SENSITIVITY OF THE GROUNDWATER SYSTEMS TO POLLUTION

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INTRODUCTION

This plate describes the sensitivity to pollution of the buried sand aquifer units and of the near-surface materials. This sensitivity assessment is based on an empirical method that estimates the time of travel for water from infiltration at the land surface to the groundwater resource. For the purpose of this study, the near surface is defined as land surface to a depth of 10 feet.

Migration of contaminants dissolved in water through unsaturated and saturated sediments is a complex process that 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. Though horizontal flow paths may be more important in specific instances, they are not considered in this sensitivity model because they have not been adequately mapped. Permeability of the sediments is evaluated only qualitatively.

The geologic sensitivity rating of the near-surface materials in Figure 1 shows geologic sensitivity corresponding to an estimate of travel time from the land surface to a depth of 10 feet. This near-surface sensitivity rating estimate focuses on travel in the vadose zone, which is the unsaturated zone between the land surface and the water table. The time of travel through this thin surface layer in Benton 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.

Figure 2 shows the rating for geologic sensitivity that corresponds to an estimate of travel time to mapped buried sand and gravel 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 sensitivity rating has the same categories as the buried aquifer sensitivity rating, but with significantly different travel times; the two sensitivity ratings are represented by two different color sets to distinguish the rating systems.

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 3. Soil properties are used to estimate the travel time from land surface to a depth of three feet and surficial geologic unit properties are used to estimate the travel time from a depth of three to ten feet. The near-surface materials sensitivity assessment was created by estimating infiltration rates using soils and surficial geologic units based on the Natural Resources Conservation Service (NRCS) hydrologic rating for Benton County soils (NRCS, 2009) and the geologic unit texture of deeper parent materials, from Plate 3, Part A, Surficial Geology. The NRCS definition of hydrologic groups is primarily based on soil texture and the presence or absence of dense, low permeability layers.

Estimates of infiltration 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.

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 in 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 that form the soil parent material. The minimum transmission rates for surficial geologic units in Benton County are similar to those used by Tipping (2006) for Scott County, but are slightly modified. 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 a significantly higher transmission rate than fine-textured material.

The near-surface materials sensitivity rating is determined by combining 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. Using geographic information system (GIS) techniques, GIS geospatially defined polygons from both the soil survey and the surficial geologic map were combined; the total travel time to 10 feet was calculated using the soil transmission rate for the upper three feet and the surficial geologic material rate for the lower seven feet.

The pollution sensitivity rating of the combined travel time estimate from both layers is shown in Figure 3 as the near-surface materials geologic sensitivity. Most of the study area is rated as very high to moderate sensitivity. Very high and high near-surface sensitivity ratings occur primarily in the areas where surficial sands are mapped in the area of Rice Area aquifer system, the Anoka Sand Plain aquifer system, and in river valleys. Moderate near-surface sensitivity occurs in the upland till plain where surface sands are typically not present.

Areas with low and very low near-surface materials sensitivity are very limited and only mapped in a portion of the Elk River, Stony Brook, St. Francis River valleys, and in isolated areas of the upland in drumlin swales. The areas with low near-surface materials sensitivity were mapped primarily with the occurrence of soil hydrologic group D, the very poorly drained hydrologic soil group. The areas with very low near-surface materials sensitivity were mapped primarily with the occurrence of surficial geologic units ƐA (bedrock outcrop) and Qnl, which is thickly bedded New Ulm lake clay and silt.

SENSITIVITY TO POLLUTION OF THE BURIED SAND AQUIFERS

Development of Sensitivity Model and Maps

The geologic maps and associated stratigraphic information created for Plates 3, 4, and 5 of Part A form the basis for all of the hydrogeologic maps and cross sections for this Part B. For this report some of the information from Part A was reclassified and reinterpreted to separate the surficial sand aquifer from the buried sand and gravel units that are most commonly treated as hydrologically confined aquifers. For example, the extent and thickness of the surficial sand and gravel model as well as units Qse and Qsb shown on Figures 3, 4, and 5, respectively, on Plate 5 of Part A have been modified. The Qse and Qsb geologic map units are shown in this report as the less extensive corresponding supra-Emerald and sub-Emerald buried sand aquifer units (se and sb, respectively). The portions of these units that appear to have direct hydrologic connection with the surficial sand aquifer have been incorporated into the surficial sand aquifer. The relationship between geologic map units and aquifers is illustrated on Plate 7.

