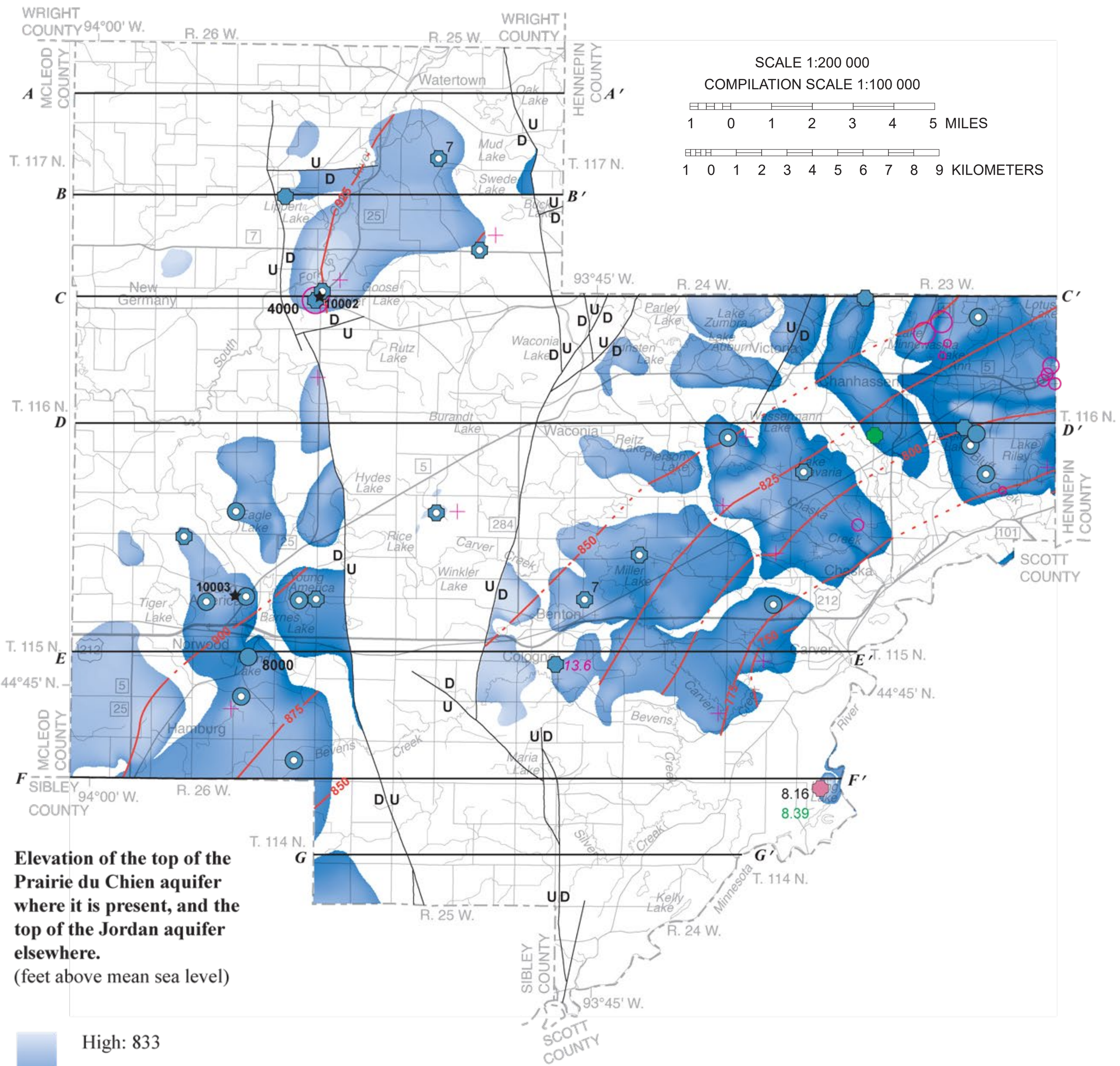
BEDROCK HYDROGEOLOGY

By Todd A. Petersen

2014



High: 833
Low: 537

FIGURE 2. ***Potentiometric surface elevation contours of the combined Prairie du Chien and Jordan aquifers.*** *Dotted lines connect contours across areas where aquifer is not present. Contour interval: 25 feet. The location of wells constructed in the Prairie du Chien and Jordan aquifers that were sampled for chemistry and isotope analysis are shown. The location of wells and reported water use by DNR groundwater appropriation permit holders are also shown.*

