HYDROGEOLOGIC CROSS SECTIONS

By

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INTRODUCTION

The six hydrogeologic cross sections on this plate illustrate the horizontal and vertical extent of aquifer and non-aquifer units in McLeod County. They also show groundwater residence time and general direction of groundwater flow. The water table is typically within 15 feet of the land surface in McLeod County. The water table is not shown on the cross sections because it is not visible at this scale (see Figure 1, Plate 7). These cross sections show most of the wells sampled for chemistry in this study.

Figure 1 shows the location of the six hydrogeologic cross sections shown on this plate. These six cross sections were selected from 41 geologic cross sections prepared for Part A because they include the deepest water wells in the county. Groundwater chemistry samples for this project, including major cations, anions, trace elements, stable isotopes, tritium, and carbon-14, were mostly collected from wells shown on these cross sections. The cross sections illustrate both shallow and deep hydrologic conditions across the county.

RELATIVE HYDRAULIC CONDUCTIVITY

Six Quaternary buried sand and gravel aquifers and six sedimentary bedrock aquifers are identified in McLeod County. The Quaternary buried sand and gravel aquifers are adequate for domestic wells, but their extent and thickness vary greatly and they may not always be adequate for municipal or industrial supply wells that require higher pumping capacities. Many wells that require higher pumping capacity, especially in the eastern part of the county, are constructed in the bedrock aquifers. The amount of water the Quaternary sand and gravel aquifers are able to transmit, calculated from aquifer transmissivity tests, varies from 17,700 to 158,100 gallons per day per foot (gpd/ft). Data from only one aquifer test is available for a bedrock aquifer. A well constructed into the Wonewoc aquifer had a transmissivity of 3,000 gpd/ft. The hydraulic properties of these aquifers are discussed in more detail on Plate 7.

The correlation of Quaternary aquifers and till units is shown in Figure 2. The sand and gravel aquifers are shown by pattern on both Figure 2 and the cross sections. The Quaternary till units have limited permeability and are considered to be non-aquifer units; these units are shown in shades of gray. The sand percentage from the matrix texture of the less than two millimeter size fraction of the till units shown in Table 1, Plate 5, Part A, is used to estimate the relative hydraulic conductivity of the non-aquifer units. It is assumed that as sand content of the till increases, hydraulic conductivity also increases, and with greater hydraulic conductivity there is more potential for water movement through the till units. Lighter grays represent relatively higher hydraulic conductivities; darker grays represent relatively lower hydraulic conductivities. The ct till, which has more than 60 percent sand, has the highest relative hydraulic conductivity. The bt till, which has 46 percent sand, and the dtv till, which has 45 percent sand, have intermediate relative hydraulic conductivities. The dth till has 36 percent sand, and the dtj and xt tills both have 40 percent sand; these tills have the lowest relative hydraulic conductivities. No textural information is available for the undifferentiated Pleistocene sediment (ups) unit; therefore, no inference of hydraulic conductivity should be made.

The sequence of bedrock geologic units, hydrogeologic units, and hydrogeologic properties is shown in Figure 3. The bedrock aquifers generally have good horizontal and vertical permeabilities. The confining units generally have low vertical permeability but may have relatively high horizontal permeability along bedding fractures. The Jordan, Wonewoc, Mt. Simon, and Hinckley aquifers are sandstones in which groundwater moves primarily through intergranular flow. Groundwater in the Upper Tunnel City aquifer mainly moves through fractures. An enhanced-permeability zone is generally found in the uppermost 50 feet of all Precambrian and Paleozoic sedimentary bedrock units that are either exposed at the land surface or directly covered by glacial sediments (Runkel and others, 2006). This enhanced permeability is mostly due to the presence of fractures developed or enlarged during weathering when the top of the bedrock surface was the land surface. The fractures in this enhanced-permeability zone generally increase the yield from units that are typically aquifers. In addition, these fractures will usually increase the permeability of units that are typically not aquifers, which may allow non-aquifer units to be used as a water source. The enhanced-permeability fractures in non-aquifer units may also compromise the confining character of those units. Enhanced-permeability zones in the Ka aquifer, bedrock units directly beneath the Ka aquifer, or non-sedimentary Precambrian bedrock may exist locally, but this has not been confirmed.