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, 2010). This method models how water from precipitation infiltrates the land surface and proceeds to directly recharge portions of the first underlying aquifer and, subsequently, portions of deeper aquifers. The central concept of the vertical recharge model is to identify or map locations of focused, relatively rapid recharge. In focused recharge, portions of aquifers overlap and are connected by complex pathways that allow surface water to infiltrate to buried aquifers. The sensitivity model for the buried aquifers simplifies this concept by dividing focused recharge into discrete surfaces at the base of each aquifer, which are called recharge surfaces. Each buried aquifer receives focused recharge from the base of the overlying aquifer if the lower permeability layer of silt or clay separating those aquifers is thin or absent.

The vertical recharge path of water for a stack of aquifers typical of the study area is shown in Figure 4. The uppermost recharge surface (RS1) is initially positioned at the land surface. 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). This model assumes that clay layers less than 10 feet thick are leaky and will allow relatively rapid recharge to the next deeper layer. 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.

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 rating. 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 otherwise 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 travel time of water to reach that depth or greater.

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

The general chemistry and isotope analysis of groundwater samples is 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 ratios of chloride to bromide concentration (Cl/Br) greater than 300 indicate a likely anthropogenic source of chloride that usually implies moderate to high sensitivity (Berg, 2004; Davis and others, 1998). In a few cases an elevated Cl/Br ratio is found in groundwater samples without detectable tritium. Concentrations of nitrate in groundwater greater than approximately 1 part per million (ppm) indicate anthropogenic sources and aquifer sensitivity (Minnesota Pollution Control Agency, 1998). The drinking water health standard for nitrate is 10 ppm. The Minnesota Pollution Control Agency (2001) found that the concentration of nitrate in groundwater was related to surrounding land use, and that nitrate concentrations were greatest under irrigated agricultural land and nonsewered residential land.

Water samples from the supra-Emerald buried aquifer unit (se) are from wells ranging in depth from 30 to 90 feet (Figure 6). Of the 23 wells sampled for tritium, all of the samples were recent or mixed age. The 23 samples of recent or mixed tritium age correspond to areas rated as high to very high sensitivity, which is consistent with the sensitivity model. All but three of the supra-Emerald aquifer unit water samples had Cl/Br values that were above the threshold of 300, and nine of the 23 water samples had nitrate concentrations that were above 1 ppm and four that were above the drinking water standard of 10 ppm, indicating a general sensitivity of the aquifer to pollution.

Forty-two water samples were collected from the sub-Emerald buried aquifer unit (sb) (Figure 7). Six of these samples had recent tritium ages and the wells are located within or near high sensitivity areas. Five samples from these wells had elevated Cl/Br ratios. Twenty-six samples had mixed tritium ages and the wells were primarily located in areas with a low to very low sensitivity rating. Ten of the water samples from the sub-Emerald aquifer unit had vintage tritium ages, and all but one of these samples were located in areas of very low sensitivity. Sixteen of the sub-Emerald aquifer unit water samples had nitrate concentrations greater than 1 ppm and four of those had concentrations greater than 10 ppm. Only one vintage age sub-Emerald aquifer unit water sample had a Cl/Br ratio greater than 300 (far western end of cross section F–F′ on Plate 7), and that well has a casing 54 feet deep, encounters bedrock at 58 feet deep, and had a unique water chemistry. The carbon-14 age for this water was estimated at 400 years old, confirming low sensitivity and vintage age. It is possible that this well draws water from an area where regional groundwater discharges to the Mississippi River.

