HYDROGEOLOGIC CROSS SECTIONS

By

Jeremy S. Rivord

2012

INTRODUCTION

The six hydrogeologic cross sections on this plate illustrate the horizontal and vertical extent of aquifer units and confining units in Benton County. Groundwater residence time and groundwater flow conditions shown on the cross sections illustrate groundwater movement and aquifer relationships. The cross sections on this plate were selected from a series of 34 west to east geologic cross sections constructed at one-kilometer intervals across Benton County. All four of the geologic cross sections in the Part A atlas (see Plate 4) are interpreted on this plate as hydrogeologic cross sections (Figure 1).

To create the hydrogeologic cross sections shown on this plate, Part A geologic cross sections were interpreted with water chemistry and isotope results of 96 sampled wells and additional water level data from the County Well Index (CWI). Four primary buried sand and gravel aquifer units are depicted together with three categories of confining layers. Some limited geologic data were adjusted in several locations where a combination of hydraulic and chemical data indicated a probable connection between a shallow buried sand unit and the surficial aquifer. In these instances, the buried sand unit and the overlying till layer were included as part of the surficial sand aquifer. The correlation between geologic units from Plate 4 with the buried sand aquifer units is described in the map explanation.

GROUNDWATER RESIDENCE TIME

Isotope Concentrations as Evidence of Groundwater Recharge

The pink, green, and blue areas on these cross sections represent the groundwater residence time. Groundwater residence time can be estimated by the level of tritium (^3H) that is present in the groundwater. Tritium is a naturally occurring radioactive isotope of hydrogen. Concentrations of ^3H in the atmosphere were greatly increased between about 1953 and 1963 by above-ground nuclear tests (Alexander and Alexander, 1989). The presence of ^3H in water samples indicates water has infiltrated the land surface since the early 1950s. Tritium has a half-life of 12.43 years and this known rate of decay allows the residence time of groundwater samples to be estimated based on ^3H concentration. Water samples with 10 or more tritium units (TU) are considered evidence of recharge since the early 1950s; water with greater than 10 TU is classified as recent. Water samples with 1 TU or less are classified as vintage water because the water in these samples entered the ground before 1953. Water samples with tritium concentrations greater than 1 TU and less than 10 TU are considered a mixture of vintage and recent waters. Tritium age does not necessarily correspond to well depth. Samples with ^3H concentrations indicating recent water were collected from aquifer units as deep as 140 feet below land surface; samples with mixed water were collected from aquifer units as deep as 150 feet below land surface; samples with vintage water were collected from aquifer units as shallow as 60 feet below land surface.

Groundwater residence time of the vintage samples suspected of being old can be estimated by sampling for the carbon-14 (^{14}C) isotope. Carbon-14 is a naturally occurring radioactive isotope of carbon with a half-life of 5,730 years; it is used to estimate groundwater residence time between 100 years and 40,000 years. Of the eight wells that were sampled for ^{14}C in this study, all eight were completed in Quaternary sand aquifer units and only five samples were old enough to provide a reliable ^{14}C age. The estimated groundwater residence times for samples from these aquifer units ranged from 400 to 2,000 years, which is relatively young for groundwater in buried sand aquifers in Minnesota. Carbon-14 ages of these magnitudes indicate a shallow groundwater system that is recharged relatively quickly and in which groundwater moves readily from recharge zones into aquifers.

Groundwater Chemistry

The chemistry of a groundwater sample is composed of a mixture of dissolved ions derived from the atmosphere, rock-water interactions, and anthropogenic sources. The major-ion chemical composition or water type can be classified by plotting data on a trilinear diagram that shows the relative concentrations of major dissolved anions and cations (Freeze and Cherry, 1979). A trilinear diagram for the Benton County groundwater chemistry data is shown in Figure 2. The two bottom triangle-shaped diagrams represent the relative composition of positively charged major ions (cations) on the left and the relative composition of negatively charged major ions (anions) on the right. Groundwater from each sampled well is represented by one point within the cation portion and one point within the anion portion; the two points projected to the diamond-shaped portion of the diagram result in a composite single point. The groundwater in Benton County is generally of the calcium-bicarbonate type that is typical of much of central and southern Minnesota.

