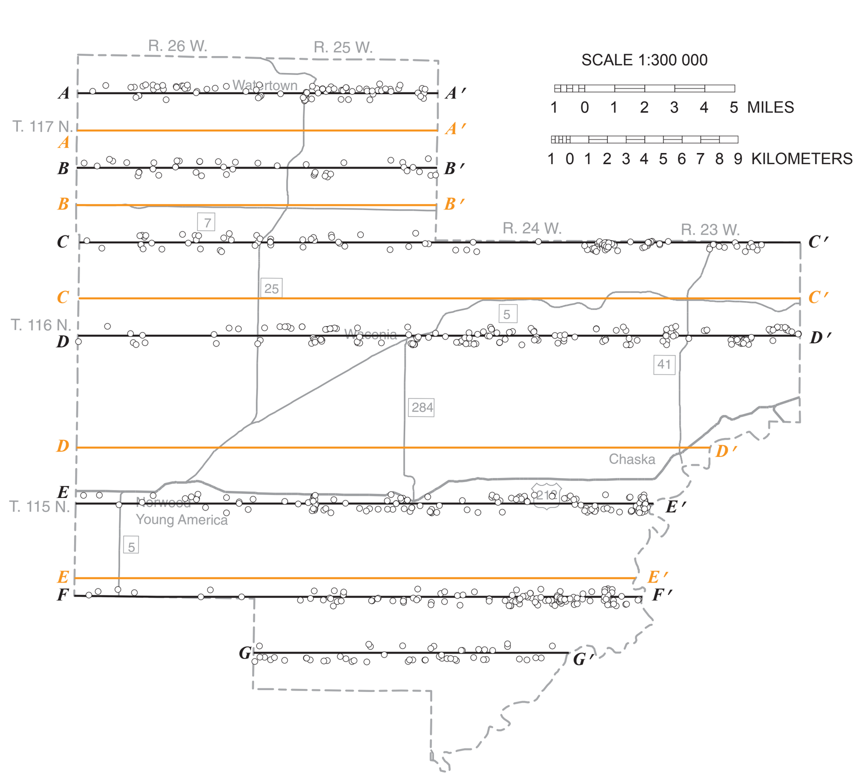


FIGURE 1. *Location of the seven hydrogeologic cross sections shown on this plate (black lines) and the five geologic cross sections shown on Plate 4, Part A (orange lines). The circles indicate the locations of wells displayed on the hydrogeologic cross sections shown on this plate.*

HYDROGEOLOGIC CROSS SECTIONS

By Todd A. Petersen

2014

INTRODUCTION

The seven hydrogeologic cross sections on this plate illustrate the horizontal and vertical extent of aquifer and nonaquifer units in Carver County. They also show groundwater residence time and general direction of groundwater flow. The water table is typically within 10 feet of the land surface in most of Carver County and slightly deeper in the surficial sand aquifer (Figure 1, Plate 6). However, because of the large surface-elevation change near the Minnesota River, the water table can locally be more than 120 feet below land surface. This deep water-table condition is shown on the eastern side of cross sections E–E′, F–F′, and G–G′ in the bluffs near the broad valley now occupied by the Minnesota River.

Figure 1 shows the location of the seven hydrogeologic cross sections shown on this plate. These were selected from the 39 geologic cross sections created for Part A because the trace of the cross section lines include the deepest water wells in the county. Selected wells along these cross sections were sampled and analyzed for most of the groundwater chemistry data, which include major cations and anions, trace elements, stable isotopes, tritium, and carbon-14. The cross sections illustrate both shallow and deep hydrologic conditions across the county.

RELATIVE HYDRAULIC CONDUCTIVITY

This report identifies a surficial sand aquifer, 6 Quaternary buried sand and gravel aquifers, and 8 bedrock aquifers in Carver County. The Quaternary buried sand and gravel aquifers are adequate for domestic wells, but their extent and thickness vary greatly and are not always be adequate for municipal or industrial supply wells that require higher pumping capacities. Many wells that require higher pumping capacities are constructed in the bedrock aquifers. The amount of water the Quaternary sand and gravel aquifers are able to transmit, calculated from aquifer transmissivity tests, varies from 89,800 to 273,000 gallons per day per foot (gpd/ft). The transmissivity in bedrock aquifers varies from 4,700 to 52,700 gpd/ft. The hydraulic properties of these aquifers are discussed in more detail on Plate 8.

