HYDROGEOLOGIC CROSS SECTIONS

By

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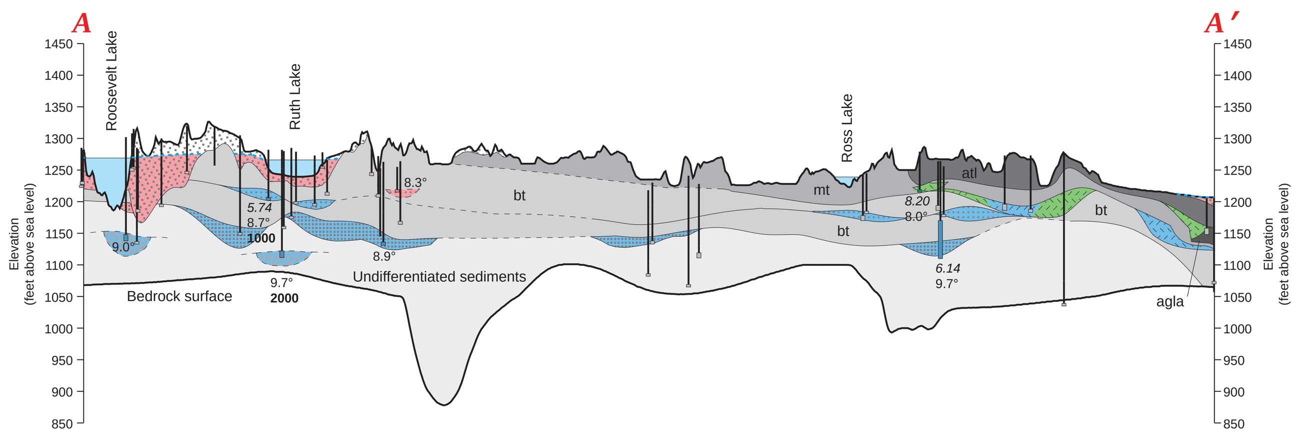
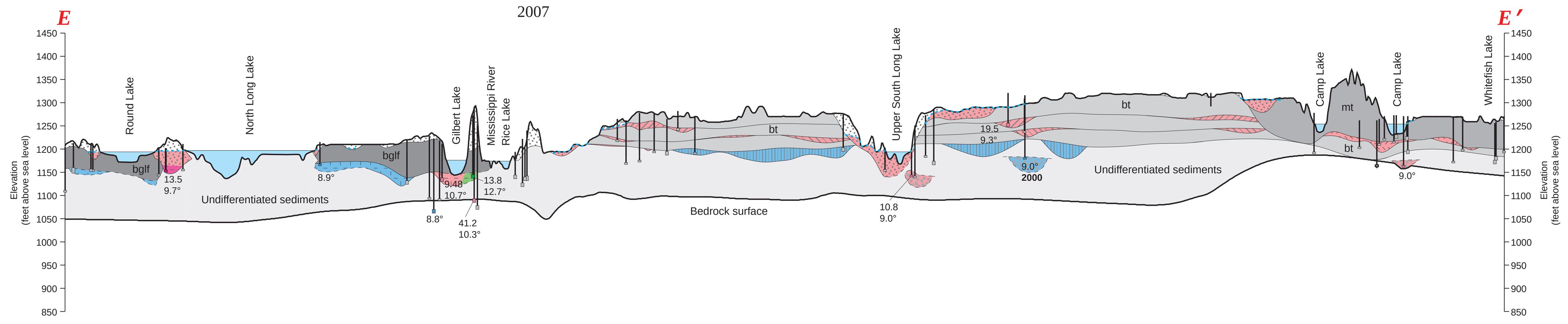
