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

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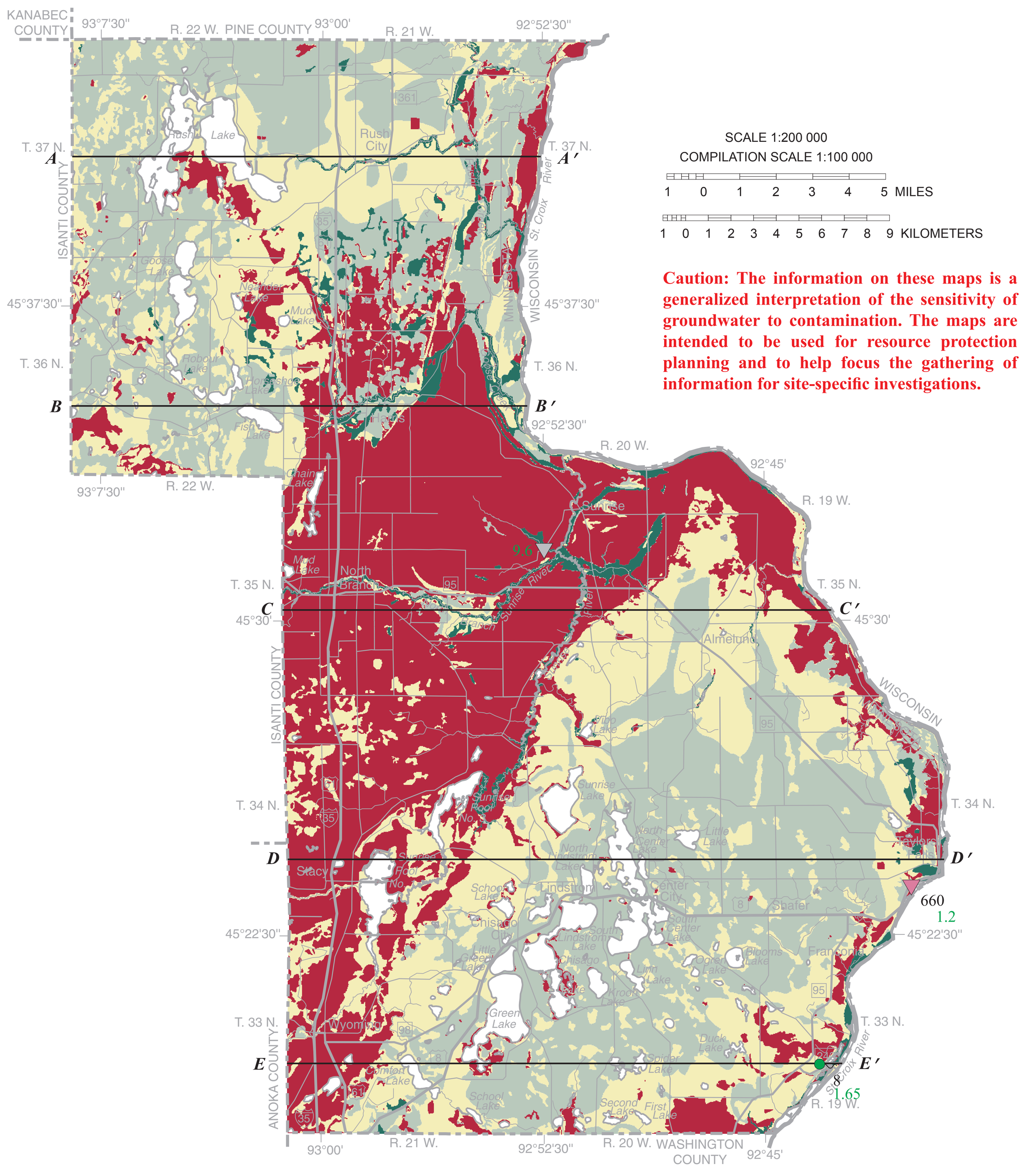
2014



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.

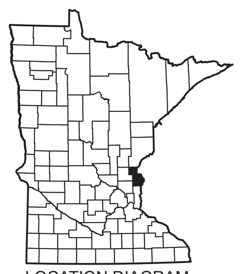


FIGURE 3. Pollution sensitivity of the near-surface materials.

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

Symbol color indicates tritium age of water sampled in well.

Surficial aquifer

- ▼ Surficial sand

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).
- Well was not sampled for tritium.

Symbols and labels

- 8 If shown, chloride concentration equals or exceeds 5 parts per million.
- 1.2 If shown, nitrate-nitrogen concentration equals or exceeds 1 part per million.
- Groundwater discharge (spring or seep); color indicates tritium age; gray symbols indicate not sampled for tritium.
- E—E′ Line of cross section
- Body of water

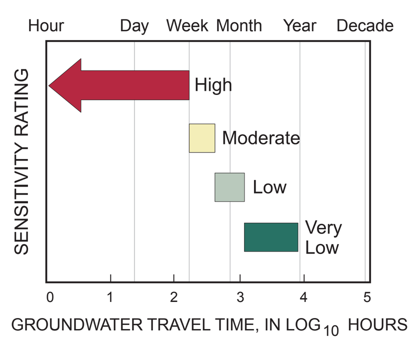


FIGURE 1. Pollution sensitivity rating for the near-surface materials as defined by vertical travel time. Ratings are based on the time required for water at the land surface to travel vertically to a depth of 10 feet through the vadose zone to the water table. Because the water table is not well mapped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

