HYDROGEOLOGIC CROSS SECTIONS

By

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INTRODUCTION

The eight hydrogeologic cross sections shown on this plate illustrate the horizontal and vertical extent of hydrogeologic units (aquifers and aquitards), ground-water residence time, and general directions of ground-water flow. The cross sections shown on this plate were selected from a set of 66 regularly spaced, west-to-east cross sections. The cross sections were constructed using a combination of well data from the County Well Index (CWI); additional well and bore hole data from the U.S. Geological Survey; electrical resistivity data; information from the surficial geology map (Plate 1) and Quaternary stratigraphy (Plate 2) in Part A of this assessment; and the Pope County Geologic Atlas, Part A (Boerboom and others, 2003). The well information for each cross section was projected onto the trace of the cross section from distances no greater than a half kilometer with a few exceptions. The locations of the eight cross sections in the study area are shown in Figure 1.

PURPOSE AND METHOD OF CONSTRUCTING THE CROSS SECTIONS

The 66 cross sections were constructed to enable extrapolation of glacial stratigraphy from known areas to the rest of the study area. The cross sections include the upper five stratigraphic units in the study area (tills and associated sands and gravels of the Upper Goose River, Lower Goose River, Otter Tail River, and Crow Wing River groups and Browerville formation). The cross sections were also used as the primary tools for plotting and interpreting the three-dimensional distribution of surficial and buried sand deposits. The stratigraphic boundaries were correlated not only from west to east along the cross section by the conventional method of matching presumed stratigraphic unit tops, but also north to south by overlaying adjacent, digitized cross sections with geographic information system (GIS) software to check for correlation discrepancies. The sand thickness information from each stratigraphic unit was then transferred to a map of the same scale, and the sand unit boundaries were drawn using geographical assumptions derived from a general understanding of the unit's depositional history and regional paleogeography. The sand unit boundaries on the cross sections on this plate were adjusted to match the boundaries of the maps on Plates 3 and 4. The digital characteristics from the set of 66 cross sections were used to help create the aquifer maps shown in this report using a variety of GIS methods, which are the same as those used to create maps for the Pope County Geologic Atlas, Part B (Berg, 2006).

HYDROGEOLOGIC FEATURES AND DATA

Relative Hydraulic Conductivity

The patterns and shades of gray shown on these cross sections represent hydrogeologic units in broadly defined categories of inferred hydraulic conductivity. The tills of the Upper and Lower Goose River groups (shown as the darkest gray) have the lowest average sand content (23 percent to 31 percent and 30 percent to 33 percent, respectively [Part A, Plate 2]), and they probably have the lowest relative hydraulic conductivities of the units shown. The Otter Tail River group and Browerville formation (shown as the medium light and dark grays, respectively) are in the middle of the continuum (sand content from 43 percent to 48 percent, respectively). The Crow Wing River group till (shown as the lightest gray) is probably the most relatively permeable with sand content ranging from 54 percent to 57 percent. Another unit (brown) shown at the surface on six of the eight cross sections in the western portion of the region is an undifferentiated layer deposited in Glacial Lake Agassiz. This unit is described in Part A as offshore lake sediment consisting of clay and silt mantled on the margins by near-shore deposits of sand and silt. The hydraulic conductivity properties of this undifferentiated unit could be highly variable depending on which type of deposit is predominant at any particular location.

The sand and gravel aquifers (surficial sand and gravel aquifer; buried aquifers: LG, OT, CW, aquifer 1, and western aquifer) are shown with patterns on the cross sections. These patterns are provided to help the reader identify the aquifers on both the cross sections and the maps; the patterns are not meant to convey any relative hydraulic conductivity information.

Ground-Water Residence Time

The pink, green, and blue overlays shown on these cross sections represent the relative age of the ground water, also known as ground-water residence time. This is the approximate time that has elapsed since the water infiltrated the land surface to when it was pumped from the aquifer for this investigation. Ground-water residence time is closely related to the aquifer pollution sensitivity concept described on Plate 6. In general, short residence time suggests high pollution sensitivity, whereas long residence time suggests low sensitivity.

Tritium (^3H) 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). This isotope decays at a known rate, with a half-life of 12.43 years. Water samples with tritium concentrations of 10 or more tritium units (TU) are considered recent water (mostly recharged in the past 50 years, shown in pink). Concentrations of 1 TU or less are considered vintage water (recharged prior to 1953, shown in blue). Water samples with tritium concentrations greater than 1 TU and less than 10 TU are considered a mixture of recent and vintage and are referred to as mixed water (shown in green).