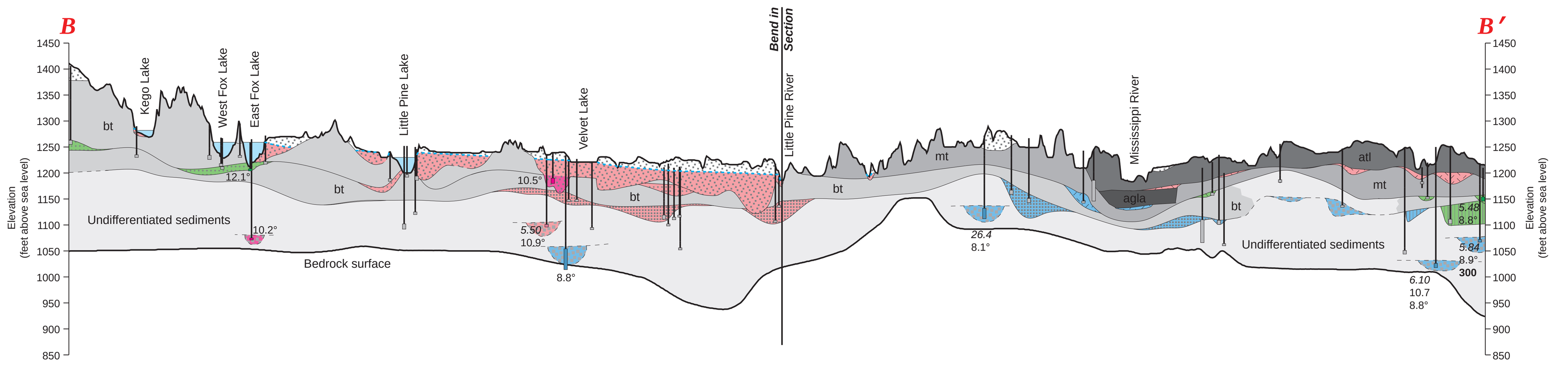
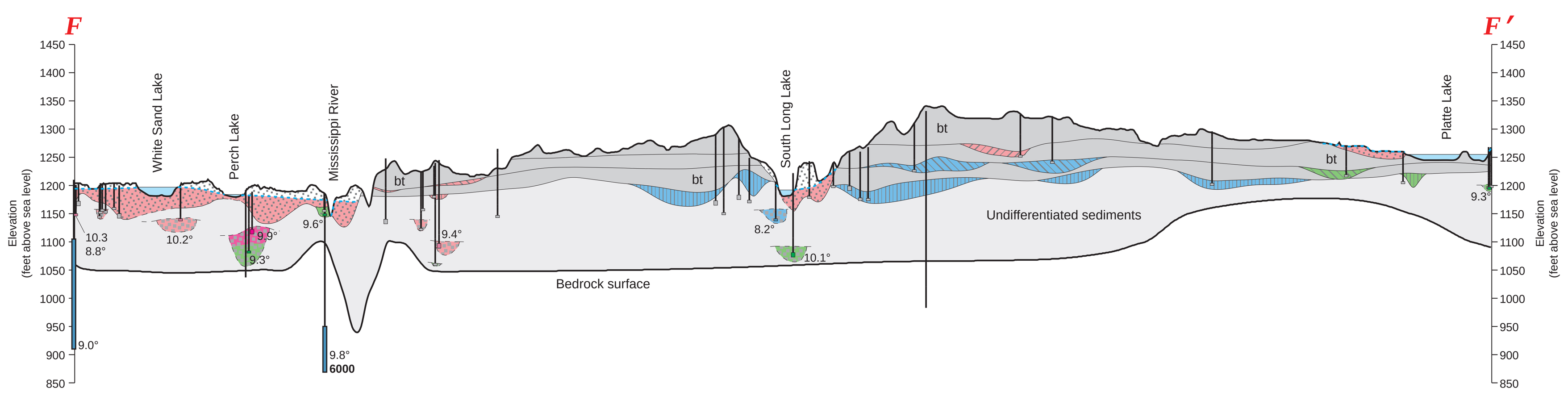
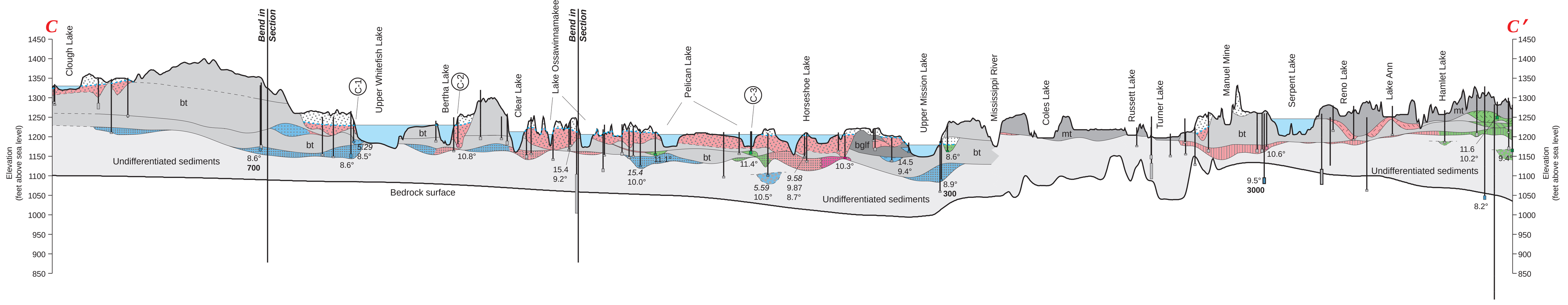
2007

