Prepared and Published with the Support of the
MINNESOTA ENVIRONMENT AND NATURAL RESOURCES TRUST FUND and the CLEAN WATER FUND

POLLUTION SENSITIVITY OF THE NEAR-SURFACE MATERIALS, BURIED SAND AND GRAVEL AQUIFERS, AND THE BEDROCK SURFACE

By

Todd A. Petersen

2014

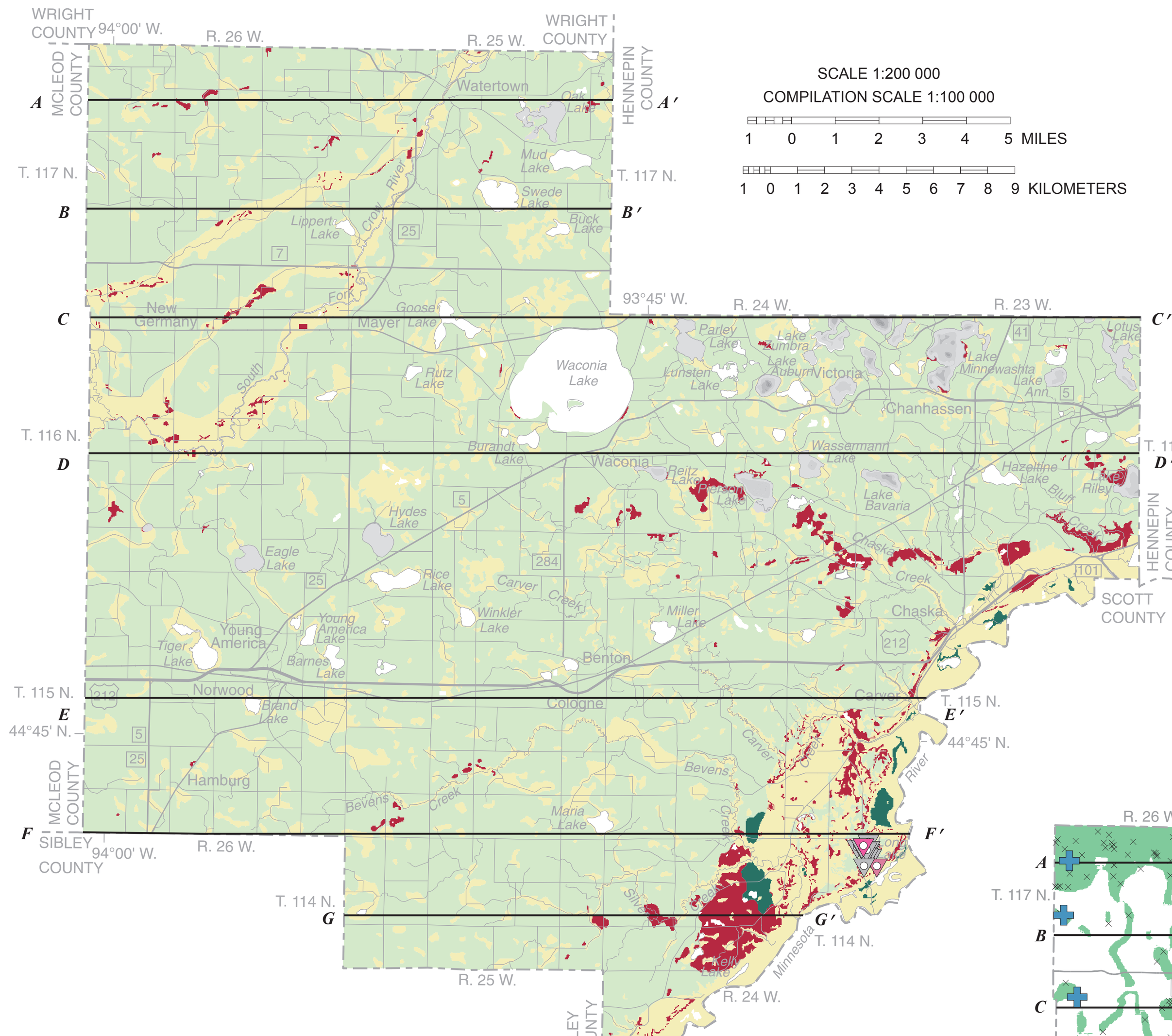
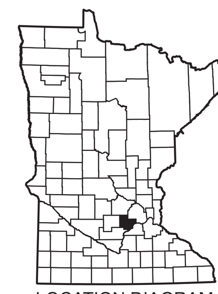


FIGURE 3. *Pollution sensitivity of the near-surface materials.*



MAP EXPLANATION
Figure 3

Pollution sensitivity ratings for near-surface materials

Estimated vertical travel time for water-borne contaminants to move from the land surface to a depth of 10 feet.