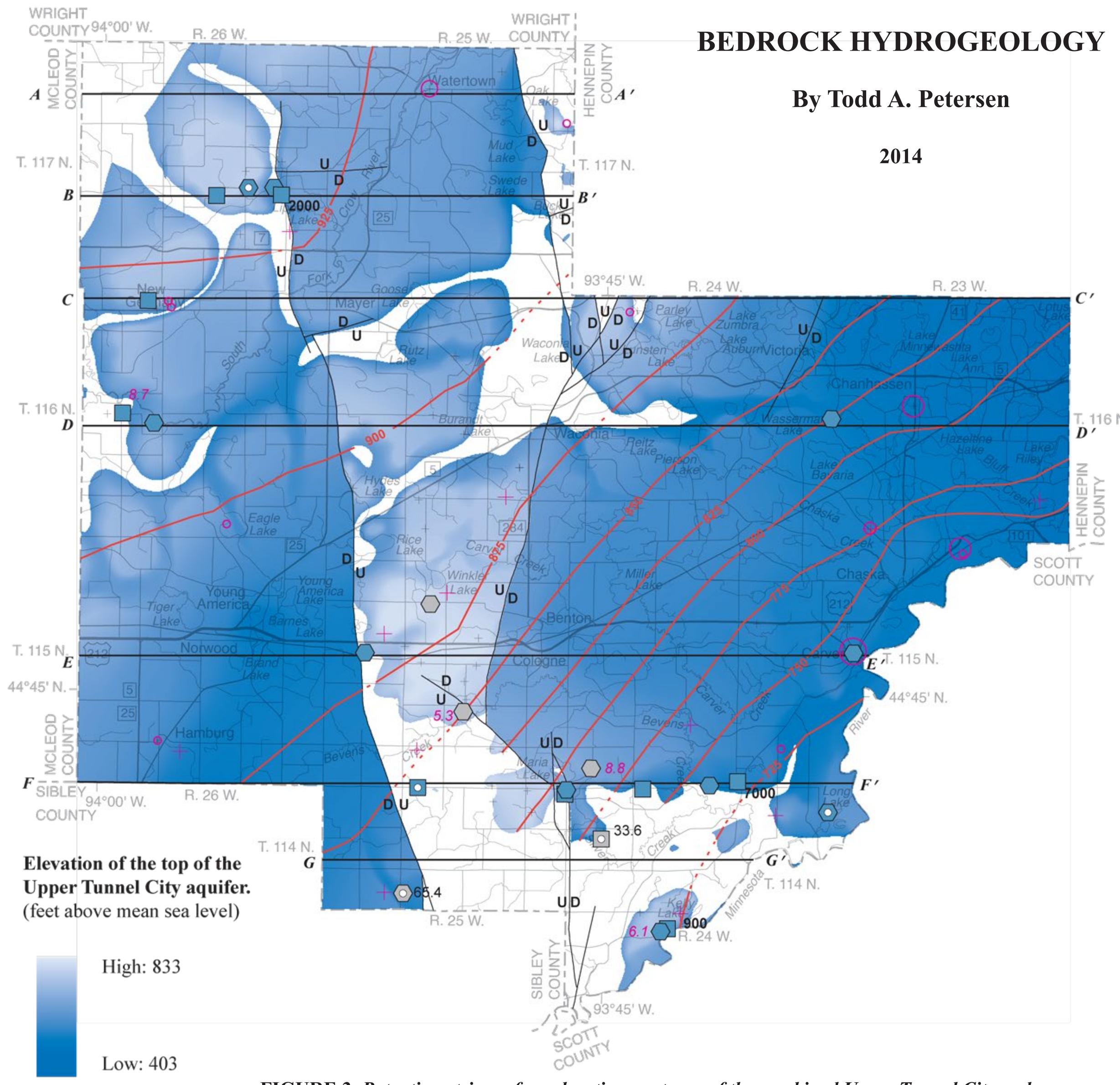


FIGURE 3. ***Potentiometric surface elevation contours of the combined Upper Tunnel City and Wonewoc aquifers.*** *Dotted lines connect contours across areas where aquifer is not present. Contour interval: 25 feet. The location of wells constructed in the Upper Tunnel City and Wonewoc aquifers that were sampled for chemistry and isotope analysis are shown. The location of wells and reported water use by DNR groundwater appropriation permit holders are also shown.*