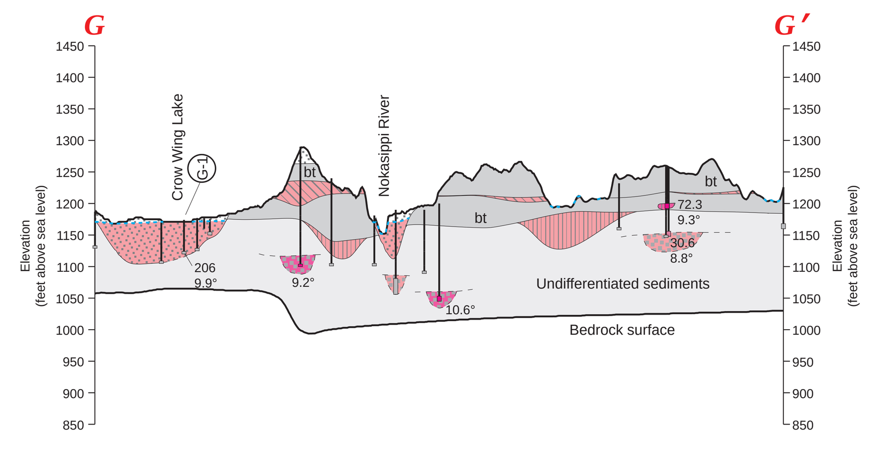


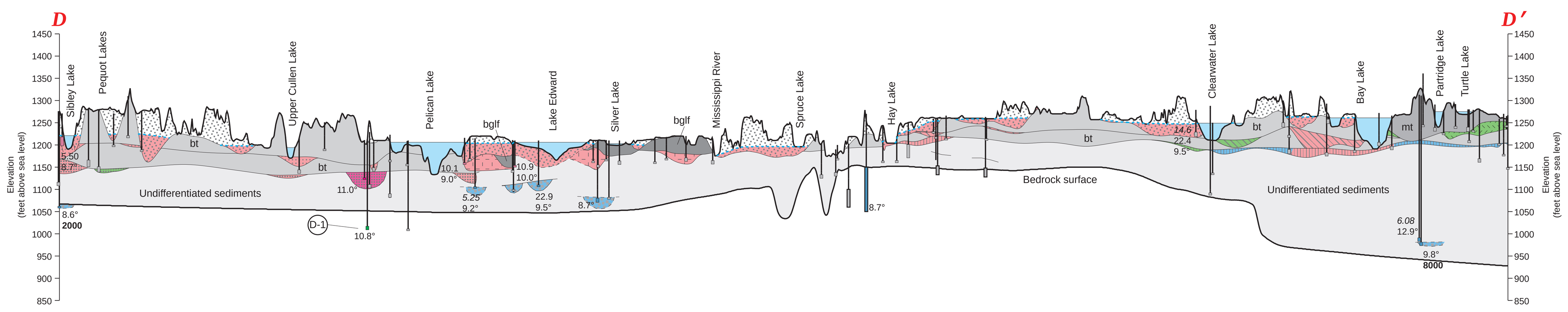












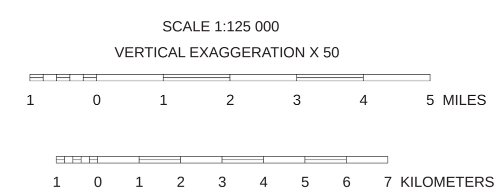


Table 1. Specific capacity* of selected large-capacity wells.

[Data from Minnesota Department of Health, County Well Index. gpm/ft, gallons per minute per foot]

Aquifer	Well diameter range (inches)	Specific capacity (gpm/ft)			Number of Tests
		Mean	Minimum	Maximum	
Surficial					
Sand and gravel	12–16	21	4	34	4
Buried					
Sand and gravel					
BTN3	10–12	12	9**	14	2
BTS3	12–12	38	38	38	1
Unnamed	12–12	11	2	17	5

*Specific capacity is the well discharge (measured in gallons per minute [gpm]) divided by the water-level drawdown in the pumping well (measured in feet).

**Well in City of Pine River, Cass County.

CROSS-SECTION EXPLANATION

Tritium age

Color indicates tritium age. Vertical rectangle indicates well screen or open hole of well. Bold vertical rectangle indicates bedrock well. No vertical rectangle indicates no well-screen or open-hole data available.

- Cold war era—Water entered the ground during the peak period of atmospheric bomb testing, 1958–1959 and 1961–1972 (20 or more tritium units [TU]).
- Recent—Water entered the ground since about 1953 (10 TU to less than 20 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.

Symbols and labels

- Water-table surface.
- *6.08* If shown, arsenic concentration equals or exceeds 5 parts per billion.
- 9.87 If shown, chloride concentration equals or exceeds 5 parts per million.
- 8.7° Temperature of water sample in degrees Celsius.
- **2000** If shown, ground-water age in years, estimated by carbon-14 isotope analysis.
- Geologic unit contact.
- Geologic unit contact, uncertain.
- Land or bedrock surface.
- Lake.
- (D-1) Referenced well location.

Nonaquifer units

- Nelson Lake till deposits (atl).
- Glacial Lake Aitkin I deposits (agla).
- Garrison till deposits (mt).
- Fine-grained Glacial Lake Brainerd deposits (bglf).
- South Long Lake till deposits (bt).
- Undifferentiated sediments.

Aquifers

- Surficial sand (water-table aquifer). Uncolored where unsaturated.
- S1AT—Beneath the Nelson Lake till.
- S1MT—Beneath the Mille Lacs deposits.
- BGLS—Associated with Glacial Lake Brainerd.

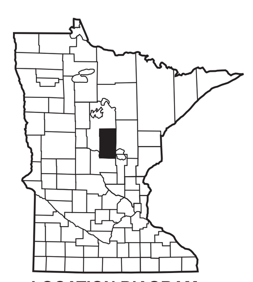
Brainerd assemblage, north

- BTN2, middle.
- BTN3, lowest.

Brainerd assemblage, south

- BTS1, uppermost.
- BTS2, middle.
- BTS3, lowest.

Older Quaternary aquifer.