Ground-water residence time for the vintage samples can also be estimated with the carbon-14 (^{14}C) isotope. This isotope, which also occurs naturally, has a much longer half-life than tritium (5730 years). Carbon-14 is used to estimate ground-water residence time in a span from about 100 years to 40,000 years.

HYDROGEOLOGY ILLUSTRATED BY THE CROSS SECTIONS

A code (**1** through **4**) indicates the type of recharge for many of the aquifers that contain or are interpreted to contain ground-water tritium concentrations in values greater than 1 TU (recent or mixed water). These codes also appear on Plate 6, Figures 4 through 8. **A 1** indicates infiltration through a thin layer of overlying fine-grained material to an underlying aquifer. **A 2** shows areas where ground water from an overlying surficial aquifer has recharged the underlying buried aquifer through leakage or a direct connection. Areas labeled with a **3** indicate ground-water leakage from an overlying buried aquifer to an underlying buried aquifer. This is illustrated by the LG aquifer leaking into the adjacent, underlying OT aquifer in the central portion of the study area where the LG is the first buried aquifer (shallowest). In the eastern portion of the region where the OT is the first buried aquifer, the **3** indicates leakage from the OT aquifer to the underlying CW aquifer. Areas labeled with a **4** indicate ground-water leakage through multiple aquifers and fine-grained layers. The other codes are **D** that indicates where ground-water discharge from buried aquifers to surface-water bodies probably occurs, **L** that indicates where lateral flow of ground water is suspected, and **U** that indicates where the source of the recent or mixed ground water is unknown.

Recharge by Infiltration through Thin, Fine-Grained Layers and Surficial Sand

Infiltration through thin, overlying, fine-grained layers (**1**) is common for the LG aquifer in central Grant (left side of cross-section D–D′ and Plate 6, Figure 4) and Stevens counties and locations along the Pomme de Terre River. This infiltration condition is also common for the OT aquifer in Pope and Douglas counties (Plate 6, Figure 5) and locations in Traverse County. Examples from the cross sections include a location west of Elbow Lake (left of center, cross-section A–A′), west of Alexandria (right of center, cross-section B–B′), west of Maple Lake (right side of cross-section D–D′), northwestern Pope County and locations northwest of Long Beach and Glenwood (right side of cross-section E–E′), east of the Chippewa River (right of center, cross-section G–G′), and southeastern Pope County (right side of cross-section H–H′). This infiltration condition is less common for the CW aquifer with more isolated examples shown in the Alexandria area (right side of cross-section B–B′), eastern Douglas County (far right side of cross-section D–D′), and south-central Pope County (right side of cross-section H–H′).

Leakage from surficial aquifers into an underlying aquifer (**2**) is common in the CW aquifer and less common in all the other aquifers. Examples of this type of recharge are shown on all cross sections, with CW aquifer occurrences particularly common on the right portions of cross-sections C–C′ through F–F′ beneath the Belgrade-Glenwood area aquifer in eastern Pope and Douglas counties. Other specific examples are shown in the Pomme de Terre River valley in Grant County (left of center, cross-section A–A′), areas around the Chippewa River in western Pope County (right of center, cross-section E–E′), and areas in eastern Stevens County associated with the Pomme de Terre River (center of cross-sections F–F′ and G–G′). Scattered occurrences of leakage from surficial aquifers to the OT aquifer are shown along the Chippewa and Pomme de Terre rivers in Grant and Stevens counties (near the center of cross-sections C–C′ through H–H′). An example of leakage from the surficial aquifer to aquifer 1 is shown in the Lake Carlos area of Douglas County (near right end of cross-section A–A′).

Recharge by Leakage through Adjacent and Multiple Aquifers

Leakage from the OT aquifer to the CW aquifer (**3**) occurs at scattered locations. Examples shown on the cross sections include an area in northeastern Grant County (left of center, cross-section A–A′), north of Reno Lake in Douglas County (right side of cross-section D–D′), and a location south of Lake Minnewaska in Pope County (right side of cross-section G–G′). Leakage from the LG aquifer to the underlying OT aquifer (**3**) is shown in eastern Stevens County (Plate 6, Figure 5); however, no examples are illustrated on the cross sections.

Infiltration through multiple aquifers and intervening fine-grained layers (**4**) is very common in eastern Pope and Douglas counties (right side of cross-section B–B′, and cross-sections D–D′ through F–F′) with the recharge from the surficial aquifer through the CW aquifer to aquifer 1 as the usual occurrence.

