STATE OF MINNESOTA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF ECOLOGICAL AND WATER RESOURCES

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COUNTY ATLAS SERIES
CARVER COUNTY
ATLAS C-21, PART B, PLATE 6 of 9
Quaternary Hydrogeology

MAP EXPLANATION - Figure 1

Water-table elevation (feet above mean sea level)

- > 1,075
- > 1,050 to 1,075
- > 1,025 to 1,050
- > 1,000 to 1,025
- > 975 to 1,000
- > 950 to 975
- > 925 to 950
- > 900 to 925
- > 875 to 900
- > 850 to 875
- > 825 to 850
- > 800 to 825
- > 750 to 800
- > 725 to 750
- > 700 to 725
- > 675 to 700
- ≤ 675

Depth of selected lakes (feet)

- > 0 to 20
- > 20 to 40
- > 40 to 60
- > 60 to 80
- > 80
- No data

Tritium age

Symbol color indicates tritium age of water sampled in well.

- Cold war era—Water entered the ground during the peak period of atmospheric tritium concentration from nuclear bomb testing, 1958-1959 and 1961-1972 (greater than 15 tritium units [TU]).
- Recent—Water entered the ground since about 1953 (8 to 15 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

Surficial sand aquifer
- sdo

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

Bedrock aquifers
- Prairie du Chien
- Jordan
- St. Lawrence and St. Lawrence-Upper Tunnel City
- 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
- c If shown, well sample chemistry obtained from Carver County Environmental Services
- g If shown, well sample chemistry obtained from Minnesota Geological Survey
- p If shown, well sample chemistry obtained from Minnesota Pollution Control Agency
- Static water level data
- Direction of groundwater flow at the water table in the surficial sand aquifer
- Direction of groundwater flow at the water table in nonaquifer areas
- Extent of surficial sand aquifer
- F—F′ Line of cross section
- Body of water