LOCATION DIAGRAM

Digital base composite:
Roads and county boundaries - Minnesota Department of Transportation GIS Statewide Base Map (source scale 1:24,000)
Hydrologic features - U.S. Geological Survey Digital Line Graphs (source scale 1:100,000)
Digital base annotation - Minnesota Geological Survey
Project data compiled from 2005 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 Todd Petersen and Greg Massaro. Edited by Nick Kroska.

INTRODUCTION

The seven hydrogeologic cross sections and three maps on this plate illustrate the horizontal and vertical extent of the hydrogeologic units (aquifers and confining units), ground-water residence time, and water-table elevation, where known. These cross sections pass through most of the wells sampled for chemistry for this study. Additional sampling helped determine the ground-water and surface-water interaction for lakes in the Thirty Lakes Watershed District in the west-central part of the county. The data from the additional sampling are shown on the relevant maps (Plate 7) but are too far from the cross sections to be depicted on them. The three maps (Figures 1, 2, and 3) show the extent and elevation of nine buried sand aquifers.

The maps and cross sections were constructed using a combination of information, including well logs and stratigraphic data from the County Well Index (CWI), Surficial Geology (Plate 3, Part A), and Quaternary Stratigraphy (Plate 4, Part A) and three-dimensional mapping done for this portion of the atlas (Part B). Seventy-five east-west cross sections spaced 1 kilometer apart were constructed to map the subsurface geology. Wells were projected into the cross sections from up to 500 meters away. These east-west cross sections were used to stratigraphically map till boundaries and the associated sands that were deposited from separate glacial events. Digital elevation model (DEM) grids were created for all of the mapped till surfaces and associated sand aquifers. These grids were used to produce the buried sand aquifer maps in Figures 1, 2, and 3.

The seven cross sections shown on this plate were constructed to approximately follow hydrogeologic flow lines toward the Mississippi River (the main river drainage in the county). The stratigraphic boundaries on these cross sections were derived from the DEM surfaces of the till units and aquifers mapped using the 75 east-west cross sections. The location of the wells that were sampled for general chemistry and isotopes (cations, anions, trace metals, tritium, and carbon-14) and the traces of the seven hydrogeologic cross sections are shown on Figure 2, plate 7.

Crow Wing County has limited topographic relief. The land surface elevation varies from approximately 1130 feet to approximately 1480 feet above mean sea level (msl), but most of the county is between about 1160 feet and 1360 feet. The cross sections have a vertical exaggeration of 50x so that small, thin units can be seen.

Highlands of Brainerd assemblage till occur in the extreme northern part of the county and on both sides of the Nokasippi River in the southern part of the county. Between the highlands, the basins of Glacial Lake Aitkin and Glacial Lake Brainerd are relatively flat, low-lying areas.

Many of the county's lakes are located in the sandy sediments of Glacial Lake Brainerd or in the adjacent outwash. Numerous lakes are also found in the Garrison till in southeastern Crow Wing County.

RELATIVE HYDRAULIC CONDUCTIVITY

Mapped aquifers are shown on the seven cross sections and the three accompanying figures on this plate. The confining units are shown in shades of gray on the cross sections. Textural information from Table 1, Plate 4, Part A, was used to estimate relative hydraulic conductivity. Darker grays represent relatively lower hydraulic conductivities; lighter grays represent relatively higher hydraulic conductivities. One exception is the undifferentiated sediments that are shown as light gray. No textural information is available for this unit, so no inference of hydraulic conductivity should be made. Most wells completed in these aquifers are 4-inch-diameter domestic wells that do not provide useful hydraulic data because the small diameter of the wells limits the maximum pumping rate and prevents a proper test of the aquifer. Twelve of the larger capacity wells, which are used for irrigation and public water supply, have been analyzed for hydrogeologic properties (Table 1). All 12 wells are at least 10 inches in diameter and were test pumped for at least 8 hours. Table 1 shows the specific capacity of four wells that are completed in the surficial aquifer and eight wells that are completed in Quaternary buried sand aquifers. Most of the wells tested have fairly high specific capacities and produce sufficient water for the high-capacity needs of municipal and irrigation wells.

As indicated in Table 1, the four wells completed in the surficial aquifer had a mean specific capacity of 21 gallons per minute per foot (gpm/ft), ranging from 4 gpm/ft to 34 gpm/ft. The eight wells completed in the Quaternary buried sand aquifers were slightly less productive on average than the four wells completed in the surficial sand aquifer, but they are still suitable for high-capacity uses. The mean specific capacity for buried sand wells was 14 gpm/ft, ranging from 2 gpm/ft to 38 gpm/ft. Three Quaternary buried sand wells are completed in mapped aquifers; two wells are completed in the BTN3 aquifer, and one well is completed in the BTS3 aquifer. The well completed in the BTS3 aquifer had the highest specific capacity (38 gpm/ft) of the wells analyzed.

GROUND-WATER RESIDENCE TIME

The pink, dark pink, green, and blue areas shown on these cross sections represent the estimated age of the ground water, also known as ground-water residence time. This is the approximate time that has elapsed from the moment the water infiltrated the land surface to the time it was pumped from the aquifer. Tritium is a naturally occurring radioactive isotope of hydrogen whose presence in water samples indicates that the water has infiltrated the land surface within about the last 50 years. Concentrations of this isotope were greatly increased between about 1953 and 1963 by above-ground nuclear tests (Alexander and Alexander, 1989). This isotope decays at a known rate (half-life of 12.43 years). Because of this, the proportion of recently recharged water in a sample can be estimated by its tritium content.

