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

By

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INTRODUCTION

This plate describes the sensitivity to pollution of the buried sand aquifers in Todd County and of the near-surface materials (land surface to a depth of 10 feet) by infiltration 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. Countywide assessment of pollution sensitivity requires some generalizing assumptions. Flow paths from the land surface through the soil and underlying sediments to an aquifer are assumed to be 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. Permeability of the sediments is evaluated only qualitatively.

The sensitivity assessment is an empirical method that estimates the time of travel for water from infiltration at the land surface to the pollution sensitivity target. Figure 1, geologic sensitivity rating for buried sand aquifers, shows geologic sensitivity corresponding to an estimate of travel time to mapped buried sand aquifers. The ratings are based on 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 (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 geologic sensitivity rating in Figure 2 shows geologic sensitivity corresponding to 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 Todd County varies from hours to approximately a year. Areas with relatively short travel times (hours to weeks) are rated high or very high. Areas with longer travel times (months to a year) are rated low or very low.

The near-surface materials sensitivity rating has the same categories as the buried aquifer sensitivity rating, but with significantly different travel times; the two sensitivity ratings are shown in different colors to differentiate them from each other.

SENSITIVITY TO POLLUTION OF THE BURIED SAND AQUIFERS

Development of Sensitivity Model and Maps

The first step in creating a sensitivity model for the buried sand aquifers was to map the subsurface geology. Plate 7 includes maps of the thickness of the surficial sand and buried sand aquifers; the depth to buried sand aquifers is also shown on Plate 7. A version of the sand distribution models of the surficial sand and seven of the eight buried sand units shown on this plate was published on Plate 5, Part A, Sand Distribution Model. These sand models were modified for Plate 7. Using geographic information system (GIS) software, elevations based on 30-meter grids were calculated for the base of the surficial sand and the top and bottom of the buried sand units that could be mapped. The fine-grained material between the sand bodies (clay or till) is considered during mapping, but does not have its own gridded elevation surface. The volume of sediment between the bottom of one sand body and the top of the next lower sand body is assumed to consist of fine-grained material that acts as an aquitard and restricts the groundwater movement to the sand below.

Next, creation of pollution sensitivity maps for the buried sand aquifers was based on the method of vertical recharge surfaces used in previous County Geologic Atlases and Regional Hydrogeologic Assessments (Berg, 2006; Tipping, 2006; Petersen, 2007; and Berg, 2008). Recharge surfaces for the buried sand aquifers (Figures 5–12) were derived from the distribution and thickness of sand layers mapped on Figures 3–10, Plate 7.

The uppermost recharge surface (RS1) is initially positioned at the land surface (Figure 3). 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 sand below, then the assumption is that the first buried sand below is probably recharged vertically from water at RS1. Thus, water will travel vertically to the bottom of this buried sand body, 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 sand 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 fairly leaky and will allow relatively rapid recharge to the next deeper layer. Groundwater often moves horizontally, but that is not accounted for in this sensitivity model.

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 4). The thickness between the top of the aquifer and the nearest overlying recharge surface is used to determine the sensitivity to pollution. If the distance from the top of the aquifer to the nearest overlying recharge surface is less than 10 feet, the sensitivity rating is very high. If that thickness is between 10 and 20 feet, the sensitivity rating is high. If that distance is between 20 and 30 feet, the sensitivity rating is moderate. If that distance is between 30 and 40 feet, the sensitivity rating is low. If that distance is greater than 40 feet, the sensitivity rating is very low. A final condition that depends on the depth of the aquifer is also imposed. If the top of the aquifer is greater than 100 feet below land surface, then the sensitivity rating can be no higher than moderate. Deep aquifers, that would have a high or very high rating due to their proximity to a recharge surface, are assigned a moderate sensitivity rating because of the estimated time delay of water to reach that depth or greater.

Comparison of Sensitivity Model to Groundwater Chemistry Data from the Buried Sand Aquifers

The general chemistry and isotope analysis of groundwater samples can be useful in evaluating geologic sensitivity. Recent and 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 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 from a deeper aquifer.

Only one well from the C1 buried sand aquifer was sampled for tritium; the sample had a mixed tritium age (see Figure 5, cross section B–B′). It is in an area with very low sensitivity based on the buried aquifer criteria. The C1 aquifer at that location is overlain by the thick, but fairly sandy Cromwell Formation.

Water samples from the H1 buried sand aquifer are all from relatively shallow wells (Figure 6). Of the 16 wells sampled for tritium, all but two samples were recent or mixed age. These 14 samples of recent or mixed tritium age correspond to areas mapped as low sensitivity or higher, which is consistent with the sensitivity model. The vintage-age water sample on the west side of cross section D–D′, which is mapped as moderate to low sensitivity, might be in a regional discharge zone. Equipotential data for cross section D–D′ are not completely clear, but it is reasonable to assume that groundwater in the aquifer is moving toward Lake Osakis. The other H1 aquifer sample with vintage tritium age is from a well on the west end of cross section F–F′. The H1 aquifer at that location is beneath the New Ulm Formation, which has a clay loam texture. Many water samples from aquifers beneath the New Ulm Formation have little or no tritium.

Only two water samples were collected from the B3 buried sand aquifer (Figure 7). Both are mixed tritium age and are associated with areas rated low or very low sensitivity; however, the overlying tills are fairly sandy.

