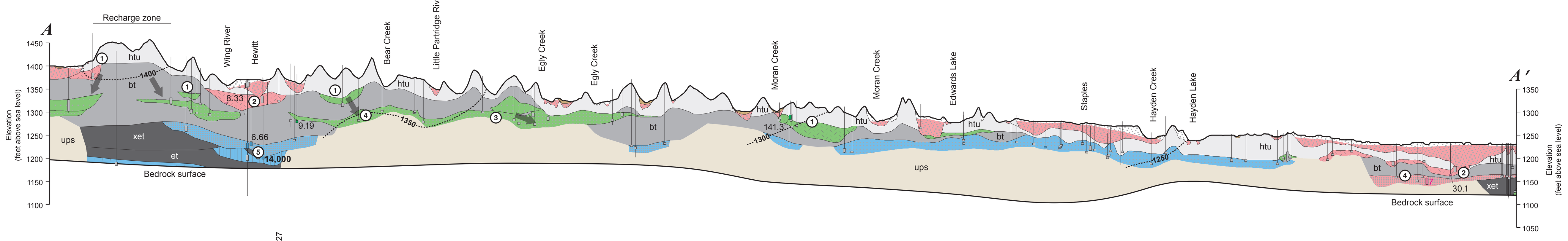

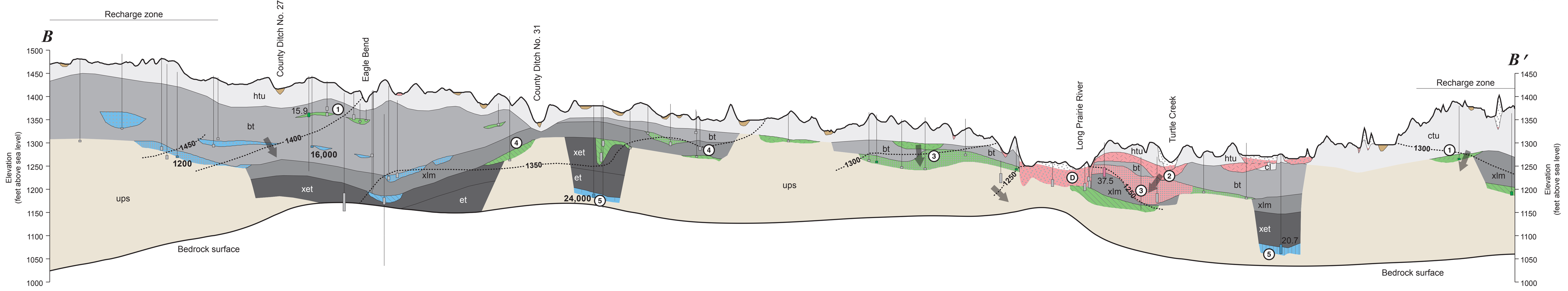

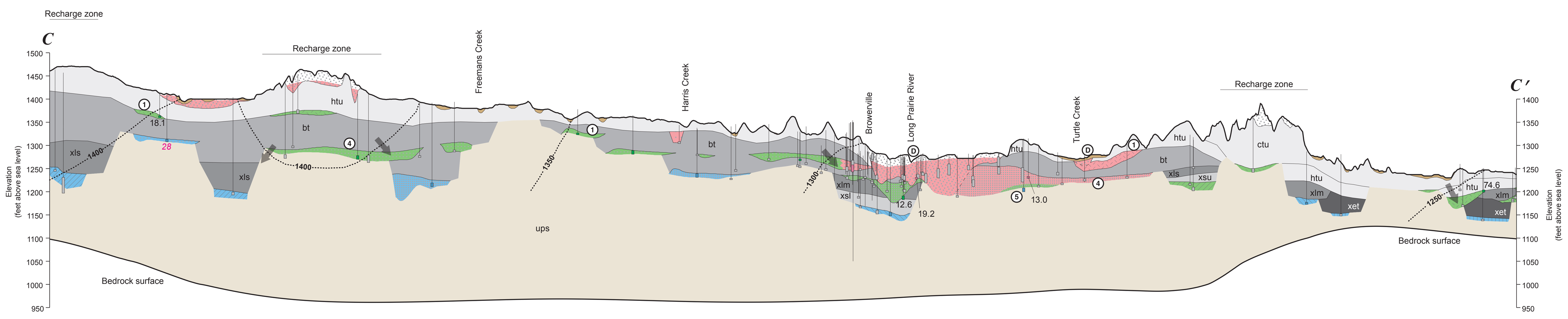

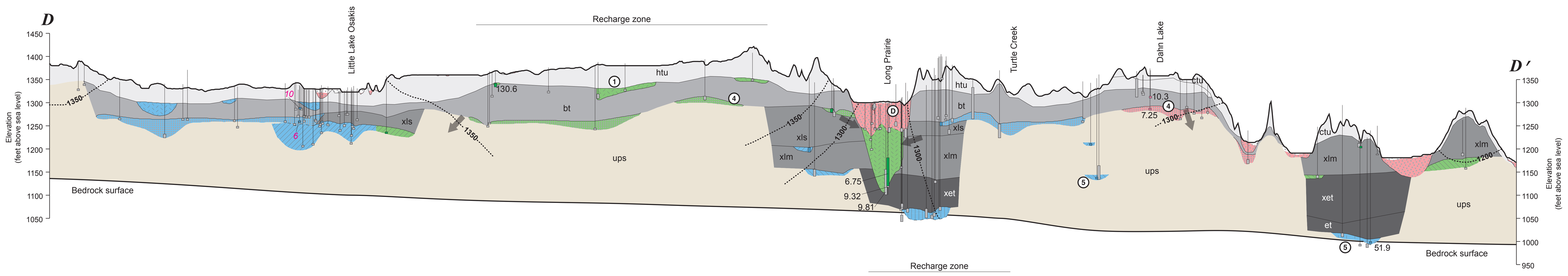

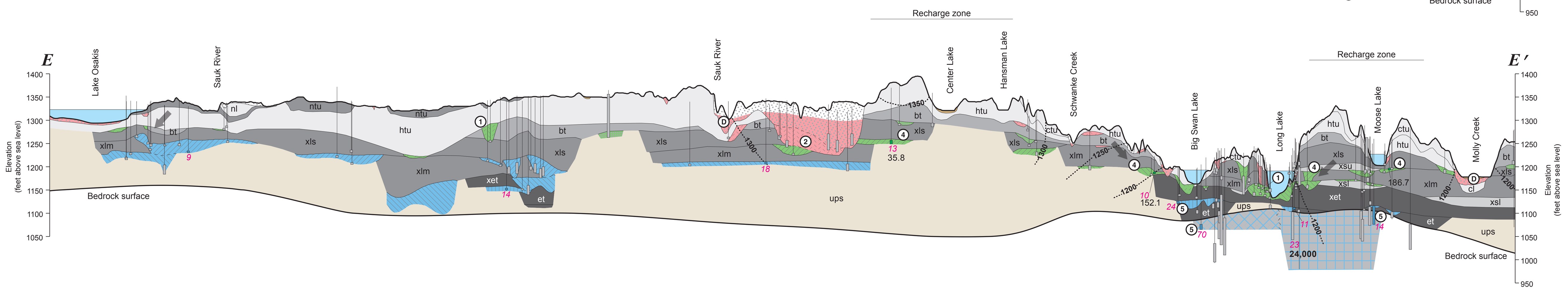

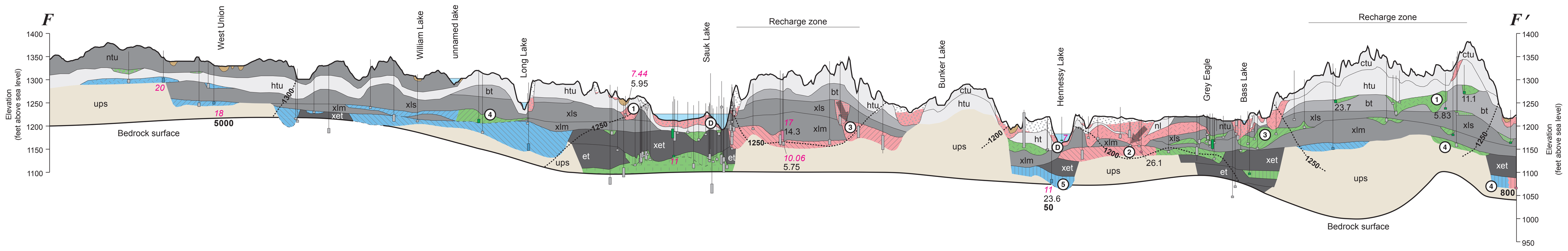