GROUNDWATER RESIDENCE TIME

The pink, green, and blue areas shown on these cross sections represent the groundwater residence time. This is the approximate length of time that has elapsed from the moment the water infiltrated the land surface to the time it was pumped from the aquifer. Groundwater residence time can be estimated by the amount of tritium (^{3}H) that is present in the groundwater. 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 tritium in the atmosphere were greatly increased between about 1953 and 1963 by above-ground nuclear tests (Alexander and Alexander, 1989). Since tritium decays at a known rate (half-life of 12.43 years), the proportion of recently recharged water in a sample can be estimated by its tritium content. Water samples with tritium concentrations of 8 or more tritium units (TU) are classified as recent water that entered the ground since the early 1950s. Water samples with tritium concentrations of 1 TU or less are classified as vintage water that entered the ground before approximately 1953. Water samples with tritium concentrations greater than 1 TU and less than 8 TU are considered mixed waters because they are a mixture of vintage and recent waters.

None of the 81 groundwater samples collected in McLeod County for this project had recent tritium age water. Five water samples collected at depths ranging from 76 to 500 feet had mixed tritium age values of between 1.3 and 2.7 TU. Three of these groundwater samples with mixed tritium age values were collected from relatively shallow wells constructed in the sdv aquifer. Two of these wells are shown on cross section A–A′ and the third well is shown on cross section D–D′. The mixed tritium ages from these three water samples reflect the local conditions in the sdv aquifer; other samples from the sdv aquifer had vintage tritium ages. However, the mixed tritium age of the other two samples, which were collected from the deeper su buried sand aquifer (shown on cross section B–B′) and the Mt. Simon aquifer (see Figure 1, Plate 7), is probably due to poor well construction and does not represent local aquifer conditions. The water sample from the 282-foot-deep well constructed in the su aquifer had elevated chloride in addition to mixed tritium age. Water samples from nearby wells in both shallower aquifers and aquifers of similar depth had vintage tritium ages and low chloride concentrations. The other deep well with mixed tritium age is DNR monitoring well 43000 which is constructed in the Mt. Simon aquifer to a depth of 500 feet. This well is not shown on the cross sections on this plate, but the location near Glencoe is shown on Figure 1, Plate 7. A sample from a neighboring Mt. Simon well had vintage tritium age and a groundwater residence time of 30,000 years as estimated by carbon-14 analysis.

HYDROGEOLOGY ILLUSTRATED BY THE CROSS SECTIONS

Groundwater Flow Direction Estimated From Equipotential Contours

Groundwater flow direction is indicated by the gray arrows in the cross sections on this plate and is interpreted from the equipotential contours constructed from measured water levels in wells. Groundwater moves from areas with higher equipotential to areas with lower equipotential. The equipotential contours can be used to identify not just the flow direction, but also groundwater recharge and discharge zones. The equipotentials and flow arrows show the groundwater flow in McLeod County is largely lateral from northwest to southeast. Major groundwater recharge zones are not present. In McLeod County, the major groundwater discharge zones are associated with larger rivers.

The general northwest to southeast groundwater flow direction is represented on the maps of the water-table elevation and the potentiometric surfaces of the buried sand and gravel aquifers (Figures 1 through 7 on Plate 7). The east-west cross sections on this plate were originally constructed to map these Quaternary buried sand and gravel aquifers. Therefore, the equipotential contours on these cross sections do not fully represent three-dimensional groundwater flow because the cross sections are not directly parallel to groundwater flow. However, the equipotential contours on these cross sections do demonstrate the general west to east and near-surface to deep flow paths that are present in the county.

Aquifer Recharge and Discharge Conditions

The downward recharge rate of water from the land surface to deeper aquifers is very slow in McLeod County. The vertical hydraulic gradient is very low and the clay till that forms most of the surficial geologic deposits in the county has a low hydraulic conductivity. This clay till does not allow much shallow groundwater to recharge deeper aquifers. Thus, there are no focused areas of groundwater recharge in McLeod County.

Mixed tritium age groundwater was found in samples from the sdv aquifer to a maximum depth of 100 feet. These areas are shown as condition ① on cross sections A–A′ and D–D′. Condition ① is defined as infiltration through fine-grained material, in this case the dtv till, to an underlying aquifer, the sdv sand and gravel aquifer. In other areas of McLeod County, groundwater samples from shallow wells had a vintage tritium age, indicating very slow groundwater recharge. Groundwater infiltrates slowly from the surface into the shallow buried sand and gravel aquifers and then moves primarily laterally to discharge zones. These discharge zones are defined by lower potentiometric surface elevation and lower topography. The major discharge zone in the county for the shallow Quaternary sand and gravel aquifers is the South Fork of the Crow River. The equipotential contours on both the west and east sides of cross section B–B′ show discharge to the South Fork of the Crow River. Where the Crow River intersects cross section B–B′ on the west end of the cross section, the discharge zone is marked with a Ⓓ. On the east side of cross section B–B′, the Crow River intersects the trace of cross section B–B′ just east of the McLeod County border. Condition Ⓓ is not shown here because the actual discharge point to the river is east of the cross section.

