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Project data compiled from 1998 to 2001 at the scale of 1:100,000. Universal Transverse Mercator projection, grid zone 15, 1983 North American datum. Vertical datum is mean sea level.

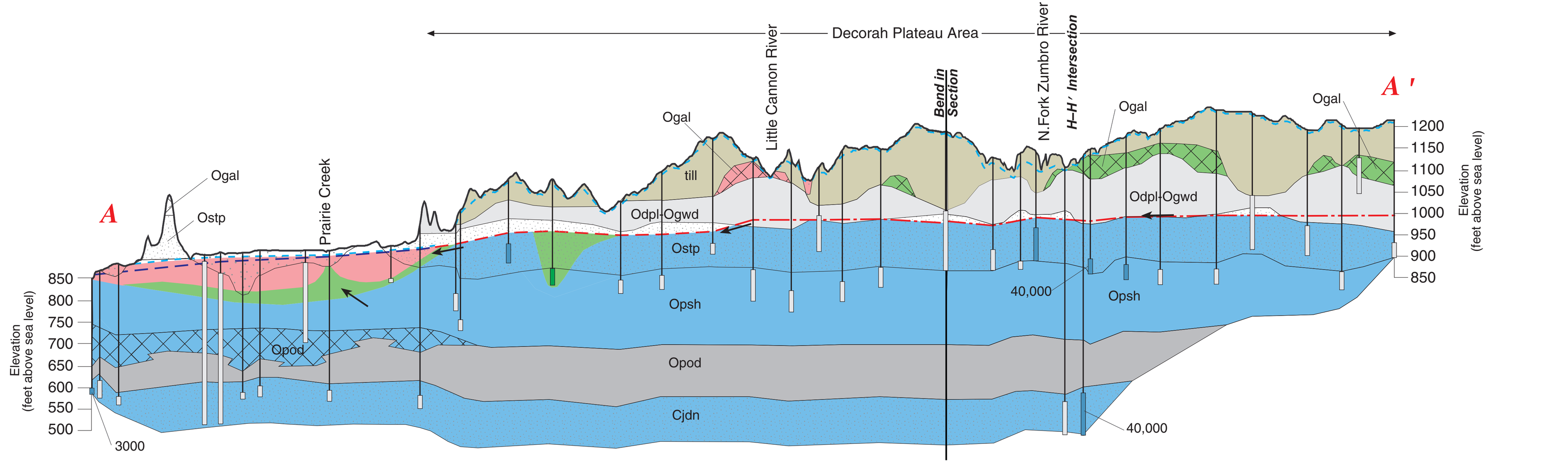
GIS and cartography by Mike Tronrud and Jim Berg. Edited by Nick Kroska.

