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

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

By

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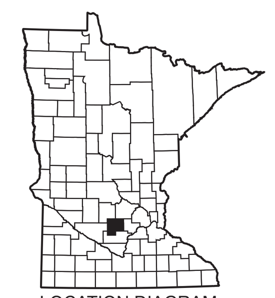
2013



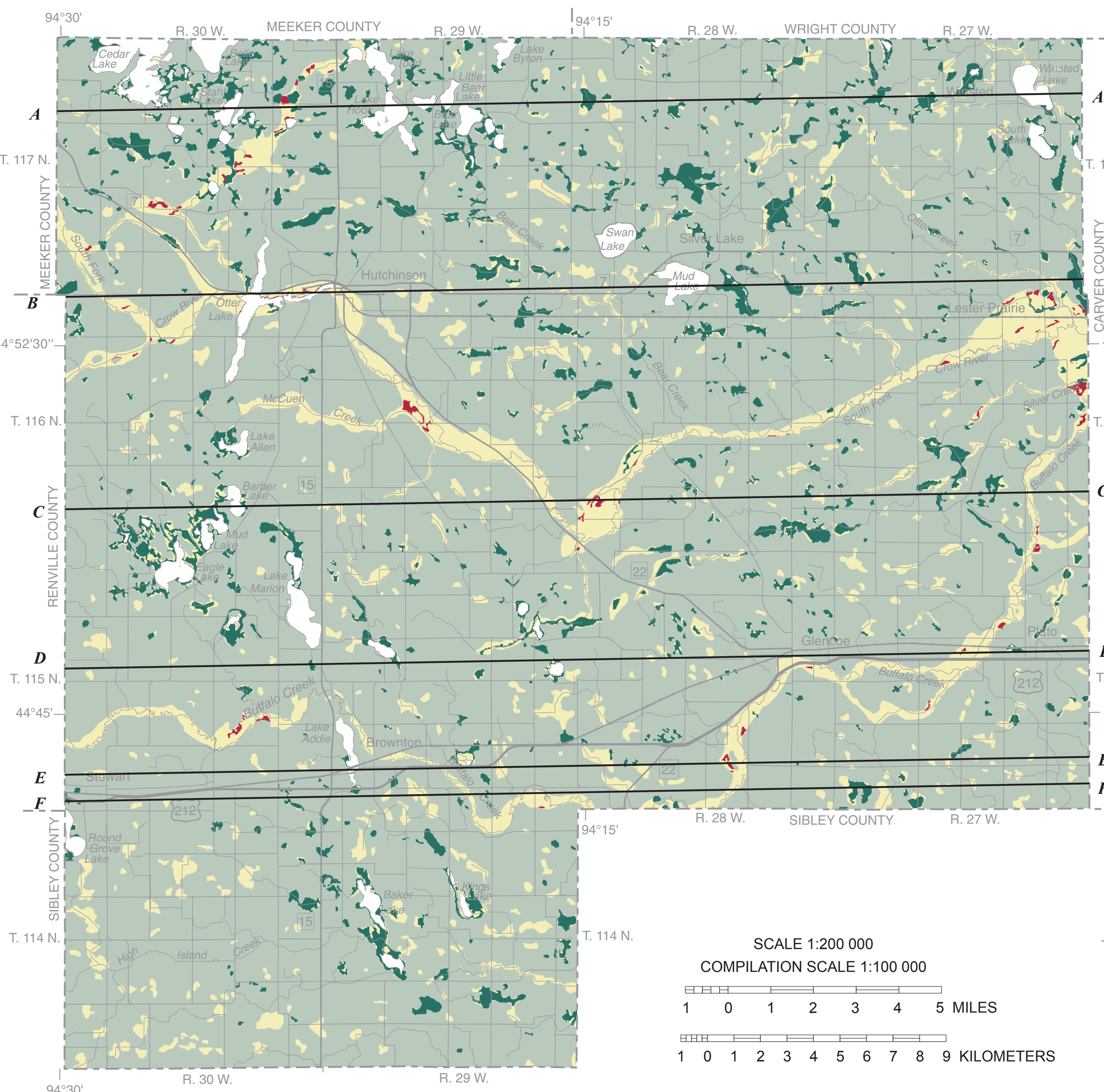


FIGURE 3. *Pollution sensitivity of the near-surface materials.*

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.