The equipotential contours on cross sections C–C′, D–D′, E–E′, and F–F′ show groundwater movement from the glacial sediments downward into the bedrock aquifers. This groundwater movement is very slow. The groundwater residence time for these deep aquifers, as estimated by carbon-14 isotope analysis, ranges from 900 to 30,000 years. The major discharge zone for bedrock aquifers in McLeod County is the Minnesota River to the south and east of the county; this zone is not directly shown on either the map or the cross sections.

If groundwater withdrawal in McLeod County increases due to growing demand, then significant local changes may occur in aquifer recharge. Increased groundwater withdrawal from sand and gravel aquifers at a depth of less than approximately 100 feet might induce greater groundwater recharge from the land surface. This might increase the rate of movement of contaminants from the surface to buried sand and gravel aquifers. Increased groundwater withdrawal from deeper aquifers probably would not increase groundwater recharge from the land surface because of the many layers of clay till that overlie deeper aquifers. However, increased pumping from wells constructed in deeply buried aquifers might reduce the available head in the aquifer. Groundwater in the deeper aquifers has a residence time of hundreds to thousands of years, so pumping is withdrawing water from these aquifers faster than it is recharged. Any increase in pumping volume would only exacerbate this effect.

ARSENIC IN GROUNDWATER

Arsenic in concentrations greater than or equal to 10 parts per billion, the EPA standard in drinking water (U.S. Environmental Protection Agency, 2001), was found in 45 of the sampled wells. Arsenic in concentrations between 5 and 10 parts per billion was found in 9 additional wells. These wells are distributed widely across the county and were constructed to varying depths in several different aquifers. The locations of all water samples with elevated arsenic concentrations collected from wells are shown on Plate 7. All but one of the wells where elevated arsenic was found are constructed in Quaternary buried sand and gravel aquifers. Only one bedrock well had elevated arsenic (7.8 parts per billion); this well is constructed in the Jordan aquifer and is located on the east end of cross section E–E′. In this well, the Jordan aquifer forms the bedrock subcrop, which is immediately overlain by undifferentiated Pleistocene sediment (ups). All of the buried sand and gravel aquifers, except for the sc buried sand and gravel aquifer, had water samples with both low and elevated arsenic concentrations. All six samples from wells constructed in the sc sand and gravel aquifer had arsenic concentrations greater than or equal to 10 parts per billion. 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). Erickson and Barnes (2005) show a strong correlation between arsenic in groundwater in Minnesota and wells constructed in aquifers associated with northwest provenance tills. In McLeod County, elevated arsenic is often present when the aquifer is overlain by either Riding Mountain or Winnipeg provenance tills, both of which are northwest provenance. The original source of arsenic in northwest provenance tills is arsenic-bearing pyrite found in shale fragments in the till. All of the mapped tills in McLeod County, with the exception of the ct till, are of Riding Mountain or Winnipeg provenance. The immediate source of arsenic to groundwater may be oxidized, sorbed species, which are released to groundwater under reducing conditions (Nicholas and others, 2011); all of the groundwater samples with elevated arsenic in McLeod County were collected under reducing conditions.