Twelve water samples were collected from the B2 buried sand aquifer (Figure 8). Two of these samples had recent tritium ages and the wells are located within or near high sensitivity areas. Four samples had mixed tritium ages and the wells were located within very low sensitivity areas. Four samples had vintage tritium ages. Three of these wells were located within very low sensitivity areas; the fourth well is located in a moderate to high sensitivity area. This fourth well with vintage tritium age is located in an area with high estimated senstivity, based on the vertical recharge model. However, groundwater in the B2 buried sand aquifer in this area is generally flowing horizontally from west to east (see cross section A–A′, Plate 8). Therefore, the vertical sensitivity model appears to overestimate the actual sensitivity near this well. Groundwater generally flows from west to east along cross section A–A′, so groundwater in the B2 buried sand aquifer receives older groundwater that is recharged through lower-permeability sediments. The mixed tritium age samples along cross section C–C′, which are located within areas rated as very low sensitivity, had tritium concentrations of 4.6, 2.2, and 1.9 tritium units (TU) from west to east, respectively. These tritium values, especially the last two, are on the low end of the mixed tritium age range. Thus, while not vintage tritium age, these samples had very little tritium present. The presence of tritium implies that the very low sensitivity rating in that area may be slightly too conservative, possibly because of undetected sand.

Twenty-one samples were collected from the B1 buried sand aquifer (Figure 9). Nine of the samples were vintage tritium age and all were collected from areas rated very low sensitivity. Seven of the samples were of mixed tritium age and were collected within or near low sensitivity areas. Five of the samples were of recent tritium age. Four of the five were collected near areas rated high sensitivity; the fifth was collected within an area rated very low sensitivity.

Fourteen wells constructed in the X3 buried sand aquifer were sampled (Figure 10) and eleven were analyzed for tritium. Five of the wells were located near areas rated high or very high sensitivity. Two of these five had tritium concentrations of 8.9 and 9.5 TU and also elevated chloride concentrations of 35.8 and 186.7 ppm, respectively. A third sample of these five also had elevated chloride (45.2 ppm); it was not sampled for tritium. The other two wells from this group had low chloride concentrations and were not sampled for tritium. All other sampled wells from the X3 buried sand aquifer were of mixed to vintage tritium age and near areas rated low sensitivity. No samples from the X3 buried sand aquifer were of recent tritium age.

Sixteen wells constructed in the X2 buried sand aquifer were sampled (Figure 11). Three of these wells are located near areas rated high to very high sensitivity. One of these three samples had recent tritium age and elevated chloride concentration. One of the three samples was mixed tritium age with very elevated chloride (152.1 ppm). The other sample was not analyzed for tritium. Nine wells are within areas mapped as very low sensitivity. Five of these nine samples had vintage tritium age, one had recent tritium, and the other three were not sampled for tritium. Two of these nine wells are located in the center of cross section F–F′; samples from both wells had elevated chloride, one had recent tritium, and the other well was not sampled for tritium. The X2 aquifer is overlain by thick till sequences in this area, suggesting that vertical travel times to this aquifer would be long. The recent tritium age water may have travelled laterally toward these two wells. Four wells were assigned to the X2 aquifer based on data from cross sections. These wells are in locations isolated from other X2 wells and the X2 aquifer was not mapped in plan view near these wells. Therefore, tritium data from these wells cannot be compared to a sensitivity rating.

Nine wells constructed in the X1 buried sand aquifer were sampled (Figure 12). Six samples had vintage tritium age, two had mixed age, and one had recent age. Most of these wells are fairly deep, with a mean depth of 140 feet and associated with areas rated very low sensitivity. Except for the one sample with recent tritium age, the tritium data are consistent with the sensitivity ratings. The sample with recent tritium age was obtained from a well located on the east side of cross section F–F′. The sample was collected from a flowing well, which had a carbon-14 age date of 800 years before present. The combination of recent tritium age and a carbon-14 age of 800 years in the same sample indicates mixing of young and old groundwater.

SENSITIVITY TO POLLUTION OF THE NEAR-SURFACE MATERIALS

The sensitivity to pollution assessment for near-surface materials estimates the time of travel for water to travel from the land surface to a depth of ten feet, and is shown in Figure 13. Soil properties are used to estimate the travel time from land surface to a depth of three feet and surficial geology properties are used to estimate the travel time from a depth of three feet to ten feet. The near-surface materials sensitivity assessment was created by estimating infiltration 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 3, Part A, Surficial Geology. Estimates of infiltration rates are shown in Table 1. The NRCS defines hydrologic groups based on a somewhat complicated system, but it is primarily based on the soil unit's texture and the presence or absence of dense, low permeability layers.

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.

Tipping (2006) estimated minimum transmission rates for the four soil hydrologic groups listed above based on an NRCS web publication that is no longer available. These estimates are reasonable, but not completely documented. The estimated rates have been used to make the near-surface materials sensitivity calculations on this plate because the numbers are of the correct order of magnitude, show the difference between coarse and fine-textured sediment, and allow consistent calculations within the county geologic atlas series.

Tipping (2006) also estimated minimum transmission rates for the surficial geologic units, which form the soil parent material. The minimum transmission rates for surficial geologic units in Todd County are mostly the same as those for Scott County used by Tipping (2006). The main difference is that ice-contact sand and gravel deposits, which have a very coarse texture, have been given a slightly higher minimum transmission rate of 0.6 inches per hour to differentiate them from sand units with less gravel. As with the estimates used for the soil hydrologic groups, these minimum infiltration rates are reasonable and in the correct order. That is, coarse-textured material is assigned significantly higher transmission rates than fine-textured material. These minimum transmission rate estimates are also used here for consistency within the county geologic atlas series.