Discharge to Surface-Water Bodies

Discharge or probable discharge of ground water to surface-water bodies (**D**) is common from the LG and OT aquifers in the Pomme de Terre and Chippewa River valleys in eastern Grant and eastern Stevens counties and western Pope County. Surficial aquifer discharge into the lakes of eastern Pope (Berg, 2006; Plate 6, Figure 3) and Douglas counties is common in the eastern portion of the study area. In addition, aquifer 1 and scattered occurrences of the CW aquifer discharge to lakes in the Alexandria area of Douglas County and Lake Minnewaska in Pope County. Scattered occurrences of surface discharge from the CW aquifer at other locations are shown on Plate 6, Figure 6.

Specific examples of LG, OT, or CW surface discharge to the Pomme de Terre and Chippewa rivers shown on the cross sections include areas near the center of cross-sections B–B′, C–C′, D–D′, E–E′, and G–G′. CW aquifer surface-water discharge to Lake Andrew is shown on the right side of cross-section C–C′. Surface discharge of aquifer 1 to Lake Ida is shown on the right side of cross-section A–A′ and to lakes Brophy, Cowdry, and Geneva on the right side of cross-section B–B′. Another surface discharge area of aquifer 1 is shown northeast of Lake Emily in Pope County (right side of cross-section G–G′).

Lateral Ground-Water Movement

Lateral ground-water movement (**L**) is pervasive in most aquifer settings. The following examples are limited to locations where recent surface-water infiltration was detected (evidence of recent or mixed tritium values or elevated chloride to bromide ratios), but the apparent recharge location was upgradient from the well location. (Some of the recharge areas are too small to see on the map at a scale of 1:250,000.) Several examples involving aquifer 1 are shown in Douglas County in the Alexandria area and locations south of there as recent tritium values on the right side of cross-section B–B′ and as mixed tritium values on the right side of cross-section C–C′. In northwestern Douglas County, an example of lateral ground-water movement in the CW aquifer is shown right of center on cross-section B–B′. Examples of lateral ground-water movement in the OT aquifer appear to exist in the Hoffman area of southeastern Grant County (near center of cross-sections C–C′ and D–D′).

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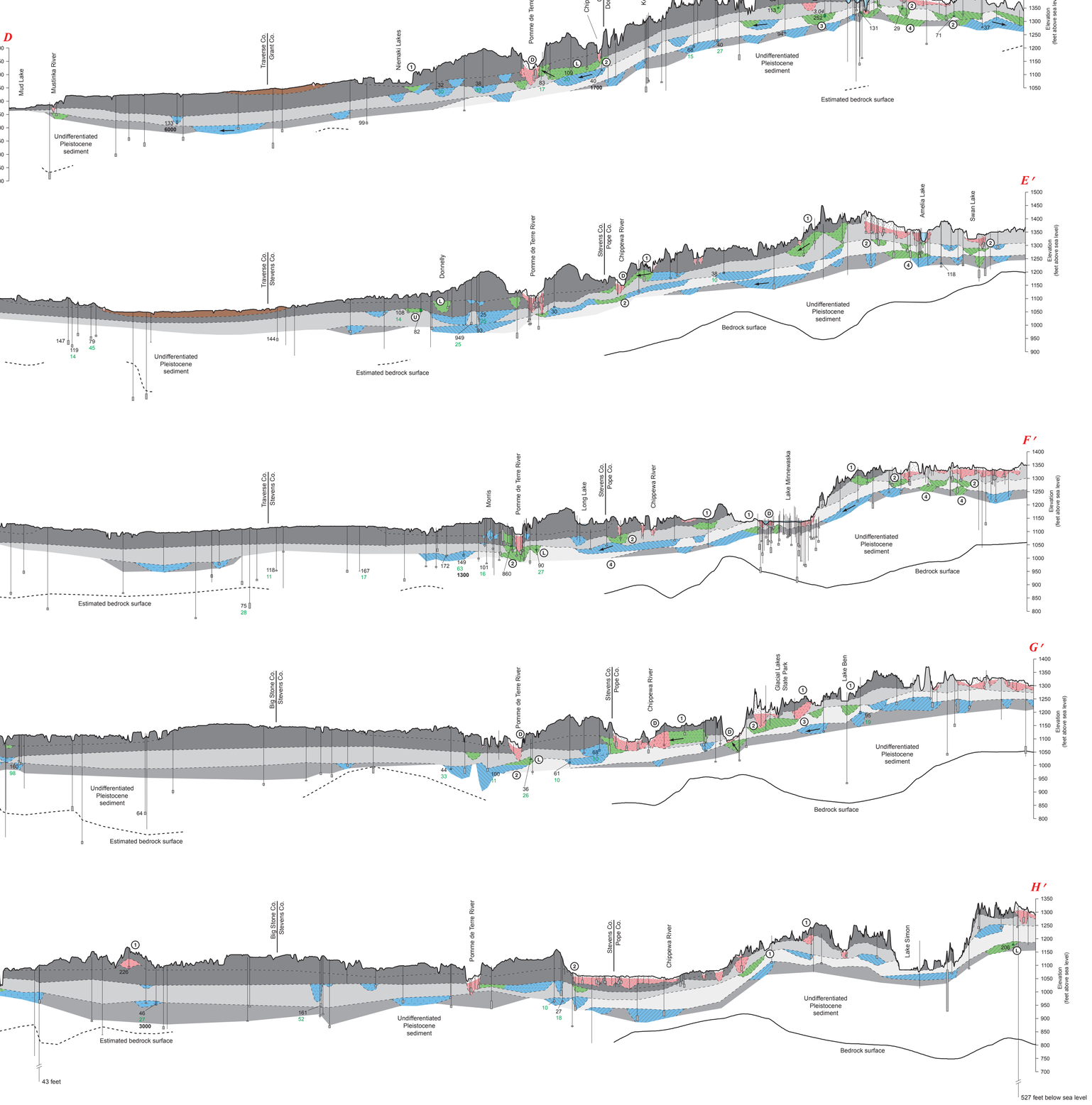