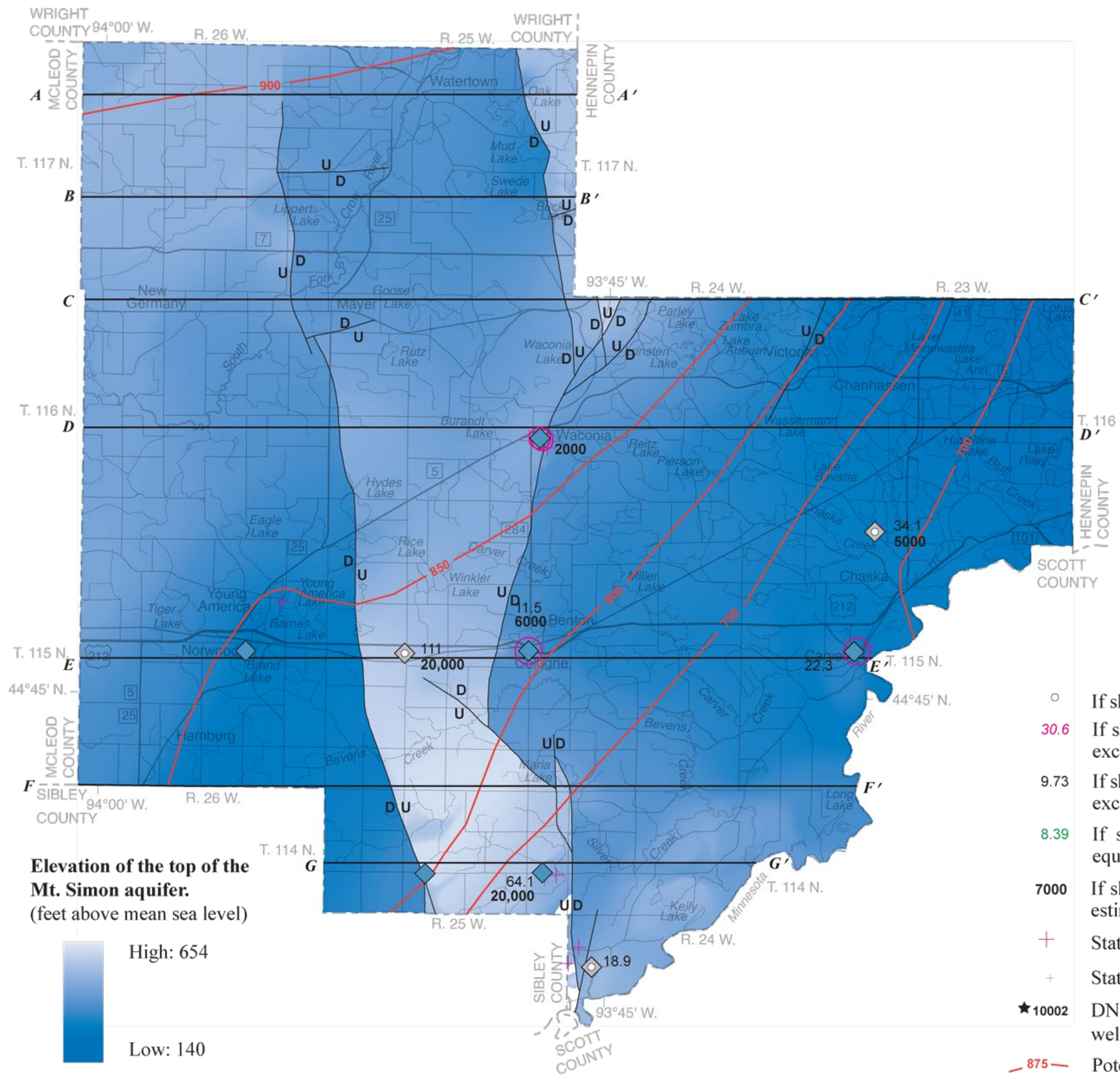


FIGURE 4. ***Potentiometric surface elevation contours of the Mt. Simon aquifer.*** *Contour interval: 50 feet. The location of wells constructed in the Mt. Simon aquifer that were sampled for chemistry and isotope analysis are shown. The location of wells and reported water use by DNR groundwater appropriation permit holders are also shown.*

MAP EXPLANATION
Figures 2–4

Tritium age

Symbol color indicates tritium age of water sampled in well.

- Recent—Water entered the ground since about 1953 (8 to 15 tritium units [TU]).
- 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.

Sampled well and aquifer symbols

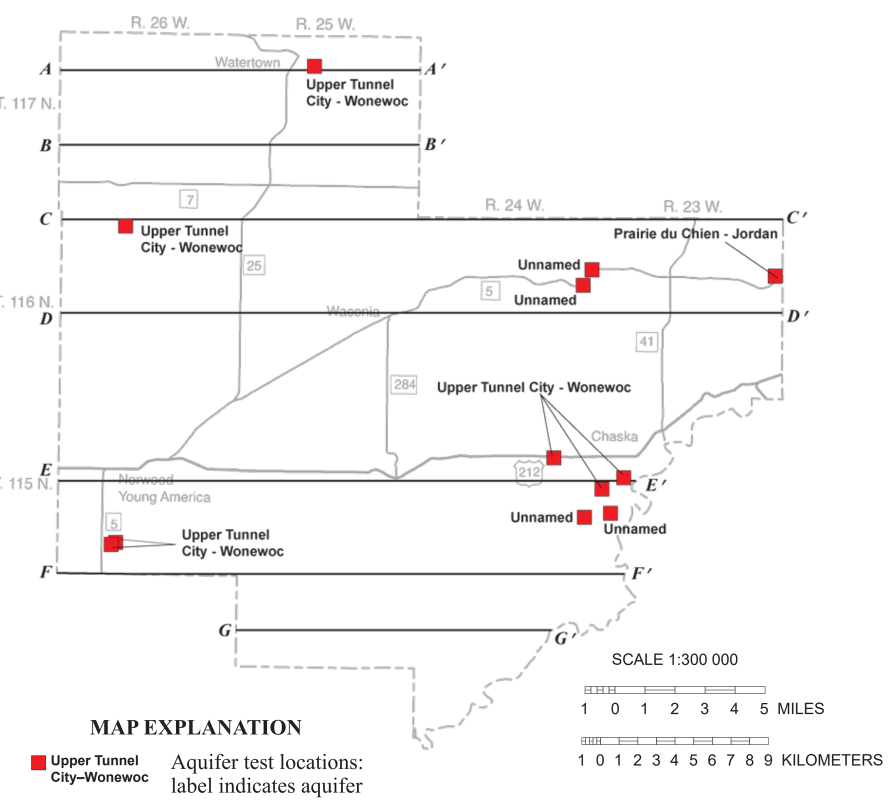
Bedrock aquifers
- Prairie du Chien
- Jordan
- Upper Tunnel City
- Wonewoc
- Mt. Simon and Fond du Lac

Map symbols and labels

- If shown on well symbol, arsenic not sampled
- 30.6 If shown, arsenic concentration equals or exceeds 5 parts per billion
- 9.73 If shown, chloride concentration equals or exceeds 5 parts per million
- 8.39 If shown, nitrate-nitrogen concentration equals or exceeds 3 parts per million
- 7000 If shown, groundwater residence time in years, estimated by carbon-14 (^{14}C) isotope analysis
- Static water level data from March 2008 synoptic
- Static water level data
- 10002 DNR groundwater level monitoring well. Label is well number
- 875 Potentiometric surface elevation contour
- Trace of fault; letters indicate relative vertical displacement: U, up; D, down
- F—F′ Line of cross section
- Body of water