- H — High—Hours to a week
- M — Moderate—A week to weeks
- L — Low—Weeks to months
- VL — Very Low—Months to a year

Sampled well and aquifer symbol

Surficial sand aquifer
- sdo

Symbols and labels

- If shown on well symbol, arsenic not sampled
- F—F′ Line of cross section
- Body of water

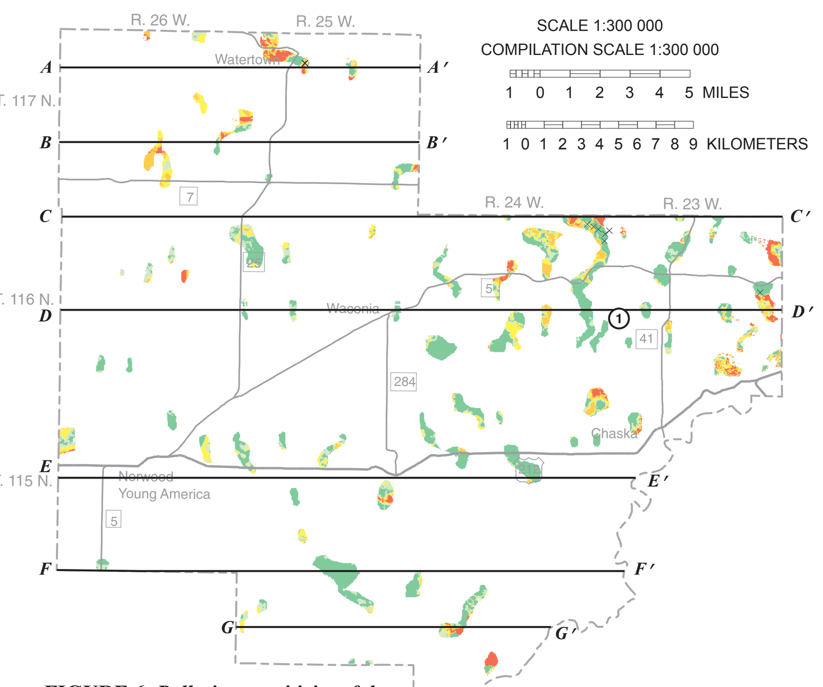


FIGURE 6. *Pollution sensitivity of the* sdv *buried sand and gravel aquifer.*

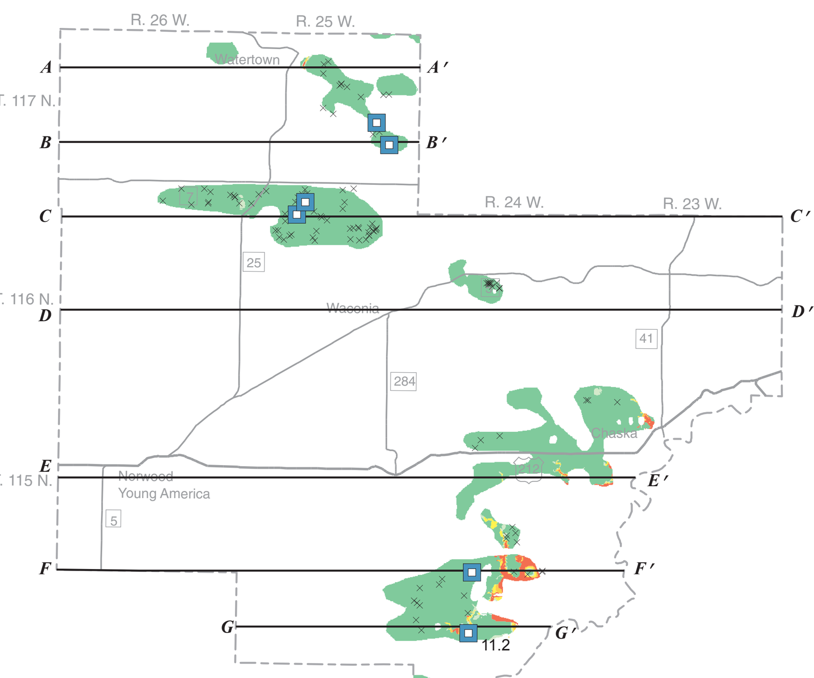


FIGURE 7. *Pollution sensitivity of the* sr *buried sand and gravel aquifer.*

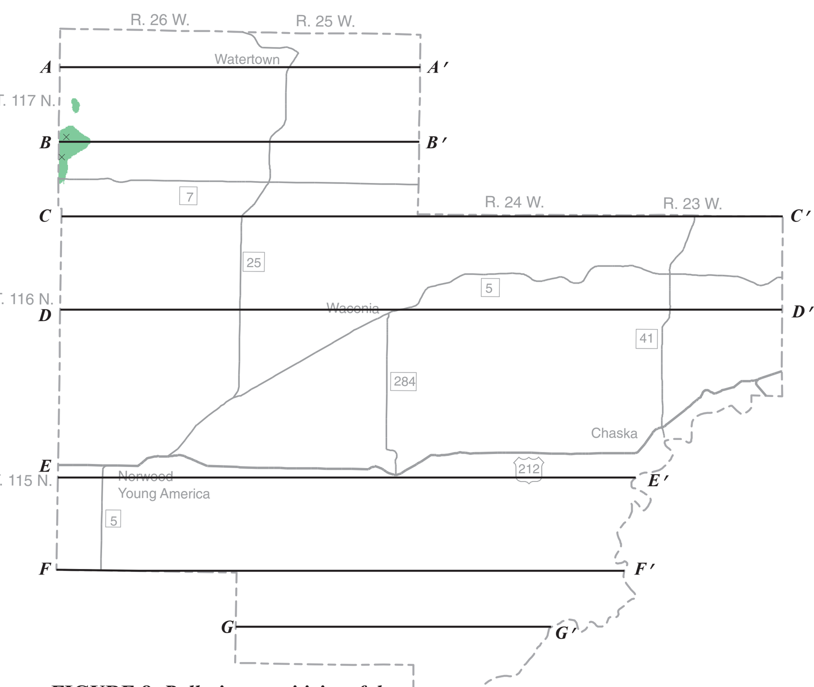


FIGURE 8. *Pollution sensitivity of the* sb *buried sand and gravel aquifer.*

Caution: The information on these maps is a generalized interpretation of the sensitivity of groundwater to contamination. The maps are intended to be used for resource protection planning and to help focus the gathering of information for site-specific investigations.