Water samples with tritium concentrations of 10 or more tritium units (TU) are considered to be recent water, entering the ground within about the last 50 years. Water samples with tritium concentrations of 20 or more TU are a special subset of recent water that entered the ground primarily during the cold war era. During 1958–1959 and 1961–1972, the original tritium concentration was so high that, even after radioactive decay, ground water that entered the subsurface during the cold war era can still have tritium values of 20 or more TU. Ground-water samples collected for this study with 20 or more TU probably entered the ground during this period of atmospheric bomb testing. Water samples with tritium concentrations of 1 TU or less are classified as vintage water; the water in these samples entered the ground before approximately 1953. Water samples with tritium concentrations greater than 1 TU and less than 10 TU are considered mixed waters. They are a mixture of vintage and recent waters.

When tritium data are not available, other geochemical indicators such as chloride concentration, nitrate concentration, or the chloride to bromide (Cl/Br) ratio can be used to estimate ground-water age. Plate 9 provides more information on the chloride concentration and the Cl/Br ratio of the water samples collected and the relationship of those values to tritium concentrations. Ground-water age for the vintage samples can be better estimated by sampling for the carbon-14 (^{14}C) isotope. It is a naturally occurring radioactive isotope of carbon, with a half-life of 5730 years, that is used to estimate ground-water residence time between 100 years and 40,000 years. Of 10 wells with vintage water that were sampled for carbon-14 in this study, the estimated ground-water ages ranged from 300 years to 8000 years.

HYDROGEOLOGY ILLUSTRATED BY THE CROSS SECTIONS

The north end (left side) of cross-section A–A′ crosses surficial outwash sand; otherwise, it mostly crosses areas with thick till at the land surface. This till protects the Brainerd assemblage sand aquifers very well. Most of the water samples from wells completed in those aquifers had no detectable tritium. Two of the samples from wells in shallower sands, which were less than 50 feet below land surface, had recent and mixed waters. One sample from a well in the BTN2 aquifer had no detectable tritium but one had 13.3 TU (recent water). The water sample collected from the S1AT aquifer immediately below the Nelson Lake till (atl) on the southeast side of the cross section had tritium values of mixed water.

Both the Garrison till (mt) and the Nelson Lake till (atl) protect the Brainerd assemblage sand aquifers very well. The thick till and limited surficial sand provide better hydrogeologic protection than other areas where the surficial sand is thicker.

Cross-section B–B′ starts in South Long Lake till (bt) in the north-central part of the county, crosses Brainerd and Mille Lacs outwash sands and Garrison till (mt), and ends in Nelson Lake till (atl) near former Glacial Lake Aitkin. The outwash sands provide much less protection from surface infiltration of contaminants than the thick tills found in cross-section A–A′. Water with recent tritium values has penetrated much more deeply (up to 150 feet below land surface) along cross-section B–B′ than along cross-section A–A′. A sample from a well about 200 feet deep near East Fox Lake had a tritium value of cold war era water. There may be an unmapped window of thick sand near this sampled well that allows a surface connection. Thick sand is present in this and nearby wells, but its areal extent is too small to map.

The Garrison till (mt) and Nelson Lake till (atl) at the land surface in the southeastern half of cross-section B–B′ provide a confining unit that protects the buried sand aquifers from infiltration at the land surface. Most of the samples from wells in the southeastern half of this cross section had vintage ground water. Many shallower sands were mapped in this area, but their ground water was not sampled for chemistry.

Cross-section C–C′ starts in the Brainerd outwash sands in the northwestern corner of the county; crosses South Long Lake till (bt), more Brainerd outwash, and a small area of Glacial Lake Brainerd sand; then follows the Garrison till (mt) and associated outwash boundary heading southeast to the eastern border of the county.

Vintage water was found in well samples from the buried sands beneath the South Long Lake till (bt), sometimes less than 50 feet below land surface. The abrupt contact between recent and vintage waters at shallow depths indicates that in this area the shallow ground water is flowing mostly laterally and not penetrating very deeply. This suggests shallow, local flow systems where ground water and lakes are linked. The water chemistry indicates a strong connection between the surface water and the ground water in the surficial aquifer, while vintage ground water occurs in the deeper buried aquifers. Ground-water temperature and the stable isotopes of oxygen and hydrogen indicate that ground water flows into some area lakes on one side and flows out the other. Ground water that is flowing toward a lake is generally colder than ground water that is exiting the lake. The connection between lakes and ground water (including more information on stable isotopes) is described on Plate 10. Ground water flows from the north into Upper Whitefish Lake and from the south into Bertha Lake (see Figure 2, Plate 7). The topographic high south of Bertha Lake appears to be a local ground-water divide. The sample from well C-1 was relatively cold (8.5°C) and was vintage ground water. The well is completed in the BTN2 aquifer. This aquifer may be locally connected to the BTN3 aquifer upgradient and to Upper Whitefish Lake downgradient. The sample from well C-2 was warmer (10.8°C) and had 12.5 TU (recent water). This is probably because this well is completed in the surficial sand aquifer and receives surface recharge. (The ground-water samples that were collected for this study from wells downgradient from a lake and that were clearly recharged from the lake had temperatures between 11.3°C and 12.9°C.)