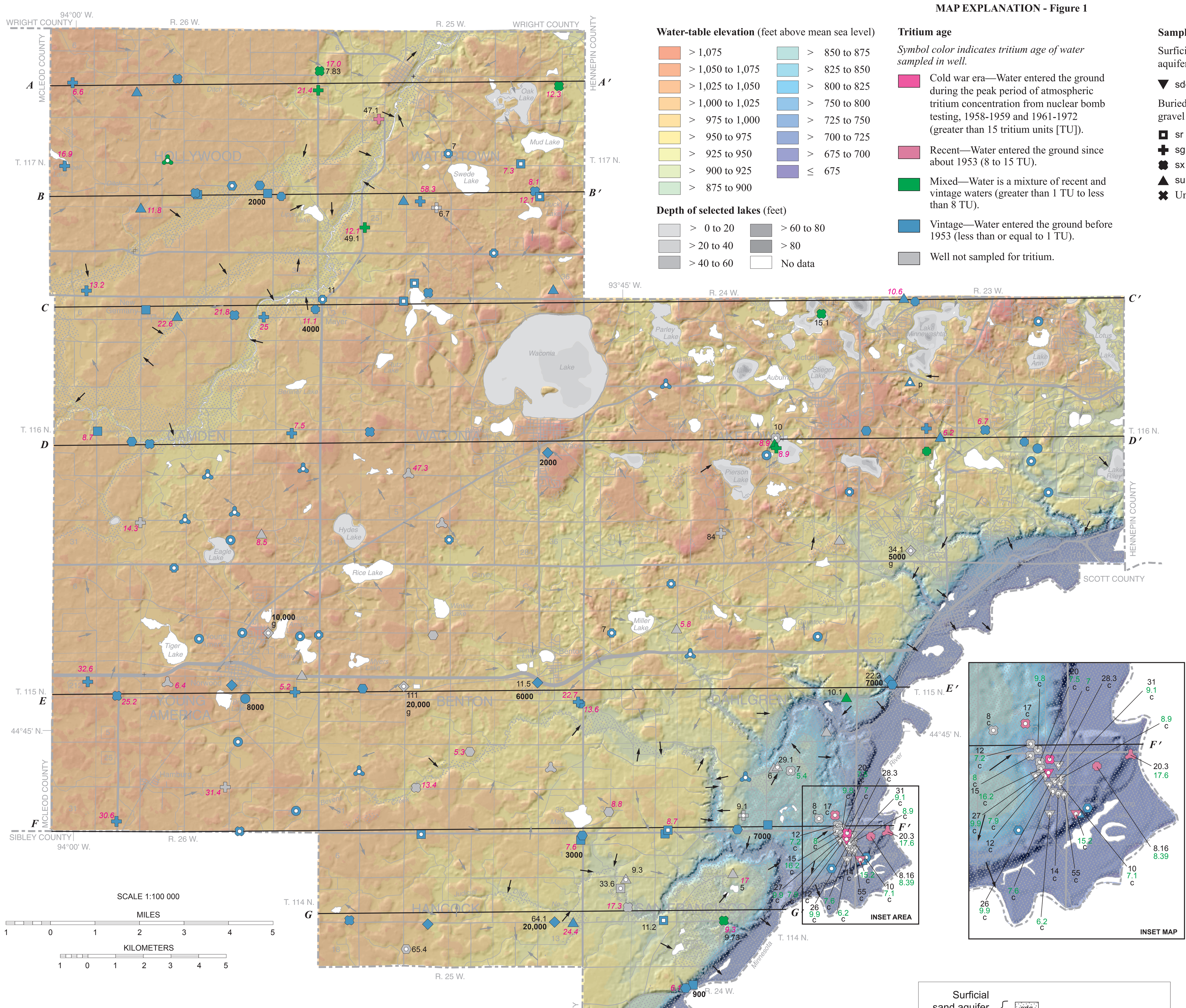


FIGURE 1. Estimated water-table elevation in surficial sediment in Carver County. *Water-table elevation is shown in color over a shaded relief of the land surface elevation. In general, water-table elevation follows surface elevation. The locations of wells that were sampled for general chemistry and isotope analysis are shown for convenience. Sampled wells that were not analyzed for arsenic are shown with a white dot on the well symbol to differentiate them from wells with a low concentration of arsenic.*

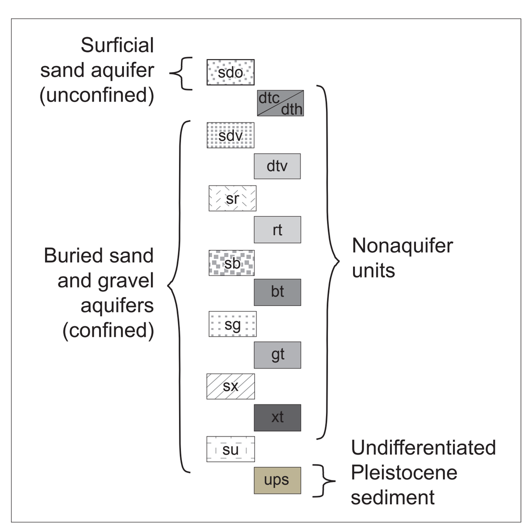
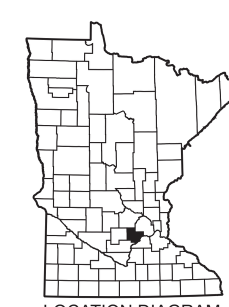


FIGURE 2. Correlation of sand and gravel aquifers and nonaquifer units. *Modified from Figure 3, Plate 4, Part A.*



HYDROGEOLOGY OF THE SURFICIAL AQUIFER AND THE BURIED SAND AND GRAVEL AQUIFERS

By Todd A. Petersen

2014

INTRODUCTION

This plate describes the distribution of Quaternary sand and gravel aquifers, groundwater flow, groundwater use, and the occurrence of arsenic in groundwater in Carver County. The groundwater resources of the county include 1 surficial sand and gravel aquifer, 6 buried sand and gravel aquifers, and 8 sedimentary bedrock aquifers. These aquifers are mapped and characterized from approximately 3,900 wells from the County Well Index (CWI), a database of wells in Minnesota described in Plate 1, Part A. Seventy-three percent of these wells are constructed in Quaternary sediment, 25 percent in bedrock aquifers, and 2 percent have no aquifer information. Approximately 78 percent of permitted water use comes from bedrock aquifers. Arsenic in concentrations exceeding the EPA standard of 10 parts per billion was found in 26 of the 96 wells sampled for arsenic.

WATER TABLE AND POTENTIOMETRIC SURFACES OF MAJOR QUATERNARY SAND AND GRAVEL AQUIFERS

Surficial Sand and Surficial Till

The water table is defined as the surface below which sediment is saturated with groundwater. The water table occurs in both aquifer and nonaquifer sediment across the entire county. Most of the county has fine-grained sediment at the land surface. This fine-grained sediment does not readily release water to wells for water supply and therefore is not considered an aquifer. Only 11 percent of Carver County has surficial sand at the surface; the surficial sand is shown in stipple pattern on Figure 1 and also on Figure 4, Plate 4, Part A. The surficial sand (water-table) aquifer is the portion of the surficial sand that is below the water table where there is sufficient saturated thickness to install a well and economically pump groundwater. The surficial sand is very thick, up to 260 feet, in southeastern Carver County near the broad valley now occupied by the Minnesota River. Elsewhere in the county the surficial sand is generally less than 20 feet thick and the water-table aquifer is very limited. Only 46 wells in Carver County are constructed in the surficial sand aquifer, so there is little direct information on the elevation of the water-table surface.