Elevated chloride and nitrate in groundwater is an indication of human impacts on recent recharge from the surface. A ratio of chloride concentration to bromide concentration from a sampled well greater than 300 (Cl/Br > 300) indicates groundwater has received recent human-influenced recharge from the surface (see Plate 6). Elevated Cl/Br ratios are often caused by increased chloride from local sources such as road salt, agriculture practices, and septic tank effluent. Elevated chloride and nitrate in recent groundwater is indicated by the small oval in the diamond part of the diagram in Figure 2. All 14 of the recent-aged waters (pink symbols) have sulfate-chloride-nitrate ion compositions greater than 15 percent millequivalents (meq) and up to 40 percent meq. Twenty-five of the 26 vintage water samples (blue symbols) have less than 15 percent meq of the sulfate-chloride-nitrate ions; this indicates that those water samples have likely not been impacted by human activity (large oval in Figure 2).

HYDROGEOLOGIC FEATURES AND DATA

Aquifer Units

The surficial sand aquifer and several buried sand aquifer units are the major sources of groundwater used in Benton County. The Quaternary sediments in which these aquifers occur were deposited by multiple glaciers that entered and receded from the county. Sediments deposited during the most recent glacial period, the Late Wisconsinan, are better understood than those from previous glaciations because they form the surface materials over most of the county (Plate 3, Part A). Three of the mapped aquifer units on this plate, namely the surficial sand aquifer and the two shallow buried aquifers units (the supra- and sub-Emerald aquifer units, se and sb, respectively), were deposited during the Late Wisconsinan. The two more-deeply buried sand aquifer units were deposited earlier in the Pleistocene prior to the Wisconsinan Episode (sx and sw). The Qu geologic unit fills a substantial bedrock valley in the western third of the cross sections. There is the potential for additional buried sand and gravel deposits to be present in the sediment of that bedrock valley. The hydrostratigraphic correlation of the aquifer units and confining till units with the Part A geologic units is shown in the map explanation. A description of the relative age for these Late Wisconsinan and pre-Wisconsinan ice lobe deposits is shown in Figure 2, Plate 4, Part A. Aquifer units shown with patterns on the cross sections represent different units and do not imply a particular characteristic.

Local Area Aquifer Systems

The Rice Area aquifer system and the Anoka Sand Plain aquifer system from Figure 1, Plate 6 are two areas of the county where the buried sand aquifer units and the surficial sand aquifer tend to function as a single groundwater system. Lines of hydraulic equipotential coupled with the chemistry and isotope results indicate that buried aquifer units in these areas and the surficial sand aquifer are a connected area aquifer system.

The Anoka Sand Plain aquifer system consists of the surficial sand aquifer and shallow buried sand aquifer units in the central third of cross sections E–E′ and F–F′. In this aquifer system groundwater flow directions are primarily lateral, but oriented perpendicular to the cross sections, as if pointing out of the paper. Chemistry of groundwater samples from the two Emerald aquifer units in the Anoka Sand Plain aquifer system indicates that recent recharge to the groundwater has been impacted by human activities.

The Rice Area aquifer system in the western quarter of cross sections A–A′, B–B′, and C–C′ closely coincides with the Mississippi River-Sartell watershed boundary. The supra- and sub-Emerald aquifer units in this area are commonly-used resources for local crop irrigation. In this aquifer system, recharge to the Emerald aquifer units moves vertically downward from the overlying surficial sand aquifer and laterally from the more-deeply buried sub-Emerald aquifer unit to the east of Little Rock Creek and Mayhew Lake. Supra- and sub-Emerald aquifer units that are overlain by the surficial sand aquifer have static water elevations similar to the surficial aquifer. Groundwater samples from the two Emerald aquifer units in the Rice Area aquifer system indicate recent recharge that is likely impacted by human activities. Water samples with recent-aged tritium were collected from pre-Wisconsinan and sub-Emerald aquifer units at an elevation lower than the Mississippi River, which is the regional groundwater discharge area. Recent-aged tritium at these elevations indicates that local pumping is likely altering flow patterns and potentially inducing vertical recharge downward from overlying buried aquifer units (western portions of cross sections A–A′ and B–B′).