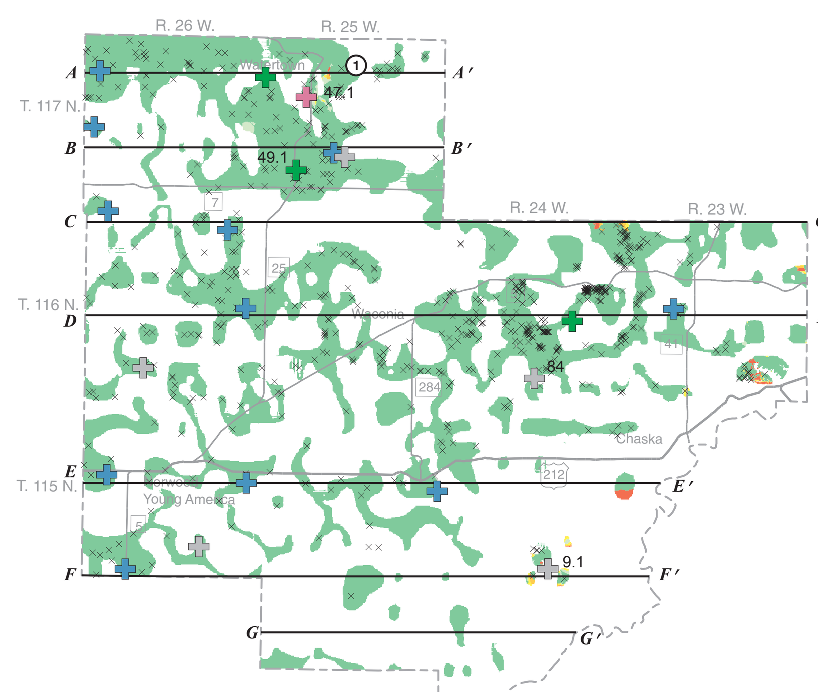


FIGURE 9. *Pollution sensitivity of the* sg *buried sand and gravel aquifer.*

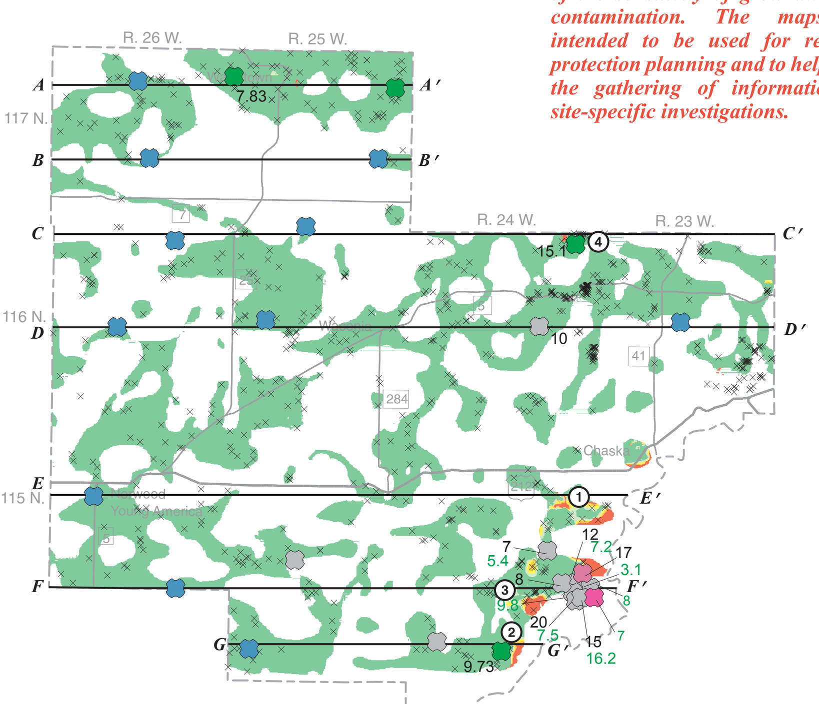


FIGURE 10. *Pollution sensitivity of the* sx *buried sand and gravel aquifer.*

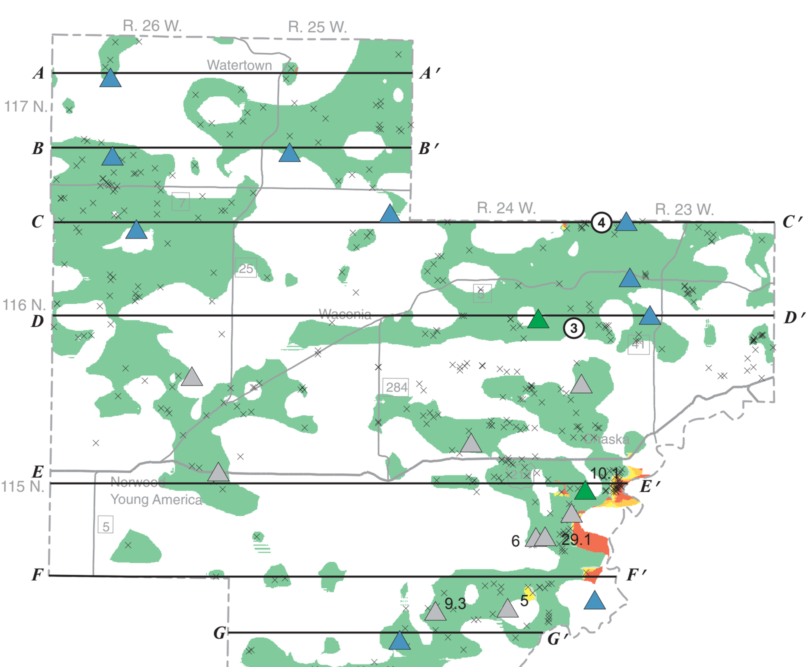


FIGURE 11. *Pollution sensitivity of the* su *buried sand and gravel aquifer.*

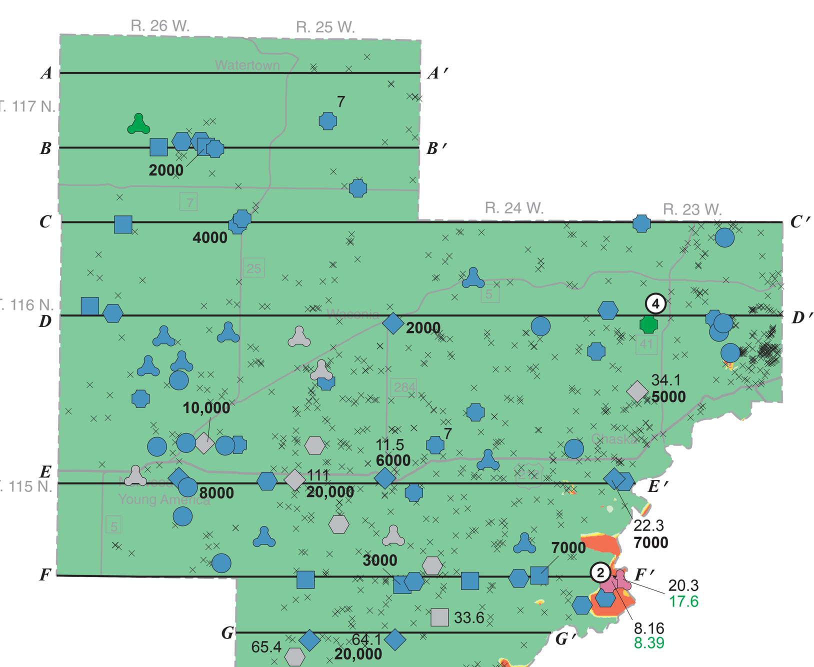


FIGURE 12. *Pollution sensitivity of the top of the bedrock. Bedrock aquifers are present throughout Carver County.*

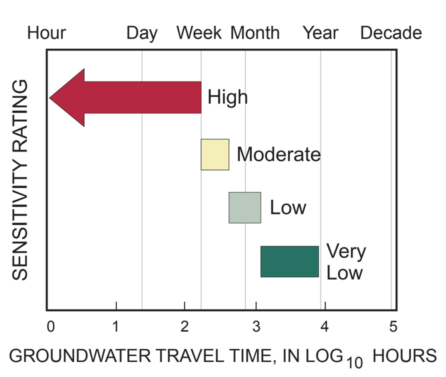


FIGURE 1. *Geologic sensitivity rating for the near-surface materials as defined by vertical travel time.