Water from Pelican Lake flows northeast to well C-3 and toward the Pine River. The stable isotopes in the water sample from this well indicated a significant evaporative signature (see well 1, Figure 10, Plate 10), strongly suggesting the source is lake water. The sample temperature (11.4°C) was high, which also indicates a lake water source. It had a tritium concentration of 4.6 TU, indicating a mixed water. The BTN2 and BTN3 aquifers merge near this well so ground waters of different ages and sources could be mixing.

Cross-section D–D′ from the northwest to the southeast crosses Brainerd outwash sands, South Long Lake till (bt) , mixed outwash, and Garrison till (mt). Recent ground water is found or expected throughout the surficial aquifer and in buried sand aquifers to about 120 feet below land surface.

Water samples from wells in parts of the BTN3 aquifer had tritium concentrations of 25 TU typical of cold war era water. Other samples from wells completed in the BTN3 aquifer or near equivalents had no detectable tritium. Samples from bedrock wells also had no detectable tritium. One anomaly was a 220-foot-deep well (D-1) just west of Pelican Lake whose water sample had 2.5 TU.

The northwest end of cross-section E–E′ starts on Glacial Lake Brainerd deposits, then crosses South Long Lake till (bt) and mixed outwash; the southeast end of the cross section shows Garrison till (mt) at land surface. A sample from a well near Gilbert Lake completed in the BGLS aquifer had recent water. Samples from deeper wells nearby had tritium concentrations that approach cold war era values or had no detectable tritium. East of Upper South Long Lake, recent tritium values were found in three samples from aquifers with less than 60 feet of overlying sediments (one sample from the BTS1 aquifer and two samples from older Quaternary aquifers). One sample from a more deeply buried, older Quaternary aquifer had vintage ground water.

The northwest end of cross-section F–F′ starts on surficial sands of Glacial Lake Brainerd deposits, then crosses to South Long Lake till (bt) south of the Mississippi River. Recent water extended into the relatively shallow, older Quaternary aquifers beneath the Glacial Lake Brainerd sands. Water samples from slightly deeper Quaternary aquifers had tritium values indicating cold war era water or mixed water. Underneath the South Long Lake till (bt) near South Long Lake, samples from deeper, older Quaternary aquifers had little tritium: one had no detectable tritium and one had 2.2 TU.

The northwest end of cross-section G–G′ starts in the upper terrace sediments and then crosses South Long Lake till (bt) for the rest of the cross section. One of the sampled wells (G-1) is completed in the terrace sediments (part of the surficial aquifer). The water sample from this well was very high in chloride, which indicated recent water. Of the other four sampled wells in this cross section, one well is completed in the BTS3 aquifer and the rest are completed in older Quaternary aquifers. Three of the samples had tritium values of cold war era water, and the other sample had recent water. None of these aquifers appear to be directly connected to the surface, but there may be unmapped connections to surficial sands.

BURIED AQUIFER MAPS

Three maps on this plate show the buried aquifers that have been mapped using the available water well logs from CWI. Nine buried aquifers have been mapped based on the stratigraphic assemblages described in Plates 3 and 4, Part A. These aquifer outlines are shown in Figures 1, 2, and 3. Figure 1 shows the extent and approximate elevation of the S1AT, S1MT, BGLS, BTN1, and BTS1 aquifers. Figure 2 shows the extent and approximate elevation of the upper surface of the BTN2 and BTS2 aquifers. Figure 3 shows the extent and approximate elevation of the upper surface of the BTN3 and BTS3 aquifers.

The S1AT aquifer consists of sands beneath the Nelson Lake till of the Aitkin assemblage (atl). The S1MT aquifer includes sands beneath the Garrison till of the Mille Lacs deposits of the Cromwell Formation (mt). These sands are probably not associated with the respective overlying tills, but more likely are stratigraphically associated with the older till deposits that underlie them.

All of the other mapped buried aquifers are associated with the Brainerd assemblage. The BGLS aquifer is a sand unit that underlies fine-grained Glacial Lake Brainerd deposits (bglf). Six aquifers are associated with South Long Lake till (bt). Three of these aquifers are in the northern part of the county (BTN1, BTN2, and BTN3) and three aquifers are in the southern part of the county (BTS1, BTS2, and BTS3). Glacial Lake Brainerd deposits, Mille Lacs deposits, and Aitkin assemblage sediments in the central portion of the county (near the Mississippi River) separate South Long Lake till in northern Crow Wing County from South Long Lake till in the southern part of the county. Because of this, the three northern aquifers cannot be directly correlated with the three southern aquifers. All six aquifers, however, are related to advances and retreats of Rainy lobe ice (see Figure 1, Plate 7), and each aquifer is stratigraphically related to the South Long Lake till.

REFERENCE 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.