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

NRCS Hydrologic Soil Group	Hydrologic Soil Group (0 to 3 feet) Transmission Rate* [inches per hour]	Geologic Texture (3 to 10 feet) Transmission Rate* [inches per hour]	Chisago County Surficial Geologic Unit (Part A, Plate 3)	Geologic Textural Classification
A, A/D	1	1	Qbg, Qci, Qni, Qno, Qwg, Qwl, Qwr, Qws	gravel, sandy gravel, silty gravel
		0.71	Qa, Qbs, Qe, Qf, Ql, Qns	sand, fine sand, silty sand
B, B/D	0.50	0.50	Qcl, Cou**	silt, silty fine sand, loamy sand
		0.28	Qcd, Qcs, Qct, Qna, Qnd, Qp	sandy loam, peat
C, C/D	0.075	0.075	Qnm, Qnt	silt loam, loam
		0.035	--	sandy clay loam
D	0.015	0.015	Qbc, Qcc, Qm Pmc**	clay, clay loam, silty clay loam, sandy clay, silty clay

*Estimated transmission rate through the matrix of unsaturated material (DNR, 2014)
**Bedrock unit at or near land surface

MAP EXPLANATION
Figures 6–11

Sampled well and aquifer symbols

Symbol color indicates tritium age of water sampled in well.

Buried sand and gravel aquifers

- sl
- sc
- se
- sx
- sr
- sp

Bedrock well construction

- St. Peter–Prairie du Chien–Mt. Simon
- Jordan, Jordan–St. Lawrence
- St. Lawrence–Upper Tunnel City
- Upper Tunnel City
- Upper Tunnel City–Wonewoc
- Upper Tunnel City–Mt. Simon, Upper Tunnel City–Eau Claire
- Wonewoc, Wonewoc–Eau Claire
- Eau Claire
- Mt. Simon, Eau Claire–Mt. Simon, Wonewoc–Mt. Simon
- Mt. Simon–Fond du Lac
- Mesoproterozoic sedimentary

Groundwater conditions

- 1 Infiltration through a thin layer of overlying, fine-grained material to an underlying aquifer
- 2 Groundwater recharge from an overlying surficial aquifer to a 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
- D Groundwater discharge to surface-water body
- L Lateral groundwater flow

Symbols and labels

- 21.1 If shown, chloride concentration equals or exceeds 5 parts per million. Naturally occurring chloride concentration greater than 5 parts per million is shown with a superscript n.
- 7.2 If shown, nitrate-nitrogen concentration equals or exceeds 1 part per million.
- 3000 yrs If shown, groundwater residence time in years, estimated by carbon-14 (^{14}C) isotope analysis
- Direction of groundwater flow
- Groundwater discharge (spring or seep); color indicates tritium age; gray symbols indicate not sampled for tritium.
- ····· 775 — Potentiometric surface elevation contour; contour dashed where uncertain or aquifer not present.
- Extent of surficial sand aquifer
- Mesoproterozoic basalt bedrock
- E—E′ Line of cross section
- Body of water

Pollution sensitivity rating for the buried sand and gravel aquifers and the bedrock surface

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 during 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 was not sampled for tritium.

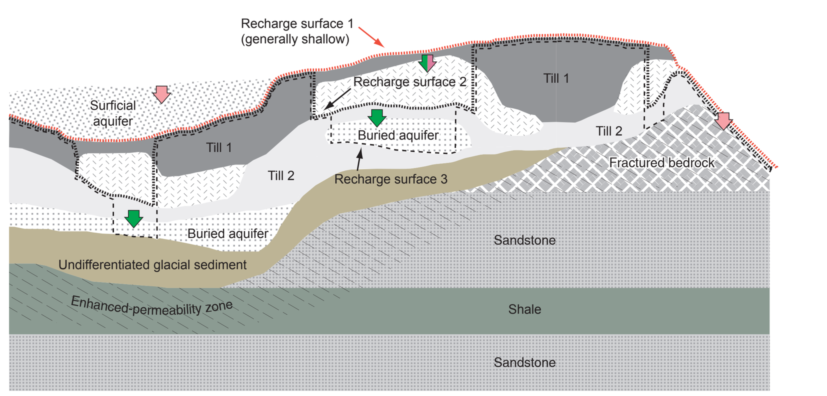


FIGURE 4. Generalized cross section showing groundwater recharge concepts for buried sand and gravel aquifers and the bedrock surface considered in the sensitivity evaluations. If there is less than 10 feet of till or fine-grained sediment between recharge surfaces and aquifers, it is assumed that the water continues to move downward through several alternating layers. In this model, all recent 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 or fine-grained sediment is present or at the bottom of the surficial sand aquifer. If less than 10 feet of fine-grained sediment exists between recharge surface 1 and the shallowest underlying buried aquifer, then recent recharge is assumed to 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 till or fine-grained sediment between it and the overlying buried aquifer, further penetration of recent 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. The pink and pink-green arrows indicate moderate groundwater recharge; the solid green arrows indicate limited recharge.