HYDROGEOLOGIC CROSS SECTIONS

By

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2010

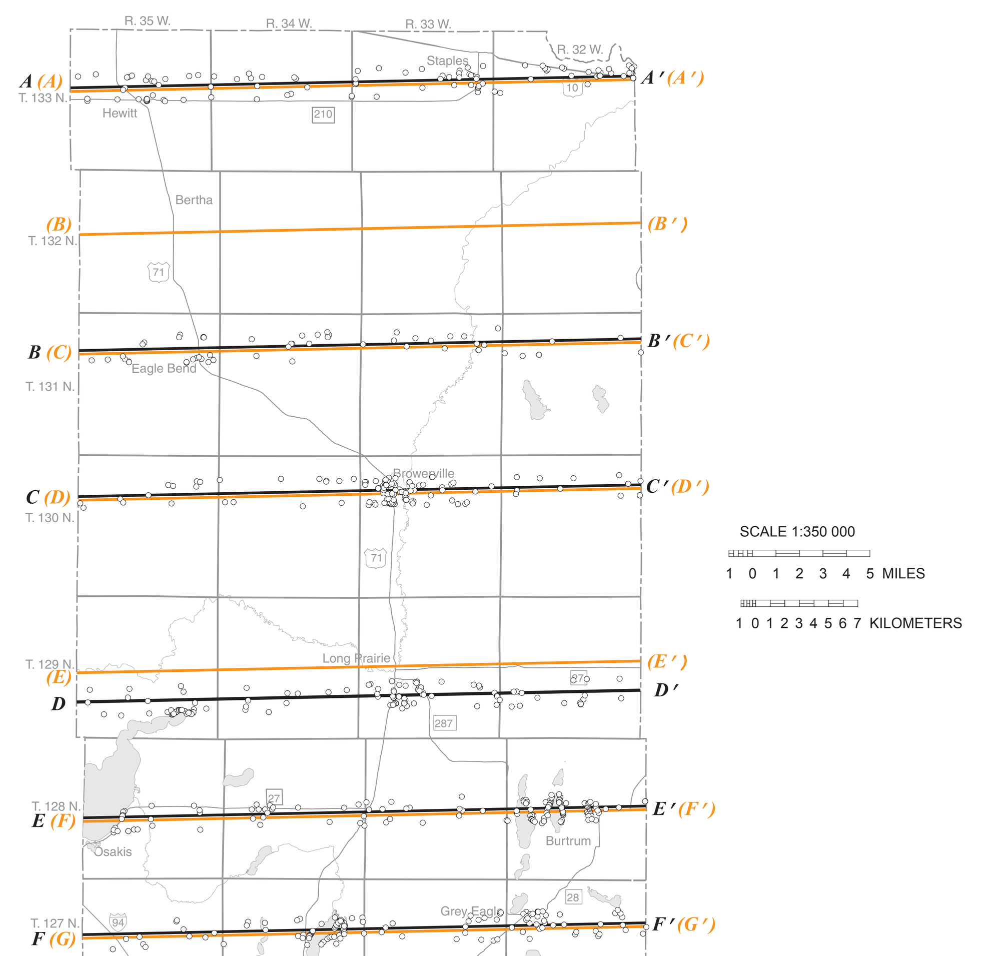

FIGURE 1. ***Location of hydrogeologic cross sections shown on this plate (black lines) and geologic cross sections on Plate 4, Part A (orange lines).*** *The small open circles indicate the locations of wells displayed on the hydrogeologic cross sections shown on this plate.*

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 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.