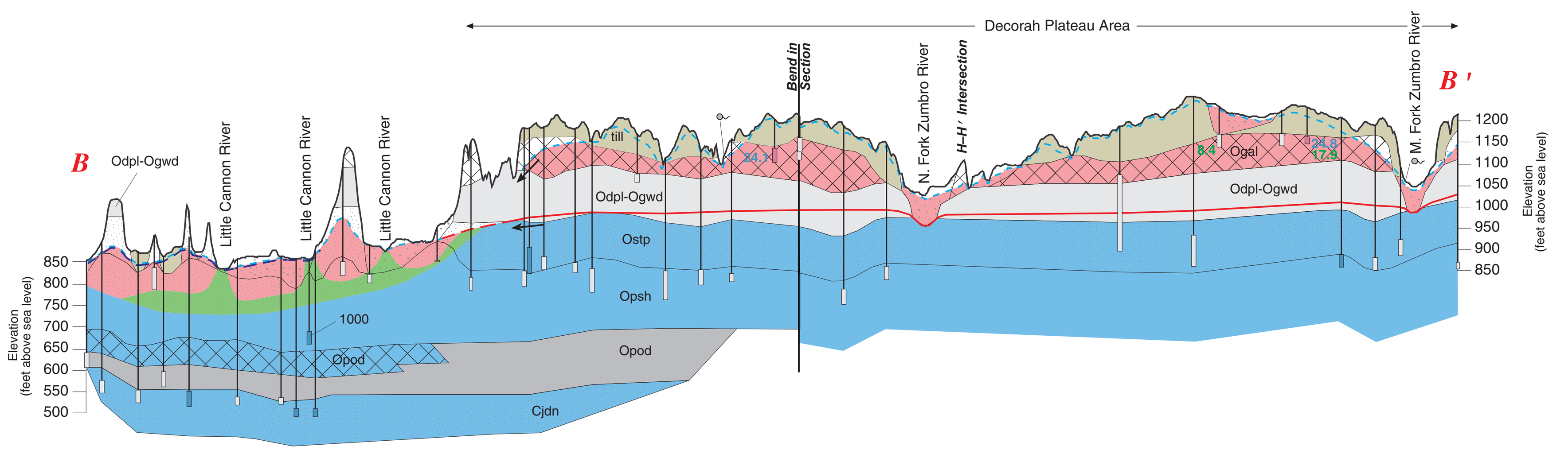
HYDROGEOLOGIC CROSS SECTIONS

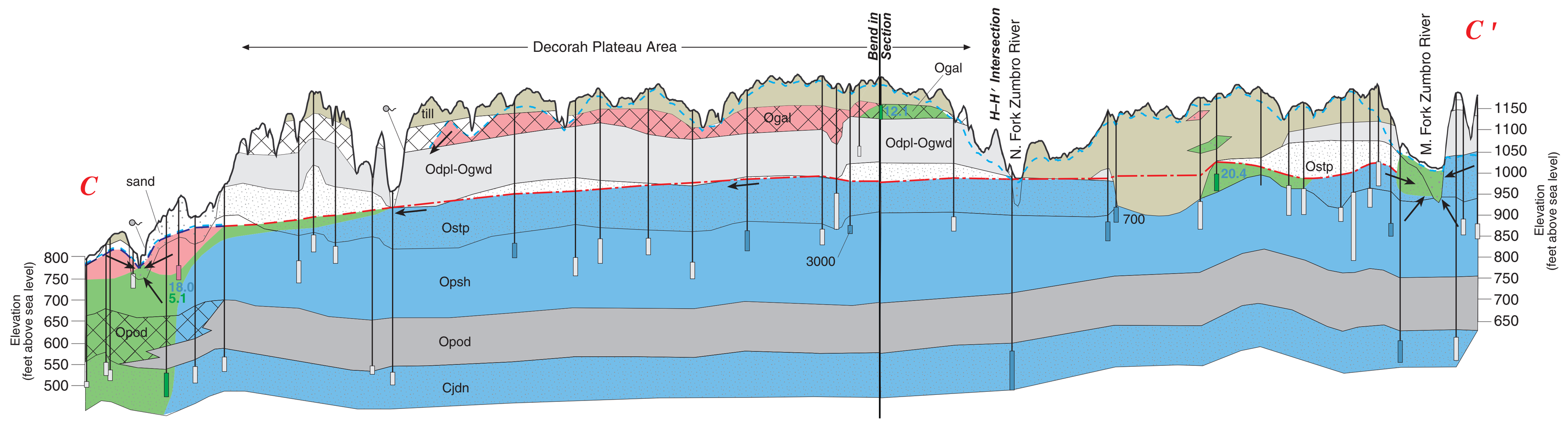
By

James A. Berg

2003



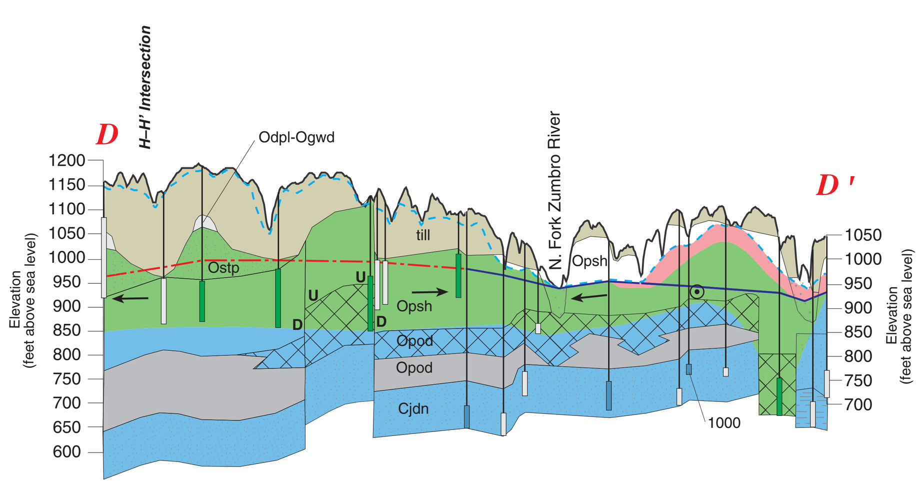


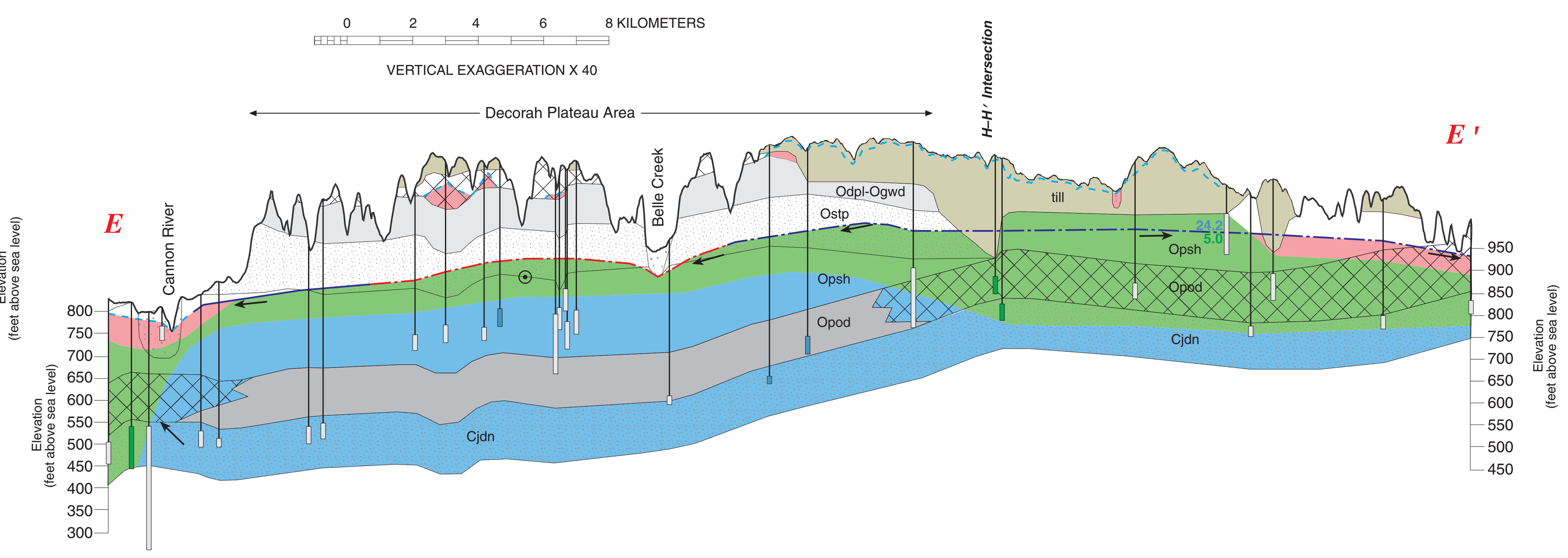


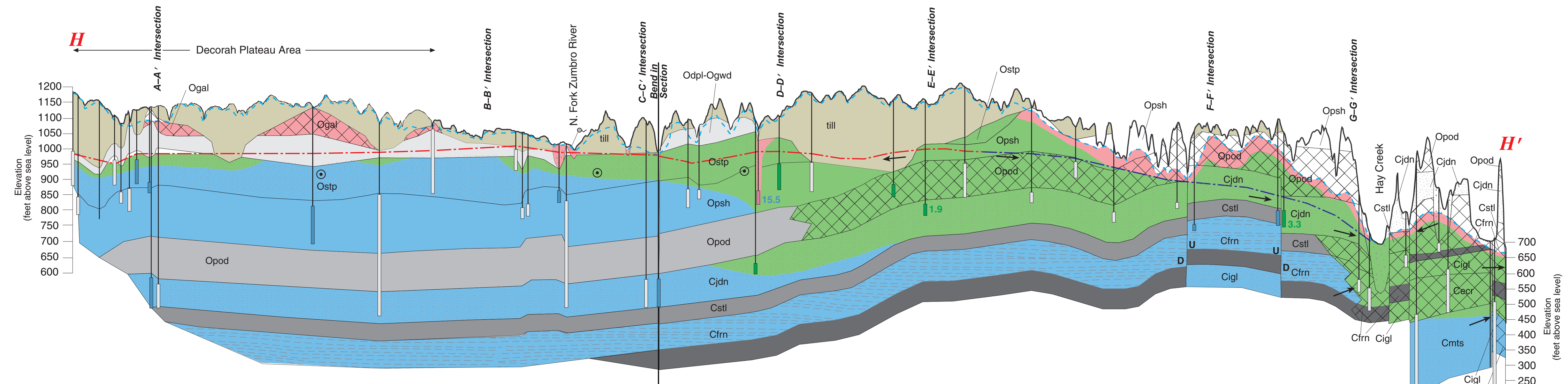
1 0 1 2 3 4 5 MILES

0 2 4 6 8 KILOMETERS

VERTICAL EXAGGERATION X 40







EXPLANATION

Tritium Age—Tritium age not shown for till or bedrock confining units. Uncolored means unsaturated. Vertical rectangle indicates well screen or open hole

- Recent—Water entered the ground since 1953 (10 or more tritium units).
- Mixed—Water is a mixture of recent and vintage waters (0.8 to less than 10 tritium units).
- Vintage—Water entered the ground before 1953 (less than 0.8 tritium units).
- Well not sampled for tritium.