The near-surface materials sensitivity rating is determined by using the minimum 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 GIS polygons from both the soil survey and the surficial geologic map are converted to grids with a 30 meter cell size. Each cell in the respective grids is assigned a minimum transmission rate as explained above. The travel time for the upper 3 feet is calculated using the minimum transmission rate of the soil unit. The travel time for 3 feet to 10 feet below land surface is calculated using the minimum 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 2). Some soil units have not been assigned a hydrologic group (for example gravel pits) and therefore have no assigned minimum transmission rate. If a minimum transmission rate was not available for a soil unit, then the surficial geology unit minimum transmission rate was used to calculate the travel time for the entire 10-foot distance.

The map of the near-surface materials sensitivity (Figure 13) rates most of Todd County as high sensitivity with fairly quick penetration of water from the land surface to a depth of ten feet. Very high near-surface sensitivity ratings are confined to surficial sands, which are primarily located in the river valleys.

Areas with low and very low near-surface materials sensitivity, in the southwest and southeast corners of Todd County, correlate with the occurence of surficial geologic units nt and nc of the New Ulm Formation. These units have very fine textures of clay loam and loam with low transmission rates. The three southwesternmost wells that were sampled for chemistry in this study are all located where New Ulm Formation is at the surface; the area has a very low near-surface sensitivity rating. Samples from two of these wells had no detectable tritium; these wells are plotted on Figure 6, pollution sensitivity of the H1 buried sand aquifer and Figure 10, pollution sensitivity of the X3 buried sand aquifer, respectively. A sample from the third well, which is completed in the N1 buried sand aquifer at the shallow depth of 35 feet, had a tritium concentration of only 1.7 TU; this well is shown on Figure 13.

Figure 13 has an overlay showing dense soil units. These dense soil units were defined by the NRCS and were assigned to hydrologic group C. The travel time model for these units predicts a travel time for water of 1000 hours from the land surface to a depth of 10 feet. This travel time is on the cusp between high and moderate near-surface sensitivity. Other factors, such as soil macropores which might increase the sensitivity, are not included in this analysis. Therefore, to be conservative, the data are grouped with the high sensitivity category. However, in the area shown by the dense soil overlay, the near-surface sensitivity may be slightly lower than indicated.

REFERENCES CITED

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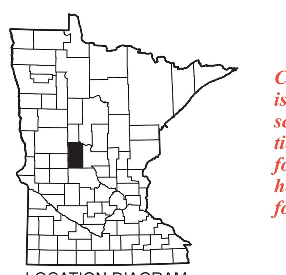

Caution: The information on these maps is a generalized interpretation of the sensitivity of groundwater to contamination. The maps are intended to be used for resource protection planning and to help focus the gathering of information for site-specific investigations.

MAP EXPLANATION
Figures 5–12

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

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).
- Well not sampled for tritium.

Well and aquifer symbols

- C1 buried sand aquifer.
- H1 buried sand aquifer.
- B3 buried sand aquifer.
- B2 buried sand aquifer.
- B1 buried sand aquifer.
- X3 buried sand aquifer.
- X2 buried sand aquifer.
- X1 buried sand aquifer.

Symbols and labels

- 5.25 If shown, arsenic concentration equals or exceeds 5 parts per billion.
- 14.5 If shown, chloride concentration equals or exceeds 5 parts per million.
- 2000 If shown, groundwater age in years, estimated by carbon-14 (^{14}C) isotope analysis.
- Well log used to map extent of aquifer.
- F F′ Line of cross section.
- Body of water.
- Extent of surficial sand aquifer.
- (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.
- (5) Distinctive groundwater chemistry; usually indicates deep groundwater of vintage tritium age that may or may not be in connection with shallow aquifers.

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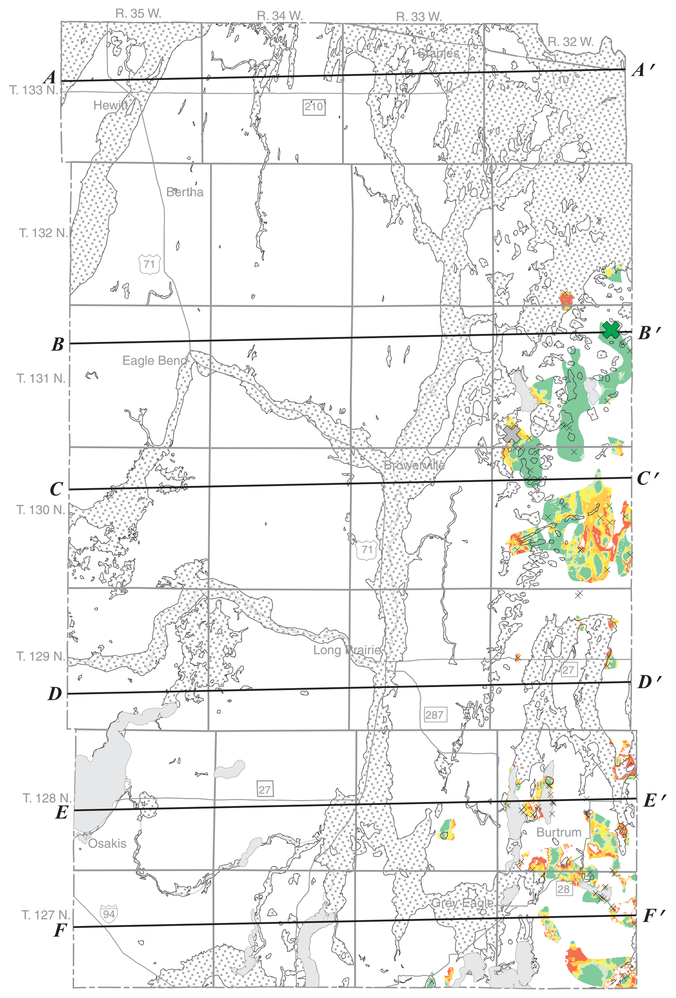