Relative Hydraulic Conductivity

The confining layers in Benton County are deposits of glacial sediment called glacial till. Thick extensive till layers with a high percentage of fine-grained sediments like silt and clay can limit the vertical flow of water between two separate aquifer units. In some areas isolated pockets of sand and gravel, a higher proportion of coarse sediment in till, and vertical fractures in an otherwise thick confining layer can allow more than expected amounts of water to reach buried sand aquifers. These “leaky” conditions support greater aquifer recharge, but may also permit greater movement of possible contaminants.

The matrix texture of till samples from Table 1, Plate 4, Part A was used to estimate relative hydraulic conductivity for the confining layers. It is assumed that hydraulic conductivity increases with higher sand content. Three categories of relative hydraulic conductivity are defined on this plate based on the percentage of sand content in a till unit and are indicated on the cross sections by a light, medium, or darker gray. The relative hydraulic conductivities are a generalization of conditions throughout the county. It is important to recognize that till composition and thickness are heterogeneous in space and that hydraulic conditions vary over short distances. As a result, site-specific investigations are required to accurately assess local conditions.

The Cromwell Formation tills (Qcr and Qce) of the Superior lobe are present throughout most of the county and each has an average thickness of 30 to 35 feet. These two units are the shallowest and likely the most permeable confining layers. Both of the shallow confining layers are composed of more than 60 percent sand with a considerable amount of gravel. The Qcr unit is the confining layer for the supra-Emerald aquifer unit (se) and the Qce unit is the confining layer for sub-Emerald aquifer unit (sb). The Lake Henry formation (Qbs), Browerville formation (Qbs) and Old Rainy (Qwt) tills contain 40 to 60 percent sand and are categorized as the confining layers that have intermediate relative hydraulic conductivity. The Eagle Bend formation (Qxe) and Elmdale formation (Qwt) tills are categorized as the lowest relative hydraulic conductivity till with approximately 20 percent sand content. Undifferentiated Quaternary sediments (Qu) are shown in light brown. No textural information is available for this unit, so no inference of hydraulic conductivity should be made.

Groundwater Flow Conditions

Analysis of groundwater flow conditions in Benton County included plotting and contouring the measured static water levels in wells. The contours are lines of equal groundwater potential called equipotentials. Groundwater moves perpendicular to the equipotential contours, from contours of higher potential to lower potential; this movement is indicated in the cross sections by gray arrows. Where data are present, several groundwater conditions of recharge, discharge, and lateral direction of movement are indicated on the cross sections and on Plate 9.

Groundwater recharge zones are defined as the portion of the drainage basin in which the net saturated flow of groundwater is directed away from the water table (Freeze and Cherry, 1979). Groundwater discharge zones occur when groundwater is directed up toward the water table and most commonly toward a surface stream that receives groundwater discharge as base flow. Groundwater recharge is identifiable in the areas where equipotential contours are locally highest and where groundwater flow arrows are directed away from the water table (conditions ①, ②, and ③). Recharge zones in Benton County are present in the highlands of the county, the Rice Area aquifer system, and the Anoka Sand Plain aquifer system. Recharge in these two systems is confirmed with the presence of tritium and elevated Cl/Br ratios in the local water samples. Groundwater discharge zones in the county are associated with the Mississippi River and Elk River. These areas are identified with a Ⓓ on the cross sections. Local conditions in the buried sand aquifer and the adjacent confining layers can be different from the general flow conditions identified on this plate and require more detailed investigations. At depths of 100 feet or more, flow can become more lateral in orientation and regional in scale. Lateral flow conditions, identified by Ⓛ and ⊙, are evident on cross sections A–A′ and B–B′ between the upland recharge zone and the Rice Area aquifer system as well as the Anoka Sand Plain aquifer system on cross sections E–E′ and F–F′.

