Prepared and published with the support of the
MINNESOTA ENVIRONMENT AND NATURAL RESOURCES TRUST FUND and the CLEAN WATER, LAND, AND LEGACY AMENDMENT

HYDROGEOLOGY OF THE SURFICIAL AQUIFER

By

James A. Berg

2011

LOCATION DIAGRAM

SCALE 1:100 000
COMPILATION SCALE 1:100 000
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 6 7 8 9 KILOMETERS

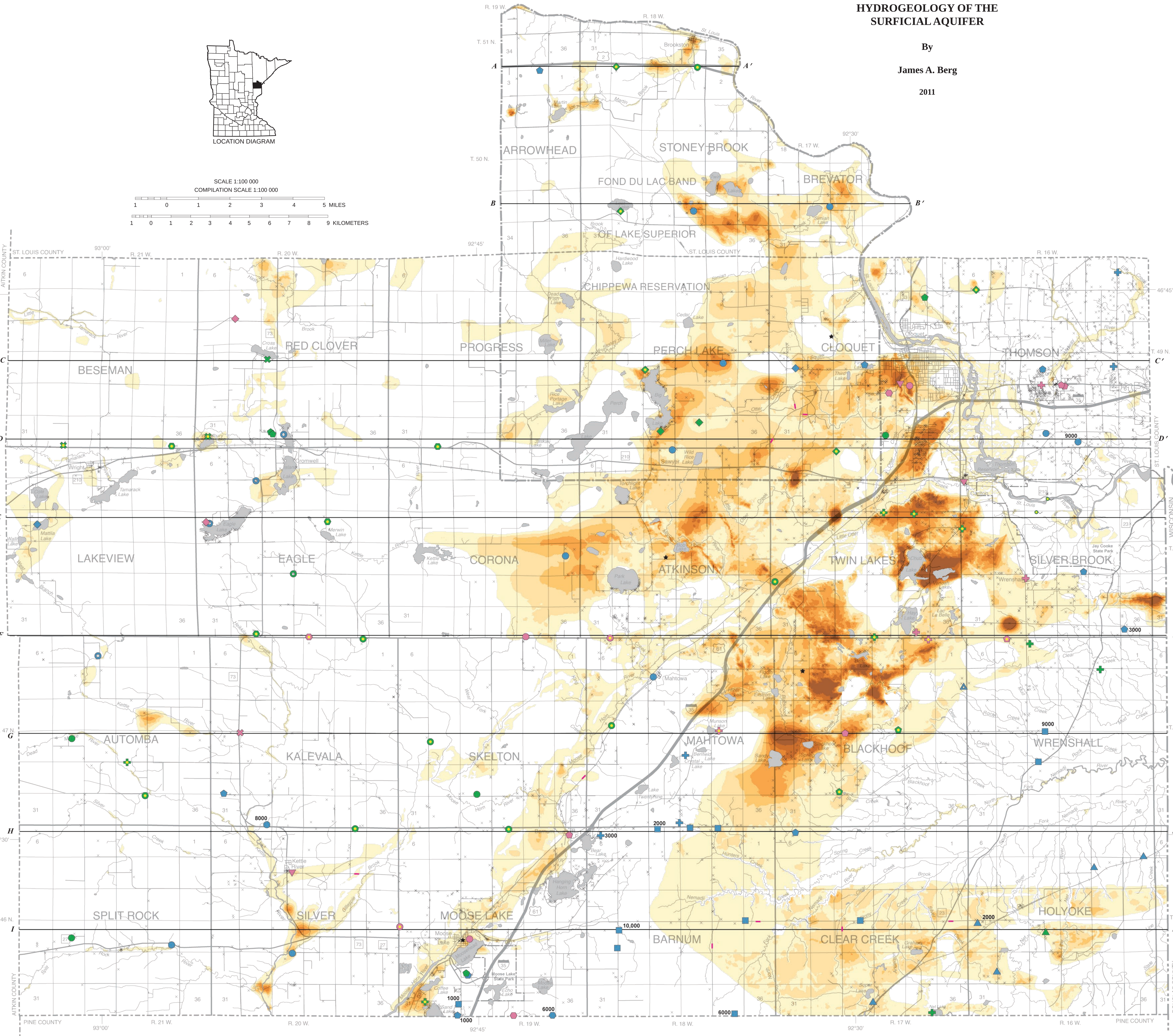


FIGURE 1. *Surficial sand aquifer extent, thickness, and selected chemistry data from sampled wells for all aquifers.* *The thickness of the surficial sand deposits, in which the surficial sand aquifer occurs, ranges from a few feet to 100 feet. The surficial sand aquifer is the saturated portion of the surficial sand deposits. In some areas the saturated thickness of the aquifer may be too thin to yield an adequate or reliable supply to a well. The location of all wells that were sampled for general chemistry and isotope analysis for this report are shown for convenience.*

MAP EXPLANATION FOR FIGURE 1