FIGURE 5. *Pollution sensitivity of the C1 buried sand aquifer.*

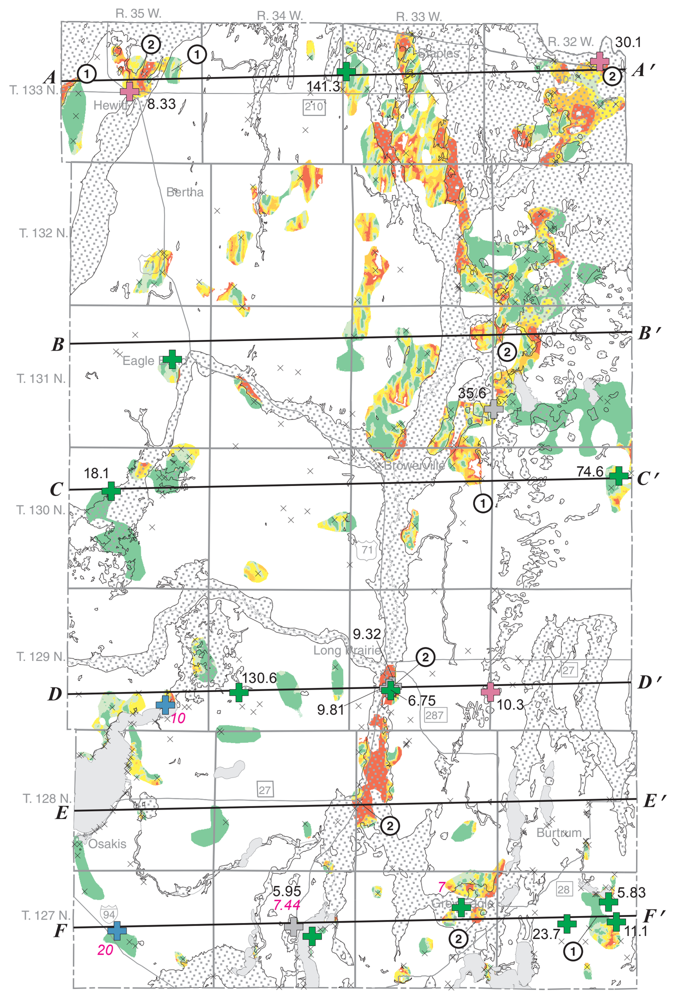

FIGURE 6. *Pollution sensitivity of the H1 buried sand aquifer.*

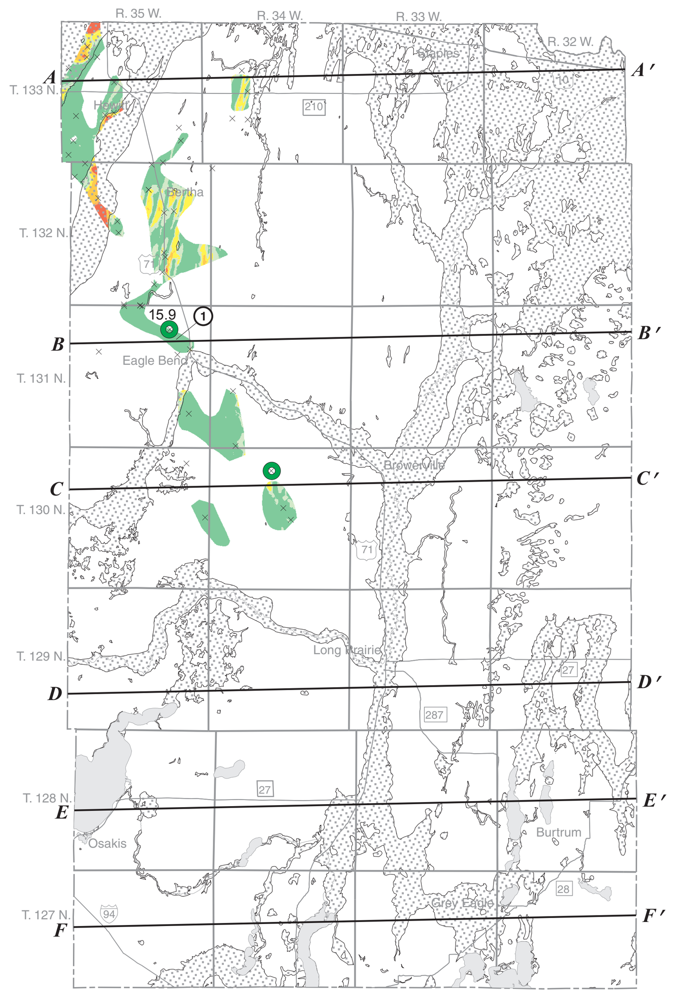

FIGURE 7. *Pollution sensitivity of the B3 buried sand aquifer.*

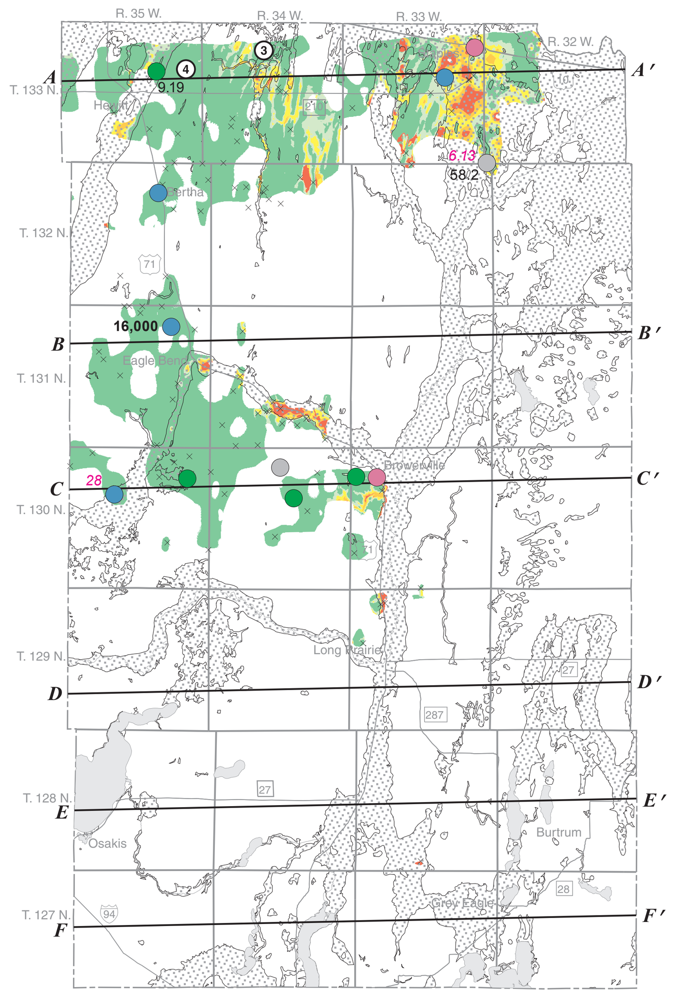

FIGURE 8. *Pollution sensitivity of the B2 buried sand aquifer.*

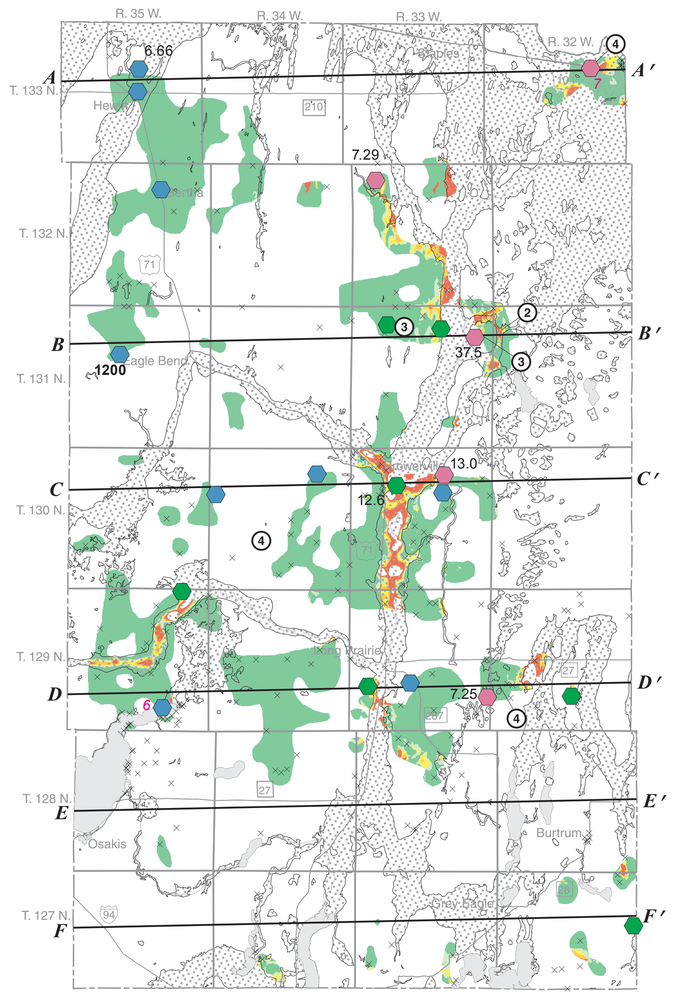

FIGURE 9. *Pollution sensitivity of the B1 buried sand aquifer.*

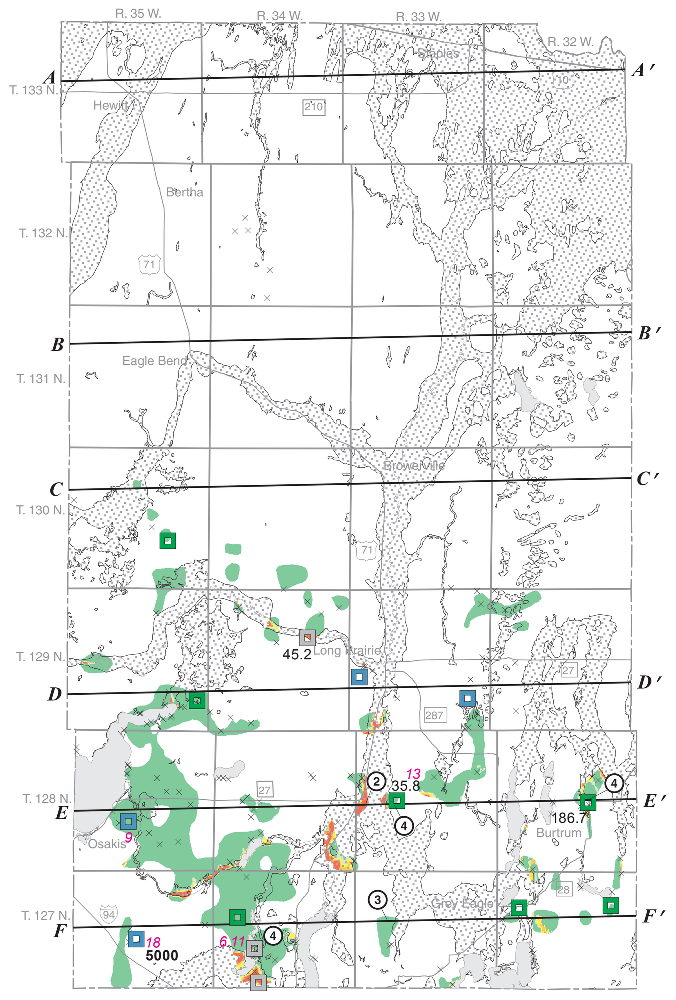

FIGURE 10. *Pollution sensitivity of the X3 buried sand aquifer.*

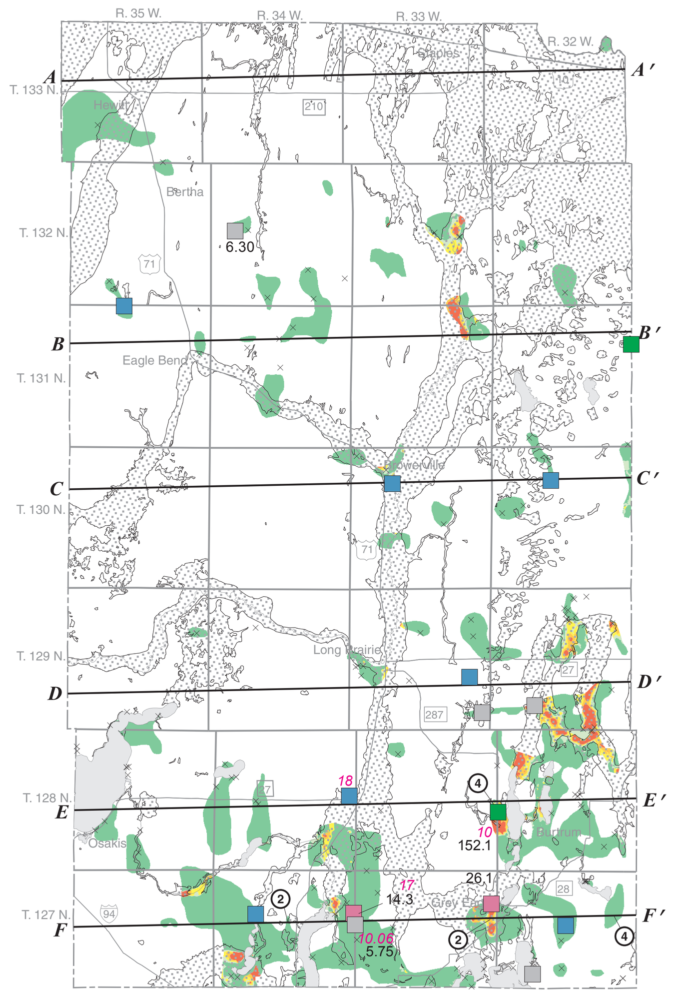

FIGURE 11. *Pollution sensitivity of the X2 buried sand aquifer.*

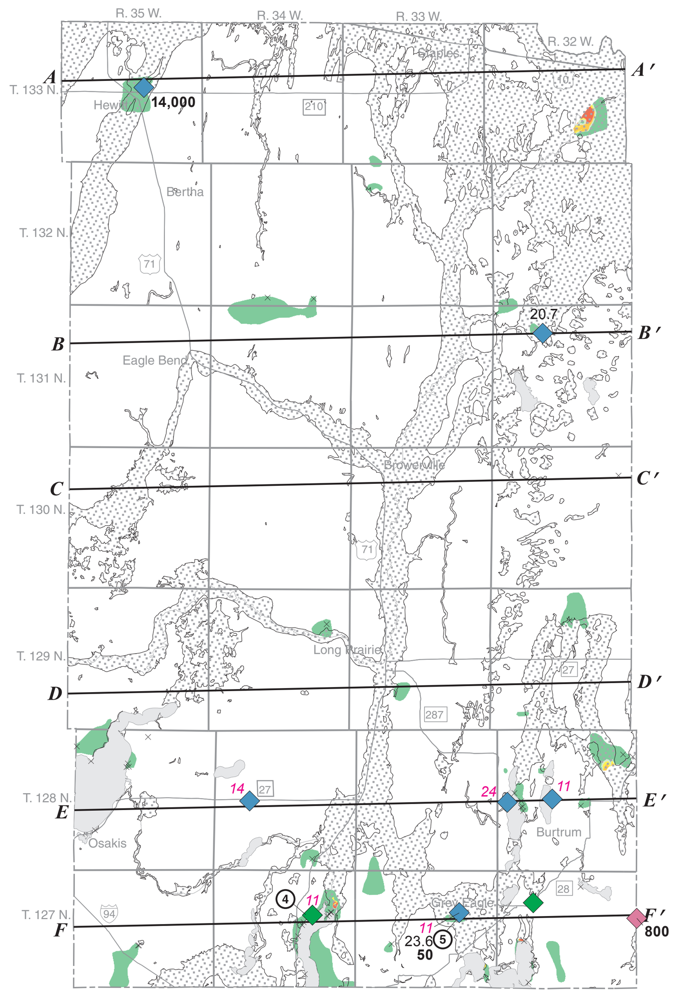

FIGURE 12. *Pollution sensitivity of the X1 buried sand aquifer.*