Potentiometric Surface

- Upper water table

Color indicates aquifer

- St. Peter-Prairie du Chien
- Jordan
- St. Lawrence-Franconia-Ironton-Galesville*

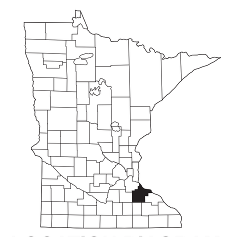
Line type indicates aquifer condition

- Unconfined
- Variable confined and unconfined, or uncertain
- Confined

**Ironton-Galesville may be a separate aquifer, but data are combined here because few wells completed in the Ironton-Galesville aquifer are present in the county.*

Cross Section Symbols and Labels

- U — Fault—Approximately located; upthrown side
- D — Fault—Approximately located; downthrown side
- Spring
- Ground-water flow out of the cross section
- General direction of ground-water movement
- 1.5 — If shown, nitrate level equals or exceeds 1 part per million
- 24.2 — If shown, chloride level equals or exceeds 12 parts per million
- 40,000 — If shown, ground-water age in years, estimated by carbon-14 isotope analysis


LOCATION DIAGRAM

Aquifer Characteristics of Lithologic Units

Moderate to high conductivity under shallow and deep conditions.

- Sand and gravel deposits
- St. Peter Sandstone (Ostp)
- Shakopee Formation (Opsh)
- Jordan Sandstone (Cjdn)
- Mt. Simon Sandstone (Cmts)

Moderate to high conductivity under shallow conditions. Low conductivity or confining (Oneota Dolomite and St. Lawrence Formation) under deep conditions. Crosshatch pattern indicates fractured, karst, or both conditions indicating enhanced hydraulic conductivity.

- Galena Group (Ogal)
- Oneota Dolomite (Opod)
- St. Lawrence Formation (Cstl)
- Franconia Formation (Cfrn)
- Ironton-Galesville Sandstone (Cigl)
- Eau Claire Formation (Cecr)

Confining Units

- Glacial till
- Decorah-Platteville-Glenwood formations (Odpl-Ogwd)*
- Franconia Formation - lower (Cfrn) (shown only on cross section)

*The Decorah Shale and Glenwood Formation both act as confining units, but the intervening Platteville Formation is a thin aquifer. Combined, these units are treated as a confining unit.