Estimated surficial sand aquifer thickness (feet)

- Surficial sand not present or no data available.
- 0 to 20
- > 20 to 40
- > 40 to 60
- > 60 to 80
- > 80 to 100
- > 100 to 120
- > 120

Sampled well and aquifer symbols

- Surficial sand aquifer.

Buried sand and gravel aquifers.*

- sm (Moose Lake till).
- sc (Cromwell till).
- sc1 (Cromwell till).
- sic (Independence till).
- sts (Old Red till units).
- stw (W sequence till).
- su undifferentiated.

Bedrock aquifers.

- Hinckley sandstone.
- Fond du Lac.
- Precambrian crystalline bedrock.

* Buried sand and gravel aquifers are listed with their associated underlying till layer (Plate 5, Part A).

Tritium age

Color indicates tritium age of water sampled in well.

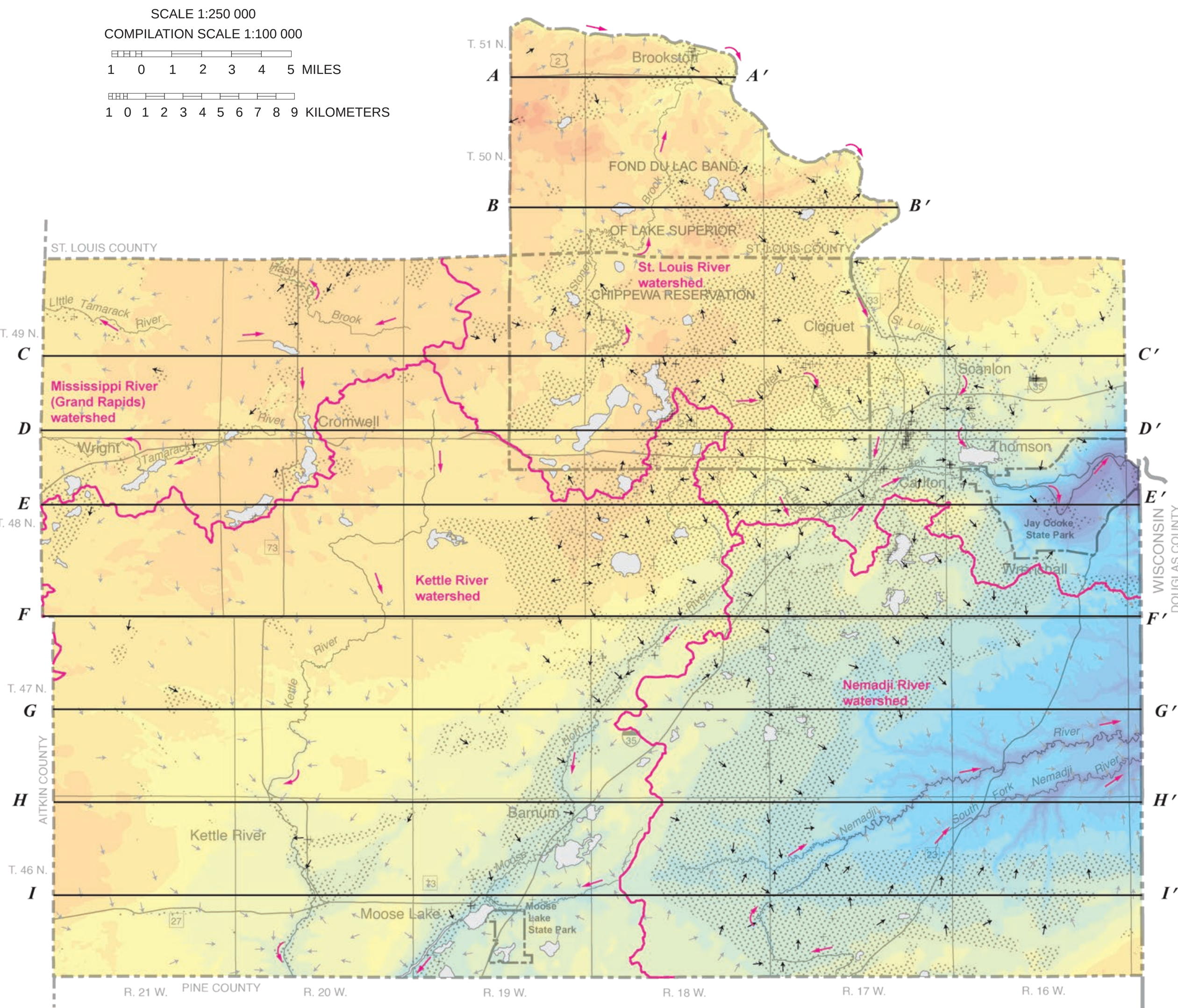
- Recent—Water entered the ground since about 1953 (10 or more tritium units [TU]).
- Mixed—Water is a mixture of recent and vintage waters (greater than 1 TU to less than 10 TU).
- Vintage—Water entered the ground before 1953 (less than or equal to 1 TU).

