SENSITIVITY TO POLLUTION OF THE UPPERMOST BEDROCK AQUIFERS

By

James A. Berg

2003

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Digital base composite:
Roads and county boundaries - Minnesota Department of Transportation GIS Statewide Base Map (source scale 1:24,000)
Hydrologic features - U.S. Geological Survey Digital Line Graphs (source scale 1:100,000)
Digital base annotation - Minnesota Geological Survey
Project data compiled from 1998 to 2001 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 Mike Tronrud and Jim Berg. Edited by Nick Kroska.

SCALE 1:100 000
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 6 7 8 KILOMETERS

LOCATION DIAGRAM

Caution: The information on this map is a generalized interpretation of the sensitivity of ground water to contamination. The map is intended to be used for resource protection planning and to help focus the gathering of information for site-specific investigations.

MAP EXPLANATION

Well Symbols

Shape indicates aquifer

- Galena
- St. Peter
- Prairie du Chien
- Jordan
- Franconia
- Ironton-Galesville
- Mt. Simon

Color indicates tritium age

- Recent—Waters with tritium concentrations of 10 tritium units (TU) or more entered the ground water since 1953.
- Mixed—Waters with 0.8 to 10 TU are a mixture of recent and vintage.
- Vintage—Waters with less than 0.8 TU entered the ground water before 1953.
- Well not tested for tritium.

Sensitivity Ratings

Estimated vertical travel time for water-borne surface contaminants to enter the uppermost bedrock aquifers (target zone)

- 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

Overlying Sediments

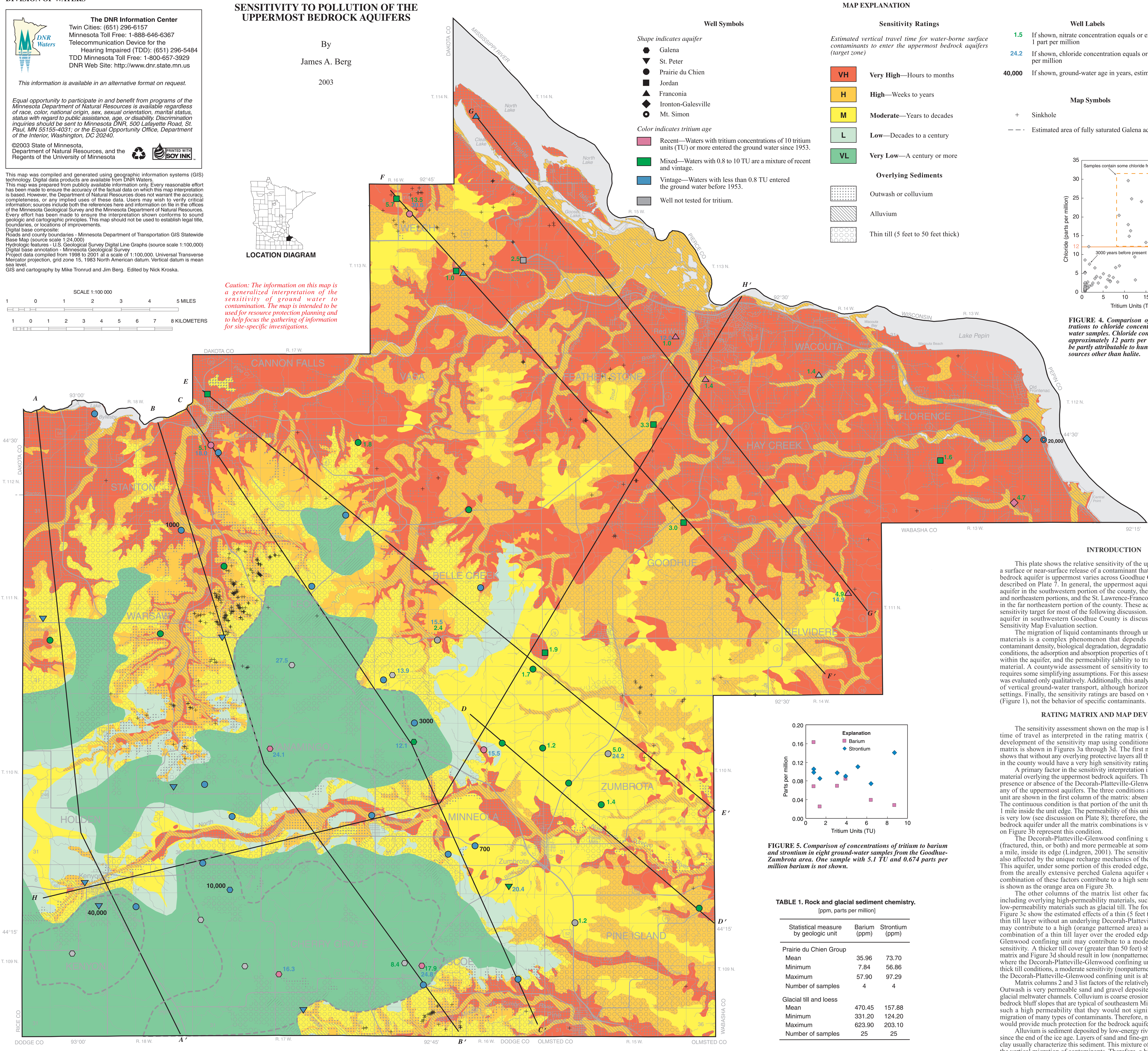
- Outwash or colluvium
- Alluvium
- Thin till (5 feet to 50 feet thick)