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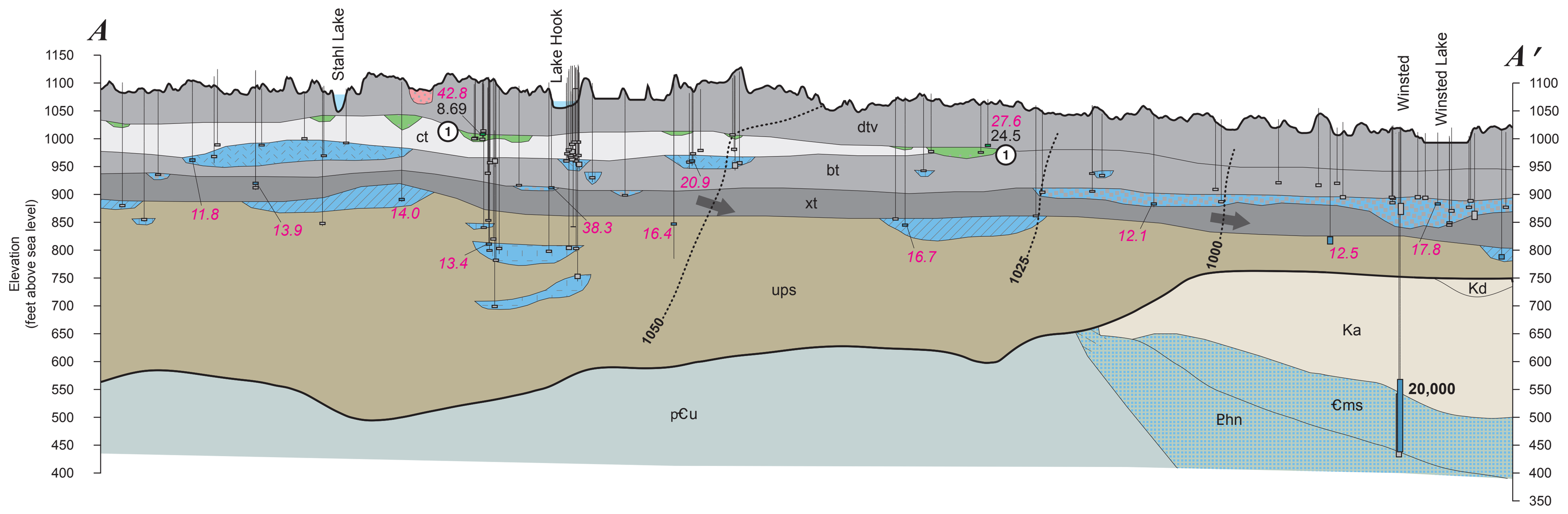