Map symbols and labels

- If shown on well symbol, chloride to bromide ratio greater than 190.
- Groundwater sample from spring collected for chemical analysis; color indicates tritium age.
- Observation well.
- Selected well log used to map extent of aquifer.
- 2000 If shown, groundwater age in years, estimated by carbon-14 (^{14}C) isotope analysis.
- Electrical resistivity data.
- F F′ Line of cross section.
- Body of water.

MAP EXPLANATION FOR FIGURE 2

SCALE 1:250 000
COMPILATION SCALE 1:100 000
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 6 7 8 9 KILOMETERS



Water table elevation (feet above mean sea level)

- > 1,500
- > 1,450 to 1,500
- > 1,400 to 1,450
- > 1,350 to 1,400
- > 1,300 to 1,350
- > 1,250 to 1,300
- > 1,200 to 1,250
- > 1,150 to 1,200
- > 1,100 to 1,150
- > 1,050 to 1,100
- > 1,000 to 1,050
- > 950 to 1,000
- > 900 to 950
- > 850 to 900
- > 800 to 850
- > 750 to 800
- > 700 to 750
- > 650 to 700
- 605 to 650

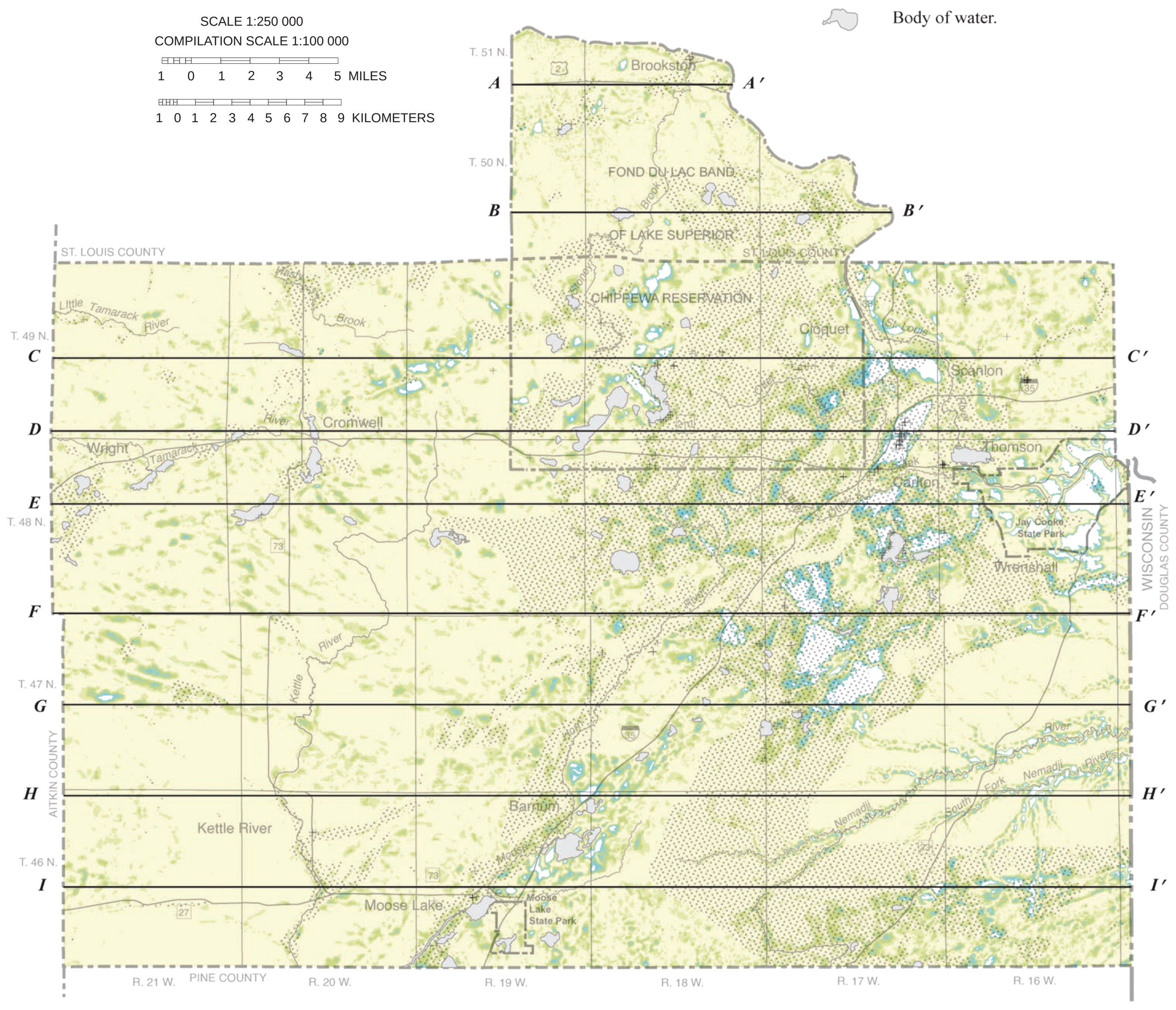
Map symbols and labels

- Static (non-pumping) water level data from the County Well Index (CWI).
- Direction of groundwater flow at the water table in the surficial sand aquifer.
- Direction of groundwater flow at the water table in non-aquifer areas.
- Downstream direction of streamflow.
- Surface watershed boundary.
- Extent of surficial sand aquifer.
- F F′ Line of cross section.
- Body of water.

FIGURE 2. *Water-table elevation in surficial sediments and groundwater flow direction.* The water-table elevation shown on this map is based on water levels in wells completed in the surficial aquifer, the known elevation of lakes and ponds measured by the U.S. Geological Survey during topographic map preparation, surface elevations along rivers and streams, and estimates made from wet soil data from the National Resource Conservation Service (NRCS). The groundwater flow arrows show the general direction of groundwater flow at the water table. The arrows are black within the area of the surficial sand aquifers and gray where this aquifer is not present.