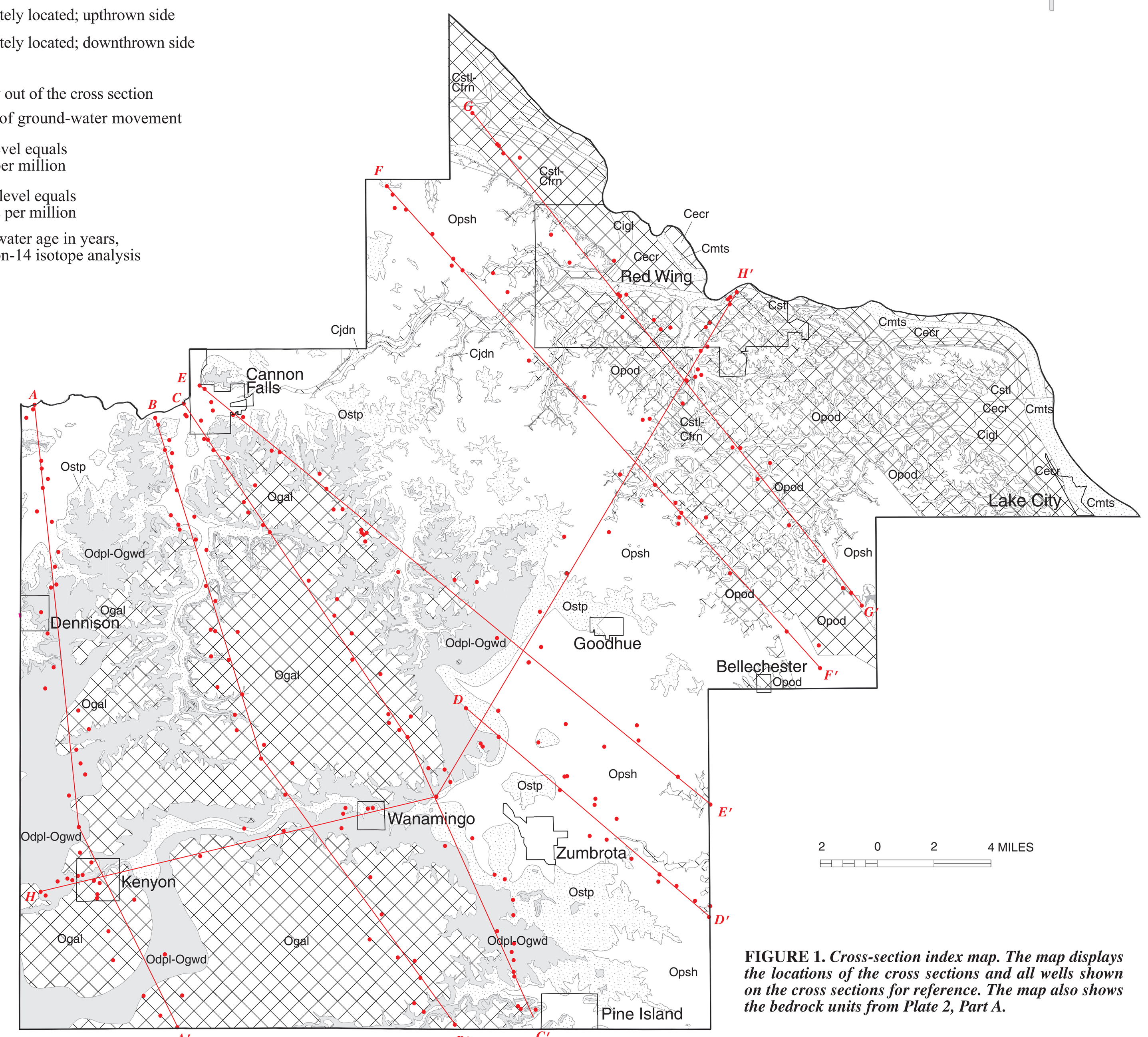
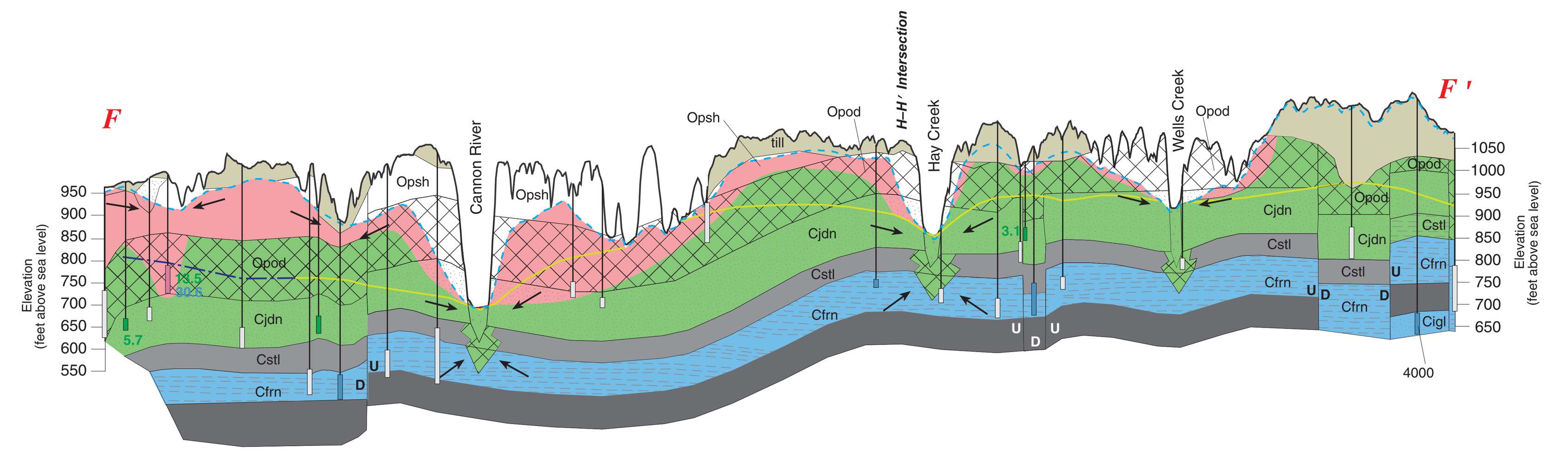
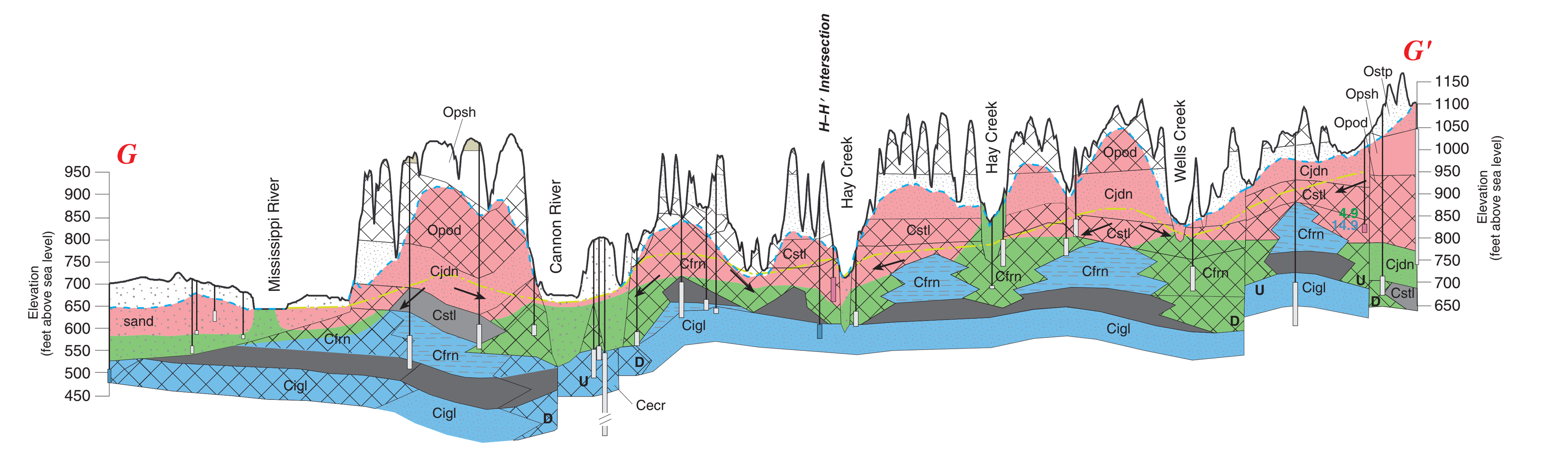