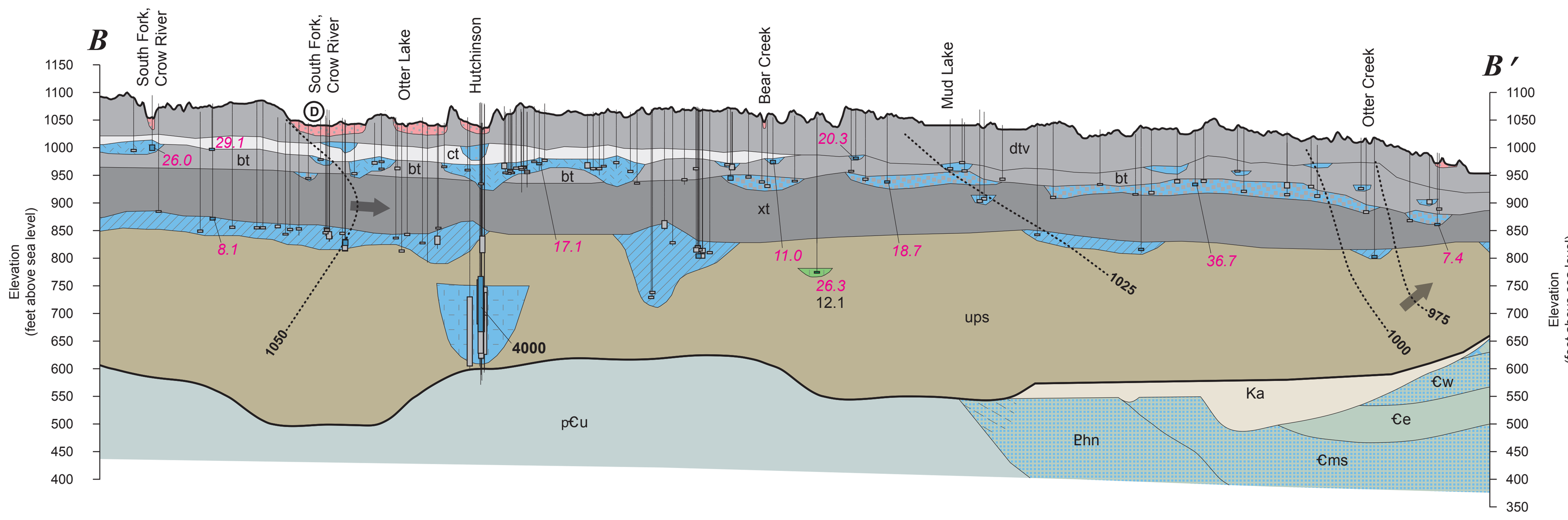
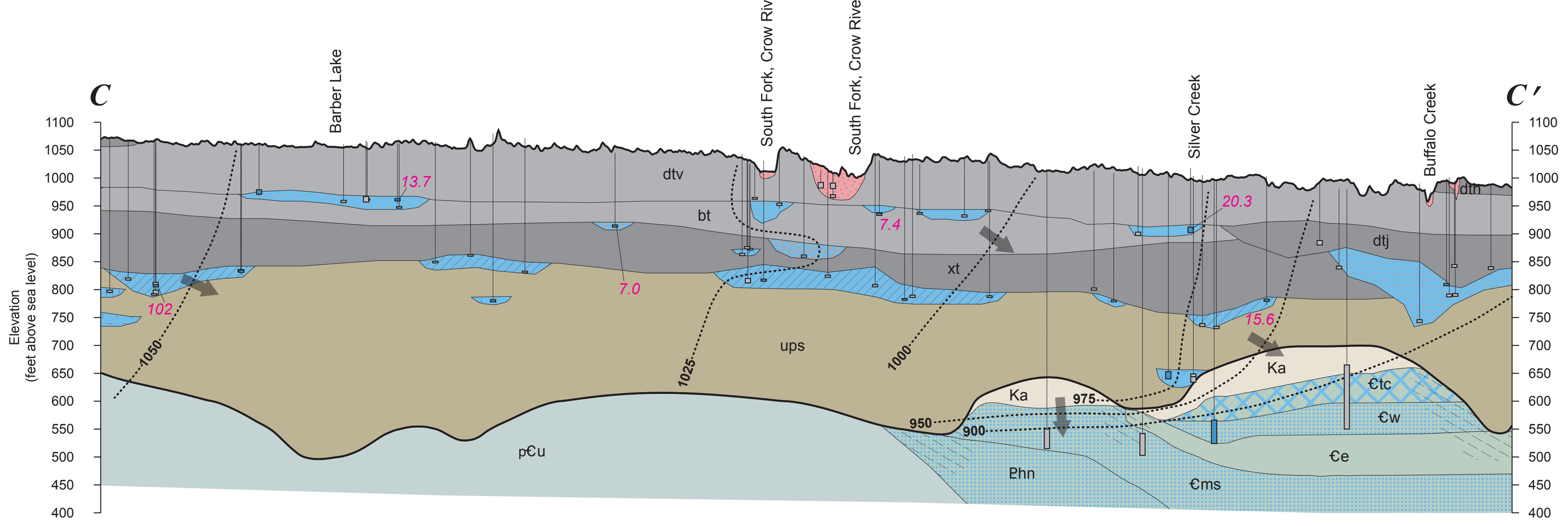
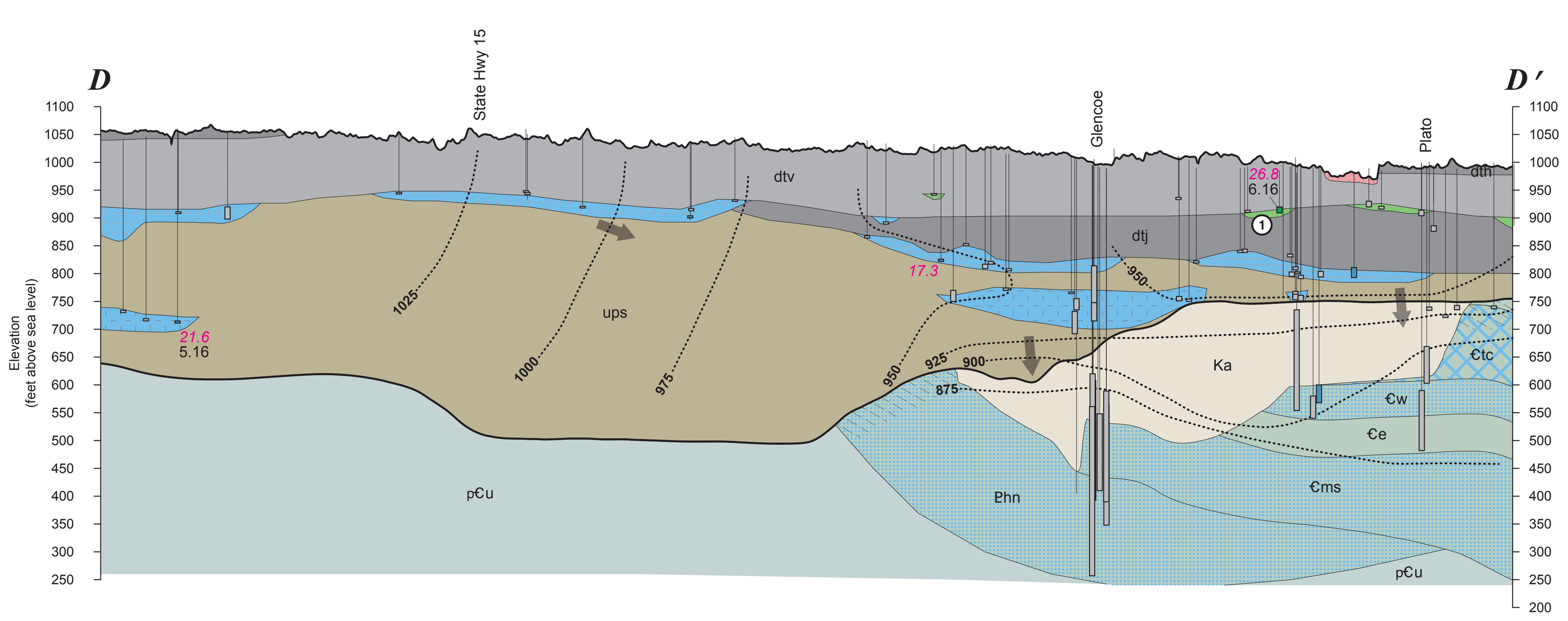