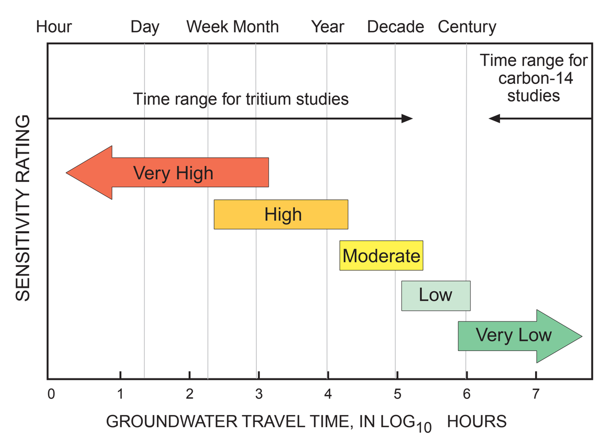


FIGURE 2. Geologic sensitivity rating for the buried sand and gravel aquifers and the bedrock surface as defined by vertical travel time (Geologic Sensitivity Workgroup, 1991). Ratings are based on the time required to travel vertically from the surface into the aquifer of interest or the pollution sensitivity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

Thickness of the 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 for the buried sand and gravel aquifers and the bedrock surface. 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. The thicker the protective layer, the lower the aquifer sensitivity. 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.

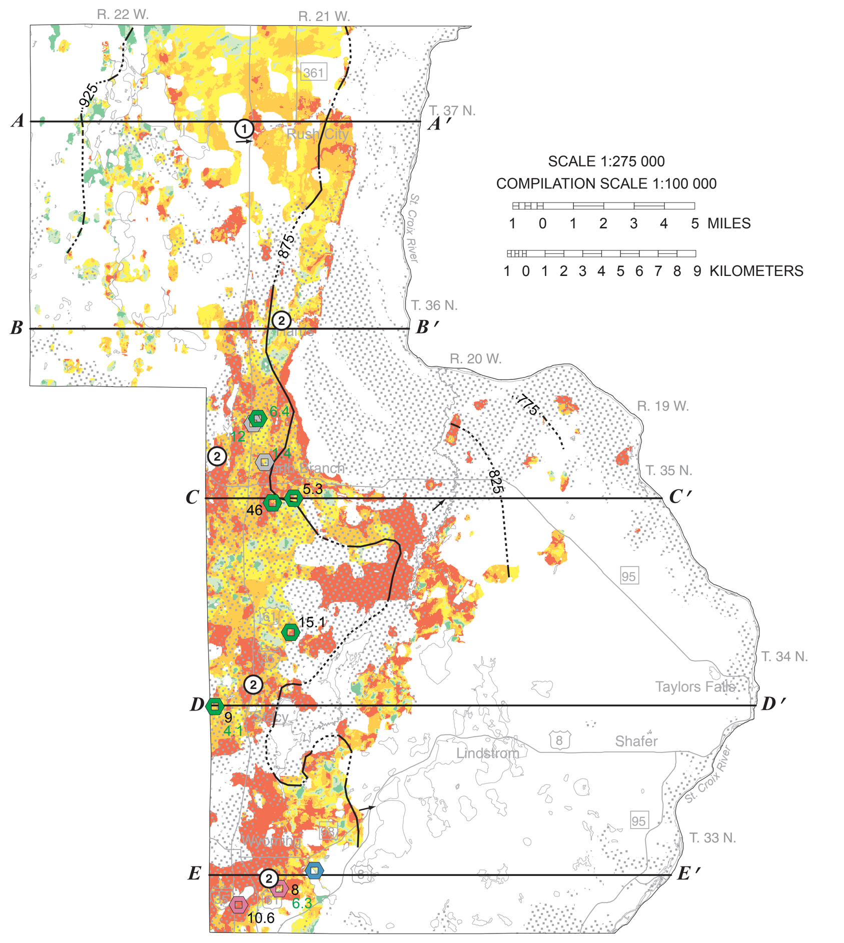


FIGURE 6. Pollution sensitivity of the sl buried sand and gravel aquifer.