FIGURE 1. *Cross-section index map. The map displays the locations of the cross sections and all wells shown on the cross sections for reference. The map also shows the bedrock units from Plate 2, Part A.*





INTRODUCTION

The eight hydrogeologic cross sections shown on this plate illustrate the horizontal and vertical extent of hydrogeologic units (aquifers and confining units), ground-water residence time, and water-table and potentiometric surface profiles. The cross sections were located within the county to show as much tritium data as possible. The cross sections were constructed using a combination of well data from the County Well Index (CWI) and information from Bedrock Geology (Plate 2) and Surficial Geology (Plate 3) in Part A. The locations of the wells and cross sections are shown in Figure 1. Some of the faults shown on the cross sections are not indicated in Part A but are suggested by abrupt elevation changes in bedrock contacts noted in CWI logs. The well information for each cross section was projected onto the trace of the cross-section line from distances no greater than a mile.

RELATIVE HYDRAULIC CONDUCTIVITY

The various hydrogeologic units shown on the cross sections are classified according to the regional average of hydraulic conductivity (Runkel and others, 2003). Hydraulic conductivity, or the water-transmitting capacity of the hydrogeologic unit, is controlled by the porosity (open spaces within the unit) and permeability (a measure of how connected the open spaces are) within the unit. These factors mostly depend on the rock type (lithology) and the depth of the hydrogeologic unit beneath the top of the bedrock. A comparison of rock types influencing hydraulic conductivity would be a shale layer versus a sandstone layer. The shale, which is a very fine-grained rock, will usually have a much lower permeability and hydraulic conductivity than the sandstone, which is a much coarser grained rock. Examples of the shallow versus deep influence of hydraulic conductivity are shown on Figure 2. On this figure are several examples of fine-grained layers, containing shale, siltstone, or fine grained sandstone, which typically have no fractures, solution-enhanced fractures, or other karst features. These units are expected to have low hydraulic conductivity and are confining units. These same layers traced to a location closer to the top of the bedrock contain fractures and solution-enhanced fractures that can totally change the hydraulic properties of the layer.

The hydraulic properties of the two types of aquifers shown on this plate are influenced by their depth and lithology. The first type of aquifer exhibits moderate to high (16 feet per day to 67 feet per day) hydraulic conductivity characteristics under shallow and deep conditions (sand and gravel, St. Peter-Shakopee, Jordan, and Mt. Simon aquifers). The second type possesses a moderate to high hydraulic conductivity range only under shallow conditions (Galena, Oneota, St. Lawrence-Franconia-Ironton-Galesville, and Eau Claire aquifers).

The confining units include the glacial till, the Decorah-Platteville-Glenwood formations, Oneota Dolomite (under deep conditions), St. Lawrence Formation (under deep conditions), and the lower portion of the Franconia Formation. These units have very low vertical hydraulic conductivities. No measured hydraulic conductivity values are available for the till unit. Furthermore, the drillers' logs in Goodhue County generally do not provide very detailed descriptions of the till. However, the tritium data (discussed below) suggest that the till may be permeable enough to allow surface water infiltration to the underlying bedrock within the last 50 years. Therefore, the till unit is classified in this report as a leaky confining unit. According to Runkel and others (2003), deep occurances of the St. Lawrence Formation at different locations can have properties of both an aquifer and a confining unit. The lower portion of the Franconia, however, may be an effective confining unit under both shallow and deep conditions.