MAP EXPLANATION FOR FIGURE 3

SCALE 1:250 000
COMPILATION SCALE 1:100 000
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 6 7 8 9 KILOMETERS



Water table depth (feet).

- 0 to 10
- > 10 to 20
- > 20 to 30
- > 30 to 40
- > 40 to 50
- > 50

Map symbols and labels

- Static (non-pumping) water level data from the County Well Index (CWI).
- Extent of surficial sand aquifer.
- F F′ Line of cross section.
- Body of water.

FIGURE 3. *Water table depth.* Shallow water table conditions (0-10 feet) are common in the study area with the exception of scattered locations mostly in the north central and northeastern parts of the study area where the water table depth is estimated to be 50 feet or more. Water table depth is derived by subtracting the water table elevation shown in Figure 2 from the elevation of the land surface.

INTRODUCTION

This atlas is designed for units of government and citizens to use in planning for land use, water supply, and pollution prevention. The data and maps in this atlas show the distribution and physical characteristics of the most important aquifers in the study area. They also describe the groundwater flow patterns, aquifer relationships, groundwater chemistry, and sensitivity to pollution of the surficial and buried aquifers. The study area consists of Carlton County and the portion of the Fond du Lac Band of Lake Superior Chippewa Reservation extending into St. Louis County.

The surficial sand aquifer shown on Figure 1 consists of water-saturated, unconsolidated sand and gravel. This aquifer is a relatively minor direct source of human water supply for domestic and municipal wells. Only eight percent of the approximately 3500 wells in the mapped area draw water from this aquifer; the remaining wells rely on water from buried sand and gravel and bedrock sources. The surficial sand aquifer is, however, a vital source of water for most aquatic habitats of rivers, lakes, and wetlands within the extent of this aquifer. Furthermore, this aquifer is the most important recharge source for the underlying buried sand and gravel and bedrock aquifers.

DATA SOURCES

Well data from the database of well logs (County Well Index [CWI]) maintained by the Minnesota Geological Survey (MGS) and the Minnesota Department of Health (MDH) provided much of the information used to produce the maps, cross sections, and tables of this atlas. Electrical resistivity surveys were conducted at nine locations (shown as short magenta lines, Figure 1) to determine the thickness of surficial sand and gravel deposits. The electrical resistivity surveys were conducted to fill in data gaps where well records or other drill hole data were rare or absent. The sand and gravel was detected by its resistivity difference from other material. The base of the surficial sand and gravel deposit is interpreted as an abrupt change from the higher electrical resistivity values of the sand and gravel to the lower resistivity values of the clay and silt of the underlying fine-grained glacial materials.

CHARACTERISTICS OF SAND AND GRAVEL AQUIFERS

Depositional History of the Surficial Sand

Figure 1 shows the distribution and thickness of surficial sand deposits in the study area. The geologic history of surficial sand deposition is derived from descriptions on Plates 3 and 4 of Part A. Most of the surficial sand deposits shown in Figure 1 are from outwash deposits of several phases of advance and retreat of the Superior ice lobe, which advanced into the area from the present-day area of Lake Superior. The oldest of these deposits are associated with the St. Croix phase and occur in the northern and western portions of the Fond du Lac Reservation with other scattered occurrences in the northwestern portion of the county. A subsequent ice lobe advance and retreat, called the Split Rock phase, deposited much of the surficial sand and gravel in the southeastern portion of the Fond du Lac Reservation and extending two to three miles south of the southern Fond du Lac Reservation boundary. The complex southwest-northeast trending series of sand and gravel deposits that underlie and surround the Moose Horn River in the south-central portion of the county and Otter Creek in the northeast portion were deposited in outwash diversion channels as the Superior ice lobe advanced and then retreated during the Nickerson Phase. Thick sand and gravel deposits southeast of these diversion channels were also deposited during this phase. During the latest stages of this retreat, glacial Lake Superior formed with a shoreline much farther to the southwest than the present day Lake Superior. The thinner sand deposits in the southeastern portion of Carlton County that roughly surround the Nemadji River drainage were near-shore and deltaic deposits of glacial Lake Superior.