Symbols and labels

- *11* If shown, arsenic concentration equals or exceeds 5 parts per billion.
- 51.9 If shown, chloride concentration equals or exceeds 5 parts per million.
- **5000** If shown, groundwater age in years, estimated by carbon-14 (^{14}C) isotope analysis.
- General direction of groundwater flow.
- ····1250···· Approximate equipotential contour. Contour interval 50 feet.
- Geologic unit contact.
- Geologic unit contact, uncertain.
- Land or bedrock surface.
- Lake.
- Peat.
- 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.
- ⑤ Distinctive groundwater chemistry; usually indicates deep groundwater of vintage tritium age that may or may not be in connection with shallow aquifers.
- Ⓓ Discharge zone.

SCALE 1:80 000
VERTICAL EXAGGERATION X 40
1 0 1 2 3 4 MILES
1 0 1 2 3 4 KILOMETERS

LOCATION DIAGRAM

Quaternary sand aquifers

- Surficial sand aquifer. Uncolored where unsaturated.
- N1 buried sand aquifer beneath the New Ulm Formation till.
- C1 buried sand aquifer beneath the Cromwell Formation till.
- H1 buried sand aquifer beneath the Hewitt formation till.
- B3 shallowest buried sand aquifer in Browerville formation till.
- B2 midlevel buried sand aquifer in Browerville formation till.
- B1 buried sand aquifer beneath the Browerville formation till.
- X3 buried sand aquifer beneath the till of the Sauk Centre member of the Lake Henry formation. Also includes sand beneath the till of the upper member of the St. Francis formation.
- X2 buried sand aquifer beneath the till of the Meyer Lake member of the Lake Henry formation. Also includes sand beneath the till of the lower member of the St. Francis formation.
- X1 buried sand aquifer beneath the Eagle Bend formation till.
- Deeper, unmapped Quaternary buried sand aquifer.

Bedrock aquifers

- Cretaceous sedimentary rock (correlates with unit Ku on Plate 2, Part A).
- Archean gneiss (correlates with unit Atg on Plate 2, Part A).

Nonaquifer units

New Ulm Formation.
- Till (ntu).
- Lake sediments (nl).

Cromwell Formation.
- Till (ctu).
- Lake sediments (cl).

Hewitt formation.
- Till (htu).

Browerville formation.
- Till (bt).

Lake Henry formation.
- Till of the Sauk Centre member (xls).

St. Francis formation.
- Till of the upper member (xsu).

Lake Henry formation.
- Till of the Meyer Lake member (xlm).

St. Francis formation.
- Till of the lower member (xsl).

Eagle Bend formation.
- Till (xet).

Elmdale formation.
- Till (et).

- Undifferentiated Pleistocene sediment (ups).

INTRODUCTION

The six hydrogeologic cross sections on this plate illustrate several important hydrogeologic features in Todd County. These hydrogeologic features include the horizontal and vertical extent of the hydrogeologic units (aquifers and nonaquifer units), groundwater residence time, and water-table elevation, where known. The water-table elevation in the surficial sand aquifer is shown on these cross sections as the boundary between the unsaturated (uncolored) portion of the aquifer and the underlying saturated (colored) portion of the aquifer. These cross sections pass through most of the wells sampled for chemistry in this study.

Figure 1 shows the location of all seven published geologic cross sections in Part A and the six hydrogeologic cross sections shown on this plate. Five of the six hydrogeologic cross sections are coincident with published cross sections in Part A. The hydrogeologic cross sections on this plate were named A through F from north to south. Because cross section B–B′ from Part A is not included as a hydrogeologic cross section, the letter names for Part B cross sections are different from the Part A cross sections. Part A cross section B–B′ was not selected to show as a hydrogeologic cross section because only one well was sampled on this transect. One hydrogeologic cross section (D–D′) is two kilometers south of Part A geologic cross section E–E′. Hydrogeologic cross section D–D′ was selected so that it transected a more favorable series of wells available for water chemistry sampling. The 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), Quaternary Stratigraphy (Plate 4, Part A), and three-dimensional mapping done for both parts A and B of the atlas. Following publication of Part A, some geologic data were revised in consultation with the Minnesota Geological Survey. Therefore, users may notice some differences between Part A and Part B portions of the atlas. Most changes relate to the interpreted extent of buried sand aquifers. The stratigraphic boundaries on the hydrogeologic cross sections are consistent with the gridded elevation surfaces of the aquifers that were used to calculate the depth to the top of various buried sand aquifers shown on Figures 3 to 10, Plate 7. The location of the wells sampled for general chemistry and isotopes (major cations and anions; trace metals; tritium; and carbon-14) and the traces of the six hydrogeologic cross sections are shown on Figure 2, Plate 7. The stratigraphic relationship of aquifers and nonaquifer units in Todd County is shown in Figure 11, Plate 7.