The correlation of Quaternary aquifers and nonaquifers is shown in Figure 2, Plate 6. The Quaternary till units have limited permeability and are considered to be nonaquifer units; these units are shown in shades of gray. The relative hydraulic conductivity of the nonaquifer units is estimated using the average sand percentage of the matrix texture of the till units (the less than 2 millimeter grain size fraction), as shown in Table 1, Plate 4, Part A. It is assumed that as the sand content of the till increases, hydraulic conductivity also increases, and with greater hydraulic conductivity there is more potential for water movement. Lighter grays represent relatively higher hydraulic conductivities; darker grays represent lower hydraulic conductivities. The rt till with 56 percent sand and the dtv till with 51 percent sand have the highest relative hydraulic conductivities of the Carver County till units and are represented by the lightest gray. The gt till, which has 42 percent sand, has an intermediate relative hydraulic conductivity. The dth till and the bt till have 39 percent and 36 percent sand respectively, and have a lower relative hydraulic conductivity; they are represented by a darker gray. The xt till has 25 percent sand, the lowest relative hydraulic conductivity, and is represented by the darkest gray. No textural information is available for the undifferentiated Pleistocene sediment (ups) unit; therefore, no inference of hydraulic conductivity should be made.

The sequence of bedrock geologic units, hydrogeologic units, and hydrogeologic properties is shown in Figure 1, Plate 8. The bedrock aquifers generally have good horizontal and vertical permeabilities. The confining units generally have low vertical permeability but may have relatively high horizontal permeability along bedding fractures. The St. Peter, Wonewoc, Mt. Simon, and Hinckley aquifers are sandstones in which groundwater moves primarily through intergranular flow. Groundwater in the Prairie du Chien and Upper Tunnel City aquifers mainly moves through fractures. Groundwater in the Jordan aquifer moves through a combination of intergranular and fracture flow. An enhanced-permeability zone is generally found in the uppermost 50 feet of all Proterozoic and Paleozoic sedimentary bedrock units that are either exposed at the land surface or directly covered by glacial sediment (Runkel and others, 2006). This enhanced permeability is attributed to the presence of fractures developed or enlarged during weathering when the top of the bedrock surface was the land surface. The fractures in this enhanced-permeability zone generally increase the yield from units that are typically aquifers. In addition, these fractures will usually increase the permeability of units that are typically not aquifers, which may allow nonaquifer units to be used as a water source. The enhanced-permeability fractures in nonaquifer units may also compromise the confining character of those units. Enhanced permeability zones in the Ka aquifer or bedrock units directly beneath the Ka aquifer may exist locally, but this has not been confirmed.

GROUNDWATER RESIDENCE TIME

The pink, green, and blue areas shown on these cross sections represent the groundwater residence time. This is the approximate length of time that has elapsed since the water infiltrated the land surface to the time it was pumped from the aquifer. Groundwater residence time can be estimated by the amount of tritium (^3H) that is present in the groundwater. Tritium is a naturally occurring radioactive isotope of hydrogen whose presence in water samples indicates that the water has infiltrated the land surface since the early 1950s. Concentrations of tritium in the atmosphere were greatly increased between about 1953 and 1963 by above-ground nuclear bomb tests (Alexander and Alexander, 1989). Since tritium decays at a known rate (half-life of 12.32 years), the proportion of recently recharged water in a sample can be estimated by its tritium content. Water samples with tritium concentrations of 8 or more tritium units (TU) are classified as recent water that entered the ground since the early 1950s. Water samples with tritium concentrations of 1 TU or less are classified as vintage water that entered the ground before approximately 1953. Water samples with tritium concentrations greater than 1 TU and less than 8 TU are considered mixed waters because they are a mixture of vintage and recent waters.

Seventy-four out of 87 groundwater samples that were analyzed for tritium had vintage tritium age, 10 samples had mixed tritium age, and 3 samples had recent tritium age. In the Minnesota River valley, much of the area is underlain by high permeability sand and gravel deposits, and recent tritium-age water has penetrated to approximately 200 to 250 feet below land surface. Outside of the Minnesota River valley most of Carver County has relatively low permeability clay-loam and loam glacial sediment at the land surface and recent tritium-age water has only penetrated to about 50 feet below land surface. Recent and mixed tritium- age water has penetrated up to a few hundred feet below land surface in a few select areas: near Watertown on cross section A–A′, near Lake Zumbra and Lake Minnetonka on cross section C–C′, and in the Jordan aquifer on the east side of cross section D–D′. Most of Carver County is underlain by low permeability, fine-grained glacial sediment. However, a few areas are underlain with near-surface sand and gravel aquifers or deep lakes that connect to buried sand and gravel aquifers, which allows for more local groundwater recharge.

HYDROGEOLOGY ILLUSTRATED BY THE CROSS SECTIONS

Groundwater-Flow Direction Estimated From Equipotential Contours

Groundwater moves from areas with higher potential energy to areas with lower potential energy. Groundwater-flow direction is indicated by the gray arrows in the cross sections on this plate and is interpreted from the equipotential contours constructed from measured water levels in wells. These contours can be used to identify the groundwater-flow direction, recharge zones, and discharge zones. The equipotential contours and flow arrows show the groundwater flow in Carver County is largely lateral from northwest to southeast. Because of the low permeability glacial sediment at the land surface, major groundwater recharge zones are generally not present. However, on the northern edge of the county, near Lake Zumbra and Lake Minnetonka on cross section C–C′, mixed tritium-age water is present to a depth of approximately 150 to 200 feet. In that area the low permeability glacial sediment layer is thin or penetrated by lakes, allowing water to move into the subsurface. This is one example of a local groundwater recharge zone. In Carver County, the major groundwater discharge zone is the Minnesota River valley.