Symbols and labels

- F F′ Line of cross section.
- Body of water.

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.

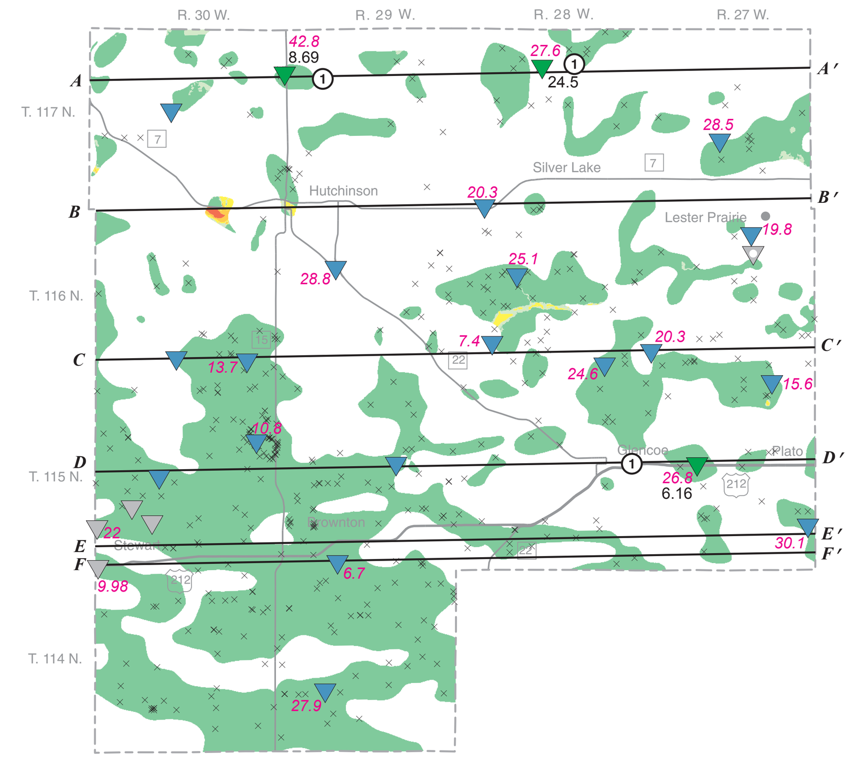


FIGURE 6. *Pollution sensitivity of