Water use reported by DNR groundwater appropriation permit holders for 2010 (millions of gallons per year)

- 0 to 20
- > 20 to 50
- > 50 to 100
- > 100 to 150
- > 150



MAP EXPLANATION

Upper Tunnel City–Wonewoc — Aquifer test locations: label indicates aquifer

FIGURE 5. ***Locations of aquifer tests described in Table 1.***

TABLE 1. Specific capacity from well development tests and transmissivity from aquifer tests for selected large-capacity wells.
[gpm/ft, gallons per minute per foot; gpd/ft, gallons per day per foot; dash marks (--), no data available]

	Specific Capacity (gpm/ft)[1]					Transmissivity from Aquifer Test (gpd/ft)[2,3]				
Aquifer	Well Diameter (inches)	Mean	Minimum	Maximum	No. of Tests	Well Diameter (inches)	Mean	Minimum	Maximum	No. of Tests
Buried sand and gravel										
sdv	--	--	--	--	--	--	--	--	--	--
sr	--	--	--	--	--	--	--	--	--	--
sb	--	--	--	--	--	--	--	--	--	--
sg	--	--	--	--	--	--	--	--	--	--
sx	12–14	74	38	111	2	--	--	--	--	--
su	14	69	69	69	1	--	--	--	--	--
Unnamed	18	47	35	60	2	6–12	175,500	89,800	273,000	4
Bedrock										
Prairie du Chien–Jordan[4]	12–18	50	15	83	4	20	52,700	52,700	52,700	1
Jordan	16–24	16	14	17	2	--	--	--	--	--
Upper Tunnel City–Wonewoc[4]	12–18	6	1	12	3	6–16	11,600	4,700	35,200	7
Upper Tunnel City–Mt.Simon[4]	12	10	10	10	1	--	--	--	--	--
Wonewoc–Mt.Simon[4]	16	11	9	13	2	--	--	--	--	--
Mt. Simon	12–18	16	7	26	4	--	--	--	--	--
Mt. Simon–Fond du Lac[4]	12–16	9	5	12	3	--	--	--	--	--

[1] Data adapted from the County Well Index.
[2] See Figure 5 for locations of aquifer tests.
[3] Data adapted from a compilation of aquifer test data from Minnesota Department of Natural Resources, Minnesota Department of Health, and the U. S. Geological Survey.
[4] Well constructed across more than one aquifer.

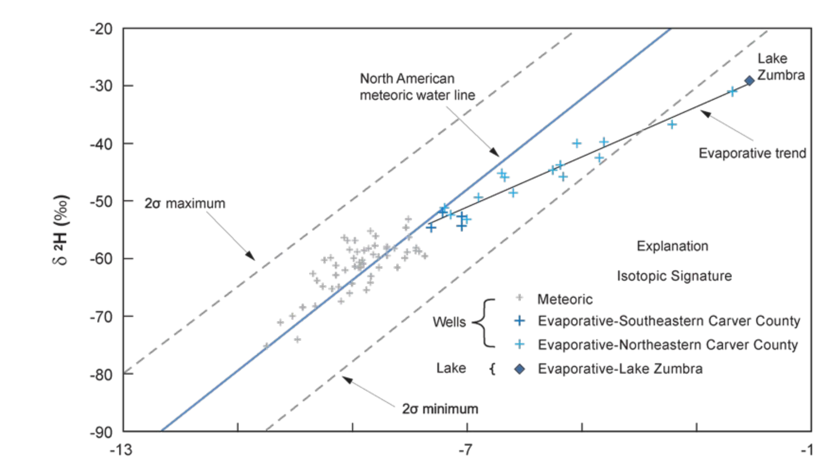


FIGURE 7. ***Graph of stable isotopes of oxygen and hydrogen from sampled groundwater and lake water in Carver County compared to the North American meteoric water line.*** *The colored well symbols indicate water samples that were affected by evaporation prior to moving into groundwater. The Lake Zumbra sample was highly fractionated by evaporation. The regression line of these samples shows the evaporative fractionation trend in Carver County. The groundwater samples shown by gray symbols represent groundwater directly recharged by precipitation. The dashed "2σ" lines show the statistical variation of stable isotope precipitation values used to derive the North American meteoric water line (IAEA/WMO, 2002).*