The water table (Figure 1) generally follows the surface topography: higher in the uplands and lower in the valleys. In general, the water table is within 10 feet of the land surface. Near the Minnesota River valley, the water table is more than 120 feet below land surface.

The water-table elevation was estimated from several sources of data including water levels in wells constructed in the surficial sand aquifer and the elevation of surface water bodies (rivers, perennial streams, and lakes) from a Light Detection and Ranging (LiDAR) based digital elevation model (DEM). These data are supplemented with polygon shapefiles of soils and associated tabular data from the Natural Resources Conservation Service (NRCS) that estimate the depth to water table for wet soils (NRCS, 2011). A 100-meter grid of points was established over wet soil polygons. Estimates of depth to water for each point are sampled from each relevant soil polygon; surface elevations are determined by sampling the LiDAR data at that location. The water-table elevation at each point was calculated by subtracting the estimated depth to water from the surface elevation. All of the data described above were assembled and interpolated to create an estimate of the county-wide water-table surface (Figure 1). A generalized depth-to-water-table grid is included with the digital GIS project data, but is not shown in this report.

Quaternary Buried Sand and Gravel Aquifers

Six Quaternary buried sand and gravel aquifers are mapped in Carver County (Figure 2). These aquifers are directly based on sand and gravel units mapped on Plate 4, Part A. Future studies will be needed to better define the hydraulic connections between these aquifers. The extent, depth, and thickness of these aquifers vary considerably across the county (five are shown on Plate 4, Part A). Some areas of Carver County are underlain by multiple buried sand and gravel aquifers; other areas are underlain by only one or two. This variation in mapped aquifer distribution is partly due to nonuniform deposition of sediment, but is also a reflection of the limited well data available.

The potentiometric surface is a contoured map of the water levels measured in wells constructed in a confined aquifer. The potentiometric surface elevations for four of these six buried sand and gravel aquifers are shown in Figures 3 through 6. The sdv and sb aquifers are not shown due to their limited extent. Topography appears to have a strong influence on groundwater flow in the buried sand and gravel aquifers. All of the potentiometric surfaces exhibit large lateral gradients that are related to surface topography. The vertical change between potentiometric surfaces is relatively small. In Carver County, groundwater movement is mostly lateral. However, groundwater can move between adjacent aquifers. Initially, groundwater moves downward into the groundwater system at the topographic highs and then mostly laterally into the rivers and other discharge areas that are typically the topographic lows.

Groundwater in Carver County is recharged across the entire landscape, but recharge is more limited in areas of fine-grained surficial sediment. The main groundwater discharge area for Carver County is the Minnesota River. Most of the tills in Carver County are relatively fine grained and low permeability. Therefore, the buried sand and gravel aquifers generally have limited recharge from the surface. Cross sections showing the hydrostratigraphy of Quaternary sediment and bedrock units and the estimated residence time of groundwater are shown on Plate 7. Additional areas with higher recharge are also shown on Plate 7.

GROUNDWATER USE PATTERNS

The State Water Use Data System (SWUDS) is maintained by the Minnesota Department of Natural Resources (DNR) and is used to regulate and better understand water-use patterns across the State of Minnesota (DNR, 2012). All water users that withdraw more than 10,000 gallons per day or 1 million gallons per year must have a valid DNR permit and report their water use. This permitting requirement applies to both surface water and groundwater users, but this plate only discusses groundwater use.

Carver County groundwater use in calendar year 2010 (Figure 7 and Table 1) is broadly representative of historical use patterns. Most of the use in 2010 was for municipal water supply, which accounted for 87.9 percent. Agricultural processing and noncrop irrigation together accounted for 8.5 percent. Only two wells were used for major crop irrigation, both in the surficial sand aquifer in southeastern Carver County. Most of the county has loam and clay loam soils which do not require irrigation. Seventy-eight percent of water use was from bedrock aquifers (Figure 8 and Table 2). Pumping from Quaternary aquifers accounted for only 17.5 percent. The Prairie du Chien and Jordan are the most-used aquifers; a total of 31.1 percent was withdrawn from these two aquifers. The Prairie du Chien and Jordan are separate aquifers, but most of the water is pumped from nine wells owned by the City of Chanhassen that are constructed across both aquifers. The Upper Tunnel City and Wonewoc aquifers are the second-most used. Wells constructed across these two adjacent aquifers account for 17.5 percent. The Mt. Simon and Fond du Lac aquifers are the third-most used, collectively accounting for 14.1 percent. Two wells constructed over the entire Wonewoc to Mt. Simon interval account for 9.3 percent. Bedrock aquifers are discussed in more detail on Plate 8.