the* sdv *buried sand and gravel aquifer.*

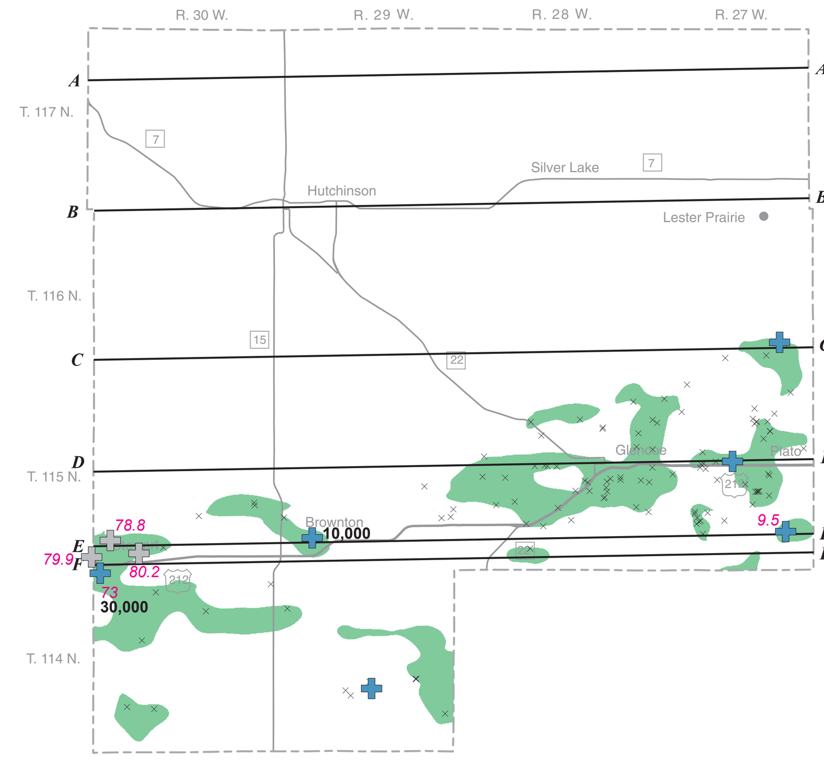


FIGURE 7. *Pollution sensitivity of the* sdj *buried sand and gravel aquifer.*

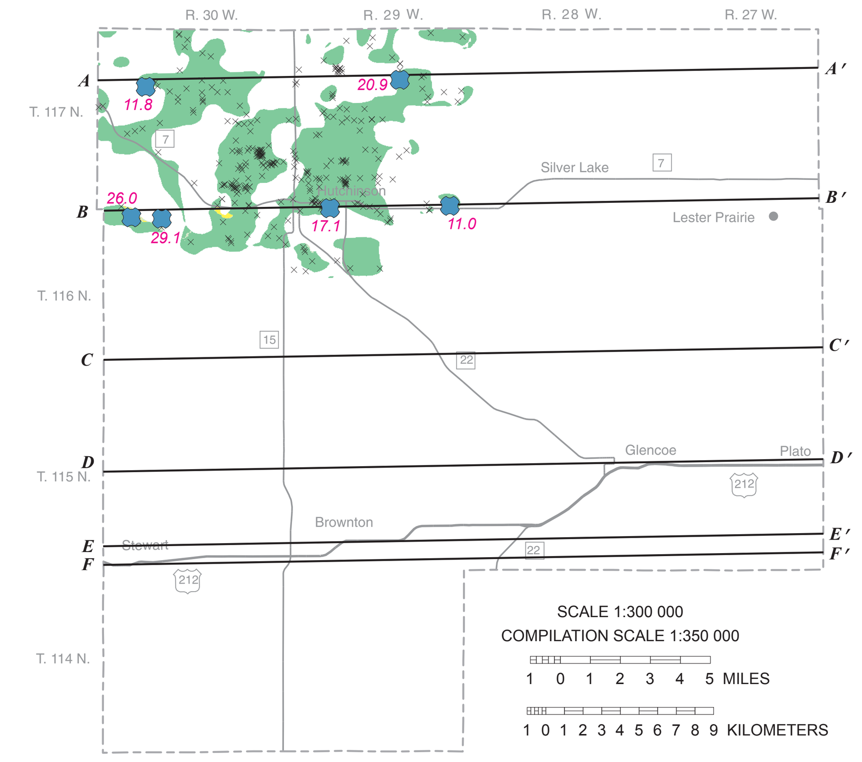