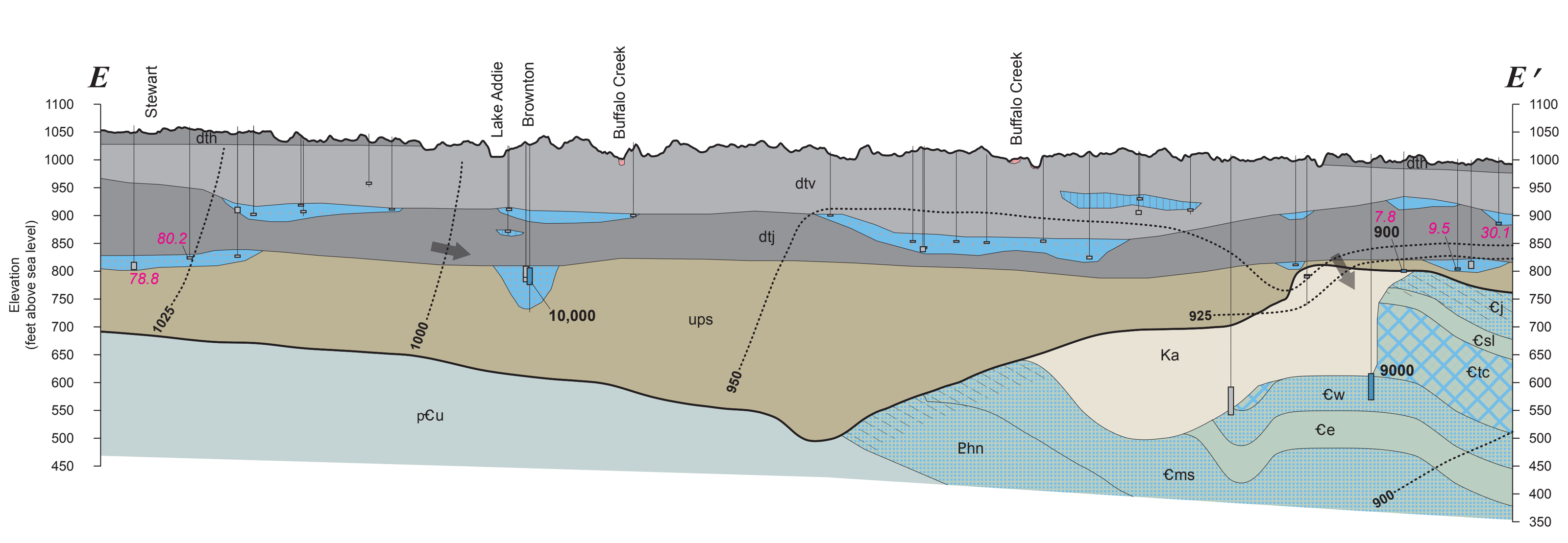
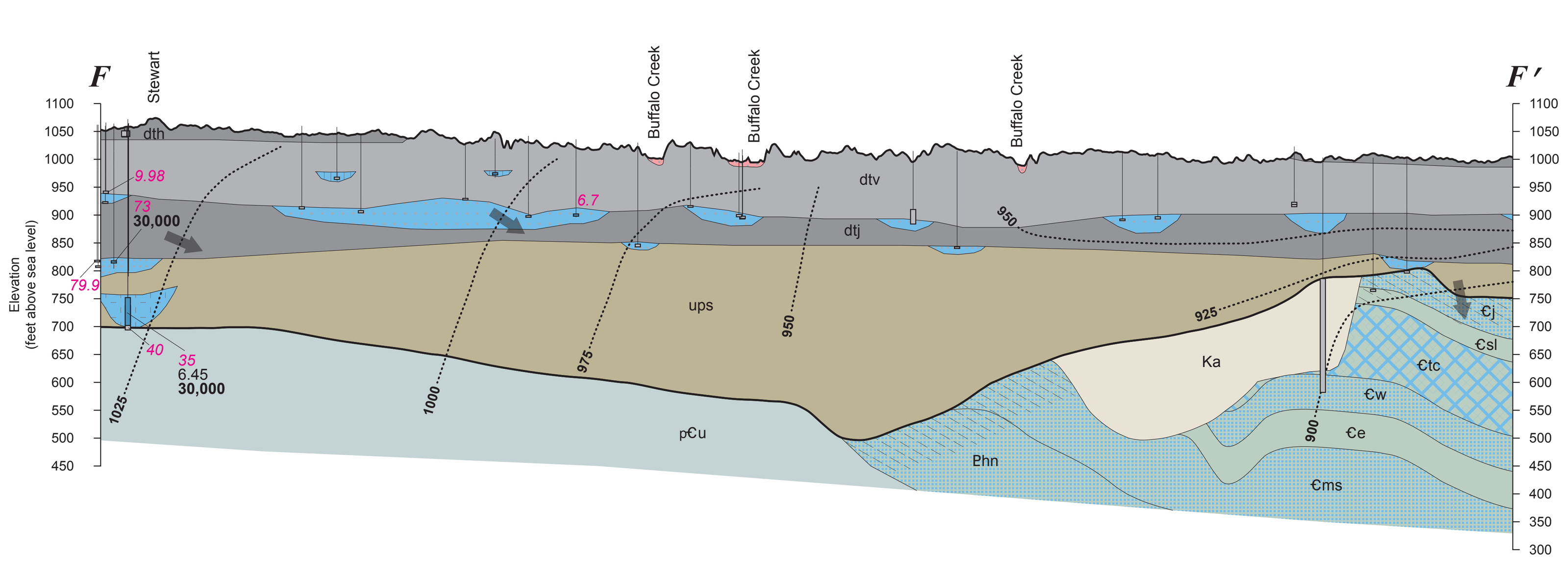