ARSENIC IN GROUNDWATER IN CARVER COUNTY

Arsenic is commonly found in the Quaternary sand and gravel aquifers and in the shallow bedrock aquifers in Carver County. Arsenic is found in many wells constructed in these aquifers. Current science cannot predict the concentrations, therefore all wells constructed in one of the sand and gravel aquifers or in a shallow bedrock aquifer should be tested for arsenic. The Environmental Protection Agency (EPA) requires that community water supplies not exceed 10 parts per billion (ppb) arsenic (Environmental Protection Agency, 2001). Figure 1 shows all water samples that had 5 ppb or more arsenic. Arsenic concentration can vary over time; well-water samples that had 5 ppb or more arsenic should be resampled to determine if the arsenic level of the first water sample is representative.

Arsenic in concentrations greater than or equal to 10 ppb was found in 26 of the 96 wells tested. Twenty-three of these wells were constructed in Quaternary buried sand and gravel aquifers, two wells were constructed in the Jordan aquifer, and one well was constructed across both the St. Lawrence confining unit and the Upper Tunnel City aquifer. Arsenic concentrations greater than or equal to 5 ppb and less than 10 ppb were found in 19 additional wells. Thirteen of these wells are constructed in Quaternary buried sand and gravel aquifers, one well is constructed in the St. Lawrence confining unit, three wells are constructed in the Upper Tunnel City aquifer, and two wells are constructed in the Wonewoc aquifer. Eight of the nine bedrock wells with arsenic concentrations greater than or equal to 5 ppb are constructed in a unit that forms the top of the bedrock surface and are probably recharged from Quaternary units.

The factors affecting elevated arsenic concentration in groundwater are not completely understood. Erickson and Barnes (2005) found a strong correlation with wells constructed in aquifers associated with northwest provenance tills. In this atlas northwest provenance tills are subdivided into the Riding Mountain and Winnipeg provenances (Figure 1, Plate 3, Part A). Except for the rt till, all of the mapped tills in Carver County are northwest provenance. The original arsenic reservoir is probably arsenic-bearing pyrite from small shale particles in these tills. Some of this arsenic has been previously released and then adsorbed to surfaces of the pyrite crystals and other small particles during earlier oxidizing conditions. This surface adsorbed arsenic, the most chemically available form, is released under reducing conditions to groundwater (Nicholas and others, 2011; Thomas, 2007).

REFERENCES CITED

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Minnesota Department of Natural Resources (DNR), 2012, State Water Use Data System: Minnesota DNR, available at http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html.

Natural Resources Conservation Service (NRCS), 2011, Soil Survey Geographic Database (SSURGO) for Carver County, Minnesota: USDA-NRCS, accessed December 19, 2011 from Soil Data Mart at http://soildatamart.nrcs.usda.gov/Report.aspx?Survey=MN019&UseState=MN.

Nicholas, S. L., Toner, B.M., Erickson, M.L., Knaeble, A.R., Woodruff, L.G., and Meyer, G.N., 2011, Speciation and mineralogy of arsenic in glacial sediments and their effect on arsenic concentrations in groundwater [abs.]: Geological Society of America Abstracts with Programs [digital version], v. 43, no. 5.

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, 2001, Arsenic rule: EPA, accessed October 30, 2012, at http://water.epa.gov/lawsregs/rulesregs/sdwa/arsenic/regulations.cfm.

TABLE 1. Water use reported by DNR groundwater appropriation permit holders for 2010 by use category
[Data from Minnesota Department of Natural Resources, State Water Use Data System. MGY, million gallons per year, total permitted wells = 72]

Use Category	Water Use (MGY)	Percent of Use
Municipal waterworks	3,055.9	87.9
Agricultural processing	179.2	5.2
Noncrop irrigation	113.7	3.3
Dewatering	61.1	1.8
Nonmunicipal waterworks	32.2	0.9
Sand and gravel washing[1]	17.3	0.5
Pollution containment[1]	16.3	0.5
Once-through heating or A/C	1.2	0.03
Major crop irrigation	0.5	0.01
Total	3,477.4	[2]100

[1] Categories are combined into "Other" in Figure 7.
[2] Sum of percentages does not equal 100 due to rounding.