REFERENCES CITED

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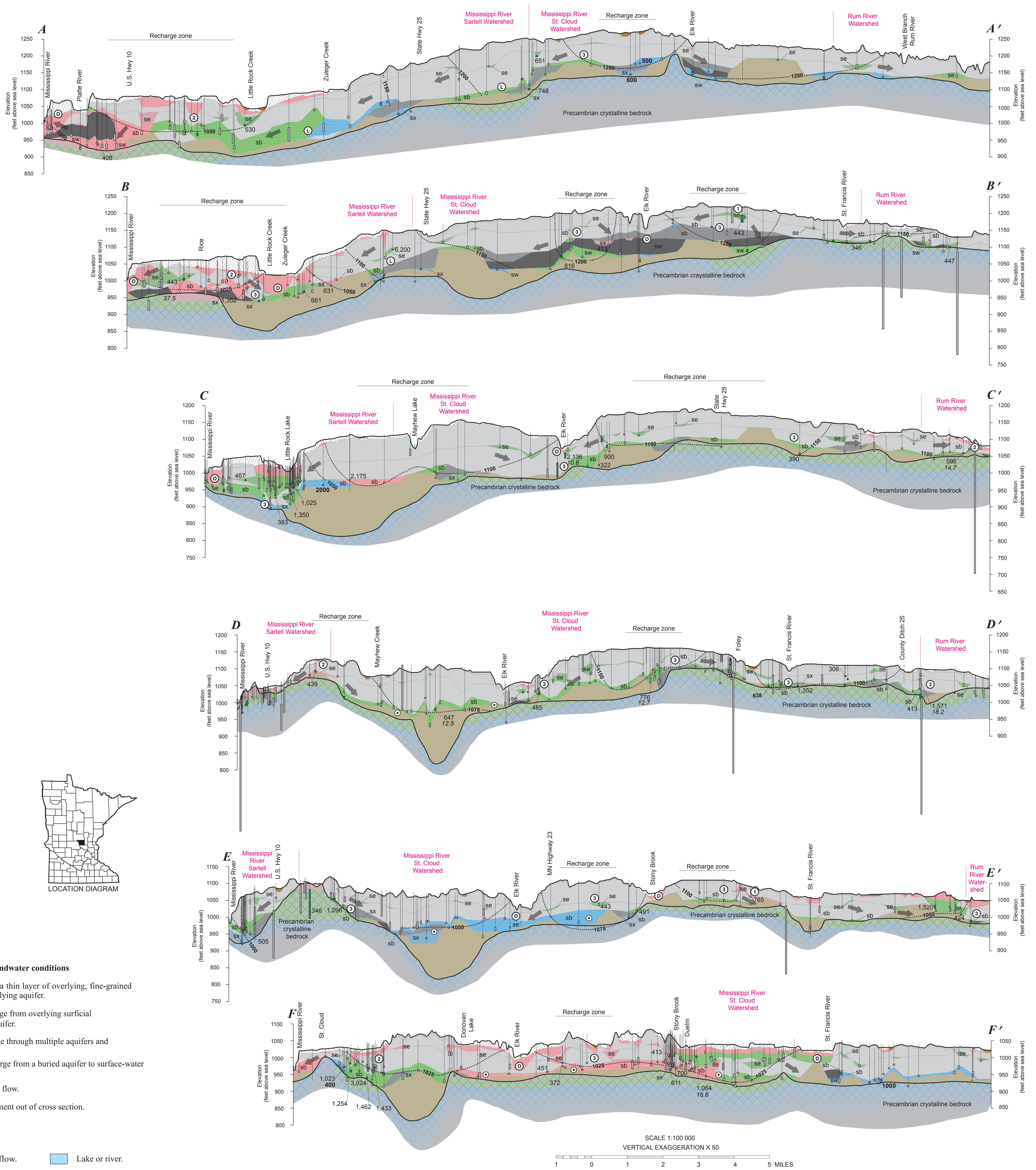