FIGURE 8. *Pollution sensitivity of the* sc *buried sand and gravel aquifer.*

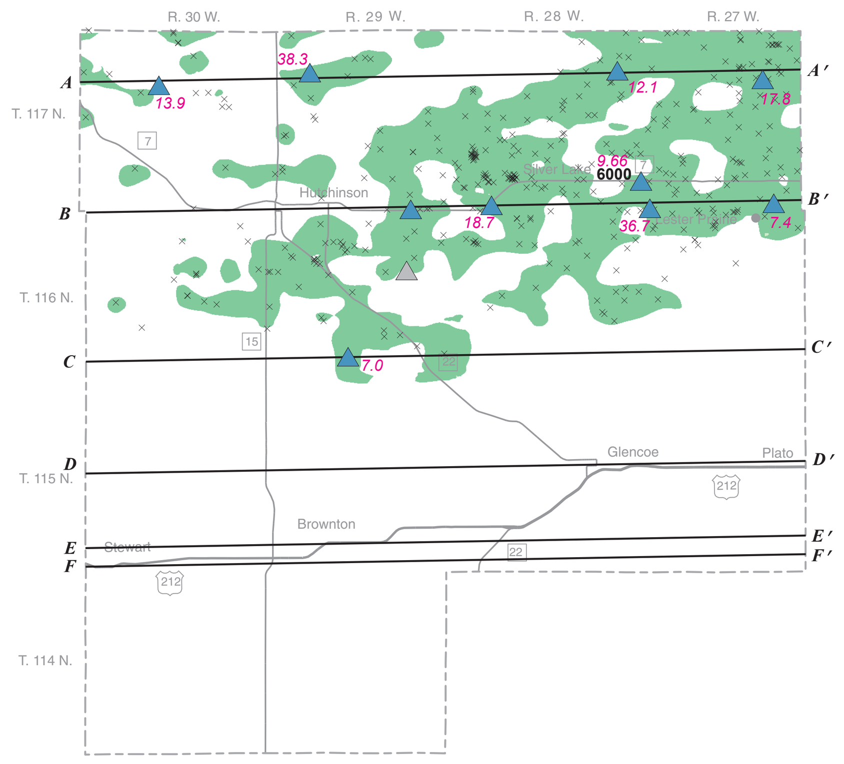


FIGURE 9. *Pollution sensitivity of the* sb *buried sand and gravel aquifer.*