* *Ratings are based on the time range required for water at the land surface to travel vertically 10 feet through the vadose zone to the water table. Because the water table is not well mapped everywhere, it is assumed to be at 10 feet below land surface for this calculation.*

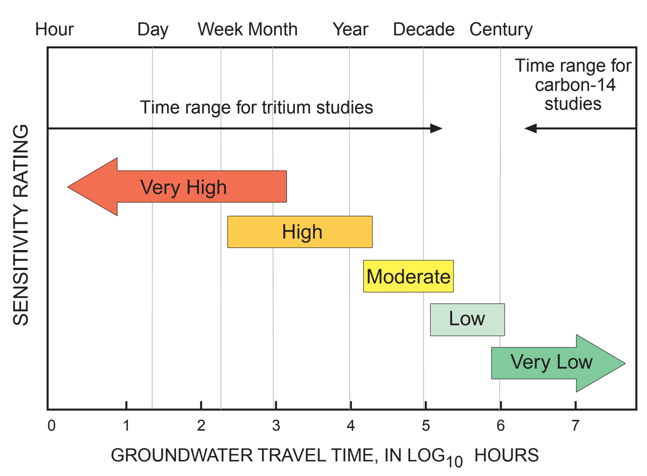


FIGURE 2. *Geologic sensitivity rating for the buried sand and gravel aquifers and the top of the bedrock as defined by vertical travel time (Geologic Sensitivity Workgroup, 1991).* *Ratings are based on the time range required for water at or near the surface to travel vertically into the aquifer of interest or to a pollution sensitivity target. Tritium and carbon-14 studies indicate the relative ages of groundwater.*