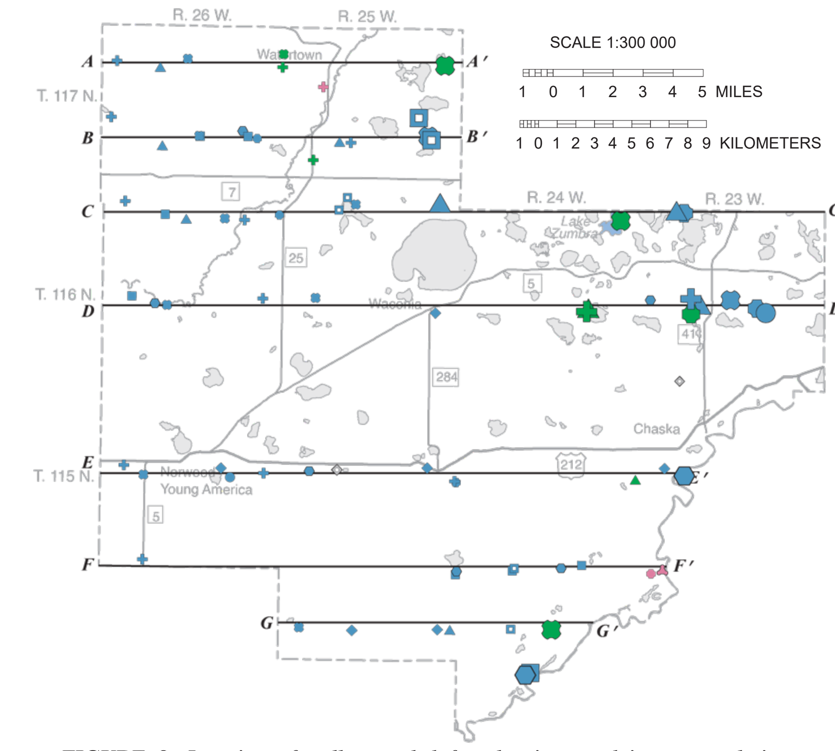


FIGURE 8. ***Location of wells sampled for chemistry and isotope analysis.*** *Groundwater samples with evaporative signatures are shown with larger symbols; they are clustered in northeastern Carver County near lakes or in southeastern Carver County near the Minnesota River.*

MAP EXPLANATION
Figure 8

Tritium age

Symbol color indicates tritium age of water sampled in well.

- Recent—Water entered the ground since about 1953 (8 to 15 tritium units [TU]).
- 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.

Sampled well and aquifer symbols

Buried sand and gravel aquifers
- sr
- sg
- sx
- su

Bedrock aquifers
- Prairie du Chien
- Jordan
- St. Lawrence and St. Lawrence–Upper Tunnel City
- Upper Tunnel City
- Wonewoc
- Mt. Simon or Fond du Lac

Map symbols and labels

- F—F′ Line of cross section
- Body of water
- Lake sampled for isotopes

INTRODUCTION

This plate describes the distribution of bedrock aquifers, groundwater flow, aquifer properties, and the connection between groundwater and surface water. The most used aquifers in Carver County are the Prairie du Chien, Jordan, Upper Tunnel City, Wonewoc, and Mt. Simon aquifers. In most of the county, the groundwater in these bedrock aquifers has very long residence times, typically thousands of years. However, recent tritium-age groundwater was sampled from both the Jordan and St. Lawrence aquifers in the Minnesota River valley, where the fine-grained glacial sediment that covers most of the bedrock aquifers in Carver County has been eroded and replaced by surficial sand.

POTENTIOMETRIC SURFACES OF MAJOR BEDROCK AQUIFERS

The eight bedrock aquifers in Carver County are the Ka (based on the geologic unit shown as PMu on Plate 2, Part A), the St. Peter, the Prairie du Chien, the Jordan, the Upper Tunnel City, the Wonewoc, the Mount Simon, and the Hinckley–Fond du Lac. The sequence of bedrock geologic units, hydrogeologic units, and hydrogeologic properties is shown in Figure 1. The confining units generally have low vertical permeability, but may have relatively high horizontal permeability along bedding fractures. In contrast, the bedrock aquifers have good vertical and horizontal permeability. The St. Peter, Wonewoc, Mt. Simon, and Hinckley aquifers are sandstones in which groundwater moves primarily through intergranular flow. Groundwater in the Prairie du Chien and Upper Tunnel City aquifers moves mainly through fractures. Groundwater in the Jordan aquifer moves through a combination of intergranular and fracture flow. Groundwater flow in the Fond du Lac aquifer is not well studied, but probably comprises both intergranular and fracture flow.

Potentiometric surfaces are shown in Figures 2, 3, and 4 for the three major bedrock aquifers in Carver County: the combined Prairie du Chien and Jordan aquifers, the combined Upper Tunnel City and Wonewoc aquifers, and the Mt. Simon aquifer. Synoptic water-level measurements in these three aquifers were collected by the U.S. Geological Survey (USGS) in March and August 2008 (Sanocki and others, 2009). In that study, the USGS considered the Prairie du Chien and Jordan aquifers to be one aquifer and the Upper Tunnel City and Wonewoc aquifers to be one aquifer. The potentiometric surfaces in this report are based on the March 2008 synoptic measurements reported by Sanocki and others (2009), modified by adding additional well data from the County Well Index (CWI) for wells drilled in the year 2000 or later.

The Prairie du Chien and Jordan aquifers are shown as a single unit in Figure 2. The blue color represents the elevation of the top surface of the Prairie du Chien aquifer where it is present and the top surface of the Jordan aquifer elsewhere. The potentiometric surface contours are based on combined water levels from both aquifers. These two aquifers are discontinuous because faulting offset the layers, rivers then eroded the area, and finally it was buried by glacial sediment. The Prairie du Chien aquifer is present in about 9 percent of the county and the Jordan aquifer is present in about 32 percent of the county. The potentiometric surface of the combined Prairie du Chien and Jordan aquifers varies from 925 feet above mean sea level in the northwest part of Carver County to 750 feet in southeast Carver County. The groundwater in these aquifers moves from northwest to southeast and eventually discharges to the Minnesota River.

The potentiometric surface contours for the combined Upper Tunnel City and Wonewoc aquifers are shown in Figure 3. The blue color represents the elevation of the top of the Upper Tunnel City aquifer where it is present. The Upper Tunnel City aquifer is also discontinuous because of faulting and subsequent erosion. The combined Upper Tunnel City and Wonewoc aquifers are present in approximately 82 percent of the county. The potentiometric surface of the combined aquifers varies from 925 feet above mean sea level in the northwest part of the county to 725 feet above mean sea level in the southeast. The groundwater in these aquifers moves from northwest to southeast and eventually discharges to the Minnesota River.