POTENTIOMETRIC SURFACES

Several different potentiometric surfaces are shown on cross sections A–A′ through H–H′ (cross-section explanation and Figure 3). The cross sections show two types of unconfined potentiometric surfaces. The line with the short dashes identifies the upper water table that exists mostly above the Decorah-Platteville-Glenwood confining unit and within thick till layers in the southern and middle portions of the county. In northeastern Goodhue County, this line represents the water table that exists deep within the river bluffs. The upper water-table lines are elevation profiles derived from the water-table DEM, which was used to create the water-table depth model (Plate 7). Near the edges of the Decorah plateau and beneath the Decorah-Platteville-Glenwood confining unit, another unconfined potentiometric surface may exist (buried unconfined). Confined conditions are shown with the solid lines and are colored to match the potentiometric contours of the three main aquifer systems shown on Plate 7. Finally, in some areas, the bedrock potentiometric surface, shown as a dash and dot line, appears to vary between confined and unconfined conditions. This line type was also used where insufficient data exist to establish confining conditions.

GROUND-WATER RESIDENCE TIME

The red, green, and blue areas shown on these cross sections represent the age of the ground water, also known as ground-water residence time. This is the approximate time that has elapsed since the moment the water infiltrated the land surface to the time it was pumped from the aquifer for this investigation. Tritium (^{3}H) is a naturally occurring isotope of hydrogen. Concentrations of this isotope in the atmosphere were greatly increased from 1953 through 1963 by above-ground detonation of hydrogen bombs (Alexander and Alexander, 1989). Since this isotope decays at a known rate (half life of 12.43 years), the proportion of recently (last 50 years) recharged water in an aquifer can be estimated from tritium concentrations. Water samples with concentrations of tritium greater than 10 tritium units (TU) are considered recent water (mostly recharged in the past 50 years, shown in red). Concentrations less than the detection limit (0.8 TU) are considered vintage water (recharged prior to 1953, shown in blue). Concentrations between these two limits are considered a mixture of recent and vintage and are referred to as mixed (shown in green).

Ground-water age for the vintage samples can be estimated with the carbon-14 (^{14}C) isotope. This also is a naturally occurring isotope, which has a much longer half life than tritium (5,730 years). Carbon-14 is used to estimate ground-water residence within a time span of 100 years to 40,000 years.

DECORAH PLATEAU AREA

The Decorah Plateau consists of remnants of the Galena Group over the Decorah-Platteville-Glenwood confining unit. The Decorah Plateau is resistant to erosion and dominates the topography of southwestern Goodhue County (cross-sections A–A′, B–B′, C–C′, E–E′, and H–H′). Water infiltration through the till in this area is rapid enough to create recent and mixed tritium concentrations in ground-water samples from wells completed in the underlying Galena aquifer (shown on Plate 7 and cross-section C–C′). The low permeability of the Decorah-Platteville-Glenwood confining unit produces a shallow water table across most of the plateau, except for the river bluff areas. The water table is probably deep within the bluff areas near the Cannon River, the Little Cannon River, Belle Creek, and the Middle Fork Zumbro River where the till is thin or absent and the Decorah-Platteville-Glenwood confining unit may be fractured and permeable.

A very low rate of surface water infiltration through the Decorah-Platteville-Glenwood confining unit is indicated by the predominance of vintage ground water sampled from the underlying St. Peter-Shakopee aquifer (cross-sections A–A′, B–B′, C–C′, E–E′, and H–H′). Two exceptions to the low rate of water infiltration are indicated by mixed concentrations of tritium in ground-water samples from the St. Peter Sandstone (right end of cross-section C–C′) and the Shakopee Formation (the left one-third of cross-section A–A′). The mixed conditions occur near the edges of the plateau where the Decorah-Platteville-Glenwood confining unit is thin, locally eroded, or possibly fractured. These conditions allow greater surface water infiltration than areas beneath the central portion of the plateau.

The Jordan aquifer beneath this plateau also characteristically contains vintage water. The aquifer is protected not only by the Decorah-Platteville-Glenwood confining unit but also by the overlying Oneota confining unit. For instance, the carbon-14 age date of a water sample from the St. Peter-Shakopee aquifer shown on cross-section C–C′ (3,000 years) is significantly younger than the age date of a water sample (40,000 years, cross-section A–A′) from the Jordan aquifer. This difference may be due to the additional protective properties of the Oneota confining unit.

ZUMBROTA–GOODHUE AREA

East of the Decorah-Platteville-Glenwood edge, in an area north of Zumbrota and southwest of Goodhue, surface water infiltration through thick till layers may be responsible for detectable concentrations of tritium in the underlying Shakopee, fractured Oneota, and Jordan aquifers (cross-section D–D′, the right end of E–E′, and the middle portion of H–H′). Several low to moderate (1 part per million [ppm] to 5 ppm) nitrate concentrations and elevated chloride concentrations (greater than 12 ppm) in water samples from the first bedrock aquifers in this area also suggest that this till layer has limited protective characteristics (see right end of cross-section E–E′ and bedrock potentiometric map on Plate 7). An alternative explanation could be that ground water from the Galena aquifer flows east from the plateau area, infiltrates laterally through the glacial till, and recharges the Shakopee and lower aquifers with water containing elevated nitrate and chloride. A combination of vertical and lateral flow is also possible. This part of the county is a topographic and potentiometric high area and is, therefore, an important ground-water recharge area for the underlying bedrock aquifers.