TABLE 2. Water use reported by DNR groundwater appropriation permit holders for 2010 by aquifer
[Data from Minnesota Department of Natural Resources, State Water Use Data System. MGY, million gallons per year; dashes (--), no data available]

Aquifer	Number of Wells	Water Use (MGY)	Percent of Use
Surficial sand			
sdo	3	80.5	2.3
Buried sand and gravel			
sdv	--	--	--
sr	--	--	--
sb	--	--	--
sg	2	30.5	0.9
sx	4	4.0	0.1
su	4	22.9	0.7
Unnamed	8	470.6	13.5
Bedrock			
Prairie du Chien-Jordan[1]	9	862.2	24.8
Jordan	4	220.6	6.3
St. Lawrence-Upper Tunnel City[1]	1	1.6	0.05
Upper Tunnel City	2	12.3	0.4
Upper Tunnel City-Wonewoc[1]	12	546.2	15.7
Upper Tunnel City-Wonewoc-Eau Claire[1]	1	40.4	1.2
Upper Tunnel City-Mt. Simon[1]	4	209.9	6.0
Wonewoc	1	6.8	0.2
Wonewoc-Mt. Simon[1]	2	322.6	9.3
Mt. Simon	7	449.9	12.9
Mt. Simon-Fond du Lac[1]	2	41.2	1.2
Undefined	6	155.2	4.5
Total	72	3,477.4	[2]100

[1] Well constructed across more than one aquifer.
[2] Sum of percentages does not equal 100 due to rounding.

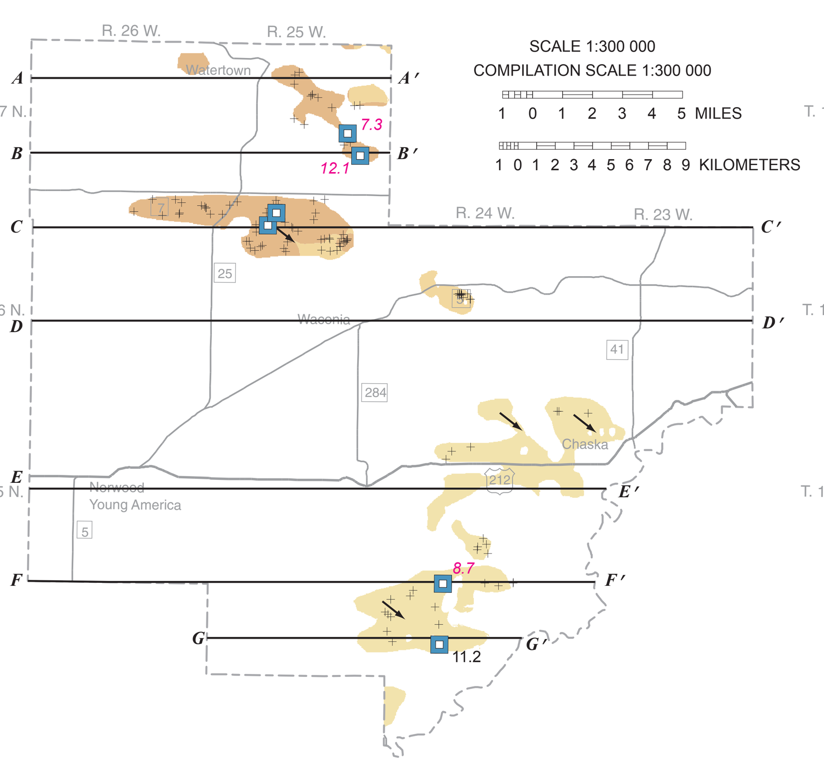

FIGURE 3. Potentiometric surface elevation of the sr buried sand and gravel aquifer. *The locations of wells that were sampled for general chemistry and isotope analysis are also shown. The extent, distribution, depth, and thickness of the sr sand and gravel unit is shown in Figure 6, Plate 4, Part A.*