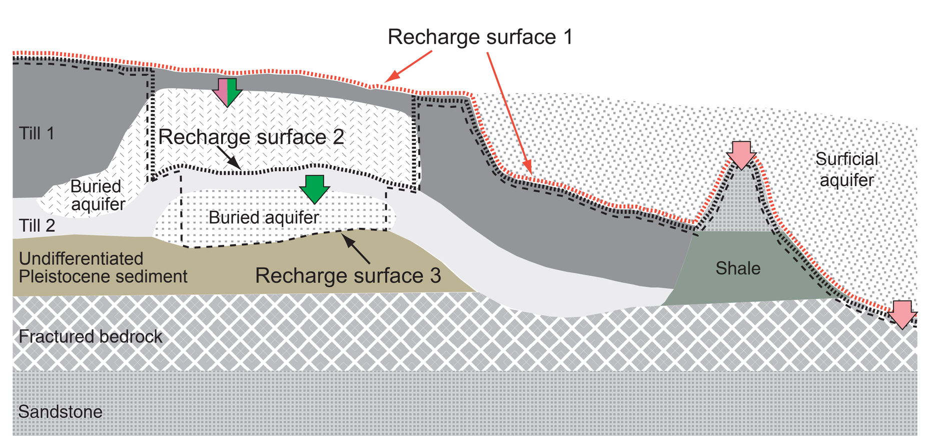


FIGURE 4. *Generalized cross section showing groundwater recharge concepts for buried sand and gravel aquifers and the top of the bedrock considered in the sensitivity evaluations.* *In this model, all recharge enters the buried aquifer system at recharge surface 1 (red dotted line). Recharge surface 1 is considered to be at the land surface where till is present or at the bottom of the surficial sand aquifer. If less than 10 feet of fine-grained sediment (clay or till) exists between recharge surface 1 and the shallowest underlying buried aquifer, then recharge is assumed to reach and move to the bottom of the aquifer which is defined as recharge surface 2. If a second deeper buried aquifer exists that has less than 10 feet of clay or till between it and the overlying buried aquifer; further penetration of recharge through the fine-grained sediment is assumed to occur. In that case, recharge surface 3 is defined at the bottom of this next deeper aquifer. If less than 10 feet of fine-grained sediment exists between the deepest recharge surface and the top of the bedrock, then recharge is assumed to reach the top of the bedrock. The pink arrows indicate rapid groundwater recharge into bedrock aquifers. The pink and green arrow indicates moderate groundwater recharge; the solid green arrow indicates limited recharge.*

MAP EXPLANATION
Figures 6–12

Pollution sensitivity rating

Estimated vertical travel time for water-borne contaminants to enter an aquifer (pollution sensitivity target).

- VH — Very High—Hours to months
- H — High—Weeks to years
- M — Moderate—Years to decades
- L — Low—Decades to a century
- VL — Very Low—A century or more

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

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

Symbols and labels

- 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 age in years, estimated by carbon-14 (^{14}C) isotope analysis
- Well constructed in aquifer
- F—F′ Line of cross section

Groundwater conditions

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

INTRODUCTION

This plate describes the sensitivity to pollution in Carver County of the near-surface materials, the buried sand and gravel aquifers, and the top of the bedrock. This is estimated by the vertical travel time of a contaminant that moves conservatively with water.

Migration of contaminants dissolved in water through unsaturated and saturated sediments is a complex process. It is affected by biological degradation, oxidizing or reducing condition, contaminant density, and other factors. A countywide assessment of pollution sensitivity requires some generalizing assumptions. One assumption is that flow paths from the land surface through the soil and underlying sediments to an aquifer are vertical. Horizontal flow paths may be important in specific instances, but they have not been adequately mapped and are not considered in the sensitivity model. The permeability of soil and surficial geologic units is considered when evaluating the pollution sensitivity of the near-surface materials. However, the permeability of deeper sediments is assessed only qualitatively when evaluating the pollution sensitivity of buried sand and gravel aquifers and of the top of the bedrock.

The sensitivity assessment is an empirical method that estimates the time required for water to travel from infiltration at the land surface to the pollution sensitivity target. Figure 1 shows the near-surface geologic sensitivity rating that is based on an estimated travel time from the land surface to a depth of 10 feet. The focus of this near-surface sensitivity rating estimate is travel through the vadose zone, which is the unsaturated zone between the land surface and the water table. The time of travel through this very thin surface layer in Carver County varies from hours to approximately a year. Areas with relatively short travel times (hours to a week) are rated high. Areas with longer travel times (weeks to a year) are rated low or very low.

The sensitivity rating for the buried sand and gravel aquifers and the top of the bedrock in Figure 2 shows geologic sensitivity corresponding to estimated travel time to mapped buried sand and gravel aquifers or the top of the bedrock. The ratings are based on estimated vertical travel times defined by the Geologic Sensitivity Workgroup (1991). The travel time to buried aquifers varies from days to thousands of years. Areas with relatively short travel times of less than a few years are rated high or very high. Areas with estimated travel times of decades or longer are rated low or very low. The near-surface materials sensitivity ratings are very similar to the buried aquifer sensitivity ratings, but the near-surface travel times are much shorter.

SENSITIVITY TO POLLUTION OF THE NEAR-SURFACE MATERIALS

The assessment of the geologic sensitivity to pollution for the near-surface materials of Carver County estimates the time required for water to travel from the land surface to a depth of 10 feet (Figure 3). The near-surface materials sensitivity assessment was developed by estimating transmission rates through soils and surficial geologic units based on the Natural Resources Conservation Service (NRCS) hydrologic rating for soils (NRCS, 2009) and the geologic unit texture of deeper parent materials, from Plate 3, Part A. The hydrologic soil group criteria are used to estimate the travel time from the land surface to a depth of three feet and surficial geologic texture is used to estimate the travel time from a depth of three feet to ten feet. Estimates of transmission rates are shown in Table 1. Hydrologic Group A soils are more than 90 percent sand and gravel, and water is freely transmitted through the soil. Group B soils are less permeable than Group A soils, but water transmission is unimpeded through the soil. In Group C soils, water transmission is somewhat restricted. In Group D soils, water movement is restricted or very restricted.