Pollution sensitivity of the two deepest pre-Wisconsinan buried aquifer units sx and sw, are combined in Figure 8. Eleven samples were collected from the sx aquifer and five were collected from the sw aquifer. Three of the sx samples were recent tritium age and showed elevated Cl/Br; three samples were mixed age tritium and one of these samples had elevated Cl/Br; and five samples were vintage tritium age with no elevated Cl/Br. One of the five sw water samples was recent tritium age and had elevated Cl/Br; two of the samples were mixed tritium age with one sample showing elevated Cl/Br; and two of the samples were vintage tritium age with no elevated Cl/Br. The only water sample from either of the two deep buried sand aquifers with a nitrate concentration greater than 1 ppm was the sx well east of Little Rock Lake, and the well sample from that well also had elevated Cl/Br. Most of the sx and sw aquifers were rated as very low pollution sensitivity. The portions of these aquifers that are moderate to very high sensitivity are a part of the Rice Area aquifer system in northwest Benton County with hydraulic connection of aquifers as discussed on Plate 8.

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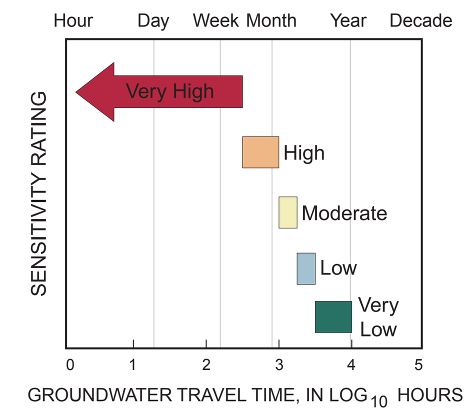


FIGURE 1. *Geologic sensitivity rating for the near-surface materials as defined by vertical travel time (Tipping, 2006).* *Ratings are based on the time range required for water at the land surface to travel vertically 10 feet through the vadose zone to the water table. Because the water table is not well mapped everywhere, it is assumed for this calculation to be at 10 feet below land surface.*

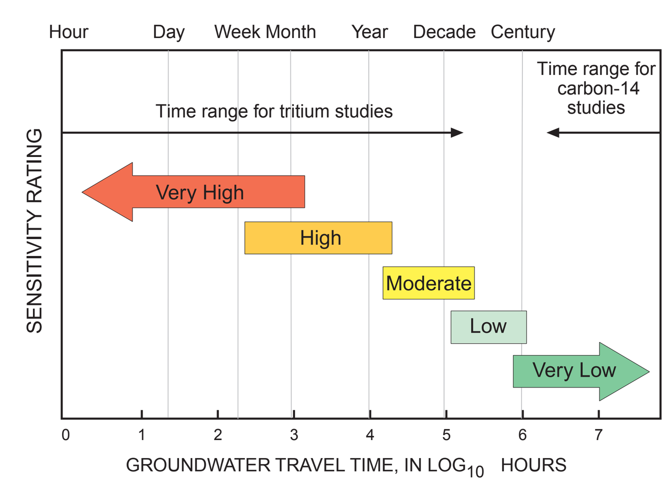


FIGURE 2. *Geologic sensitivity rating for the buried sand and gravel aquifers as defined by vertical travel time (Geologic Sensitivity Workgroup, 1991).* *Ratings are based on the time range required for water at or near the surface to travel vertically into the groundwater of interest or a pollution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

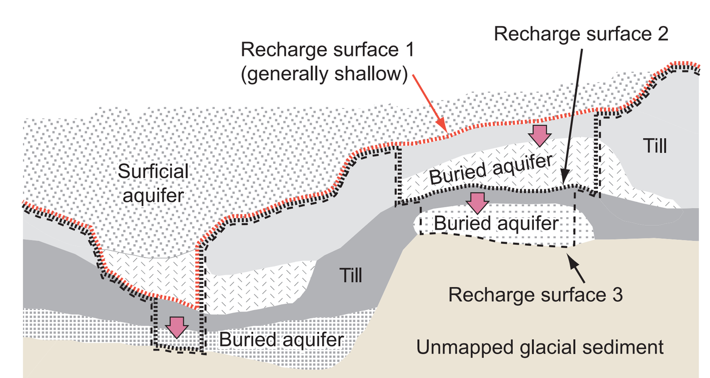


FIGURE 4. *Generalized cross section showing recharge concepts for buried aquifers considered in the sensitivity evaluations.* *In this model, recent recharge enters the buried aquifer system at recharge surface 1 (red dotted line). Recharge surface 1 is at the land surface where till is present or at 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.*