NORTHEASTERN GOODHUE COUNTY AND MAJOR RIVER VALLEYS

In these remaining parts of the county, the Decorah-Platteville-Glenwood confining unit has been eroded and thick till layers only exist in isolated areas. The water table tends to be deeper in these areas with no surficial or near-surface confining layers that limit infiltration elsewhere in the county. The Oneota Dolomite, which is a confining unit beneath the Decorah Plateau, is commonly a shallow aquifer (less than 200 feet below the top of the bedrock) in the northeastern portion of the county (cross-sections F–F′ and H–H′). Recent and mixed tritium values that dominate ground-water samples from these areas indicate relatively rapid recharge through the permeable shallow bedrock (see bedrock potentiometric surface map, Plate 7). Recent tritium concentrations were detected in five bedrock water samples in this area from somewhat deep wells (100 feet to 200 feet) suggesting enhanced permeability resulting from extensive fractures or solution features in these areas (left end of cross-section F–F′ and right end of cross-section G–G′).

There are several notable exceptions from these areas where the deeper aquifers are protected by deep confining units. Vintage tritium concentrations are found in samples from the Jordan aquifer (left ends of cross-sections A–A′ and B–B′) beneath a deep section of the Oneota Dolomite, which is apparently a confining unit in this area. Similarly, vintage water was extracted from deep wells in the lower formations (St. Lawrence, Franconia, Ironton-Galesville, and Eau Claire) that are protected by the low-permeability characteristics of these formations under deep conditions (cross-section F–F′, center of cross-section G–G′, and right end of cross-section H–H′). Several vintage water samples were collected from wells in the Cannon, Little Cannon, and Mississippi river valleys, which probably represent old discharging water (left ends of cross-sections B–B′ and G–G′ and bedrock potentiometric surface map, Plate 7).

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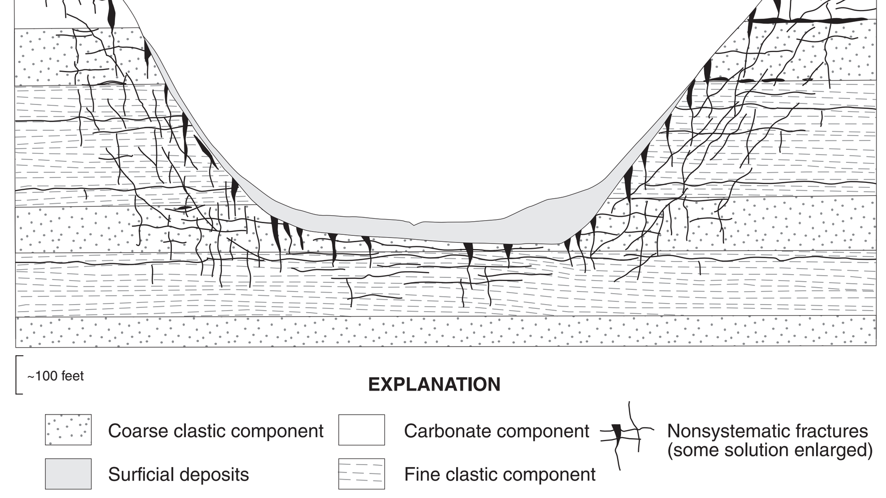

FIGURE 2. *The distribution of fractures and solution-enhanced fractures in shallow settings (less than 200 feet below the top of bedrock) for the three general rock types in the county. These features are combined and shown as a crosshatch pattern on the cross sections. From Runkel and others (2003).*

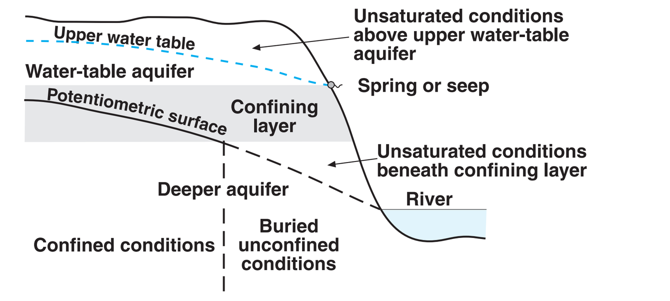

FIGURE 3. *Schematic diagram showing the relationship between buried confined and buried unconfined conditions in a deeper aquifer. Modified from Palen (1990).*