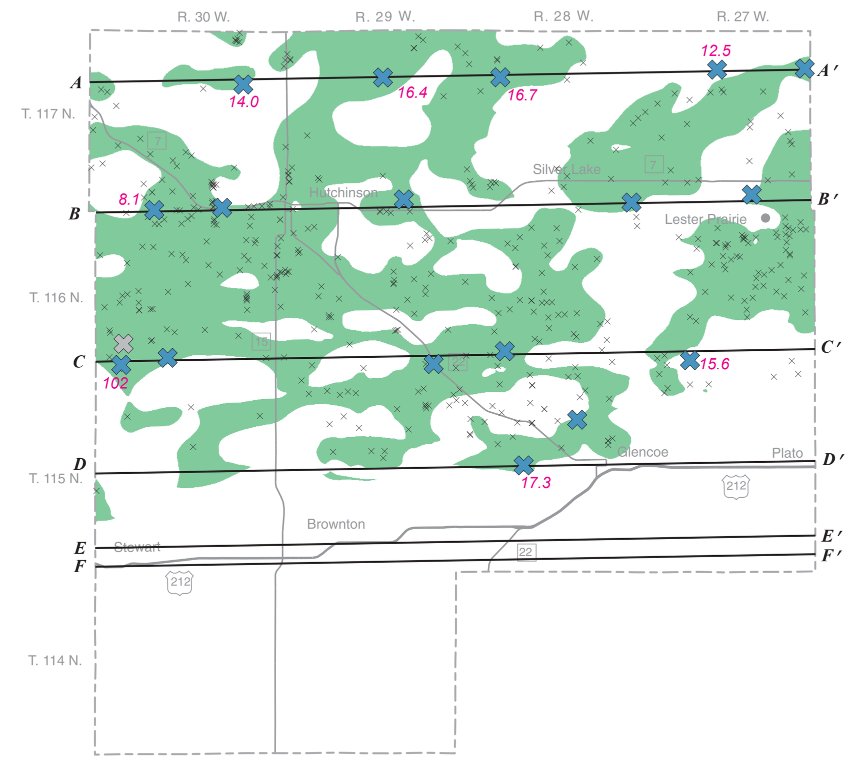


FIGURE 10. *Pollution sensitivity of the* sx *buried sand and gravel aquifer.*

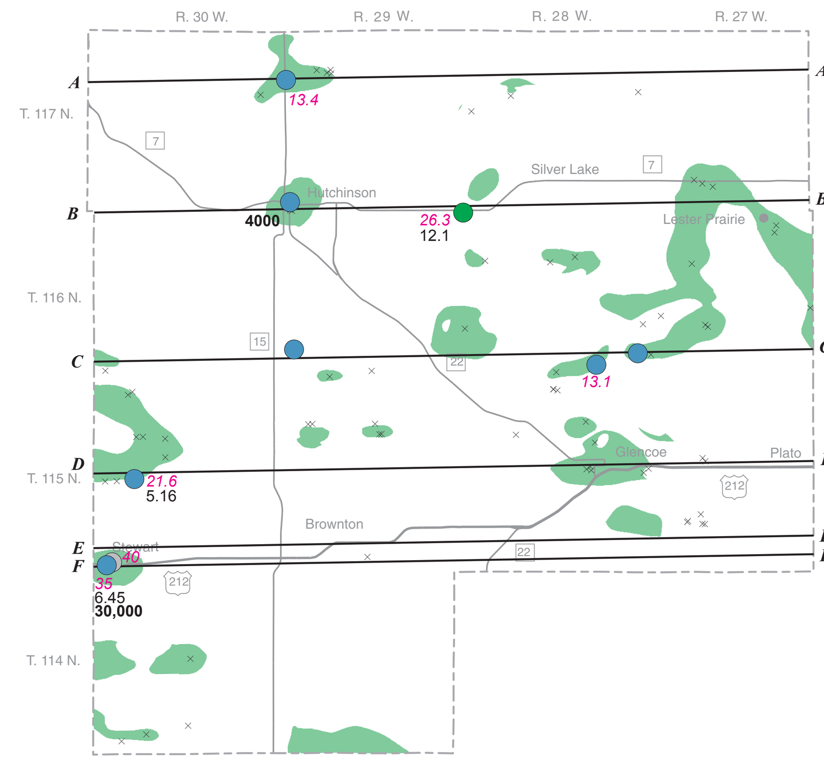
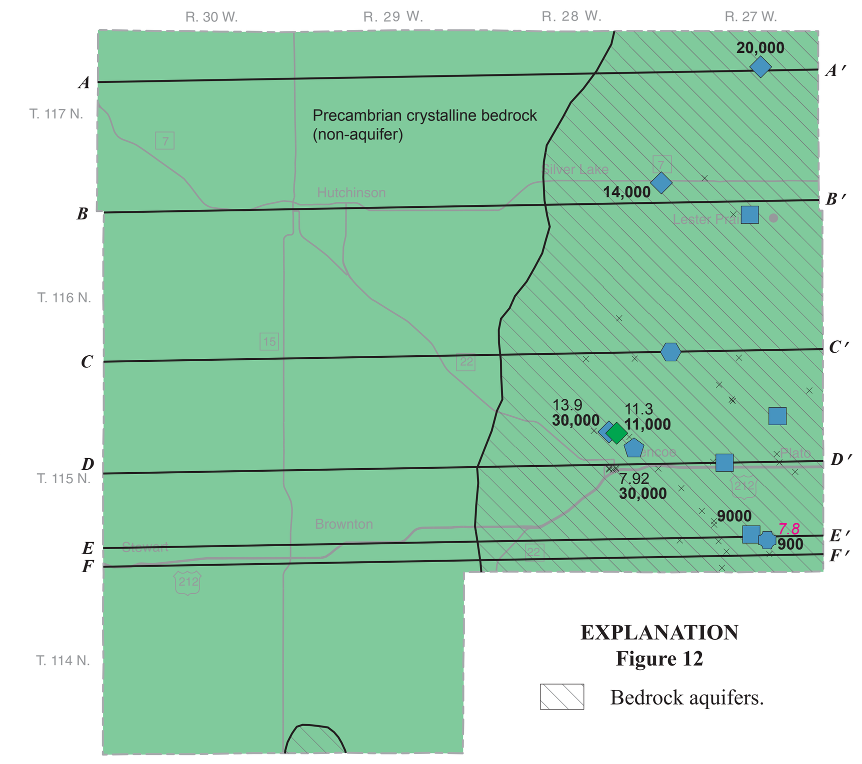