Aquifer Specific Capacity and Hydraulic Conductivity

Estimating the yield of groundwater from an aquifer requires information about an aquifer's extent and saturated thickness, hydraulic conductivity (ability to transmit water), and other information about the groundwater system, such as the relationship to recharge sources and other aquifers. The map of the surficial sand aquifer on this plate (Figure 1) and Figures 3 through 11 on Plate 5 of Part A provide aquifer extent and thickness. Data to estimate aquifer specific capacity and hydraulic conductivity are obtained by pumping water from a well at a constant rate for a certain period of time. The simplest test of this type, the specific capacity test, is defined as well discharge, measured in gallons per minute, divided by feet of water-level drawdown (gpm/ft) in the pumped well. Generally the well is pumped for a limited amount of time, such as an hour. High well specific capacity values indicate that large amounts of groundwater can be withdrawn with limited water-level drawdown in the well. In addition, a high well specific capacity value usually indicates the aquifer has a high hydraulic conductivity value.

Limited specific capacity data were available for the mapped area (Table 1). The data in Table 1 were grouped by general aquifer type including the surficial sand aquifer that is shown on this plate, buried sand and gravel aquifers (Plate 9), and the Fond du Lac aquifer. Data from other bedrock aquifers were not available. Wells in the surficial sand and buried sand and gravel aquifers have much higher specific capacities than wells in the Fond du Lac aquifer; their higher specific capacities indicate that these aquifers, where they are present in the mapped area, might be better water sources.

Table 2 is a summary of available aquifer test data in the mapped area. This type of test requires pumping the well for a longer period of time than the specific capacity tests. These data are from municipal and public water supply wells in Barnum, Kettle River, Moose Lake, Moose Lake correctional facility, Carlton, and Cloquet. These data show that the hydraulic conductivity values of the surficial sand and buried sand and gravel aquifers are roughly comparable, with the surficial sand aquifer having somewhat higher values.

Water Table Elevation and Depth

The mapped area is within four major surface watersheds (Figure 2): Mississippi River (Grand Rapids), St. Louis River, Kettle River and Nemadji River. The mapped area is at the crest of a major continental hydrologic divide that roughly splits the area east and west. The surface watersheds in the western portion of the mapped area discharge to the Mississippi River Basin, whereas the surface watersheds of the eastern portion of the mapped area discharge to the Great Lakes Basin. Since the groundwater sheds within the water table system are typically very similar to the surface watersheds, the watershed boundaries shown on Figure 2 may be considered approximate groundwater flow divides for the water table system.

The water table elevation of the mapped area is shown in Figure 2. The water table elevation is based on water levels in wells completed in the surficial sand aquifer, the known elevation of lakes and ponds, surface elevations along rivers and streams, and estimates of wet soil conditions from the Carlton and St. Louis county soil surveys. The water level data in completed wells was obtained from well records in the CWI database; these records represent various climatic conditions from the 1960s to 2008. In addition, the water table elevation varies seasonally and yearly according to precipitation conditions. This data variability creates some uncertainty in the water table elevations shown on the map.

The water table elevation map depicts groundwater flow directions in both the surficial sand aquifer and locations where this aquifer is not present. The lakes and streams in the surficial sand aquifer area likely receive groundwater discharge that maintains lake levels and stream flow; the water table elevation map can be used to identify the groundwater source areas of those surface-water bodies. In addition, groundwater flow gradients can be derived from these maps and used with other information to estimate groundwater flow velocity. For all of these applications, additional site-specific information would be required to make accurate determinations.