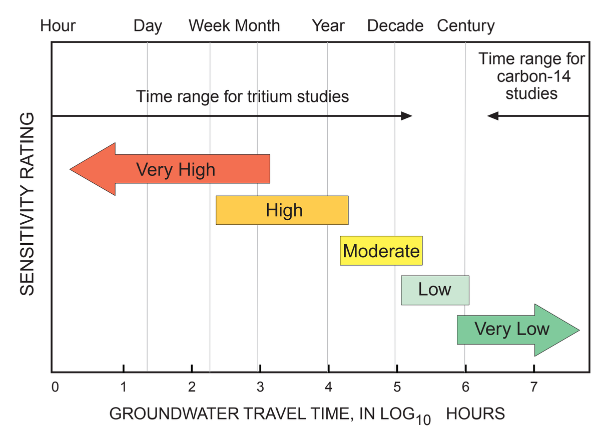

FIGURE 1. ***Geologic sensitivity rating for the buried sand aquifers as defined by vertical travel time*** *(Geologic Sensitivity Workgroup, 1991). Ratings are based on the time range required for water at or near the surface to travel vertically into the groundwater of interest or a pollution sensitivity target. Tritium and carbon-14 studies indicate the relative ages of groundwater.*

Depth from land surface to top of aquifer (in feet)	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	Greater than 40
Less than or equal to 100	VH	H	M	L	VL
Greater than 100	M	M	M	L	VL

FIGURE 4. ***Pollution sensitivity rating matrix.*** *Pollution sensitivity is inversely proportional to the thickness of a protective layer between the top of the aquifer and the nearest overlying recharge surface as defined in Figure 3. 