MAP EXPLANATION FOR 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.

- 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.

Well and aquifer symbols

- Surficial sand aquifer.

Tritium age

Color indicates tritium age of water sampled in well.

- Mixed—Water is a mixture of recent and vintage waters (greater than 1 TU to less than 10 TU).

Symbols and labels

- 20.2 — If shown, nitrate as nitrogen concentration equals or exceeds 10 parts per million.
- If shown on well symbol, chloride to bromide ratio greater than 300.
- Selected well log used to map extent of aquifer.
- Area Aquifer System.
- F F′ — Line of cross section.
- Body of water.

SCALE 1:200 000
COMPILATION SCALE 1:100 000
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 KILOMETERS

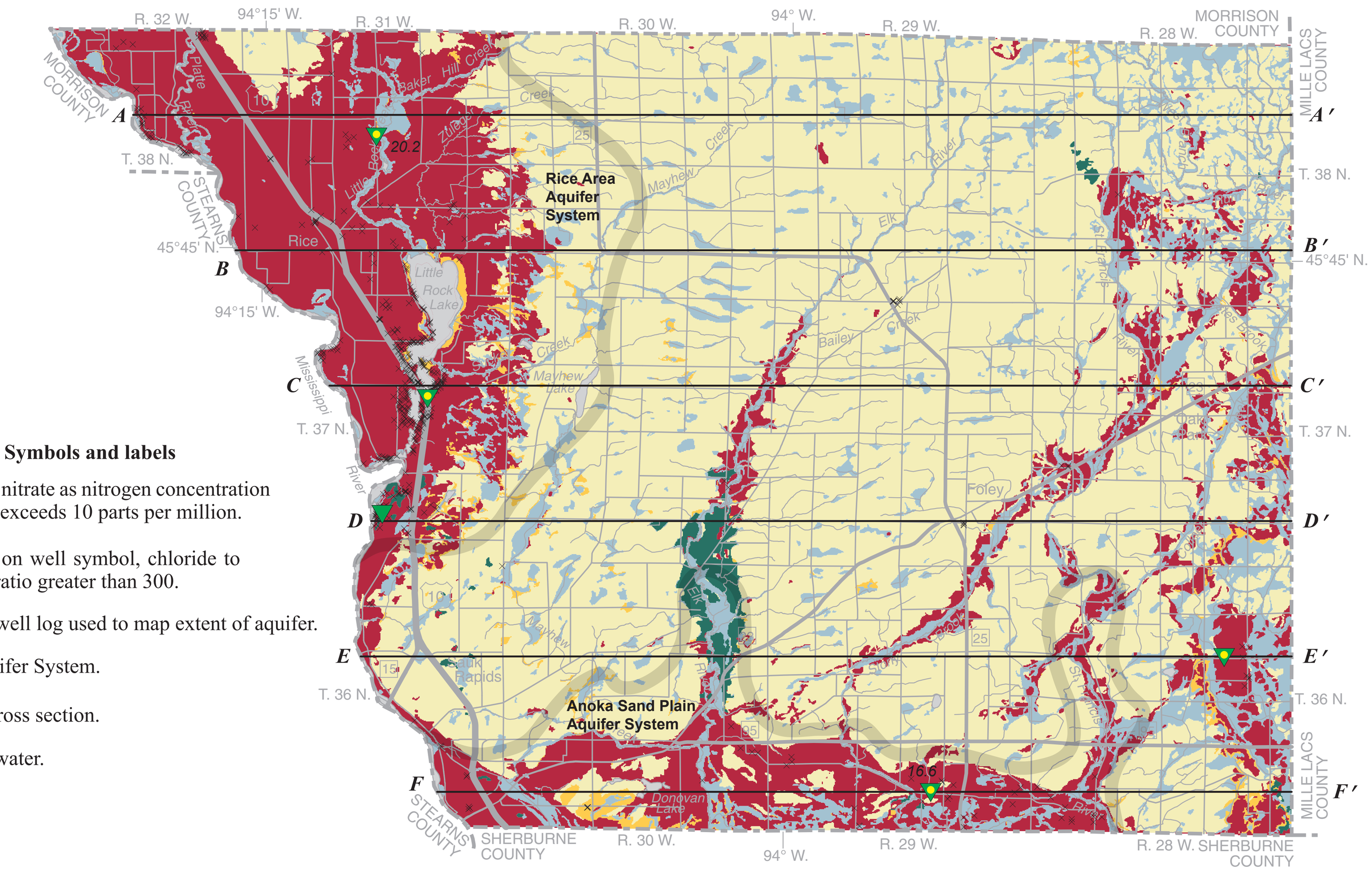


FIGURE 3. *Pollution sensitivity of the near-surface materials.*

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.

Depth from land surface to top of aquifer (in feet)	Thickness of fine-grained 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 5. *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 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 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.*