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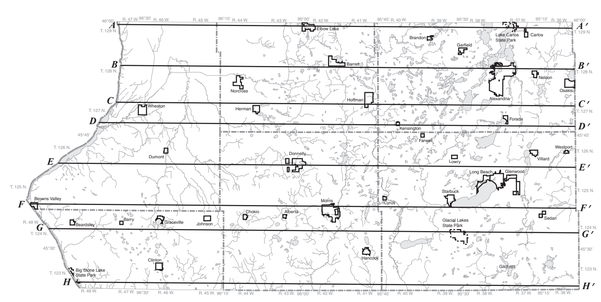

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FIGURE 1. *Locations of the cross sections in the study area.*

EXPLANATION

Tritium age

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

Aquifers

- Surficial sand and gravel aquifer.
- Buried LG aquifer
- Buried OT aquifer
- Buried CW aquifer
- Buried aquifer 1
- Buried western aquifer

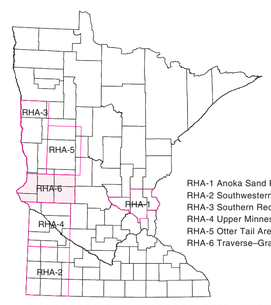
Low-permeability geologic units (aquitards)

- Undifferentiated glacial lake sediment.
- Upper and Lower Goose River groups. Dashed line is contact between groups.
- Otter Tail River group.
- Crow Wing River group.
- Browerville formation and other unnamed till units (east) and unnamed till units (west).

Symbols and labels

- *12.60* If shown, nitrate as nitrogen concentration equals or exceeds 3 parts per million.
- 407 Chloride to bromide ratio.
- 32 If shown, arsenic concentration equals or exceeds 10 parts per billion.
- **2000** If shown, ground-water age in years, estimated by carbon-14 isotope analysis.
- General direction of ground-water flow.
- Geologic unit contact, uncertain.
- Bedrock surface, uncertain.
- Land or bedrock surface.
- Lake.

- ① Infiltration through a thin layer of overlying, fine-grained material to an underlying aquifer.
- ② Ground-water recharge from overlying surficial aquifer to buried aquifer.
- ③ Ground-water leakage from an overlying buried aquifer to an underlying buried aquifer.
- ④ Ground-water leakage through multiple aquifers and fine-grained layers.
- Ⓓ Ground-water discharge from a buried aquifer to a surface-water body.
- Ⓛ Lateral ground-water flow.
- Ⓤ Unknown source of recent or mixed ground water.



RHA-1 Anoka Sand Plain
RHA-2 Southwestern Minnesota
RHA-3 Southern Red River Valley
RHA-4 Upper Minnesota River Basin
RHA-5 Otter Tail Area
RHA-6 Traverse–Grant Area

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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.

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