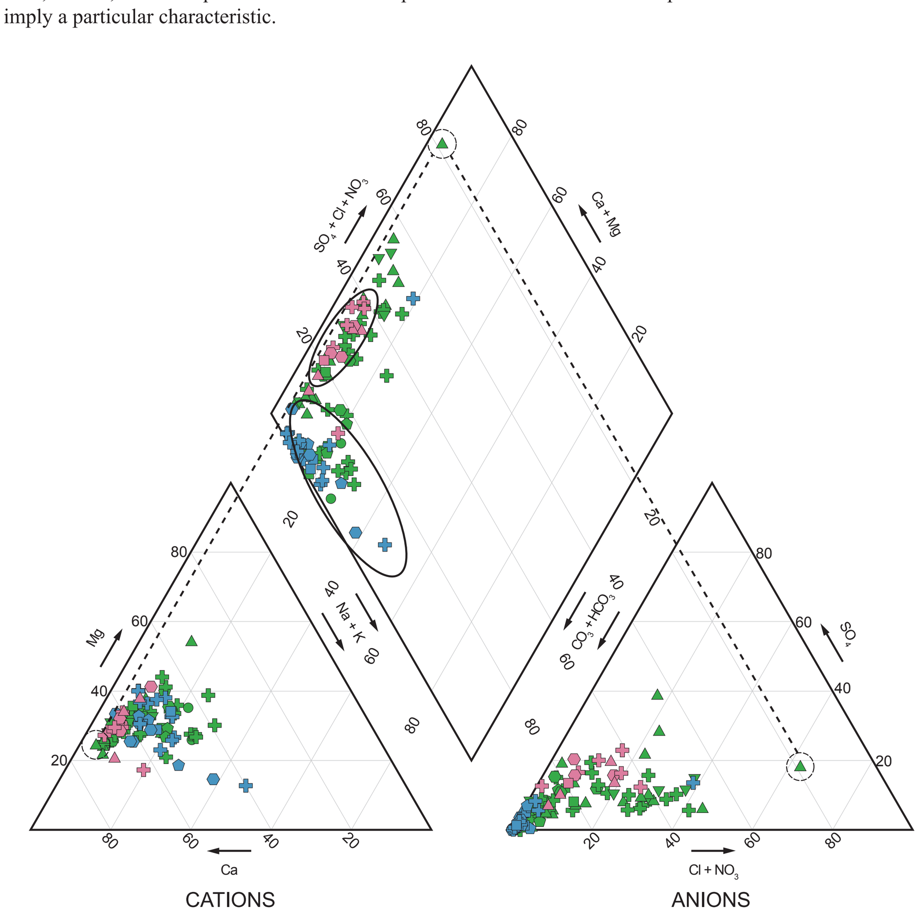

EXPLANATION

Sampled well and aquifer symbols

▼ Surficial sand aquifer

Buried sand and gravel aquifers.

▲ Supra-Emerald aquifer unit (se)

✚ Sub-Emerald aquifer unit (sb)

⬢ Pre-Wisconsinan aquifer unit (sx)

■ Pre-Wisconsinan aquifer unit (sw)

Other wells.

⬟ Unmapped buried aquifer

● Bedrock

Tritium age

▼ Recent

▼ Mixed

▼ Vintage

FIGURE 2. ***Trilinear diagram.*** *This diagram compares the relative proportions of cations and anions in groundwater samples from all of the sampled wells. The left triangle shows cation composition, the right triangle shows anion composition, and the center diamond shows a composite of cations and anions. Wells are symbolized according to the source aquifer unit and colored according to tritium age. The majority of groundwater samples are of calcium-bicarbonate type. As an example, the dashed circles and lines connect data from the well number 480849; this well had an atypical, excessively high* $Cl + NO_3$ *composition.*

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.

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.

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 through multiple aquifers and fine-grained layers.

Ⓓ Groundwater discharge from a buried aquifer to surface-water body.

Ⓛ Lateral groundwater flow.