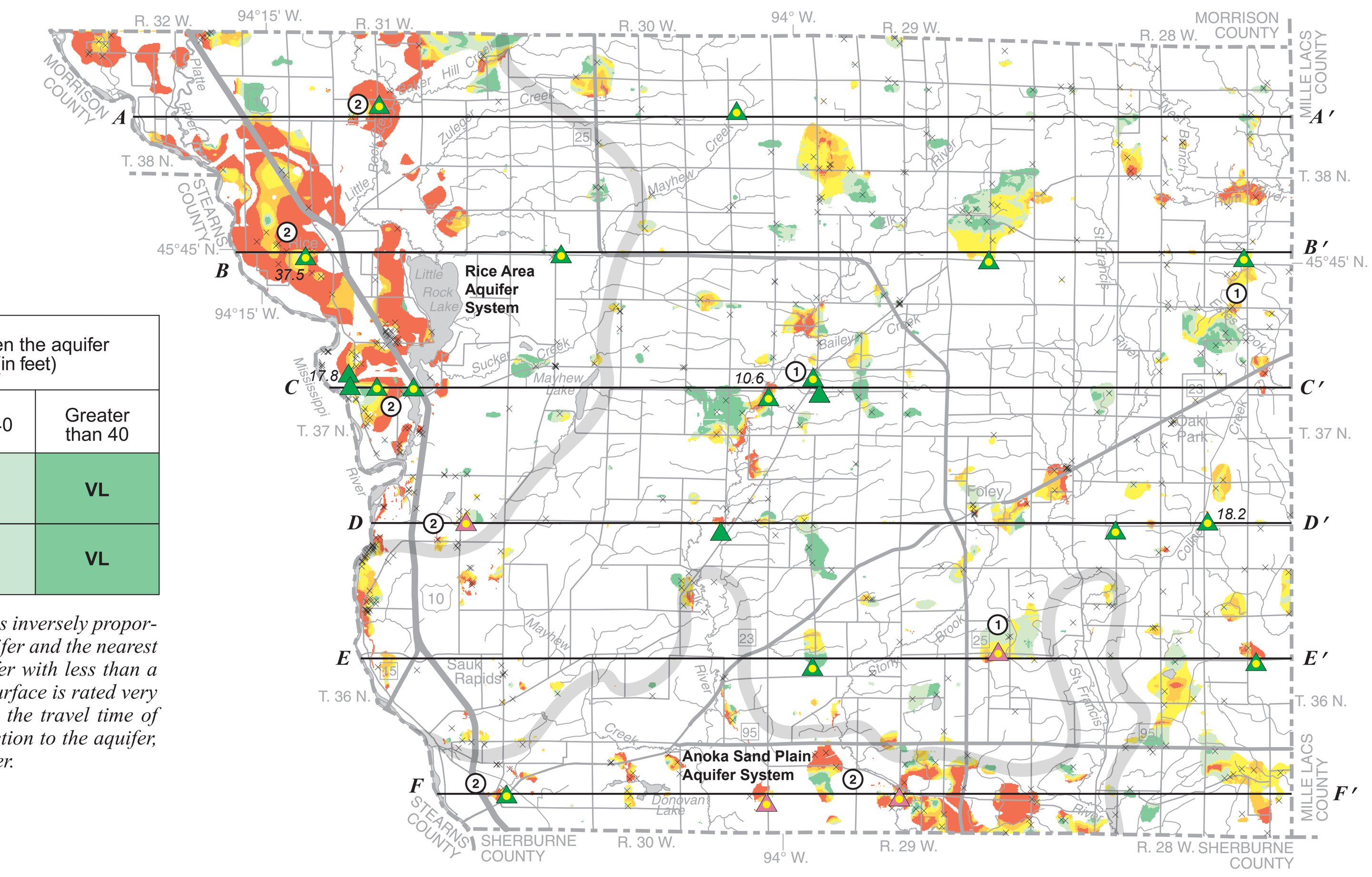


FIGURE 6. *Pollution sensitivity of the supra-Emerald buried aquifer unit (se).*

SCALE 1:200 000
COMPILATION SCALE 1:100 000