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 to slow the travel time of water. A thicker overlying protective layer provides additional protection to the aquifer, and sensitivity ratings are assigned based on the thickness of this layer.*

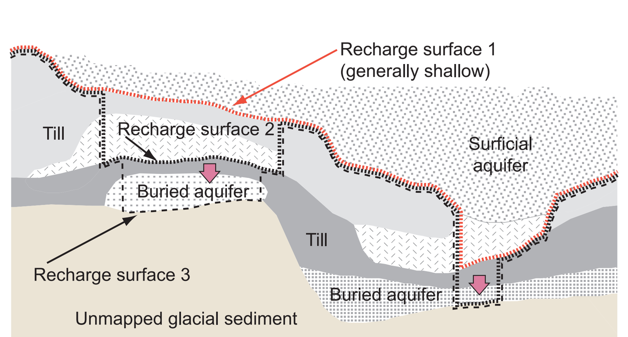

FIGURE 3. ***Generalized cross section showing recharge concepts for buried aquifers considered in the sensitivity evaluations.*** *In this model, all recent recharge enters the buried aquifer system at recharge surface 1 (red dotted line). Recharge surface 1 is considered to be at the land surface where till is present or at the bottom of surficial sand deposits. 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. A second deeper buried aquifer that has less than 10 feet of clay or till between it and the overlying buried aquifer is also assumed to allow further penetration of recent recharge. In that case, recharge surface 3 is defined at the bottom of this next deeper aquifer. The pink arrows indicate groundwater recharge of recent tritium age through a recharge surface.*

TABLE 1. Infiltration rates used to assess pollution sensitivity rating of near-surface materials. Minimum transmission rates for NRCS hydrologic groups are from Tipping (2006). Minimum transmission rates for surficial geology map units are modified from Tipping (2006). To differentiate sand deposits with significant gravel from other sand units, a separate designation for sand and gravel with a minimum transmission rate of 0.6 inches per hour has been added to the table.