SCALE 1:150 000
VERTICAL EXAGGERATION X 50
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 6 7 8 9 KILOMETERS

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 (8 or more tritium units [TU]). No samples analyzed contained recent tritium age water.
- Mixed—Water is a mixture of recent and vintage waters (greater than 1 TU to less than 8 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.
- Ⓓ Groundwater discharge from a buried aquifer to surface-water body.

Symbols and labels

- 14.0 — If shown, arsenic concentration equals or exceeds 5 parts per billion.
- 12.1 — If shown, chloride concentration equals or exceeds 5 parts per million.
- **4000** — If shown, groundwater residence time in years, estimated by carbon-14 (^{14}C) isotope analysis.
- General direction of groundwater flow.
- ····1025···· Approximate equipotential contour. Contour interval 25 feet.
- Geologic contact.
- Land or bedrock surface.
- Lake.

Aquifers - grouped by stratigraphy

Surficial sand aquifer.

- sda

Buried sand and gravel aquifers.

- sdv
- sdj
- sc
- sb
- sx
- su
- Unnamed

Sedimentary bedrock aquifers.

- Ka — Ka (probably low yielding)
- €j — Jordan
- €tc — Upper Tunnel City
- €w — Wonewoc
- €ms — Mt. Simon
- Ꝑhn — Hinckley
- Enhanced-permeability zone.

Quaternary non-aquifer units - grouped by texture ranging from highest sand content (light gray) to lowest sand content (dark gray) indicating relative hydraulic conductivity.

Percent sand*	Color code	Geologic unit code
Greater than 60		ct
Greater than 40 and less than or equal to 50		dtv, bt
Greater than 30 and less than or equal to 40		dth, dtj, xt
Texture unknown		Undifferentiated Pleistocene sediment (ups)

*Percent sand indicates relative hydraulic conductivity.

Bedrock non-aquifer units

- Kd — Dakota Formation
- €sl — St. Lawrence Formation
- €e — Eau Claire Formation
- p€u — Precambrian crystalline bedrock