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 KILOMETERS

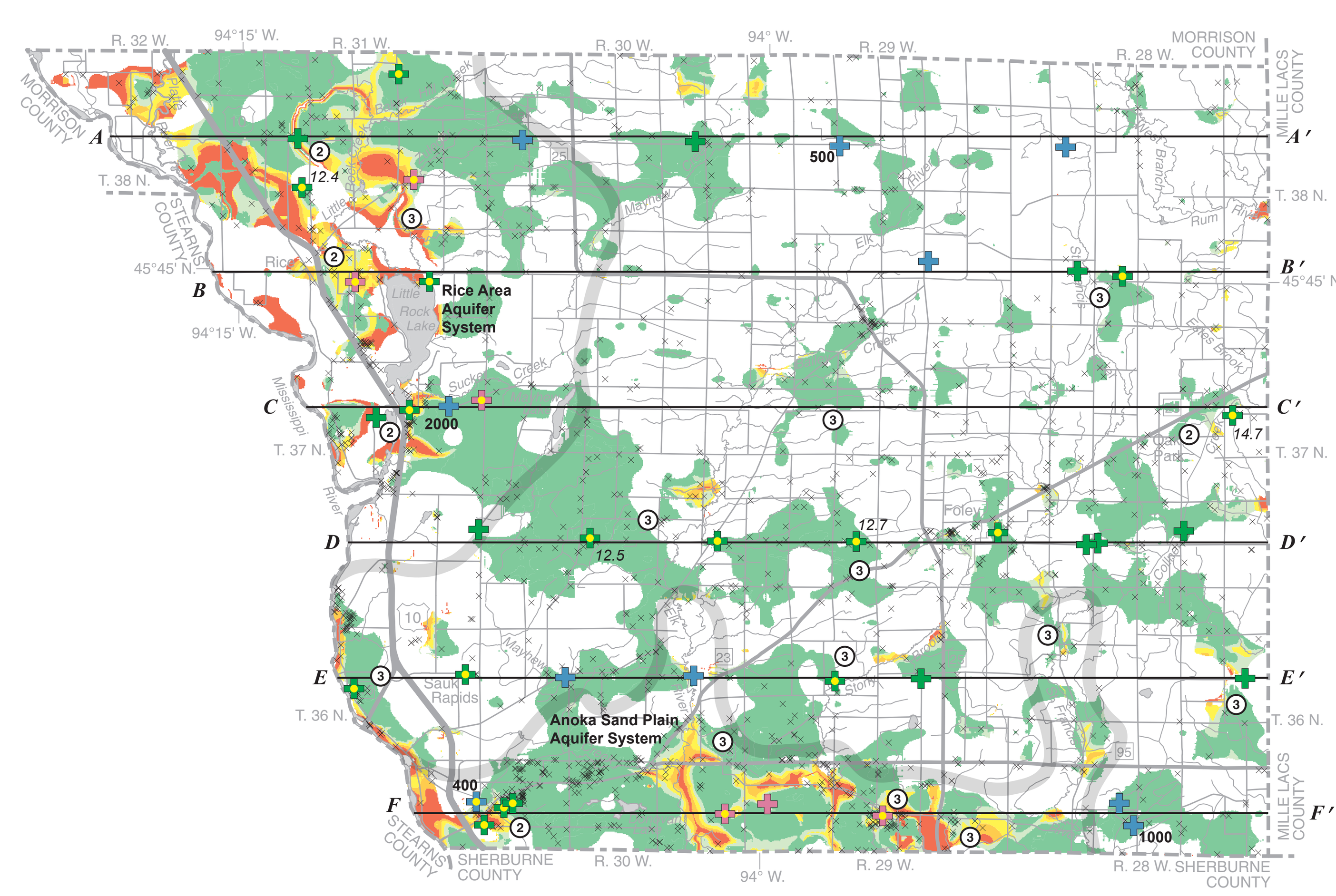
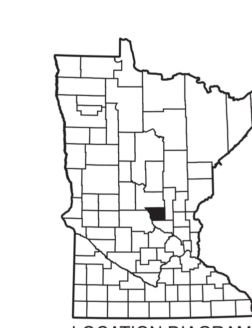