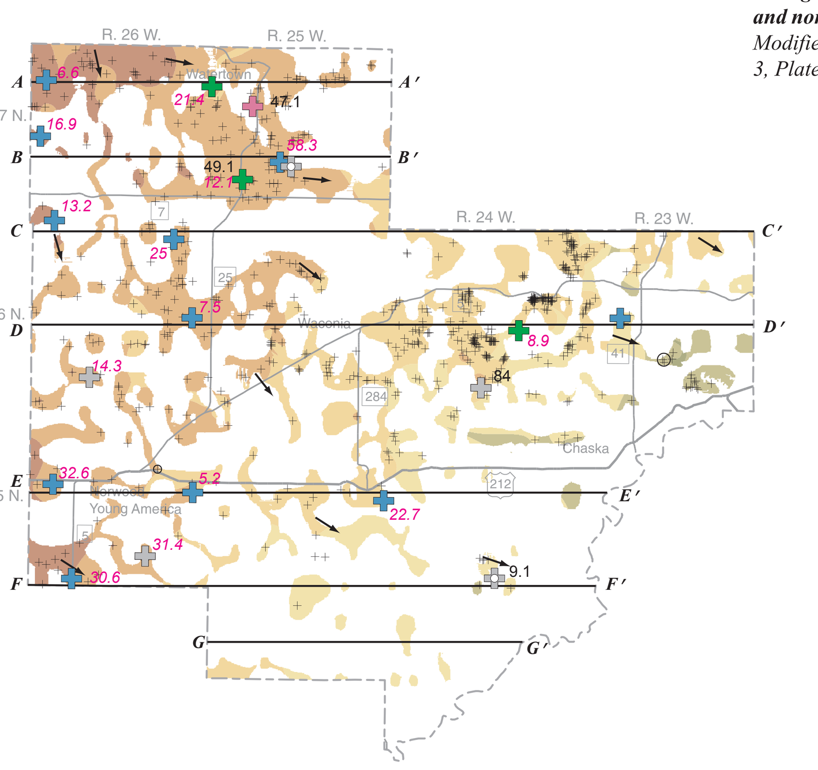

FIGURE 4. Potentiometric surface elevation of the sg buried sand and gravel aquifer. *The locations of wells that were sampled for general chemistry and isotope analysis are also shown. The extent, distribution, depth, and thickness of the sg sand and gravel unit is shown in Figure 7, Plate 4, Part A.*

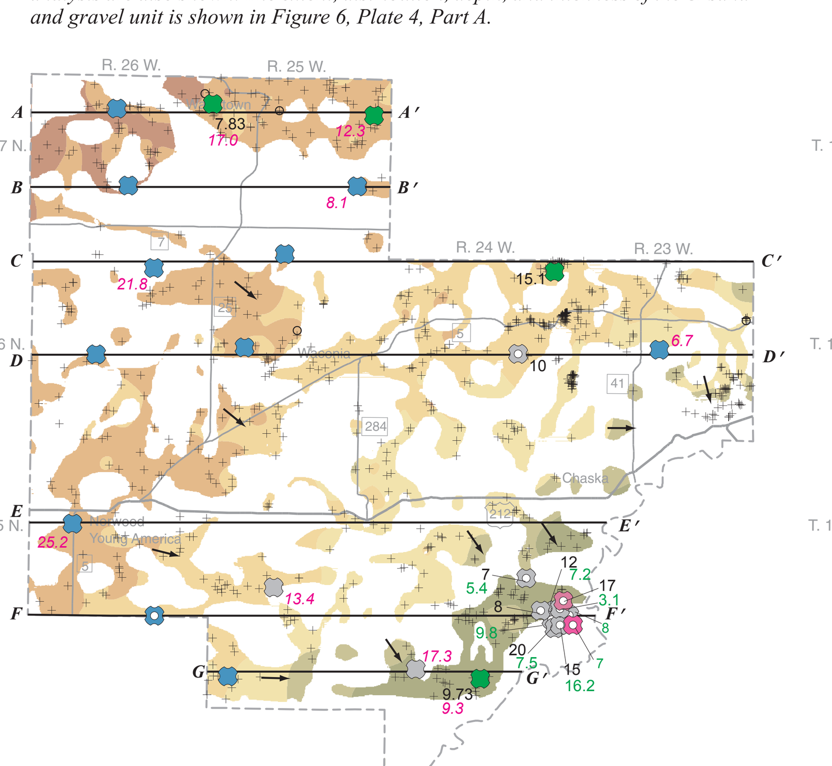

FIGURE 5. Potentiometric surface elevation of the sx buried sand and gravel aquifer. *The locations of wells that were sampled for general chemistry and isotope analysis are also shown. The extent, distribution, depth, and thickness of the sx sand and gravel unit is shown in Figure 8, Plate 4, Part A.*