RELATIVE HYDRAULIC CONDUCTIVITY

Eleven Quaternary sand aquifers and two bedrock aquifers were identified; nine of the sand aquifers were mapped where sufficient data were available (Plate 7). The shallowest buried sand aquifer, N1, on cross sections E–E′ and F–F′ and the deeper unmapped Quaternary buried sand aquifers are only shown on the cross sections; they are not shown on the other plates. The Quaternary sand aquifers are adequate for local needs, but their hydraulic properties vary based on extent and thickness and may not be adequate for all needs. The transmissivity of the Quaternary sand aquifers, calculated from aquifer tests, varies from 6700 to 145,000 gallons per day per foot (gpd/ft). The hydrogeologic properties of these aquifers are discussed in more detail on Plate 9. Hydrogeologic properties of bedrock aquifers are poorly known and are not discussed further.

The nonaquifer units are shown in shades of gray on the cross sections. The matrix texture of the less than two millimeter grain size fraction from Table 1, Plate 4, Part A, was used to estimate the relative hydraulic conductivity of the nonaquifer units. Lighter grays represent relatively higher hydraulic conductivities; darker grays represent relatively lower hydraulic conductivities. The Cromwell (ctu) and Hewitt (htu) tills, which have more than 60 percent sand, are shown in the lightest gray. Lake sediments of both the New Ulm Formation (nl) and the Cromwell Formation (cl) are very sandy and are also shown in the lightest gray. The next lightest gray represents tills of the St. Francis formation (xsu and xsl), which have 47 to 51 percent sand. The Browerville till (bt), with 44 percent sand, is represented by an intermediate gray. Tills of the Lake Henry formation (xls and xlm) and the New Ulm Formation (ntu) are represented by the next darker gray; they have sand contents ranging from 35 to 38 percent. The Eagle Bend (xet) and Elmdale (et) formations, which have sand contents of less than 32 percent, are shown in the darkest gray. It is assumed that as sand content of the till increases, hydraulic conductivity also increases, with greater potential for water movement through the till units. Till density can affect hydraulic conductivity, but it is not discussed on this plate because there are insufficient data.

Undifferentiated Pleistocene sediment (ups) is shown in light tan. No textural information is available for this unit, so no inference of hydraulic conductivity should be made.

GROUNDWATER RESIDENCE TIME

The pink, green, and blue areas shown on these cross sections represent the estimated age of the groundwater, also known as groundwater 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 since the early 1950s. 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 since the early 1950s. 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. Water samples with tritium concentrations indicating recent tritium age were collected from aquifers as deep as 175 feet below land surface. Water samples with tritium concentrations indicating mixed tritium age were collected from aquifers as deep as 200 feet below land surface. On the other hand, some shallow groundwater, often beneath the New Ulm Formation till (for example, on cross section F–F′), has little or no detectable tritium and indicates that surface infiltration may be very limited. When tritium data are not available, other geochemical indicators such as chloride concentration or nitrate concentration can be used as indicators of groundwater residence time. Water samples from shallow wells that had elevated chloride more than five parts per million but were not sampled for tritium were probably recent tritium age water.

Groundwater residence time for the vintage samples suspected of being older can be 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 groundwater residence time between 100 years and 40,000 years. Of the eight wells that were sampled for carbon-14 in this study, seven were constructed in Quaternary sand aquifers and one was constructed in Cretaceous bedrock. The estimated groundwater residence time for samples from Quaternary aquifers ranged from 50 to 24,000 years. The groundwater residence time for the sample from the Cretaceous aquifer was estimated to be 24,000 years. The depth to these aquifers ranged from 125 to 200 feet below land surface.

HYDROGEOLOGY ILLUSTRATED BY THE CROSS SECTIONS

Groundwater Flow Direction Estimated From Equipotential Contours

Groundwater flow direction indicated in the cross sections on this plate (gray arrows) was interpreted from the equipotential contours that were constructed from measured water levels in wells. Groundwater will move from areas with higher equipotential to areas with lower equipotential. The equipotential contours can be used to identify not just groundwater flow direction, but also groundwater recharge and discharge zones. Where possible with the available data, general zones of groundwater recharge have been indicated on the cross sections. In Todd County, the major groundwater discharge zones are associated with larger rivers and lakes.