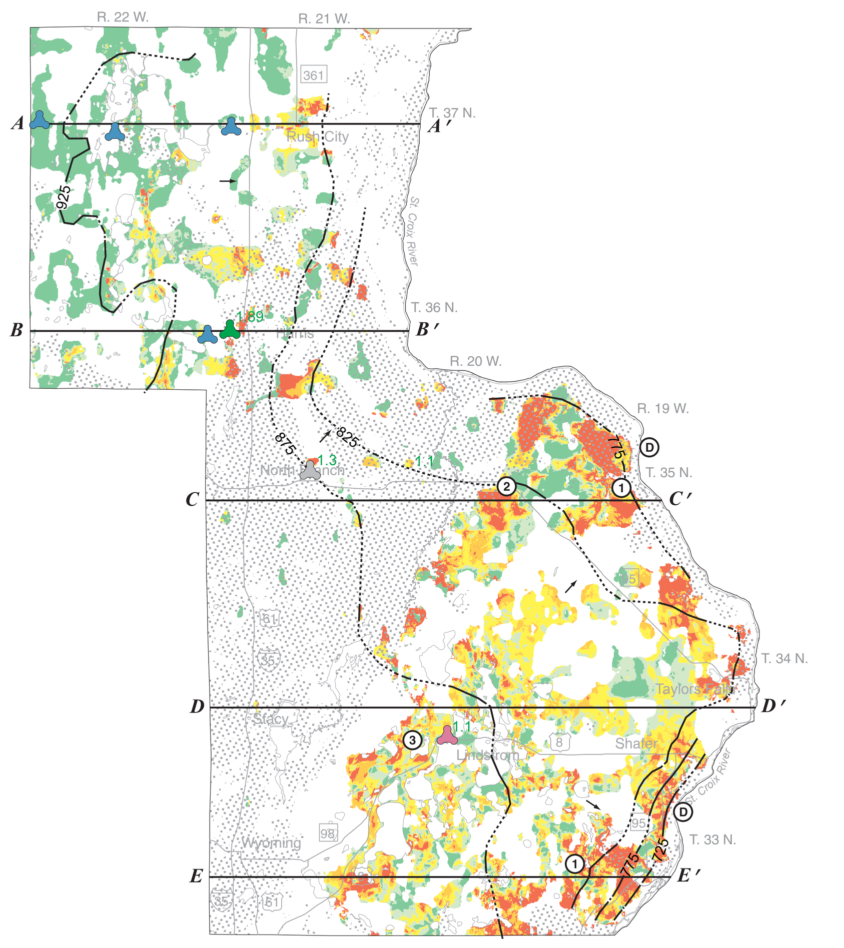


FIGURE 7. Pollution sensitivity of the sc buried sand and gravel aquifer.

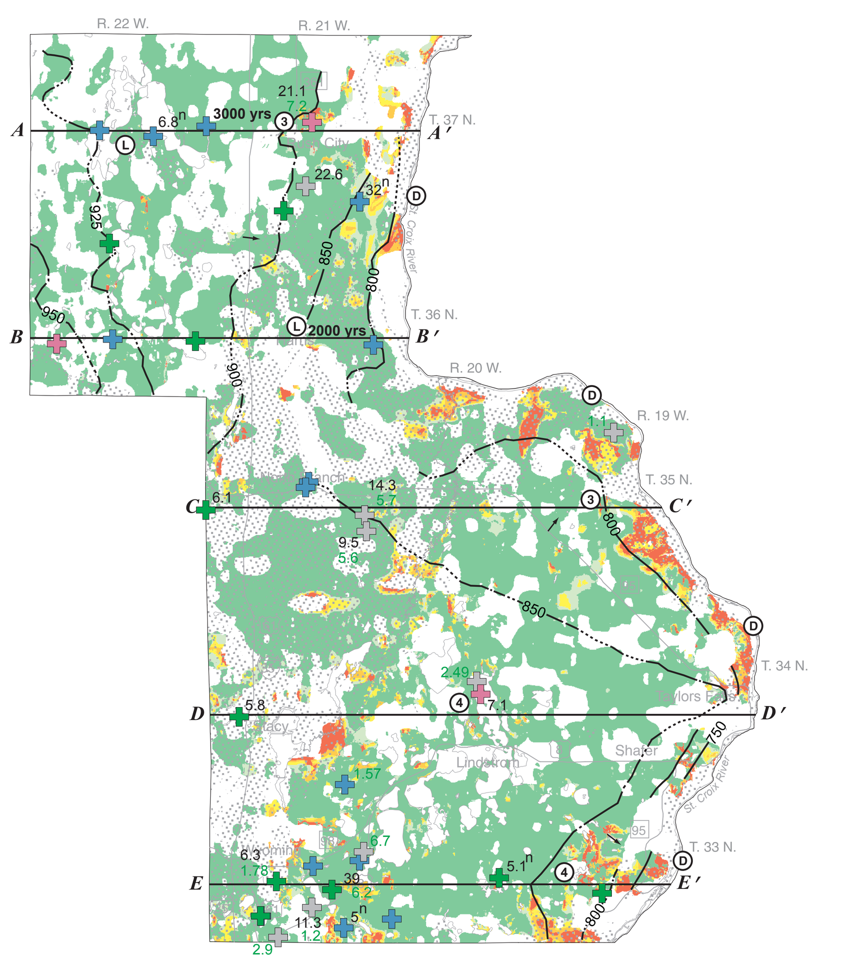


FIGURE 8. Pollution sensitivity of the se buried sand and gravel aquifer.