Transmission rates for unsaturated soils and surficial geologic units are estimated based on the matrix texture (DNR, 2014). Transmission rates for unsaturated soils are estimated for the four NRCS hydrologic soil groups. Transmission rates for unsaturated surficial geologic units are estimated from the matrix texture of the less-than-2-millimeter size fraction of each of these units. The matrix texture of each surficial geologic unit is correlated with a similar soil unit and assigned a transmission rate consistent with its texture (Table 1). The unsaturated transmission rates shown in Table 1 were calculated by converting saturated hydraulic conductivity values into unsaturated transmission rates using a method described by Bouwer (2002). The specific methodology used on this plate is explained in DNR (2014). In Bouwer's method, unsaturated transmission rates for soils are assumed to be a direct percentage of saturated hydraulic conductivity values. The transmission rate for Group A and B soils is estimated to be 50 percent of the saturated hydraulic conductivity. For Group C and D soils, the transmission rate is estimated to be 25 percent of the saturated hydraulic conductivity. These two conversion factors were applied to both the soil and surficial geologic units to determine the transmission rates shown in Table 1. The calculated transmission rate does not account for soil compaction, macropores, drain tiles, or seasonal recharge events in the spring and fall. Soil compaction can decrease transmission rates. Macropores and fully saturated soils during seasonal recharge events often increase transmission rates.

The near-surface materials sensitivity rating is determined by using the matrix transmission rates for the soil and surficial geologic units to calculate the estimated travel time. For this calculation, the water table is assumed to be 10 feet below the land surface throughout the county. The geographic information system (GIS) polygons from both the soil and surficial geologic units are brought together by the GIS union process. The union process creates new polygons that have both the soil and surficial geologic unit attributes. The travel time for the upper 3 feet is calculated using the transmission rate of the soil unit. The travel time for 3 feet to 10 feet below land surface is calculated using the transmission rate of the surficial geologic unit. The total travel time to 10 feet is then used to estimate the near-surface materials geologic sensitivity (Figure 3). Some soil units such as gravel pits have not been assigned a hydrologic group and therefore have no assigned transmission rate. If a transmission rate is not available for a soil unit, then the surficial geologic unit transmission rate is used to calculate the travel time for the entire 10-foot thickness.

The map of the near-surface materials sensitivity (Figure 3) rates most of Carver County as low sensitivity. The dth and dtv tills that are at the surface in most of Carver County are fine grained with clay loam and loam texture (Plate 3, Part A) and therefore have low transmission rates. Areas of high to moderate sensitivity are found in the surficial sand surrounding the South Fork of the Crow River and its two northern tributary creeks and in the surficial sand and gravel deposits near the Minnesota River valley. The other small scattered areas of moderate sensitivity in the county are largely organic peat and muck deposits. Water samples from wells constructed in the surficial sand aquifer had evidence of high sensitivity, such as recent tritium age, elevated chloride, or elevated nitrate-nitrogen.

SENSITIVITY TO POLLUTION OF THE BURIED SAND AND GRAVEL AQUIFERS AND TO THE TOP OF THE BEDROCK

Development of Sensitivity Model and Maps

The pollution sensitivity maps are primarily based on the depth to the top of the mapped aquifers. Plate 4, Part A includes maps of the depth to the top of the buried sand and gravel aquifers. Plate 5, Part A includes a map of the depth to the bedrock surface. The fine-grained sediment between aquifers is assumed to act as an aquitard that restricts the vertical movement of groundwater between aquifers.

Pollution sensitivity maps for the buried sand and gravel aquifers (Figures 6 through 11) and the top of the bedrock (Figure 12) are based on the method of vertical recharge described in Figure 4 and the ratings matrix described in Figure 5. This method for determining pollution sensitivity was used in previous County Geologic Atlas and Regional Hydrogeological Assessment reports (Berg, 2006; Tipping, 2006; Petersen, 2007; Berg, 2008; Petersen, 2010; Rivord, 2012). Recharge surfaces for the buried sand and gravel aquifers and the top of the bedrock are derived from the distribution and thickness of sand layers and undifferentiated Pleistocene sediment mapped on Figures 5 through 10, Plate 4, Part A. The uppermost recharge surface (RS1) is initially positioned at the land surface (Figure 4). Where surficial sand is present, RS1 is repositioned to the base of this sand unit. The assumption is that precipitation can quickly travel to the base of the surficial sand unit.

If less than 10 feet of fine-grained sediment such as clay or till is present between RS1 and the top of the first buried aquifer below, then the assumption is that the first buried aquifer below is probably recharged vertically from water at RS1. Thus, water will travel vertically to the bottom of this buried aquifer, which is labeled recharge surface 2 (RS2). RS2 is the same as RS1 where more than 10 feet of fine-grained sediment exists immediately below RS1.

Deeper recharge surfaces (below RS2) are defined similarly. If the next deeper buried aquifer below RS2 has less than 10 feet of fine-grained sediment between RS2 and the top of that aquifer, then a third recharge surface (RS3) will be defined at the bottom of this aquifer. This model assumes that fine-grained layers that are less than 10 feet thick are leaky and will allow relatively rapid recharge to the next deeper layer.

Finally, the sensitivity ratings for the buried aquifers are calculated by comparing the elevation of the upper surface of each buried aquifer with the nearest overlying recharge surface (Figure 5). The thickness between the top of the aquifer and the nearest overlying recharge surface is used to determine the sensitivity to pollution. Thicknesses greater than 40 feet are rated very low; thicknesses of less than or equal to 10 feet are rated very high, and thicknesses that are greater than 10 feet and less than or equal to 40 feet have intermediate sensitivity ratings.

Most aquifers in Carver County are rated very low sensitivity. The sdv buried sand and gravel aquifer (Figure 6) is relatively shallow and has many areas of moderate to high pollution sensitivity. The sb sand and gravel aquifer (Figure 8) has a very low sensitivity rating. The sr, sg, sx, and su sand and gravel aquifers (Figures 7, 9, 10, and 11, respectively) and the top of the bedrock (Figure 12) all have pollution sensitivity ratings of high to very high in southeast Carver County and ratings of very low elsewhere. These aquifers are overlain by the surficial sand and gravel aquifer in the southeast area of the county, which is much more permeable than the clay loam and loam tills that overlie these units in most of the rest of the county.