Groundwater flow is three-dimensional, but can be represented in two-dimensional cross sections if the direction of the cross section is approximately parallel to groundwater flow. In Todd County, groundwater flows largely in the same direction as cross sections A–A′, B–B′, C–C′, and F–F′; in the eastern half of cross sections D–D′ and E–E′ groundwater also flows in the same direction as the cross sections. In the western half of cross sections D–D′ and E–E′, groundwater flow has a significant component of flow perpendicular to these cross sections. Groundwater flow into and out of the plane of these cross sections may be important.

Area groundwater recharge zones correspond to topographically higher areas in the county. Area groundwater recharge zones identified by higher equipotential contours in topographically higher areas occur throughout the county. Examples of groundwater discharge zones include the west part of cross sections A–A′, B–B′, and C–C′; the east part of cross sections B–B′, C–C′, E–E′, and F–F′; and the middle portion of cross sections D–D′, E–E′, and F–F′. From these area recharge zones, groundwater will first move downward through glacial sediments and buried sand aquifers; groundwater will then move laterally to discharge zones defined by lower equipotential contours and lower topography. The valley of the Long Prairie River is a regional groundwater discharge zone; in addition, the Sauk River and Sauk Lake are other area groundwater discharge zones.

Aquifer Recharge and Discharge Conditions

A code (1 through 4) on the cross sections indicates a condition of recharge for many aquifers where the groundwater was interpreted to be of mixed or recent tritium age. A code of 5 indicates vintage tritium age groundwater that appears to be poorly connected to surface recharge. Condition 1 indicates infiltration through a thin overlying layer of fine-grained material into the aquifer. Condition 2 indicates recharge from the surficial aquifer to an underlying buried aquifer either through leakage or direct connection. Condition 3 indicates groundwater leakage from an overlying buried aquifer into an underlying buried aquifer. Condition 4 indicates groundwater leakage through multiple buried aquifers and fine-grained layers. Condition 5 indicates groundwater that has a distinctive chemistry with elevated sodium concentration, usually indicating older waters that may or may not be in connection with surface recharge. In addition, groundwater discharge zones are labeled as condition D.

Recharge by Infiltration through Thin Fine-Grained Layers and Surficial Sand. Infiltration through thin fine-grained material such as the htu and ctu nonaquifer units, defined as condition 1, or directly from surficial sands to underlying buried sand aquifers, defined as condition 2, is very common in the H1 buried sand aquifer in most areas of the county where the aquifer is present.

The B3 buried sand aquifer is also generally recharged through thin fine-grained material, defined as condition 1, and is seen on the west side of cross sections A–A′, B–B′, and C–C′. Because it is a little deeper and is covered by the Browerville formation (bt), a relatively clay-rich Winnipeg provenance till (Figure 3, Plate 4, Part A), the B3 aquifer is not as readily recharged from the surface as the H1 aquifer. Most groundwater in the B3 aquifer is mixed tritium age.

Recent and mixed tritium age water may occur up to 200 feet below land surface in areas with very thick surficial outwash and underlain by buried sand aquifers (condition 2). One example of condition 2 is the thick outwash and sand and gravel aquifer underlain by the H1 buried aquifer east of the Sauk River in the center of cross section E–E′.

Recharge by Leakage through Adjacent and Multiple Aquifers. Leakage from a buried aquifer to a deeper buried aquifer, condition 3, is found in a number of locations on cross sections A–A′, B–B′, and F–F′. On cross section A–A′ near Egly Creek, groundwater flows from the B3 aquifer to the B2 aquifer. On cross section B–B′, groundwater moves from the H1 aquifer to the underlying B1 aquifer between the Long Prairie River and Turtle Creek. Also, on cross section F–F′, groundwater flows from the B1 aquifer to the X3 aquifer west of Bunker Lake, and from the C1 aquifer to the X3 aquifer near Bass Lake.