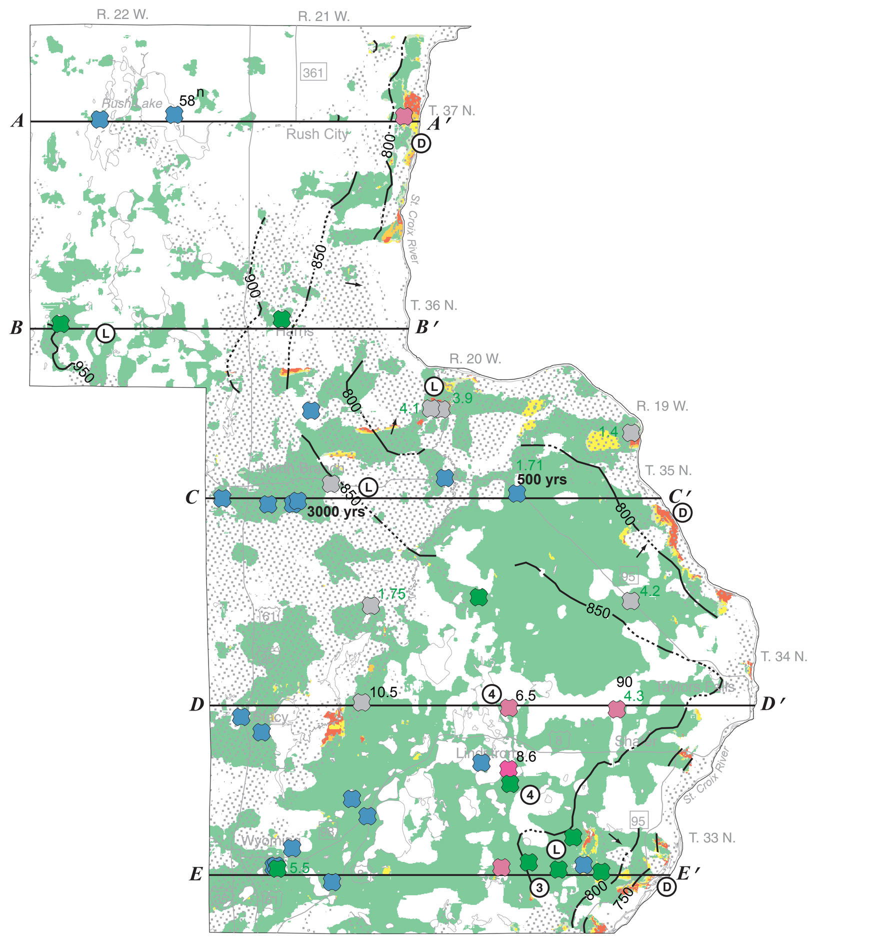


FIGURE 9. Pollution sensitivity of the sx buried sand and gravel aquifer.

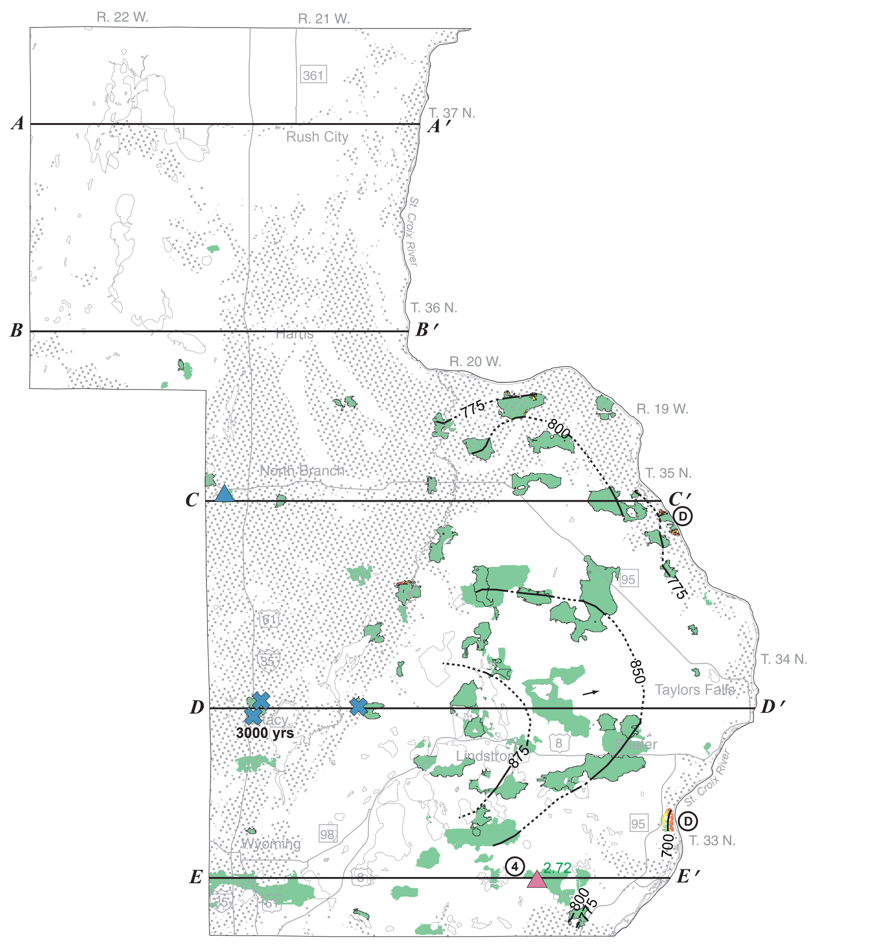


FIGURE 10. Pollution sensitivity of the sr and the sp buried sand and gravel aquifers. The sr aquifer is stratigraphically above the sp aquifer. For clarity in the figure, the sp aquifer (shown with border) is positioned above the sr aquifer (shown without border), in reverse of their stratigraphic relationship.