Comparison of Sensitivity Model to Groundwater Chemistry Data from the Surficial Sand Aquifer, Buried Sand and Gravel Aquifers, and the Top of the Bedrock

The general chemistry and isotope analysis of groundwater samples is useful for evaluating geologic sensitivity. Mixed tritium-age results indicate that at least a portion of the groundwater has been recharged since the 1950s. Elevated chloride concentration in samples equal to or greater than 5 parts per million (ppm) often indicates a local anthropogenic source of chloride; this usually implies a moderate or higher sensitivity. In a few cases elevated chloride is found in deeper groundwater samples with no detectable tritium. In such instances, the chloride source is probably from a deeper aquifer.

Twenty-one wells that are constructed in the surficial aquifer (sdo) were sampled for chemistry by Carver County Environmental Services between 1993 and 2001 (Figure 3). Fifteen of these wells had a chloride concentration greater than or equal to 5 parts per million (ppm) or a nitrate concentration greater than or equal to 3 ppm (Figure 1, Plate 6). Two of the 15 water samples were tested for tritium; both samples had recent tritium age. All of these wells are in areas rated either moderate or high near-surface sensitivity.

No water chemistry samples were collected from either the sdv or the sb aquifers. All six water chemistry samples from the sr aquifer (Figure 7) had vintage tritium age. All of these samples were collected in areas rated very low sensitivity.

Most of the sg aquifer is rated as very low pollution sensitivity (Figure 9). A few areas have overlying sand and gravel aquifers with higher sensitivity ratings. Eleven of the 15 wells sampled for tritium had vintage tritium age, 1 water sample had recent tritium age, and 3 samples had mixed tritium age. The 11 samples that had a vintage tritium age are consistent with the predominant very low pollution sensitivity rating. In northwestern Carver County near Watertown, 1 water sample from the sg aquifer had recent tritium age and 2 water samples had mixed tritium age. In this area, the sg aquifer is overlain in places by shallower sand and gravel aquifers, which may allow recharge of younger water into the sg aquifer locally. A water sample from the sg aquifer in northeastern Carver County on cross section D–D′ also had a mixed tritium age. Several lakes near this well, which are 40 to 50 feet deep, may be a conduit for local groundwater recharge.

Eleven of the 17 wells sampled for tritium in the sx aquifer had vintage tritium age, 4 had mixed tritium age, 1 had recent tritium age, and 1 had cold-war era tritium age (Figure 10). The 11 samples with vintage tritium age and the 4 samples with mixed tritium age were all from areas rated with very low sensitivity. Two of the wells with mixed tritium age are located on cross section A–A′. The sx aquifer on this cross section is well connected with the overlying sg aquifer. Two nearby samples from the sg aquifer had recent and mixed tritium age indicating that groundwater from the sg aquifer is probably recharging the deeper sx aquifer in this location. The third well with mixed tritium age is on cross section C–C′ and is covered by a relatively thick layer of dth till at the land surface, but the sdv, sg, sx, and su buried sand and gravel aquifers are stacked one above the other in this area and are directly connected to Lake Zumbra and Lake Minnetonka (cross section C–C′ on Plate 7). These stacked sand and gravel aquifers form a local groundwater recharge zone; a mixed tritium age for this water sample is consistent with the other hydrogeologic data. The other mixed tritium-age sample is near the edge of the Minnesota River valley; lateral groundwater flow probably accounts for the mixed tritium age. Two sx aquifer wells at the eastern end of cross section F–F′ had recent and cold war era tritium ages, respectively. Both wells are located near areas rated as very high sensitivity. This portion of the sx aquifer discharges groundwater to the adjacent surficial aquifer. This discharge relationship is shown on the east end of cross section F–F′ on Plate 7.

Ten of the 12 wells sampled for tritium in the su aquifer had vintage tritium age, which is consistent with the very low sensitivity rating for most of the su aquifer in Carver County (Figure 11). Two water samples from the su aquifer had mixed tritium age. The sample along cross section D–D′ is located in an area rated very low sensitivity. However, the sdv, sg, and su sands are all closely stacked in this area (cross section D–D′, Plate 7, beneath Wassermann Lake) and groundwater is likely slowly moving from an overlying buried aquifer to an underlying buried aquifer. The other mixed tritium-age sample from the su aquifer is located on the east end of cross section E–E′. This well is close to areas rated as very high sensitivity.

Two wells constructed in bedrock aquifers, one Jordan and one St. Lawrence (Figure 12), had recent tritium age; they are located on the east end of cross section F–F′, just east of the two sx aquifer samples with recent and cold war era tritium ages discussed above. Both wells are in areas rated as very high sensitivity. Two water samples from bedrock wells had mixed tritium ages. The mixed tritium-age water sample from the St. Lawrence-Upper Tunnel City aquifer near the west end of cross section B–B′ had 1.3 tritium units (TU). All of the surrounding wells had vintage tritium age; the low tritium concentration might be due to sample contamination or poor well construction. The mixed tritium-age water sample from the Jordan aquifer near the east end of cross section D–D′ had 5.2 TU. Samples from up gradient wells in the overlying sx and su buried sand and gravel aquifers also had mixed tritium ages (cross section D–D′, Plate 7). High volume pumping in eastern Carver County has changed the natural groundwater gradients and induced movement of shallow groundwater with short residence times into deeper aquifers. All other bedrock water samples had vintage tritium age, which is consistent with the very low sensitivity rating for most of the top of the bedrock.