NRCS hydrologic group rating	Texture	Minimum transmission rate (inches per hour)	Surficial geology map unit (Plate 3)	Texture	Minimum transmission rate (inches per hour)
Group A, A/D	sandy loam, loamy sand, loamy coarse sand, muck	0.3	ci, hhi, ni	sand and gravel	0.6
Group B, B/D	sandy loam, loamy sand	0.15	al, cho, cl, co, hl, ho, ld, nco, nho, nl, nuo	sand, sand and gravel	0.5
Group C, C/D	dense sandy loam or loamy sand	0.05	cc, ct, ctb, cth, ctp, ctt, hc, ht, htm, htp, htt	sandy-loam	0.3
Group D	peat and muck	0.01	bt, ntc, nth, pe	loam, peat	0.15
			nc, xt	loam to clay loam, dense silty-loam	0.05
			nt	clay loam	0.01

MAP EXPLANATION

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.

- VH Very High—Hours to weeks.
- H High—Weeks to a month.
- M Moderate—A month.
- L Low—Several months.
- VL Very Low—Months to a year.

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).
- Well not sampled for tritium.

Well and aquifer symbols

- Surficial sand aquifer.
- N1 buried sand aquifer.

Symbols and labels

- 14.5 If shown, chloride concentration equals or exceeds 5 parts per million.
- F F′ Line of cross section.
- Dense soil.

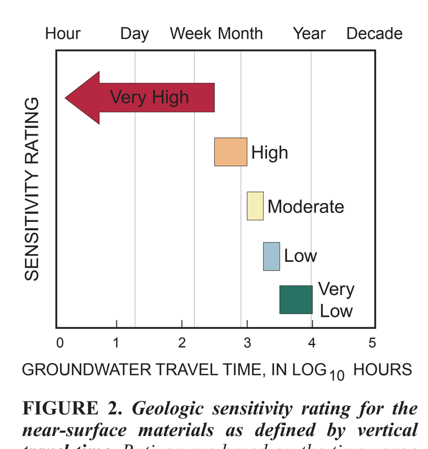

FIGURE 2. ***Geologic sensitivity rating for the near-surface materials as defined by vertical travel time.*** *Ratings are based on the time range required for water at or near the surface to travel vertically 10 feet through the vadose zone to the water table. Because the water table is not well mapped everywhere, it is assumed to be at 10 feet below land surface for this calculation.*

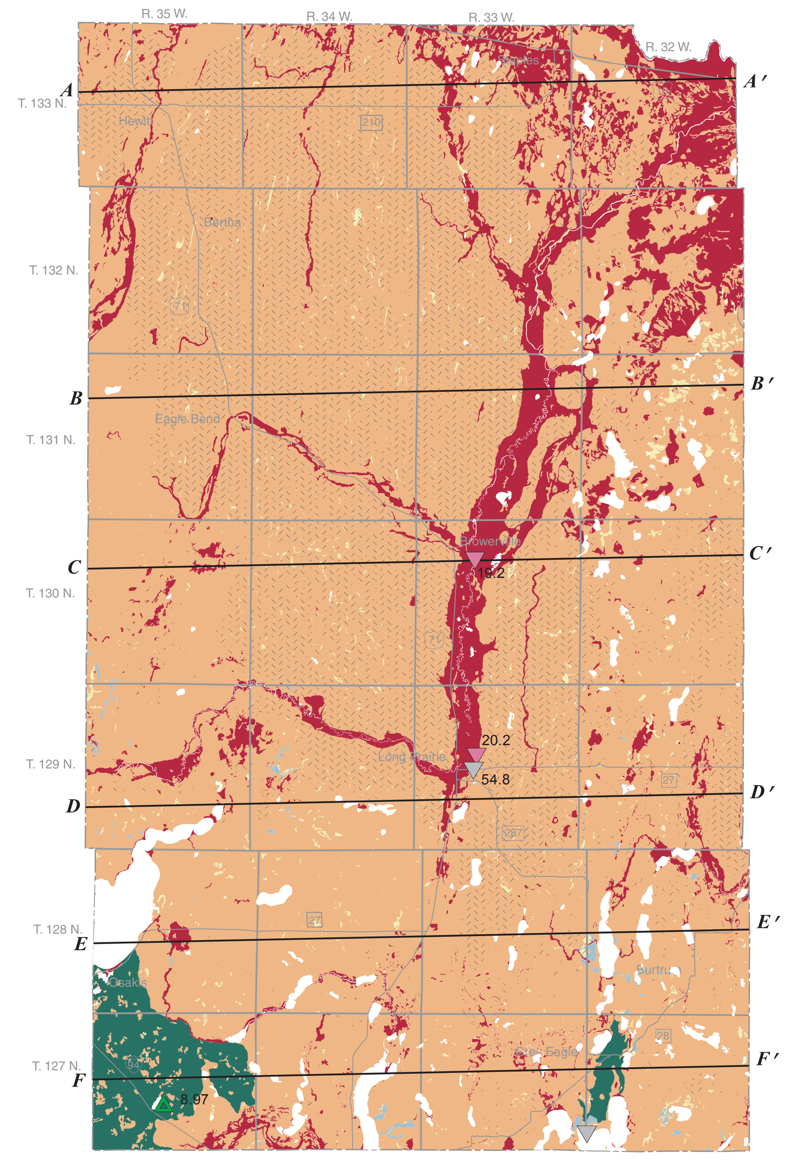

FIGURE 13. ***Pollution sensitivity of the near-surface materials.***

SCALE 1:300 000
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

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This information is available in alternative format on request.

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

Base modified from Minnesota Geological Survey, Todd County Geologic Atlas, Part A, 2007.
Project data compiled from 2006 to 2009 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 Todd Petersen and Greg Massaro. Edited by Neil Cunningham.