The potentiometric surface contours for the Mt. Simon aquifer are shown in Figure 4. The blue color represents the elevation of the top of the Mt. Simon aquifer. The Mt. Simon aquifer is also discontinuous because of faulting and subsequent erosion. The Mt. Simon aquifer is present across almost all of Carver County because it is stratigraphically deep and only partially eroded. The potentiometric surface of the Mt. Simon aquifer is highest in the northwest part of the county and lowest in the southeast; it varies from 900 feet above mean sea level to 700 feet above mean sea level. The groundwater in the Mt. Simon aquifer moves from northwest to southeast and eventually discharges to the Minnesota River.

AQUIFER SPECIFIC CAPACITY AND TRANSMISSIVITY

Table 1 shows specific capacity and transmissivity for the mapped Quaternary aquifers on Plate 6 and the bedrock aquifers on this plate. The specific-capacity data were determined from short-term pumping or well-development tests performed when the well was drilled. The pumping-test data for specific capacity were obtained from the CWI for wells with the following conditions: (1) a casing diameter of at least 12 inches, (2) pumped at least 4 hours, (3) the pumping water level was inside the well casing, at least 2 feet above the well screen or open hole. Transmissivity data were calculated from longer term and larger scale aquifer tests that provide a better test of the aquifer properties. Transmissivity data provide more accurate aquifer parameters than specific-capacity values determined at individual wells.

As indicated in Table 1, five wells constructed in buried sand and gravel aquifers had specific capacities that ranged from 35 to 111 gallons per minute per foot (gpm/ft) with a combined mean specific capacity of 62 gpm/ft. The 19 bedrock wells tested had specific capacities ranging from 1 to 83 gpm/ft. Wells constructed across the Prairie du Chien and Jordan aquifers had the highest specific capacity of the bedrock aquifers, averaging 50 gpm/ft. Wells constructed across the Upper Tunnel City and Wonewoc aquifers had the lowest specific capacity, averaging 6 gpm/ft.

Aquifer tests to determine aquifer transmissivity were conducted using four wells constructed in Quaternary buried sand and gravel aquifers, one well constructed across the Prairie du Chien and Jordan aquifers, and seven wells constructed across the Upper Tunnel City and Wonewoc aquifers. The transmissivity in buried sand and gravel aquifers varied from 89,800 gallons per day per foot (gpd/ft) to 273,000 gpd/ft. The transmissivity of the bedrock aquifers varied from 4,700 to 52,700 gpd/ft.

GROUNDWATER LEVEL, PRECIPITATION, AND GROUNDWATER RESIDENCE TIME

The Department of Natural Resources, in cooperation with the Carver County Environmental Services Department, actively measures five deep groundwater-level monitoring wells in Carver County. Hydrographs from two groundwater-level monitoring wells constructed in the Jordan aquifer, 10002 and 10003, are shown in Figures 6a and 6b respectively; the map locations of these wells are shown on Figure 2. Hydrographs from the other three wells are not shown because they had an insufficient period of record. Both hydrographs show annual variations in water level of 3 to 5 feet, which are due to seasonal pumping. The average annual water level has varied during the period of record, but has stayed within a few feet of the long-term average. The hydrographs for wells 10002 and 10003 do not show short-term changes in response to annual precipitation changes. This lack of response of groundwater levels in those wells to precipitation changes also means that these deeper aquifers are not quickly recharged by local precipitation. The residence time of groundwater in the Jordan aquifer near these two wells is thousands of years. The City of Mayer well number 2, which is 750 feet southwest of monitoring well 10002 and is also constructed in the Jordan aquifer, had a carbon-14 age of 4000 years. A domestic well, which is 1.5 miles south of monitoring well 10003 and constructed in the Prairie du Chien aquifer, had a carbon-14 age of 8000 years. Groundwater from the underlying Jordan aquifer should have a similarly long residence time.

In the Minnesota River valley in southeastern Carver County, recent tritium-age groundwater samples were collected from two bedrock wells; one well is constructed in the Jordan aquifer and the other is constructed in the St. Lawrence Formation. In the broad valley of the Minnesota River and in the surrounding bluffs, these shallow bedrock aquifers are overlain by the surficial sand aquifer. Unlike other areas in the county where fine-grained glacial sediment is at the land surface, precipitation rapidly infiltrates through the surficial sand aquifer to deeper aquifers.

STABLE ISOTOPE ANALYSIS OF GROUNDWATER AND SURFACE WATER

Isotopic chemical changes as water moves from precipitation to surface water and groundwater are complex but can be reconstructed to help determine whether groundwater was recharged directly from precipitation, lake water, or a mixture of the two. Stable isotopes of hydrogen and oxygen were analyzed for 79 groundwater samples from wells and one lake-water sample from Lake Zumbra.