The general northwest to southeast groundwater-flow direction is represented on the maps of the water-table elevation and the potentiometric surfaces of the buried sand and gravel aquifers (Figures 1 and 3 through 6 on Plate 6). The east-west cross sections on this plate were originally constructed to map the Quaternary buried sand and gravel aquifers. Therefore, the equipotential contours on these cross sections do not fully represent three-dimensional groundwater flow because the cross sections are not directly parallel to groundwater flow. However, the equipotential contours shown on these cross sections do demonstrate the general northwest to southeast and near surface to deep flow paths that are present in the county.

Aquifer Recharge and Discharge Conditions

Most of Carver County has fine-grained Quaternary glacial sediment with relatively low permeability at the land surface which greatly limits groundwater recharge. A few areas are underlain by a relatively thick surficial sand unit or a stacked sequence of sand and gravel units. These areas act as groundwater recharge zones and are shown on cross sections C-C′, E-E′, F-F′, and G-G′. Recent or mixed tritium-age groundwater has penetrated as deep as about 150 feet in all four of these recharge zones.

Mixed tritium-age groundwater was found as deep as 125 feet below land surface in the sg aquifer as shown on cross section A–A′, as deep as 100 feet in the sdv aquifer as shown on cross section D–D′, and as deep as 140 feet in the sx aquifer as shown on cross section E–E′. These areas are shown as condition ①, which is defined as infiltration through a thin layer of fine-grained material to an underlying aquifer.

Recent and mixed tritium-age groundwater has penetrated to the Jordan aquifer as shown on cross section F–F′ and to the sx aquifer on cross section G–G′. These areas are shown as condition ②, where groundwater is recharged from an overlying surficial aquifer to a buried aquifer.

Mixed tritium-age groundwater was found in the su aquifer in cross section D–D′. Elevated chloride was found in groundwater in the sx aquifer in cross section F–F′. Tritium was not analyzed for this sample. These areas are shown as condition ③, groundwater leakage from an overlying buried aquifer to an underlying buried aquifer.

Mixed tritium-age groundwater was found as deep as 200 feet below land surface in the sx aquifer, near Lake Zumbra and Lake Minnetonka on cross section C–C′. Mixed tritium-age groundwater was found in the Jordan aquifer on cross section D–D′. Both of these areas are shown as condition ④ groundwater leakage through multiple aquifers and fine-grained layers. The Jordan aquifer groundwater sample was collected from an elevation of approximately 550 feet. This is below the elevation of the regional discharge for this aquifer at the Minnesota River valley of approximately 700 feet. This is deeper than expected, and is probably due to nearby high volume wells that capture groundwater that would naturally flow to the Minnesota River.

The bedrock faults, which often function as good conduits for groundwater recharge, do not act as groundwater recharge zones in Carver County. The bedrock aquifers are buried under a thick sequence of fine-grained low permeability glacial sediment that prevent recent or mixed tritium-age groundwater from penetrating to most bedrock aquifers. Many water samples from bedrock wells near the faults have elevated chloride and low chloride to bromide ratios. This indicates a connection to deep groundwater. The overlying low permeability glacial sediment prevents shallow groundwater from reaching the bedrock faults.

The equipotential contours on the cross sections show groundwater movement from the Quaternary sediments downward into the bedrock aquifers. Except for limited areas near the broad valley of the Minnesota River this groundwater movement is very slow. The groundwater residence time for these deep aquifers, as estimated by carbon-14 isotope analysis, ranges from 2,000 to 20,000 years. The major discharge zone for bedrock aquifers in Carver County is the Minnesota River valley at the southeast border of the county.

Except for the recharge zone and groundwater conditions described above, most other areas of Carver County have very limited recharge of recent tritium-age water below about 100 feet. In these limited recharge areas, groundwater withdrawal increases due to growing demand, then significant local changes may occur in aquifer recharge. Increased groundwater withdrawal from sand and gravel aquifers at a depth of less than approximately 100 feet might induce greater groundwater recharge from the land surface. This might increase the rate of movement of contaminants from the surface to buried sand and gravel aquifers. Increased groundwater withdrawal from deeper aquifers probably would not increase groundwater recharge from the land surface because of the many layers of fine-grained till that overlie deeper aquifers. However, increased pumping from wells constructed in deeply buried aquifers might reduce the available head in the aquifer. Groundwater in the deeper aquifers has a residence time of hundreds to thousands of years, so pumping is withdrawing water from these aquifers faster than it is recharged. Any increase in pumping volume could only exacerbate this effect.