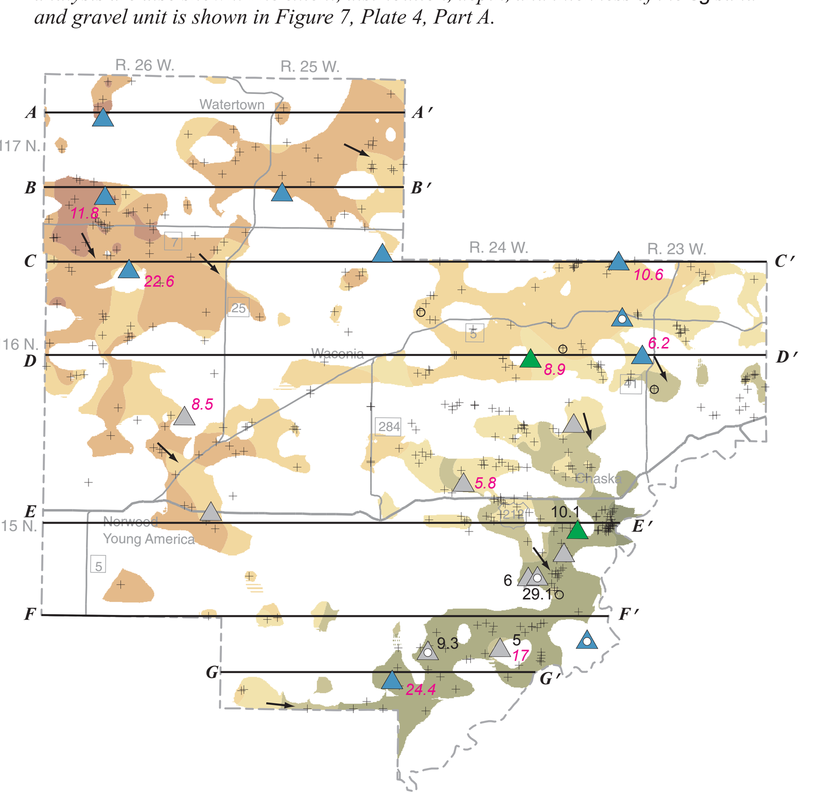

FIGURE 6. Potentiometric surface elevation of the su buried sand and gravel aquifer. *The locations of wells that were sampled for general chemistry and isotope analysis are also shown. The extent, distribution, depth, and thickness of the su sand and gravel unit is shown in Figure 9, Plate 4, Part A.*

MAP EXPLANATION Figures 3–6

Potentiometric surface elevation (feet above mean sea level)

- > 950 to 1,000
- > 900 to 950
- > 850 to 900
- > 800 to 850
- > 750 to 800
- > 700 to 750
- ≤ 700

Tritium age

Symbol color indicates tritium age of water sampled in well.

- Cold war era—Water entered the ground during the peak period of atmospheric tritium concentration from nuclear bomb testing, 1958-1959 and 1961-1972 (greater than 15 tritium units [TU]).
- Recent—Water entered the ground since about 1953 (8 to 15 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

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
- Static water level data
- Groundwater flow direction
- F—F′ Line of cross section

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

- 0 to 20
- > 20 to 50

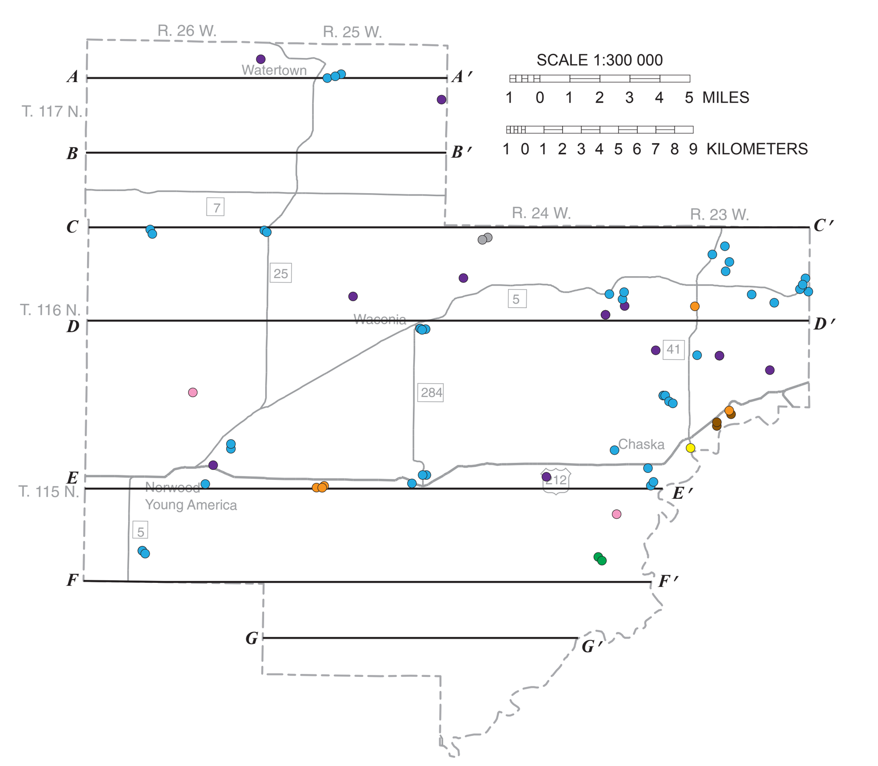

FIGURE 7. Distribution of DNR permitted groundwater use for 2010 by use category. *Most groundwater appropriators use the water for municipal waterworks (Table 1). Agricultural production and noncrop irrigation are also common. Major crop irrigation is not common because the relatively fine-grained sediment found over most of the county tends to retain moisture and drain slowly. The two wells used for major crop irrigation are located in sandy sediment.*