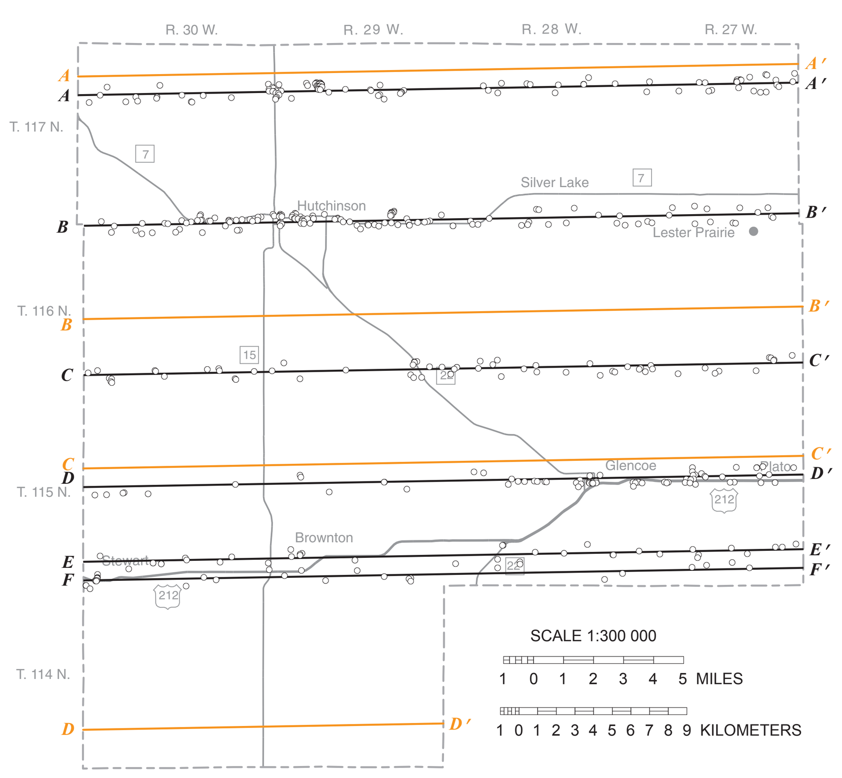


FIGURE 1. *Location of hydrogeologic cross sections shown on this plate (black lines) and geologic cross sections on Plate 5, Part A (orange lines). The small open circles indicate the locations of wells displayed on the hydrogeologic cross sections shown on this plate.*

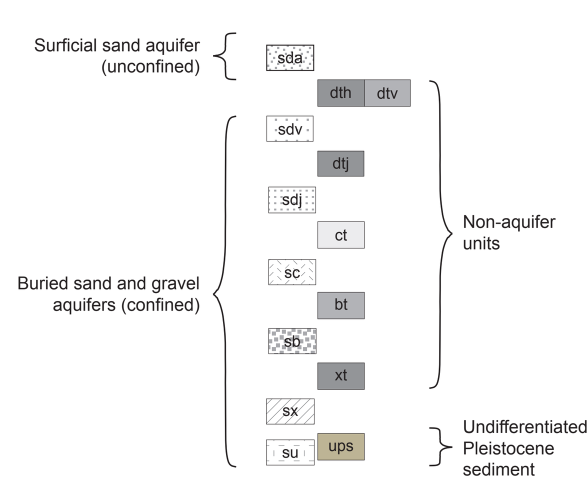


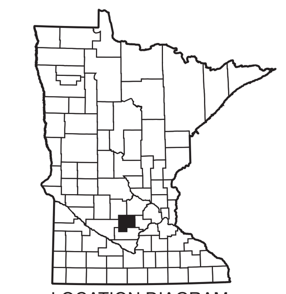
FIGURE 2. *Correlation of Quaternary buried sand and gravel aquifers, till units (shown in gray), and undifferentiated Pleistocene sediment (shown in brown) in McLeod County.*

Geologic Unit		Hydrogeologic Unit	Hydrogeologic Unit Properties
Unnamed Unit (Ka)		Ka aquifer	Low to moderate intergranular permeability. Thin sandstones are interlayered with siltstone and claystone. Probably low yielding aquifer.
Jordan Sandstone		Jordan aquifer	Relatively high intergranular permeability.
			Confining unit.
St. Lawrence Formation			Confining unit.
Tunnel City Group	Lone Rock Formation	Upper Tunnel City aquifer	Relatively low intergranular permeability with high permeability bedding fractures.
			Confining unit. Not shown on cross sections; included with €tc aquifer unit.
Wonewoc Sandstone		Wonewoc aquifer	Moderate intergranular permeability.
Eau Claire Formation			Confining unit.
Mt. Simon Sandstone		Mt. Simon aquifer	Moderate intergranular permeability.
Hinckley Sandstone		Hinckley aquifer	Moderate intergranular permeability.

FIGURE 3. *Sequence of bedrock geologic units and hydrogeologic units in McLeod County. The Ka geologic unit is shown in Plate 2 of Part A as map unit PMu.*

EXPLANATION
Figure 3

- Aquifer.
- Low to moderate permeability aquifer. Thin sandstones interbedded with siltstone and claystone.
- Confining unit, generally low permeability.
- High permeability bedding fracture.



LOCATION DIAGRAM

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Twin Cities: (651) 296-6157
Minnesota toll free: 1-888-646-6367
Information for the hearing impaired (TDD/TTY): (651) 296-5484
TDD/TTY Minnesota toll free: 1-800-657-3929
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Base modified from Minnesota Geological Survey, McLeod County Geologic Atlas, Part A, 2009.
Project data compiled from 2010 to 2012 at a scale of 1:100,000 to 1:350,000. Universal Transverse Mercator projection, grid zone 15, 1983 North American datum. Vertical datum is mean sea level.
GIS and cartography by Todd Petersen, Shana Pascal, and Greg Massaro. Edited by Neil Cunningham.