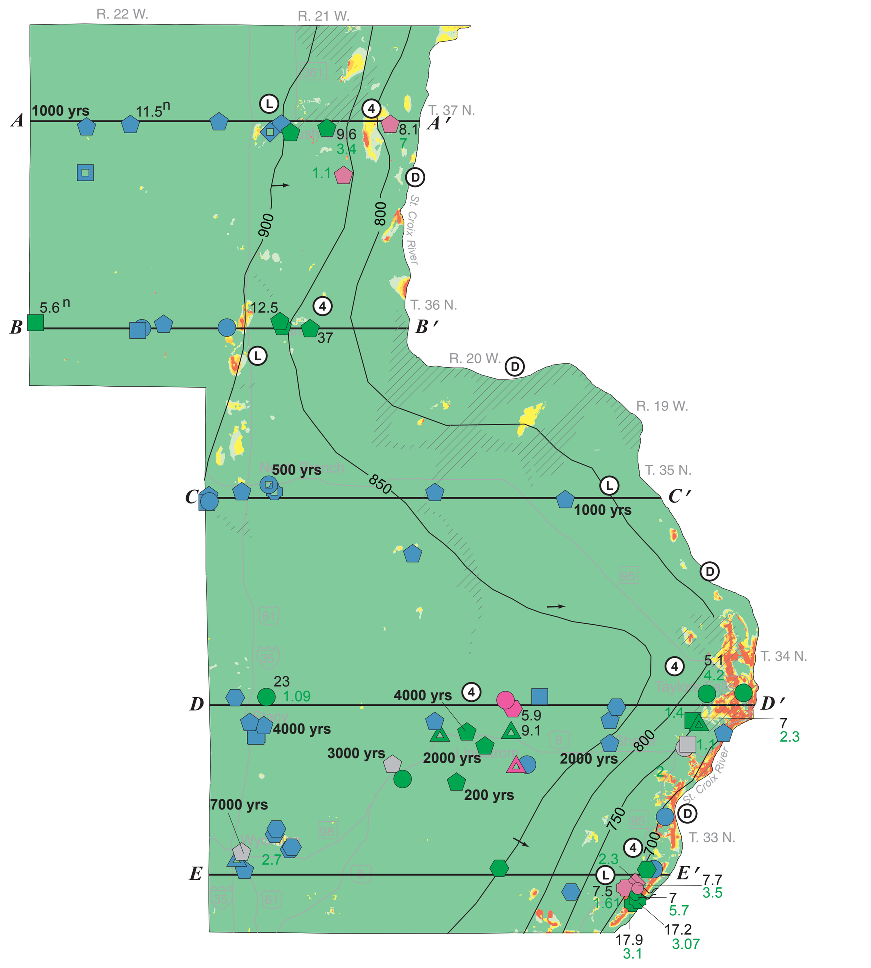


FIGURE 11. Pollution sensitivity of the bedrock surface. Groundwater contours are shown for the Mt. Simon aquifer.

INTRODUCTION

This plate shows maps of the sensitivity to pollution of near-surface materials, buried sand and gravel aquifers, and the bedrock surface in Chisago County. Sensitivity to pollution is an estimate of the time of travel for a contaminant to move conservatively with water from the land surface to the aquifer of interest. In general, a contaminant that moves conservatively is not chemically or physically altered over time. Migration of contaminants dissolved in water through sediments is a complex process. The process is affected by a number of factors, including biological degradation, oxidizing or reducing conditions, and contaminant density. A countywide assessment of pollution sensitivity requires some general assumptions. One assumption is that flow paths are vertical from the land surface through the soil and underlying sediments. Though horizontal flow paths are important in specific instances, they are not considered in this sensitivity model. The permeability of soil and surficial geologic units is considered in calculating the pollution sensitivity of the near-surface materials. For buried sand and gravel aquifers and the bedrock surface, the permeability is calculated using only the thickness of the overlying aquitard.

The near-surface pollution sensitivity ratings are shown in Figure 1. These ratings are based on an estimate of vertical time of travel from the land surface to a depth of 10 feet through unsaturated sediment (the vadose zone). The time of travel through this surface layer varies from hours to approximately a year. Areas with relatively short time of travel (hours to a week) are rated high. Areas with longer time of travel (weeks to a year) are rated low or very low. The sensitivity ratings for the buried sand and gravel aquifers and the bedrock surface in Figure 2 correspond to an estimated time of travel to deeper aquifers (Geologic Sensitivity Workgroup, 1991). The time of travel to buried aquifers varies from days to thousands of years. Areas with relatively short time of travel of less than a few years are rated high or very high. Areas with a longer time of travel of decades or more are rated low or very low. The sensitivity rating categories of the near-surface materials are very similar to the buried aquifer ratings, but the near-surface travel time is much shorter.

SENSITIVITY TO POLLUTION OF THE NEAR-SURFACE MATERIALS

The pollution sensitivity of the near-surface materials (Figure 3) estimates the time required for water to travel from the land surface to a depth of 10 feet. The assessment was developed by estimating transmission rates through soils and surficial geologic units. Hydrologic soil groups from the Natural Resources Conservation Service (NRCS) are used to estimate the travel time from the land surface to a depth of three feet. Surficial geologic unit texture from Part A, Plate 3 is used to estimate the travel time from a depth of 3 to 10 feet. The total travel time to 10 feet is then used to estimate the near-surface pollution sensitivity.