The B1 and B2 aquifers at a number of locations in the county show evidence of recharge through multiple overlying aquifer and nonaquifer units (condition 4). On the eastern edge of cross section A–A′ and in the center of cross sections B–B′, C–C′, and D–D′, thick vertical sequences of multiple sand units that are either contiguous or separated by thin till units allow infiltration of groundwater from the surface. In these areas, the tritium data indicate relatively deep infiltration of recent and mixed tritium age groundwater.

Deeper Aquifers with Long Residence Time Groundwater and Different Chemistry Signature. In areas identified as condition 5, groundwater has a vintage tritium age and a different proportion of cations compared to shallower waters. Deeper waters have more sodium and less calcium or magnesium relative to shallower, more recently-recharged water. Condition 5 is found in the B1 and X1 aquifers in the western portion of cross section A–A′. Condition 5 is also found in the unmapped Quaternary aquifer beneath the et till in the center of cross section B–B′ and in the X1 aquifer beneath the xet till unit in the eastern end of the same cross section. Condition 5 is also found in the deeper aquifers in cross sections D–D′ and E–E′, especially in the bedrock aquifers on the eastern edge of cross section E–E′. Water from the Cretaceous bedrock aquifer has an estimated residence time of 24,000 years based on carbon-14 analysis. The groundwater from the deep unmapped Quaternary aquifer on the east side of cross section D–D′ is considered sodium type and is probably isolated from surface recharge. Condition 5 is also found in the X1 aquifer beneath Hennessey Lake on cross section F–F′.

Other Aquifers with Long Residence Time Groundwater

The clay-rich New Ulm Formation (ntu) has very low hydraulic conductivity. Water samples from aquifers beneath this unit collected from wells as shallow as 60 feet deep (see west side of cross sections E–E′ and F–F′) had little detectable tritium.

In some areas, samples from the B1 and B2 buried sand aquifers had vintage age tritium dates and were analyzed for carbon-14 to determine residence time. On the western edge of cross section B–B′, a carbon-14 analysis of a water sample from the B2 aquifer had an estimated residence time of 16,000 years. A sample from the stratigraphically deeper B1 aquifer just to the west had a residence time of 1200 years. The long residence time of the groundwater is probably due to relatively slow groundwater travel along a regional flow path. However, the sample from the B2 aquifer is relatively older than the sample from the B1 aquifer, and the sample from B2 aquifer was collected from a higher elevation. This may indicate that the B2 aquifer is more isolated from other buried sand aquifers near that well and little recharge is occurring at that location.

Discharge to Surface-Water Bodies

Discharge zones from the surficial aquifer to the Long Prairie and Sauk rivers and in other locations to local streams and lakes are identified as condition D on the cross sections. Groundwater discharge to streams and lakes sustains stream flow and lake levels in the absence of precipitation.

Arsenic in Groundwater in Todd County

Arsenic in concentrations greater than or equal to 10 parts per billion, the EPA standard in drinking water (U.S. Environmental Protection Agency, 2006), was found in 17 wells. Arsenic concentrations between 5 and 10 parts per billion were found in 7 additional wells. Most of those wells are located in the southern third of the county (Figure 2, Plate 7). The factors affecting elevated arsenic concentration in groundwater are complex and not completely understood. The factors may include the redox condition of the groundwater and specific groundwater chemistry (Thomas, 2007). In Todd County, elevated arsenic is often present when the aquifer is overlain by tills that have a northwestern provenance including the New Ulm Formation (ntu), Browerville formation (bt), Lake Henry formation (xls or xlm), Eagle Bend formation (xet), and Elmdale formation (et). Elevated arsenic occurs in aquifers where groundwater has moved through northwest provenance tills; this is most commonly observed in the southern half of the county.

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.

Thomas, M.A., 2007, The association of arsenic with redox conditions, depth, and ground-water age in the glacial aquifer system: U.S. Geological Survey Scientific Investigations Report 2007–5036, 26 p.

U.S. Environmental Protection Agency, 2006, Arsenic rule: EPA, accessed May 12, 2010, at <http://www.epa.gov/safewater/arsenic/regulations.html>

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Base modified from Minnesota Geological Survey, Todd County Geologic Atlas, Part A, 2007.
Project data compiled from 2006 to 2009 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 Neil Cunningham.