Common hydrogen has only one proton; its stable isotope, deuterium (hydrogen-2 or ^{2}H), has one proton and one neutron. Because of this difference, deuterium has approximately twice the mass of common hydrogen. Oxygen-16 (^{16}O) contains eight protons and eight neutrons, and its stable isotope, oxygen-18 (^{18}O), contains 8 protons and 10 neutrons; thus, oxygen-18 has slightly more mass than oxygen-16. This mass difference causes the stable isotopes of hydrogen and oxygen to fractionate or separate during evaporation (Ekman and Alexander, 2002). The lighter isotopes will evaporate more easily than the heavier isotopes. Because lake water is exposed to the atmosphere, evaporation causes significant fractionation of the stable isotopes of hydrogen and oxygen; as a result, lake water contains more of the heavier isotopes than are found in precipitation. Groundwater is more isolated from the atmosphere, however, so negligible fractionation occurs.

Figure 7 is a plot of the stable isotopes of hydrogen and oxygen in sampled groundwater and sampled lake water. The value on the x-axis represents the ratio of oxygen-18 to oxygen-16 in the sample divided by the same ratio in a standard. The value on the y-axis represents the ratio of deuterium to hydrogen in the sample divided by the same ratio in a standard. Values to the left on the x-axis or to the bottom on the y-axis indicate relatively more of the lighter isotope, while values to the right or to the top indicate more of the heavier isotope.

Regional background precipitation values for the stable isotopes of hydrogen and oxygen generally plot along a trend called the meteoric water line shown in Figure 7 (IAEA/WMO, 2002). The stable isotope values of the water samples from Lake Zumbra and some of the groundwater samples plot on a slightly lower slope than the meteoric water line, which indicates that the water has undergone some fractionation during evaporation. This evaporative trend crosses the meteoric water line at the average value for precipitation in the county. The slope of the evaporative trend and the location where it meets the meteoric water line depend on the local climate, primarily the average temperature and humidity (Kendall and Doctor, 2003).

The groundwater samples that plot on the evaporative trend line away from the meteoric water line have undergone some evaporative fractionation, which means that part of this groundwater was recharged from lake water. These samples are shown in Figure 7 as symbols with colors indicating an evaporative isotopic signature. The locations of these wells are shown in Figure 8 as large well symbols. Groundwater samples that were recharged directly from precipitation plot on the meteoric water line. These samples are plotted on Figure 7 as small gray symbols and the well locations are shown in Figure 8 as small symbols.

Groundwater flow paths cannot be determined by hydrologic data or isotopes alone. Water may take a complex path through the watershed, part on the surface and part in the subsurface. The mingling of groundwater and surface water is most clearly seen by the continuum of values of stable isotope samples along the evaporative trend line. Recharge from surface water forms an important component of groundwater in northeastern Carver County, where there are many lakes, and in southeastern Carver County, near the Minnesota River valley. Recharge to groundwater by surface water is not common elsewhere in the county where groundwater is more typically recharged by direct infiltration of precipitation to the subsurface.

REFERENCES CITED

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Sanocki, C.A., Langer, S.K., and Menard, J.C., 2009, Potentiometric Surfaces and Changes in Groundwater Levels in Selected Bedrock Aquifers in the Twin Cities Metropolitan Area, March-August 2008 and 1988-2008: U.S. Geological Survey Scientific Investigations Report 2009-5226, 67 p.

ACKNOWLEDGMENTS

I received much help from my colleagues at DNR. Jan Falteisek provided assistance and guidance throughout the project. Shana Pascal, Greg Massaro, and Neil Cunningham made the plates more understandable through their GIS, layout, and editing. Joe Enfield of Carver County Environmental Services provided many years of historical groundwater chemistry data. Jim Berg provided geologic insight and data from his "South-Central Minnesota Groundwater Monitoring of the Mt. Simon Aquifer" report that was funded by the Minnesota Environment and Natural Resources Trust Fund. John Barry reviewed the final report. Thanks are due also to my colleagues at other agencies who provided excellent suggestions during peer review: Bob Tipping and Barb Lusardi of the Minnesota Geological Survey; Rich Soule of the Minnesota Department of Health; and Madeline Seveland of Carver County Water Management Department. I would like to thank Scott Alexander of the University of Minnesota, Department of Earth Sciences for collecting the carbon-14 water samples for analysis and interpreting the results.