REFERENCES CITED

Alexander, S.C., and Alexander, E.C. Jr., 1989, Residence times of Minnesota groundwaters: Minnesota Academy of Sciences Journal, v. 55, no. 1, p. 48-52.

Runkel, A.C., Tipping, R.G., Alexander, E.C. Jr., and Alexander, S.C., 2006, Hydrostratigraphic characterization of intergranular and secondary porosity in part of the Cambrian sandstone aquifer system of the cratonic interior of North America–Improving predictability of hydrogeologic properties: Sedimentary Geology, v. 184, p. 281-304.

CROSS SECTION EXPLANATION

Tritium age

Darker color in small vertical rectangle (well screen symbol) indicates tritium age of water sampled in well. Lighter color indicates interpreted age of water in aquifer.

- Cold war era—Water entered the ground during the peak period of atmospheric tritium concentration from nuclear bomb testing, 1958-1959 and 1961-1972 (Greater than 15 tritium units [TU]).
- Recent—Water entered the ground since about 1953 (8 to 15 TU).
- Mixed—Water is a mixture of recent and vintage waters (greater than 1 TU to less than 8 TU).
- Vintage—Water entered the ground before 1953 (less than or equal to 1 TU).
- Well not sampled for tritium.

Symbols and labels

- 30.6 — If shown, arsenic concentration equals or exceeds 5 parts per billion
- 9.73 — If shown, chloride concentration equals or exceeds 5 parts per million
- 8.39 — If shown, nitrate-nitrogen concentration equals or exceeds 3 parts per million
- 7000 — If shown, groundwater residence time in years, estimated by carbon-14 (^{14}C) isotope analysis
- General direction of groundwater flow
- 800 — Approximate equipotential contour; Contour interval 25 feet
- Geologic contact
- Land or bedrock surface
- Water table
- Lake
- U/D — Relative direction of fault movement

Aquifers - grouped by stratigraphy

Surficial sand aquifer
- sdo

Buried sand and gravel aquifers
- sdv
- sr
- sb
- sg
- sx
- su
- Unnamed

Sedimentary bedrock aquifers
Color overlay indicates tritium age.
- Ka — Ka (probably low yielding)
- Os — St. Peter*
- Op — Prairie du Chien**
- Cj — Jordan***
- Ctc — Upper Tunnel City**
- Cw — Wonewoc*
- Cms — Mt. Simon*
- Ꞓh — Hinckley*/ Fond du Lac
- Enhanced-permeability zone
- * Primarily intergranular flow
- ** Primarily fracture flow
- *** Combination of intergranular and fracture flow

Quaternary nonaquifer units - grouped by texture

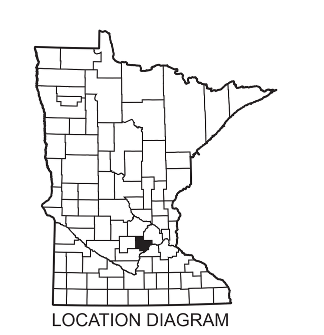
Geologic unit	Percent sand *Sand content indicates relative hydraulic conductivity.*
dtv, rt	Greater than 50 and less than or equal to 60
gt	Greater than 40 and less than or equal to 50
dth, bt	Greater than 30 and less than or equal to 40
xt	Less than 30
ups	Texture unknown (Undifferentiated Pleistocene sediment)

Bedrock nonaquifer units

- Csl — St. Lawrence Formation
- Ce — Eau Claire Formation
- Ꞓu — Proterozoic undifferentiated

Groundwater conditions

1. Infiltration through a thin layer of overlying, fine-grained material to an underlying aquifer
2. Groundwater recharge from overlying surficial aquifer to buried aquifer
3. Groundwater leakage from an overlying buried aquifer to an underlying buried aquifer
4. Groundwater leakage through multiple aquifers and fine-grained layers
D. Groundwater discharge from a buried aquifer to surface-water body



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This map was compiled and generated using geographic information systems (GIS) technology. Digital data products, including chemistry and geophysical data, are available from DNR Ecological and Water Resources at http://www.dnr.state.mn.us/waters.

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Base modified from Minnesota Geological Survey, Carver County Geologic Atlas, Part A, 2009.
Project data compiled from 2010 to 2012 at a scale of 1:100,000 to 1:300,000. Universal Transverse Mercator projection, grid zone 15, 1983 North American datum. Vertical datum is mean sea level.
GIS and cartography by Todd Petersen, Shana Pascal, and Greg Massaro. Edited by Neil Cunningham.

GEOLOGIC ATLAS OF CARVER COUNTY, MINNESOTA