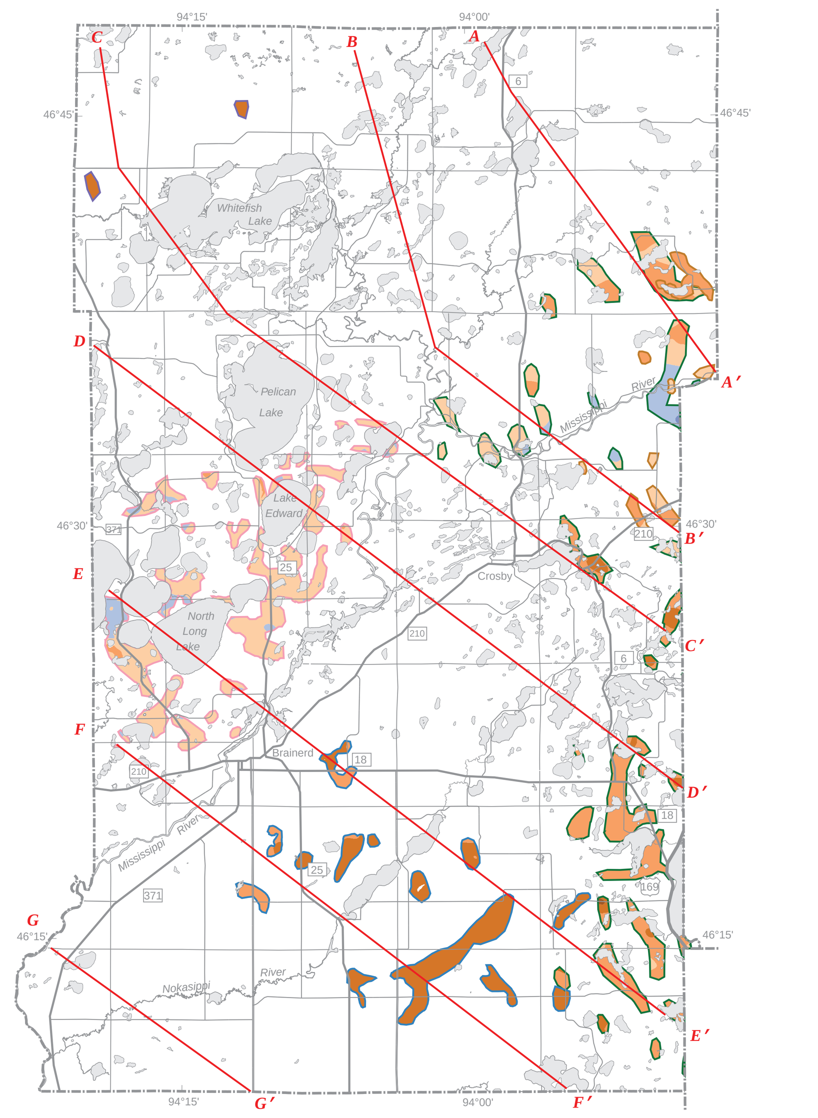


FIGURE 1. ***Location and approximate upper-surface elevation of five uppermost buried sand aquifers.*** *These include aquifers beneath the Nelson Lake till (S1AT); aquifers beneath Mille Lacs deposits (S1MT); aquifers associated with Glacial Lake Brainerd deposits (BGLS); and two other aquifers associated with the Brainerd assemblage, north, uppermost (BTN1) and south, uppermost (BTS1).*