FIGURE 7. *Pollution sensitivity of the sub-Emerald buried aquifer unit (sb).*



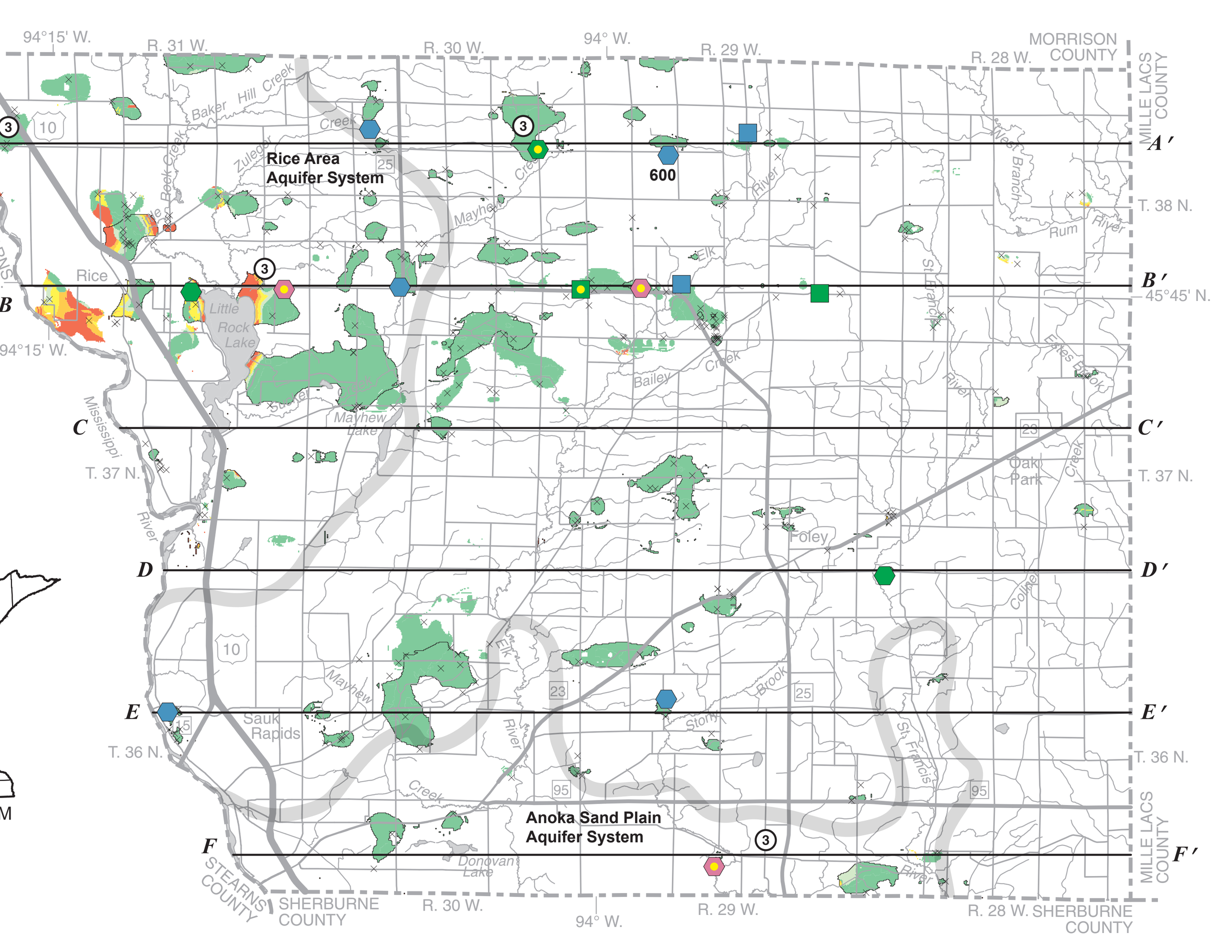


FIGURE 8. *Pollution sensitivity of the composite pre-Wisconsinan buried sand aquifer units, sx and sw (sx if outlined).*

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).

NRCS hydraulic group rating	Texture	Minimum transmission rate (inches per hour)	Surficial geology map unit (Plate 3 of Part A)	Texture	Minimum transmission rate (inches per hour)
Group A, AD	loamy sand, loamy fine sand, loamy coarse sand, fine sand, fine sandy loam	0.3	Qa, Qcf, Qci, Qco, Qcs,Qf, Qno, Qnw, Qwh, Qwl, Qwr	sand and gravel to sand	0.5
Group B, BD	silt loam, loamy fine sand, fine sandy loam, sandy loam, loam	0.15	Qcd, Qct, Qe, Ql, Qnd, Qns	loamy fine sand to sandy loam	0.3
Group C, CD	fine sand, fine sandy loam, loamy fine sand, loam	0.05	Qp	peat	0.15
Group D	mucky silty clay loam, loamy, silt loam, fine sandy loam	0.01	ƐA, Qnl	clay loam or bedrock outcrop	0.01

MAP EXPLANATION
Figures 6, 7, 8

Pollution sensitivity rating for buried sand aquifers

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

- Surficial sand aquifer.

Buried sand and gravel aquifer units.

- Supra-Emerald aquifer unit (se)
- Sub Emerald aquifer unit (sb)
- Pre-Wisconsinan aquifer unit (sx)
- Pre-Wisconsinan aquifer unit (sw)

Other wells.

- Unmapped buried aquifer
- Bedrock

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).

Symbols and labels

- 12.5 — If shown, nitrate as nitrogen concentration equals or exceeds 10 parts per million.
- If shown on well symbol, chloride to bromide ratio greater than 300.
- 2000 — If shown, groundwater age in years, estimated by carbon-14 (^{14}C) isotope analysis.
- Selected well log used to map extent of aquifer.
- Area aquifer system.
- F F′ — Line of cross section.
- Body of water.

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 through multiple aquifers and fine-grained layers.

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.

Base modified from Minnesota Geological Survey, Benton County Geologic Atlas, Part A, 2010.
Project data compiled from 2010 to 2011 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 Jeremy Rivord, Greg Massaro, and Shana Pascal. Edited by Neil Cunningham and Jan Falteisek.