FIGURE 11. *Pollution sensitivity of the* su *buried sand and gravel aquifer.*



EXPLANATION
Figure 12

Bedrock aquifers.

FIGURE 12. *Pollution sensitivity of the top of the bedrock. Sedimentary bedrock aquifers are only present in eastern McLeod County. Bedrock in western McLeod County is not considered an aquifer.*

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.

Sampled well and aquifer symbols

Buried sand and gravel aquifers.

- sdv
- sdj
- sc
- sb
- sx
- su

Bedrock aquifers.

- Jordan
- Upper Tunnel City-Wonewoc
- Wonewoc
- Mt. Simon
- Hinckley

Tritium age

Color indicates tritium age of water sampled in well.

- Recent—Water entered the ground since about 1953 (8 or more tritium units [TU]).*
- Mixed—Water is a mixture of recent and vintage waters (greater than 1 TU to less than 8 TU).
- Vintage—Water entered the ground before 1953 (less than or equal to 1 TU).
- Well not sampled for tritium.

*No samples analyzed in this project contained recent age water.

Symbols and labels

- 14.0 — If shown, arsenic concentration equals or exceeds 5 parts per billion.
- 11.3 — If shown, chloride concentration equals or exceeds 5 parts per million.
- 4000 — If shown, groundwater age in years, estimated by carbon-14 (^{14}C) isotope analysis.
- Well constucted in aquifer.
- Major bedrock aquifer contact (Figure 12 only).
- F F′ Line of cross section.

Groundwater condition

① Infiltration through a thin layer of overlying, fine-grained material to an underlying aquifer (Figure 6 only).

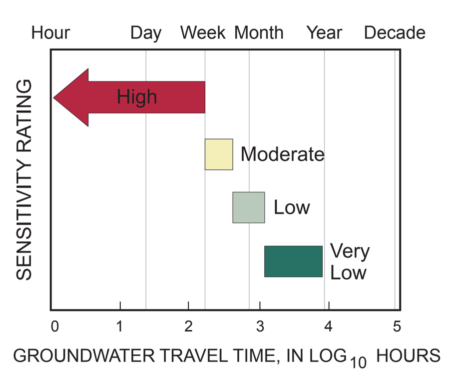


FIGURE 1. *Geologic sensitivity rating for the near-surface materials as defined by vertical travel time.* *Ratings are based on the time range required for water at the land surface to travel vertically 10 feet through the vadose zone to the water table. Because the water table is not well mapped everywhere,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

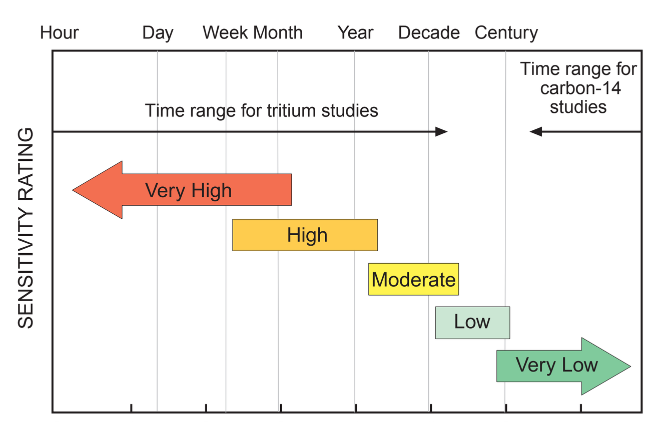


FIGURE 2. *Geologic sensitivity rating for the buried sand and gravel aquifers and the top of the bedrock as defined by vertical travel time (Geologic Sensitivity Workgroup, 1991).* *Ratings are based on the time range required for water at or near the surface to travel vertically into the aquifer of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