MAP EXPLANATION Figure 7

DNR permitted groundwater use for 2010 by use category

- Municipal waterworks
- Agricultural processing
- Noncrop irrigation
- Dewatering
- Nonmunicipal waterworks
- Other:
  - Sand and gravel washing
  - Pollution containment
- Major crop irrigation
- Multi-use:
  - Nonmunicipal waterworks
  - Noncrop irrigation
  - Once-through heating or A/C

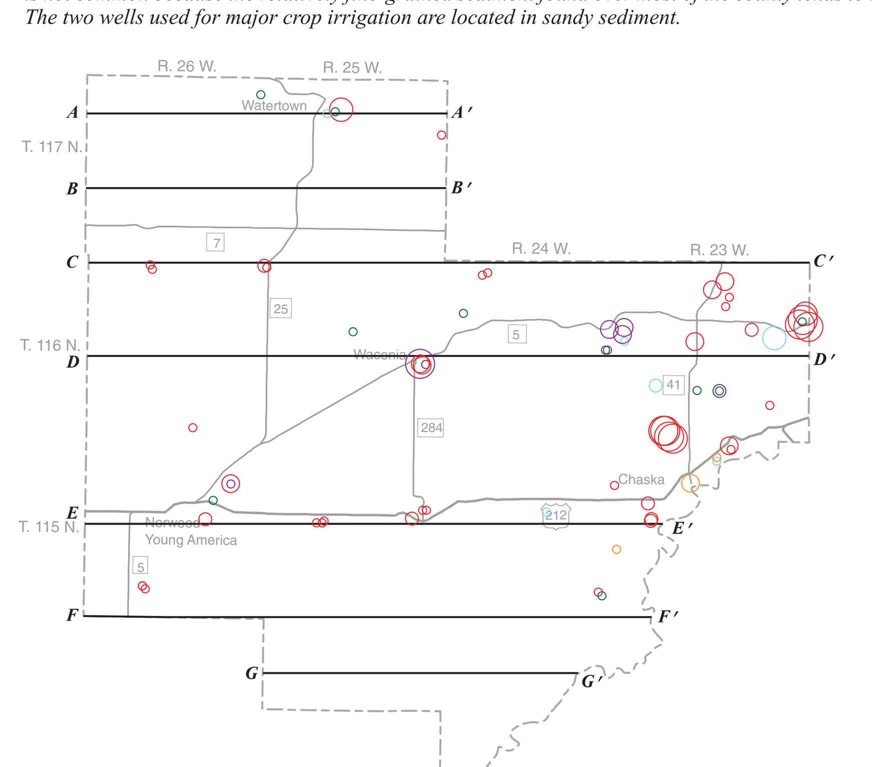

FIGURE 8. Distribution of DNR permitted groundwater appropriations by aquifer type and volume. *The highest volume groundwater appropriations are from bedrock aquifers. The next highest volume appropriations are from buried sand and gravel aquifers. In 2010, approximately 78 percent of groundwater used in Carver County was pumped from bedrock aquifers, about 15 percent was pumped from buried sand and gravel aquifers, and about 7 percent came from other aquifers (Table 2).*

MAP EXPLANATION Figure 8

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

Aquifer source of DNR water appropriation

- Surficial sand aquifer
- Buried sand and gravel aquifer
- Unnamed buried sand and gravel aquifer
- Bedrock aquifer
- Aquifer undefined

This map was compiled and generated using geographic information systems (GIS) technology. Digital data products, including chemistry and geophysical data, are available from DNR Ecological and Water Resources at http://www.dnr.state.mn.us/waters.

This map was prepared from publicly available information only. Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based. However, the Department of Natural Resources does not warrant the accuracy, completeness, or any implied uses of these data. Users may wish to verify critical information; sources include both the references here and information on file in the offices of the Minnesota Geological Survey and the Minnesota Department of Natural Resources. Every effort has been made to ensure the interpretation shown conforms to sound geologic and cartographic principles. This map should not be used to establish legal title, boundaries, or locations of improvements.

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.