Estimates of transmission rates used in the calculations are presented in Table 1. Hydrologic Group A soils are more than 90 percent sand and gravel, and water is freely transmitted through the soil (NRCS, 2009). Group B soils have loamy sand or sandy loam textures and are less permeable than Group A soils, though water transmission is unimpeded through the soil. Group C soils are typically loam to clay loam in texture with water transmission that is somewhat restricted. Group D soils typically have clayey textures that restrict water movement. 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 fraction 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 specific methodology used on this plate is explained in the *Procedure for determining near-surface pollution sensitivity maps* (DNR, 2014).The unsaturated transmission rates shown in Table 1 are calculated by converting saturated hydraulic conductivity values into unsaturated transmission rates using a method described by Bouwer (2002). 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 are applied to both the soil and surficial geologic units to determine the transmission rates shown in Table 1. The rates do not account for soil compaction, macropores, drain tiles, or seasonal recharge events in the spring and fall. Soil compaction can decrease transmission rates. Macropores, drain tiles, and seasonal recharge events often increase transmission rates.

The near-surface materials sensitivity map was prepared by using the matrix transmission rate as determined above for the soil and surficial geologic units to calculate the estimated travel time. The GIS polygons from both the soil and surficial geologic units are brought together by the GIS union process. This creates new polygons that have attributes of both the soil and surficial geologic units. Some soil units, such as gravel pits, have no assigned hydrologic soil group and therefore have no assigned transmission rate. If a transmission rate is not available for a soil unit, the surficial geologic unit transmission rate is used to calculate the travel time for the entire 10-foot thickness. Figure 3 illustrates the near-surface sensitivity of Chisago County. The near-surface pollution sensitivity is higher in central Chisago County and along the St. Croix River. Lower sensitivities exist in the more clayey soil and geologic units of the northwest and south central regions of the county.

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

Development of the Sensitivity Model and Maps

Pollution sensitivity maps for the buried sand and gravel aquifers (Figures 6 through 10) and the bedrock surface (Figure 11) are based on the method of vertical recharge surfaces described in Figure 4 and the ratings matrix described in Figure 5. This model assumes that the fine-grained sediment layers between aquifers act as aquitards that restrict the vertical movement of groundwater between aquifers. 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; Petersen, 2013; and Petersen, 2014). Recharge surfaces for the buried sand and gravel aquifers and the bedrock surface are derived from the distribution and thickness of sand layers and undifferentiated Pleistocene sediment mapped on Part A, Plate 5, Figures 4 through 9.

The uppermost recharge surface (RS1) is initially positioned at the land surface (Figure 4). If surficial sand is present, RS1 is repositioned to the base of this sand unit under the assumption that precipitation can quickly travel to the base of the surficial sand unit. If less than 10 feet of till or fine-grained sediment is present between RS1 and the top of the first buried aquifer below, then it is assumed the first buried aquifer below is 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. If the next buried aquifer below RS2 has less than 10 feet of fine-grained sediment between RS2 and the top of that sand, then a third recharge surface (RS3) will be defined at the bottom of this sand. Deeper recharge surfaces (below RS3) are defined similarly.

This model assumes that till and fine-grained sediment layers that are less than 10 feet thick are leaky and will allow relatively rapid recharge to the next deeper layer. Groundwater often moves horizontally, but only vertical movement is considered in this sensitivity model. 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 4). The thickness of the aquitard between the top of the aquifer and the nearest overlying recharge surface is used to assign the sensitivity to pollution according to the rating matrix. Thicknesses of less than or equal to 10 feet are rated very high, thicknesses greater than 10 and equal to 40 feet have intermediate sensitivity ratings, and thicknesses greater than 40 feet are rated very low.

Buried sand and gravel aquifers in Chisago County vary in their pollution sensitivity from the sl aquifer which has predominantly very high to moderate sensitivity to the sr and sp aquifers with predominately very low sensitivity. The pollution sensitivity of the bedrock surface is primarily very low, but there are scattered areas with very high to moderate sensitivity where the depth to bedrock is less than 50 feet from land surface.

Comparison of Sensitivity Model to Groundwater Chemistry

The chemical and isotopic analysis of groundwater samples is useful for evaluating geologic sensitivity. Tritium results showing recent and mixed ages indicate that at least a portion of the groundwater has been recharged since the 1950s. An elevated chloride concentration in samples equal to or greater than 5 parts per million (ppm) or a nitrate concentration exceeding 1 ppm often indicate an anthropogenic (human influenced) source of chloride or nitrate, implying a moderate or higher pollution sensitivity. Elevated chloride is sometimes found in deeper groundwater samples with no detectable tritium or with chloride to bromide (Cl/Br) ratios less than 300. In Chisago County, a chloride to bromide ratio less than 270 indicates chloride is likely from a deep natural source. The sensitivity model results are generally consistent with the water chemistry results. Potentiometric surface contours are shown on Figures 6 through 11 to qualitatively account for a lateral groundwater flow component not explicitly accounted for in the pollution sensitivity model. Comparison results for each mapped aquifer and the bedrock surface are discussed below. The stratigraphic sequence of buried sand and gravel aquifers is shown on Plate 9, Figure 2.

The sl aquifer is the buried sand and gravel aquifer closest to the land surface over portions of the northwest and western areas of the county. It has very high to moderate sensitivity over the majority of its mapped extent. In this aquifer, 9 of 10 wells sampled had either recent or mixed tritium-age values, elevated chloride, or elevated nitrate. Water sampled from a well constructed to 59 feet in the Forest Lake area had a vintage tritium age and low chloride and nitrate. This well likely pumps older groundwater from either the New Ulm Formation (Qnu) or the Cromwell Formation (Qcr) (Part A, Plate 4).