The water table depth map (Figure 3) was derived by subtracting the water table elevation in Figure 2 from the land surface elevation. Shallow water table conditions (0–10 feet) are common in the mapped area. In scattered locations in the north-central and northeastern parts of the mapped area, the depth to the water table was estimated at 50 feet or greater. These areas are generally located at higher land surface elevation areas where water table depth data were generally not available, but the interpolation model suggested deep values.

Water table depth is commonly evaluated to determine the type of septic system that might be needed for a new dwelling or development. Depth to water table data is also considered for construction projects and land use management programs. Groundwater resource protection programs also assess the depth to water to evaluate the impact of potential pollutant sources.

Groundwater Residence Time

Groundwater samples from selected wells across the study area were analyzed to determine the approximate age of groundwater, also called residence time. Groundwater residence time is the approximate time that has elapsed from the time the water infiltrated the land surface to the time it was pumped from the aquifer for this investigation; it is closely related to the pollution sensitivity concept described on Plate 10. In general, shorter residence time suggests higher pollution sensitivity, whereas longer residence time suggests lower sensitivity. The sample locations are shown on Figure 1 by aquifer and tritium age. In addition, some vintage groundwater samples suspected of have long residence times were analyzed using the carbon-14 isotope. Groundwater residence time estimated by tritium and carbon-14 analysis are explained in greater detail on Plate 8.

Aquifer symbols with a yellow dot indicate that the groundwater sample from that aquifer had an elevated value of the ratio of chloride to bromide concentration. The groundwater samples with chloride to bromide ratios greater than 190 are interpreted as originating from human activities (anthropogenic). Chloride concentration and the ratio of chloride to bromide in water samples have been used in previous groundwater studies (Berg, 2008) as an indicator of chloride contamination. Elevated values of the chloride to bromide ratio were not found in any groundwater samples of vintage age. Elevated ratios were found in some recent and mixed groundwater samples scatted throughout the mapped area. Most of the wells with these elevated values were shallower than approximately 150 feet.

REFERENCE CITED

Berg, J.A., 2008, Hydrogeology of the surficial and buried aquifers [Plate 3], *in* Regional hydrogeologic assessment, Traverse-Grant area, west-central Minnesota: St. Paul, Minnesota Department of Natural Resources, Regional Hydrogeologic Assessment Series, RHA-6, Part B, scale 1:200,000.

TABLE 1. Specific capacity of selected wells.
[Data adapted from the County Well Index; gpm/ft, gallons per minute per foot; QWTA, Quaternary water-table aquifer; QBAA, Quaternary buried artesian aquifer; PMFL, Fond du Lac aquifer]

Aquifer (CWI aquifer code)	Well diameter (inches)	Specific capacity (gpm/ft)*			Number of tests
		Mean	Minimum	Maximum	
Surficial sand (QWTA)	8 to 48	22	6	54	6
Buried sand and gravel (QBAA)	8 to 12	14	7	18	6
Fond du Lac (PMFL)	60	0.2	0.2	0.2	2

*Specific capacity is defined as well discharge in gallons per minute per foot (gpm/ft) of water level drawdown. The data set includes only information from wells that were pumped at discharge rates greater than 20 gallons per minute.

TABLE 2. Hydraulic conductivity data from municipal wells.
[Data from the Minnesota Department of Health; gpd/ft, gallons per day per foot; QWTA, Quaternary water-table aquifer; QBAA, Quaternary buried artesian aquifer]

Aquifer (CWI aquifer code)	Well diameter (inches)	Hydraulic conductivity (gpd/ft)			Number of tests
		Mean	Minimum	Maximum	
Surficial sand (QWTA)	6 to 12	138	57	350	6
Buried sand and gravel (QBAA)	10 to 12	92	5	200	3

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 mndnr.gov/groundwatermapping.
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, Carlton County Geologic Atlas, Part A, 2009.
Project data compiled from 2009 to 2010 at a scale of 1:100,000. Universal Transverse Mercator projection, grid zone 15, 1983 North American datum. Vertical datum is mean sea level.
GIS and cartography by Jim Berg, Greg Massaro, and Shana Pascal. Edited by Neil Cunningham.