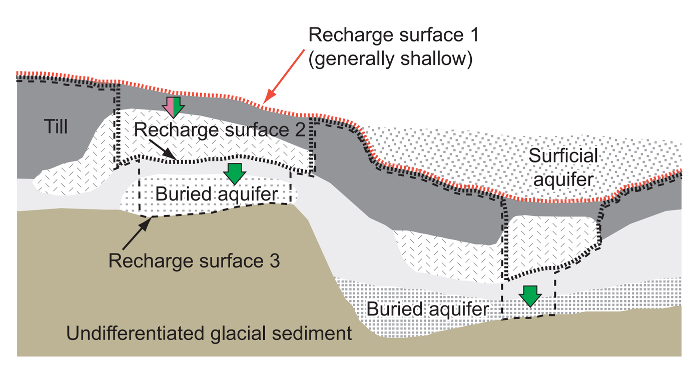


FIGURE 4. *Generalized cross section showing groundwater recharge concepts for buried sand and gravel aquifers considered in the sensitivity evaluations.* *In this model, all recent recharge enters the buried aquifer system at recharge surface 1 (red dotted line). Recharge surface 1 is considered to be at the land surface where till 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 recent 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 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 green arrow indicates moderate groundwater recharge; the solid green arrows indicate limited recharge.*

INTRODUCTION

This plate describes the sensitivity to pollution of the near-surface materials, of the buried sand and gravel aquifers, and of the top of the bedrock of McLeod County by estimated 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 conditions, 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 in calculating the pollution sensitivity of the near-surface materials. However, the permeability of deeper sediments is evaluated only qualitatively in calculating the pollution sensitivity of buried sand and gravel aquifers and of the bedrock surface.

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 estimate of travel time from the land surface to a depth of 10 feet. The focus of this near-surface sensitivity rating estimate is travel in 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 McLeod 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 an estimate of 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 time criteria are much shorter.

SENSITIVITY TO POLLUTION OF THE NEAR-SURFACE MATERIALS

The geologic sensitivity to pollution assessment for the near-surface materials of McLeod County estimates the time required for water to travel from the land surface to a depth of ten feet, and is shown in Figure 3. The near-surface materials sensitivity assessment was developed by estimating transmission rates through soils and surficial geology units based on the Natural Resources Conservation Service (NRCS) hydrologic rating (NRCS, 2009) for soils and the geologic unit texture of deeper parent materials, from Plate 4, 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 geology 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, 2013). 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 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 (2013). 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, drain tiles, 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 geology 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 McLeod County as low sensitivity. The dtv and dth tills that form most of the landscape in McLeod County have a high percentage of clay and therefore low water transmission rates. The areas of moderate sensitivity in the county are largely organic peat and muck deposits. The areas of high and very high sensitivity are primarily in areas of outwash sands and gravels and alluvium.

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 5, Part A includes maps of the depth to the top of the buried sand and gravel aquifers. Plate 6, 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 surface (Figure 12) are based on the method of vertical recharge surfaces 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 surface are derived from the distribution and thickness of sand layers and undifferentiated Pleistocene sediment mapped on Figures 5 through 12, Plate 5, 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 clay between RS2 and the top of that sand, then a third recharge surface (RS3) will be defined at the bottom of this sand. This model assumes that clay 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. Large thicknesses of greater than 40 feet are rated very low; small 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 McLeod County are rated very low sensitivity. The sdv buried sand and gravel aquifer and the sc buried sand and gravel aquifer have a few small areas with higher sensitivity ratings. These areas of higher sensitivity occur where the surficial aquifer overlies these buried sand and gravel aquifers.