The sc aquifer is the buried sand and gravel aquifer located stratigraphically below the sl aquifer, except in locations where the sl does not exist. It has very high to moderate sensitivity over large portions of its mapped extent. However, in the northwest region of the county, west of Rush City and Harris, the aquifer primarily has very low sensitivity due to the presence of a relatively thick lacustrine clay and silt layer that acts as an aquitard. Groundwater samples collected from wells in the northwest area of the county where this aquitard is present are vintage in tritium age and do not show geochemical signatures of human influence. Elsewhere in the county, thin thicknesses of till or fine-grained sediment result in modeled sensitivity values that are very high and moderate over large portions of the county. Groundwater samples collected from wells constructed in the sc in or near areas mapped as very high and moderate have geochemical signatures that suggest connectivity to the land surface. In these locations, nitrate values are in excess of the background concentration of 1 ppm.

The se aquifer is the buried sand and gravel aquifer stratigraphically below the sc aquifer. It varies in pollution sensitivity from very low to very high. The majority of the se aquifer is at a depth of 70 feet or more from the land surface and the model indicates a very low sensitivity. However, very high sensitivity areas exist within this unit, especially where the aquifer is close to the St. Croix River. In these areas the overlying sc aquifer is in direct contact with the se aquifer. Groundwater samples collected from wells constructed in or close to se aquifer areas mapped as very high to moderate generally have geochemical signatures that suggest connectivity to the land surface. In these locations, nitrate values are often in excess of 1 ppm and chloride concentrations often exceed 5 ppm. Other samples from the se aquifer with elevated chloride and nitrate concentrations do not fit neatly with modeled high sensitivity regions. In these locations, leakage from surface water features and lateral flow appears to have transported the human-influenced water to the sampled locations. In the Rush City and Chisago Lakes region, steep gradients from municipal wells may bring recent waters to greater depths. Four samples from this aquifer show naturally elevated chloride levels. Two of the elevated samples are from wells in the northern section of the county and two moderately elevated levels are from wells in southern Chisago County.

The sx aquifer is the buried sand and gravel aquifer stratigraphically below the se aquifer. This aquifer varies in pollution sensitivity from very low to very high. The majority of the aquifer is classified with a very low sensitivity, with high to moderate regions along the St. Croix River bluffs and in scattered locations in the center of the county. Wells with vintage tritium-age water generally are located in areas classified as very low sensitivity. Water samples that had mixed tritium age, recent tritium age, elevated nitrate, or elevated chloride are generally close to areas classified as very high to moderate sensitivity or are down gradient of such areas. Conversely, water with recent tritium age was sampled on the east side of Center Lake where the model predicts very low sensitivity. Cross section D–D′ on Plate 9 illustrates this scenario, with recent tritium-age water and elevated chloride present in the aquifer in the vicinity of Pioneer Lake. The mechanism for recent tritium-aged water with elevated chloride levels reaching these wells is unclear. Steep gradients from municipal wells "pulling" younger water to greater depths may allow movement of recent tritium-age water to greater depths. One well constructed in the northwestern region of the county near Rush Lake shows a naturally elevated chloride level. The sx aquifer is likely in connection with naturally elevated chloride in the se and Mt. Simon aquifers.

The sr and sp aquifers are the deepest mapped buried sand and gravel aquifers in the county; these aquifers underlie the sx aquifer and are stratigraphically above deeper bedrock aquifers and aquitards. Both the sr and sp aquifers are modeled as mostly very low sensitivity. Geochemical results from four of the five samples collected from the sr and sp aquifers are consistent with the model showing vintage tritium-age water and no elevated concentrations of chloride or nitrate. One sample, which had recent tritium-age water and elevated nitrate, is located to the southeast of the Chisago Lakes district suggesting that the sensitivity rating of the sr and sp aquifers in this region is higher than the model predicts most likely due to interconnected buried sand and gravel layers and lateral flow.

The bedrock surface sensitivity is primarily very low, except in areas where depth to bedrock is shallow (approximately 50 feet) and along the bluffs of the St. Croix River. In these areas, sensitivity of the bedrock surface ranges from moderate to very high. Tritium and geochemical results from the majority of bedrock wells sampled suggest the model is consistent with chemistry. In general, water sampled from most bedrock wells was of vintage tritium age and had chloride concentrations less than 5 ppm and nitrate concentrations less than 1 ppm. However, mixed and recent tritium-aged water and water with elevated chloride and nitrate concentrations occurs in and down gradient of areas where the bedrock surface is close to the land surface and where heavy groundwater appropriation occurs. Examples of locations where recent or mixed tritium-age water and heavy groundwater appropriation coincide include Rush City, Harris, and the Chisago Lakes region. Two wells constructed in bedrock aquifers in the northwest region of the county show naturally elevated chloride levels.

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Base modified from Minnesota Geological Survey, Chisago County Geologic Atlas, Part A, 2010. Project data compiled from 2010 to 2012 at a scale of 1:100,000. Universal Transverse Mercator projection, grid zone 15, North American Datum of 1983. Vertical datum is mean sea level.

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