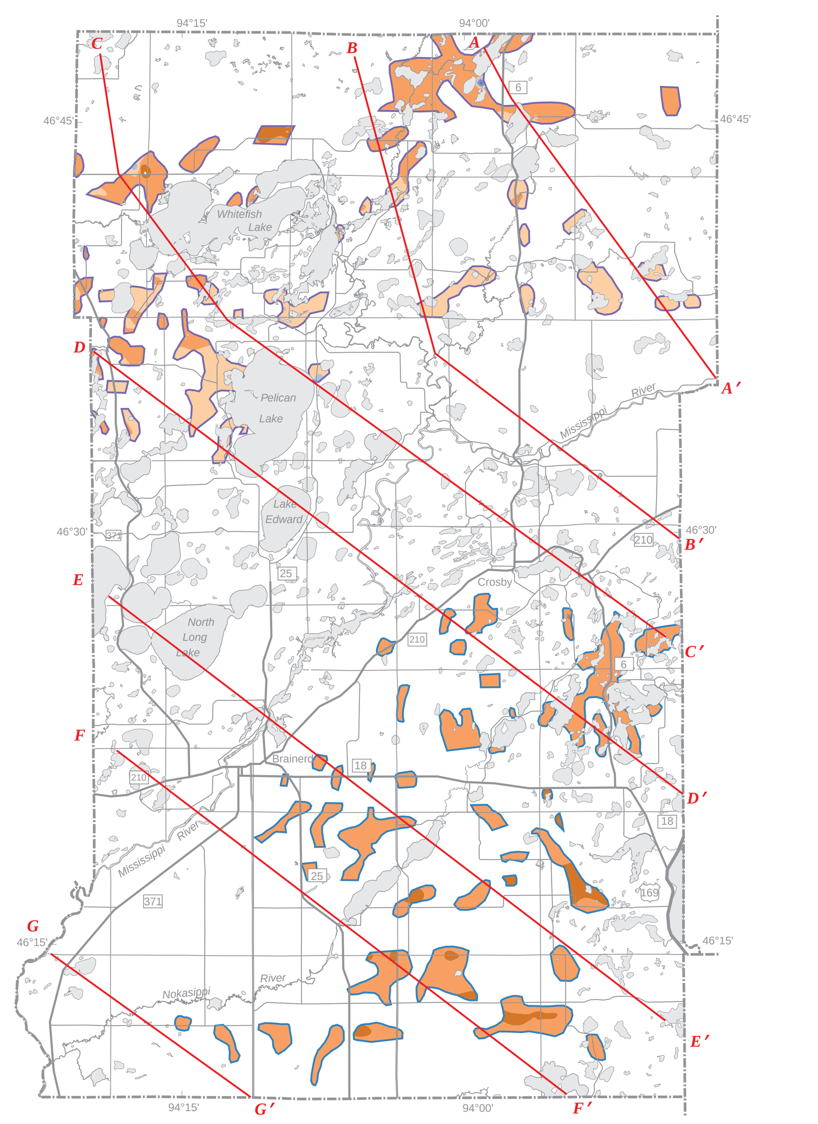


FIGURE 2. ***Location and approximate upper-surface elevation of two midlevel buried sand aquifers in the Brainerd assemblage, north, middle (BTN2) and south, middle (BTS2).***

MAP EXPLANATION
Figures 1, 2, and 3

Elevation of buried sand aquifers (in feet above mean sea level).

- 1350–1300
- 1300–1250
- 1250–1200
- 1200–1150
- 1150–1100
- 1100–1050
- 1050–1000
- 1000–950

Buried sand aquifers—Colored border identifies aquifer.

- S1AT
- S1MT
- BGLS
- BTN1, BTN2, BTN3
- BTS1, BTS2, BTS3

F F′ Line of cross section.

Body of water.

SCALE 1:350 000
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 6 7 KILOMETERS

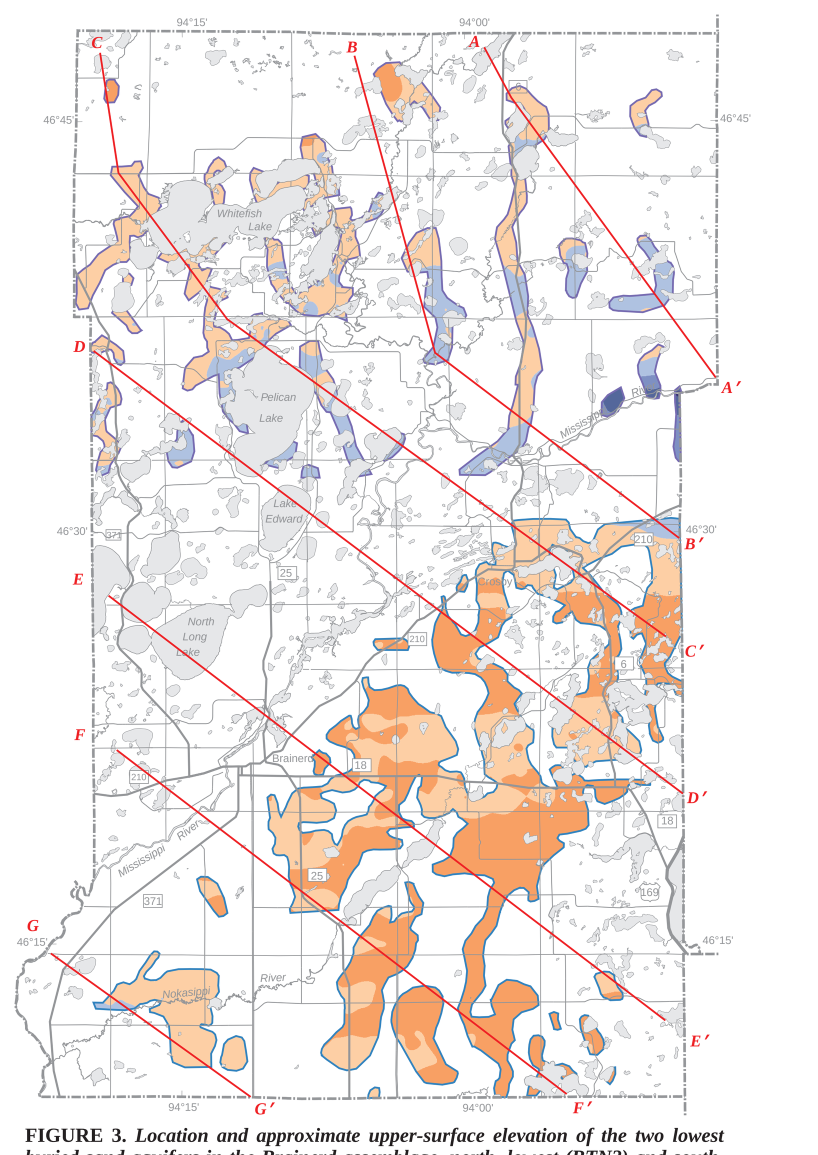


FIGURE 3. ***Location and approximate upper-surface elevation of the two lowest buried sand aquifers in the Brainerd assemblage, north, lowest (BTN3) and south, lowest (BTS3).***