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

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.

Three out of 21 wells sampled in the sdv buried sand and gravel aquifer (Figure 6) had mixed tritium age; the other 18 samples had vintage tritium age. Samples from the three wells with mixed age tritium had elevated chloride concentrations. The sdv buried sand and gravel aquifer is relatively shallow and the low tritium values (1.3, 2.1, and 2.3 TU) in the three mixed age tritium samples and vintage tritium age in all other wells constructed into the sdv aquifer indicate relatively slow groundwater recharge from the land surface. All six water samples from the sdj buried sand and gravel aquifer (Figure 7) that were sampled for tritium had vintage tritium age, which is a strong indication of very low recharge rates.

With only two exceptions, all samples collected from wells stratigraphically deeper than the sdj buried sand and gravel aquifer (Figures 8 through 12) had vintage tritium age. This implies there is very little surface recharge below a depth of approximately 100 feet. The detectable tritium in samples from two deep wells is probably due to leakage of younger water into the well due to poor or degraded well construction. One well constructed in the su buried sand and gravel aquifer (Figure 11, center of cross section B–B′) to a depth of 282 feet had mixed tritium age and 12.1 ppm chloride. This well was drilled in 1961 and may have a problem with the casing. The other deep well that had a sample with mixed tritium age is a Mt. Simon well (shown on Figure 12) constructed to a depth of 500 feet. The water sample from this well had a tritium concentration of 2.7 TU. The estimated carbon-14 age of 11,000 years for this well is much less than the estimated carbon-14 ages from nearby deep bedrock wells, and is probably a result of younger water leaking into the well casing.

The well chemistry data affirm the sensitivity model. Three of the five water samples that had mixed tritium ages were collected from wells constructed in the shallow sdv buried sand and gravel aquifer. The other two water samples that had mixed tritium age are constructed in deeper aquifers and indicate problems with well construction. All other water samples had vintage tritium age and were consistent with the very low sensitivity rating of most of the buried aquifers.

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

NRCS Hydrologic Soil Group	Hydrologic Soil Group (0-3 feet) Transmission Rate [inches per hour]*	Geologic Texture (3 to 10 feet) Transmission Rate [inches per hour]*	McLeod County Surficial Geologic Unit (See Plate 4, Part A)	Geologic Textural Classification
A, A/D	1	1	--	gravel, sandy gravel, silty gravel
		0.71	sd	sand, fine sand, silty sand
B, B/D	0.50	0.50	al	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	--	clay, clay loam, silty clay loam, sandy clay, silty clay

*Estimated transmission rate through the matrix of unsaturated material (DNR, 2013).

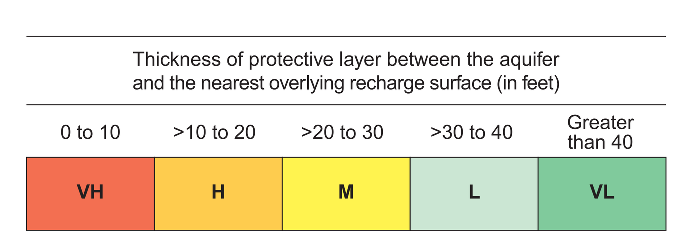

FIGURE 5. *Pollution sensitivity rating matrix.* *Pollution sensitivity is inversely proportional to the thickness of a protective layer between the top of an aquifer and the nearest overlying recharge surface as defined in Figure 4. Any buried aquifer with less than a 10-foot-thick protective layer 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.*

Base modified from Minnesota Geological Survey, McLeod County Geologic Atlas, Part A, 2009.
Project data compiled from 2010 to 2012 at a scale of 1:100,000 to 1:350,000. 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.