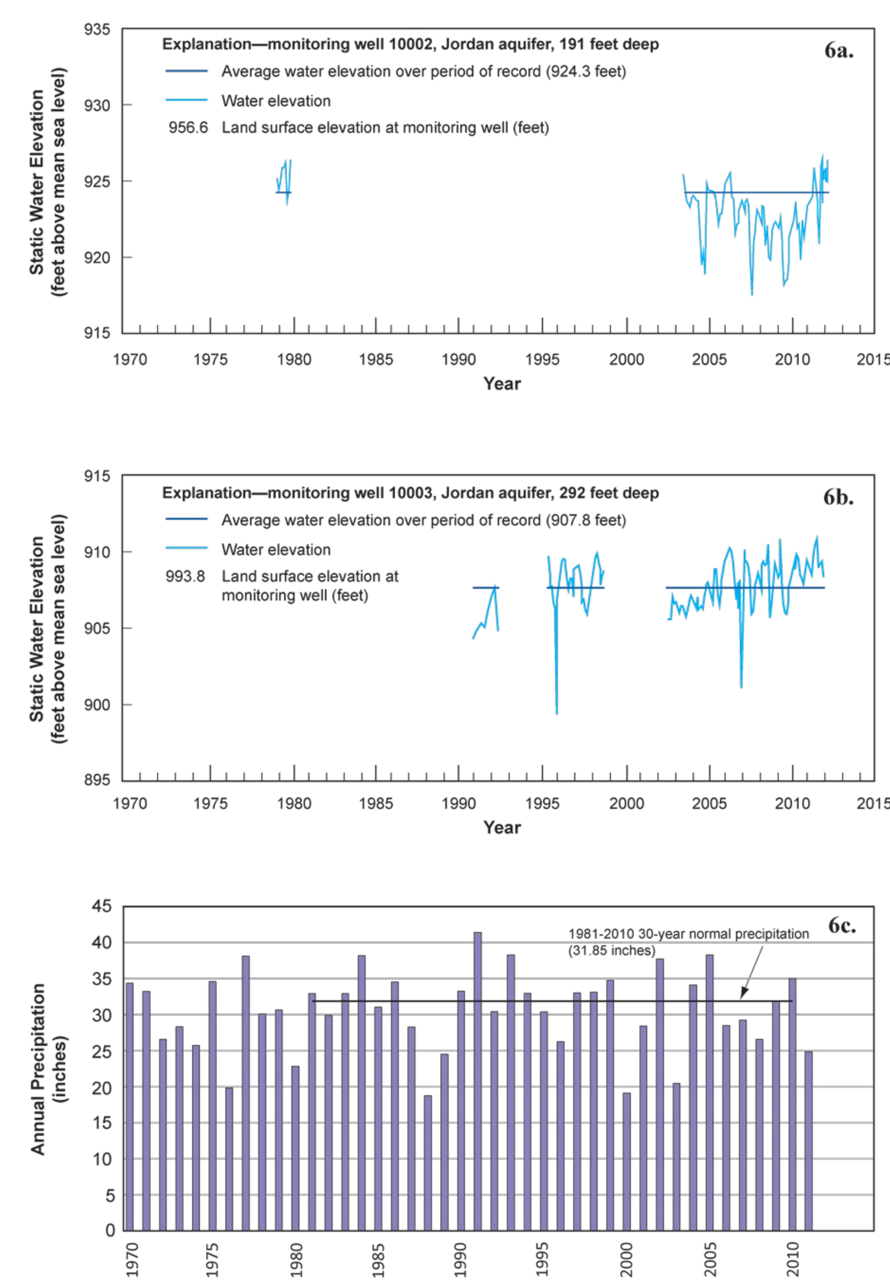
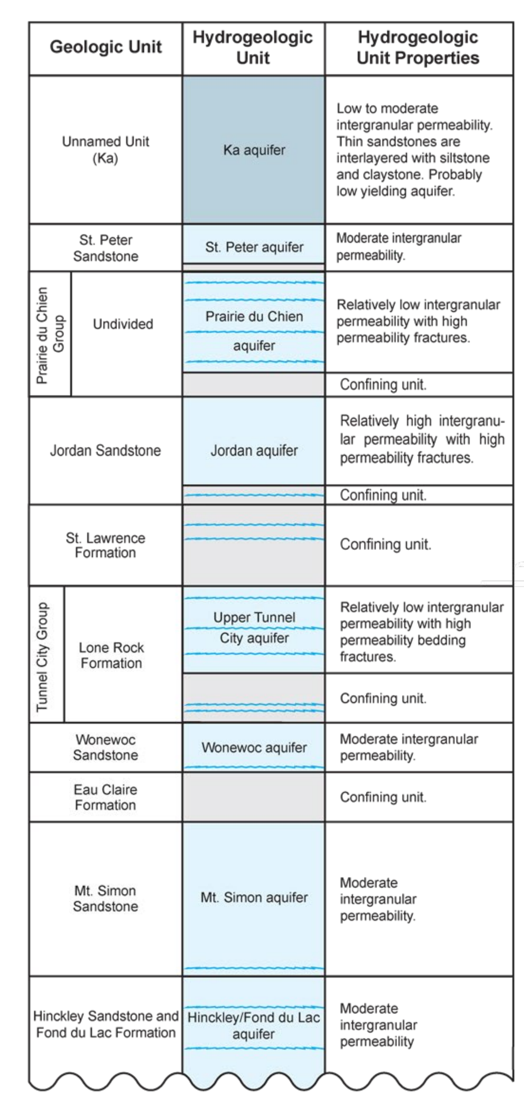


FIGURE 6. ***Comparison of hydrographs of two DNR groundwater-level monitoring wells to 1970–2011 precipitation.*** *The hydrograph of DNR Jordan aquifer monitoring well 10002 is shown in Figure 6a. The hydrograph of DNR Jordan aquifer monitoring well 10003 is shown in Figure 6b. A chart of precipitation at Chaska is shown in Figure 6c. The elevation of water levels in these two wells are not directly influenced by short-term trends in local precipitation. The location of these two monitoring wells is shown on Figure 2.*

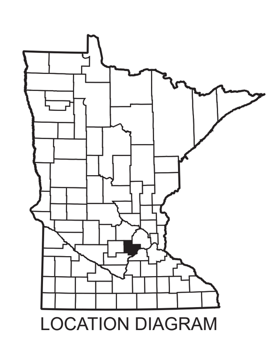


EXPLANATION

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

FIGURE 1. ***Sequence of bedrock geologic units and hydrogeologic units in Carver County.*** *The* Ka *geologic unit is shown in Part A as* PMu.

Base modified from Minnesota Geological Survey, Carver County Geologic Atlas, Part A, 2009.
Project data compiled from 2010 to 2012 at a scale of 1:100,000 to 1:300,000. 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.



LOCATION DIAGRAM

GEOLOGIC ATLAS OF CARVER COUNTY, MINNESOTA