⊙ Groundwater movement out of cross section.

Symbols and labels

300 If shown, chloride to bromide ratio greater than 300.

2000 If shown, groundwater residence time in years, estimated by carbon-14 (^{14}C) isotope analysis.

12.6 If shown, nitrate as nitrogen concentration equals or exceeds 10 parts per million.

General direction of groundwater flow.

····**1030**···· Approximate equipotential contour as labeled.

Land or bedrock surface.

Lake or river.

Peat.

Aquifers - grouped by stratigraphy

Aquifer unit name	Aquifer unit code	Geologic unit code
Surficial sand aquifer		Qe, Qf, Qa, Qp, Qwl, Qwr, Qns, Qno, Qnw, Qcf, Qci
Supra-Emerald aquifer unit	se	Qse
Sub-Emerald aquifer unit	sb	Qsb
Pre-Wisconsinan aquifer units	sx	Qsx
	sw	Qsw

Crystalline bedrock - can be a low hydraulic conductivity aquifer or aquitard depending on location

Precambrian crystalline bedrock

Confining units - grouped by texture ranging from highest sand content (light gray) to lowest sand content (dark gray) indicating relative hydraulic conductivity (Plate 4, Part A, Table 1). Relative hydraulic conductivity based on texture as derived from Dingman (2002).

Relative hydraulic conductivity	Color code	Geologic unit code
Highest relative conductivity >60% sand gravelly, sandy loam		Qnd, Qcr, Qce, western Qbs
Intermediate relative conductivity >40-60% sand loam to clay loam		Eastern Qbs (Browerville), Qbs (Lake Henry and St. Francis), Qwt (Old Rainy)
Lowest relative conductivity <40% sand clay loam		Qxe and Elmdale Qwt
Not determined		Qu

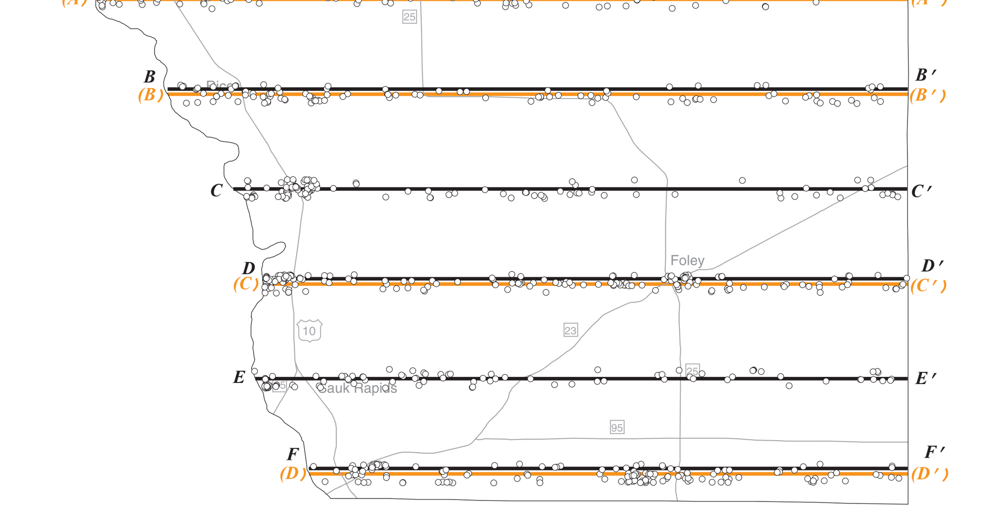

FIGURE 1. *Location of hydrogeologic cross sections shown on this plate (black lines) and geologic cross sections on Plate 4, Part A (orange lines). The small open circles indicate the locations of wells displayed on the hydrogeologic cross sections shown on this plate.*

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This information is available in alternative format on request.

Base modified from Minnesota Geological Survey, Benton County Geologic Atlas, Part A, 2010.
Project data compiled from 2010 to 2011 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 Jeremy Rivord, Greg Massaro, and Shana Pascal. Edited by Neil Cunningham and Jan Falteisek.