The well chemistry data generally affirm the sensitivity model. Most of Carver County is covered by fine-grained glacial sediment and the sensitivity rating of buried aquifers is generally very low. Most groundwater samples from these very low pollution sensitivity areas had vintage tritium age. Near the Minnesota River in the southeastern part of the county, thick sand and gravel units are present at the land surface and the groundwater sensitivity to pollution rating is very high, high or moderate. In that area many groundwater samples had recent or mixed tritium ages reflecting relatively rapid recharge conditions.

REFERENCES CITED

Berg, J. A., 2006, Geologic atlas of Pope County, Minnesota: St. Paul, Minnesota Department of Natural Resources, County Atlas Series C-15, Part B, 4 pls., scale 1:100,000.

Berg, J. A., 2008, Regional hydrogeologic assessment, Traverse-Grant area, West-Central Minnesota: St. Paul, Minnesota Department of Natural Resources, Regional Hydrogeologic Assessment, Series RHA-6, Part B, 4 pls., scale 1:250,000.

Bouwer, H., 2002, Artificial recharge of groundwater: Hydrogeology and engineering, Hydrogeology Journal, v. 10, p. 121-142.

Geologic Sensitivity Workgroup, 1991, Criteria and guidelines for assessing geologic sensitivity of ground water resources in Minnesota: St. Paul, Minnesota Department of Natural Resources, Division of Waters, 122 p.

Minnesota Department of Natural Resources (DNR), 2014, Procedure for determining near-surface pollution sensitivity maps, v.1: accessed at http://www.dnr.state.mn.us/waters/groundwater_section/mapping/sensitivity.html#nearsurface.

Natural Resources Conservation Service (NRCS), 2009, Hydrologic soil groups, chap. 7 of NRCS National Engineering Handbook, accessed at http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=22526.wba.

Petersen, T.A., 2007, Geologic atlas of Crow Wing County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-16, Part B, 4 pls., scale 1:100,000.

Petersen, T.A., 2010, Geologic atlas of Todd County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-18, Part B, 4 pls., scale 1:100,000.

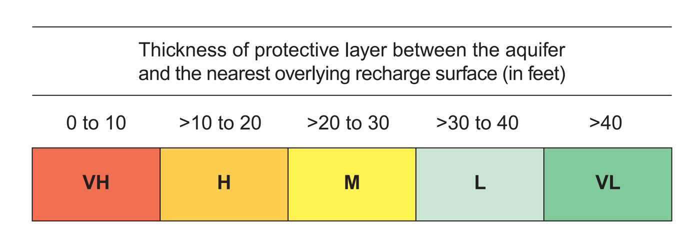
Rivord, J.S., 2012, Geologic atlas of Benton County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-23, Part B, 4 pls., scale 1:100,000 and 1:200,000.

Tipping, R.G., 2006, Subsurface recharge and surface infiltration [Plate 6], in Geologic Atlas of Scott County, Minnesota: Minnesota Geological Survey, County Atlas Series C-17, Part A, scale 1:150,000.

TABLE 1. Transmission rates used to assess pollution sensitivity rating of near-surface materials
[Dash marks (--) indicate no corresponding surficial geologic unit]

NRCS Hydrologic Soil Group	Hydrologic Soil Group (0-3 feet) Transmission Rate[1] [inches per hour]	Geologic Texture (3 to 10 feet) Transmission Rate[1] [inches per hour]	Carver County Surficial Geologic Unit (Plate 3, Part A)	Geologic Textural Classification
A, A/D	1	1	sdi	gravel, sandy gravel, silty gravel
		0.71	lb, sd, tg, tl, tr	sand, fine sand, silty sand
B, B/D	0.50	0.50	af, al, co	silt, silty fine sand, loamy sand
		0.28	pe	sandy loam, peat
C, C/D	0.075	0.075	dl, dth, dtv	silt loam, loam
		0.035	--	sandy clay loam
D	0.015	0.015	dtc	clay, clay loam, silty clay loam, sandy clay, silty clay

[1]Estimated rate through the matrix of unsaturated material (DNR, 2014).



Thickness of protective layer between the aquifer and the nearest overlying recharge surface (in feet)				
0 to 10	>10 to 20	>20 to 30	>30 to 40	>40
VH	H	M	L	VL

FIGURE 5. *Pollution sensitivity rating matrix.* *Pollution sensitivity is inversely proportional to the thickness of a protective layer between the top of an aquifer and the nearest overlying recharge surface as defined in Figure 4. Any buried aquifer with less than a 10-foot-thick protective layer between it and an overlying recharge surface is rated very high sensitivity because there is little fine-grained material above it to retard downward groundwater movement. A thicker overlying protective layer provides additional protection to the aquifer and sensitivity ratings are assigned based on the thickness of this layer.*

The DNR Information Center

Minnesota DEPARTMENT OF NATURAL RESOURCES

Twin Cities: (651) 296-6157
Minnesota toll free: 1-888-646-6367
DNR web site: http://www.mndnr.gov

This information is available in alternative format on request.

Equal opportunity to participate in and benefit from programs of the Minnesota Department of Natural Resources is available regardless of race, color, national origin, sex, sexual orientation, marital status, status with regard to public assistance, age, or disability. Discrimination inquiries should be sent to Minnesota DNR, 500 Lafayette Road, St. Paul, MN 55155-4031, or the Equal Opportunity Office, Department of the Interior, Washington, DC 20240.

© 2014 State of Minnesota,
Department of Natural Resources and the
Regents of the University of Minnesota.

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.