Well Labels

- 1.5 — If shown, nitrate concentration equals or exceeds 1 part per million
- 24.2 — If shown, chloride concentration equals or exceeds 12 parts per million
- 40,000 — If shown, ground-water age in years, estimated by carbon-14

Map Symbols

- + Sinkhole
- – – Estimated area of fully saturated Galena aquifer



Decorah-Platteville-Glenwood confining unit	Uppermost bedrock aquifer at or near surface	Characteristic of sediment overlying uppermost bedrock aquifer			
		Outwash or colluvium	Alluvium	Till thickness 5 to 50 feet	Till thickness more than 50 feet
Absent	VH	VH	H	H*	M
Eroded edge	H*	H	M	M*	L
Continuous	VL	VL	VL	VL	VL

*Very high locally where sinkholes are present; may imply increased sensitivity over a large area where sinkholes occur in clusters. See Plate 10.

FIGURE 2. ***Sensitivity matrix for sensitivity ratings. Ratings show the influence of combinations of geologic features on the sensitivity of the uppermost bedrock aquifers (except Galena aquifer; see text). Features include the Decorah-Platteville-Glenwood confining unit and various surficial sediments.***

FIGURE 4. ***Comparison of tritium concentrations to chloride concentrations from well water samples. Chloride concentrations above approximately 12 parts per million appear to be partly attributable to human activities from sources other than halite.***

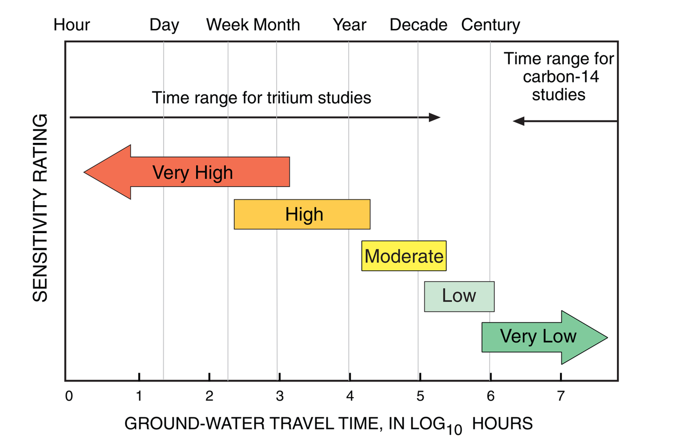


FIGURE 1. ***Geologic sensitivity rating as defined by vertical travel time (Geologic Sensitivity Workgroup, 1991). Ratings are based on the time range required for water at or near the surface to travel vertically into the uppermost bedrock aquifers (sensitivity target). Tritium and carbon-14 studies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

FIGURE 5. ***Comparison of concentrations of tritium to barium and strontium in eight ground-water samples from the Goodhue-Zumbrota area. One sample with 5.1 TU and 0.674 parts per million barium is not shown.***

TABLE 1. Rock and glacial sediment chemistry.
[ppm, parts per million]

Statistical measure by geologic unit	Barium (ppm)	Strontium (ppm)
Prairie du Chien Group		
Mean	35.96	73.70
Minimum	7.84	56.86
Maximum	57.90	97.29
Number of samples	4	4
Glacial till and loess		
Mean	470.45	157.88
Minimum	331.20	124.20
Maximum	623.90	203.10
Number of samples	25	25

INTRODUCTION

This plate shows the relative sensitivity of the uppermost bedrock aquifers to a surface or near-surface release of a contaminant that would act like water. Which bedrock aquifer is uppermost varies across Goodhue County because of erosion as described on Plate 7. In general, the uppermost aquifer is the St. Peter-Shakopee aquifer in the southwestern portion of the county, the Jordan aquifer in the central and northeastern portions, and the St. Lawrence-Franconia-Ironton-Galesville aquifer in the far northeastern portion of the county. These aquifers will be considered the sensitivity target for most of the following discussion. The sensitivity of the Galena aquifer in southwestern Goodhue County is discussed below at the end of the Sensitivity Map Evaluation section.

The migration of liquid contaminants through unsaturated and saturated earth materials is a complex phenomenon that depends on many factors, including contaminant density, biological degradation, degradation under oxidizing or reducing conditions, the adsorption and absorption properties of the geologic materials, dilution within the aquifer, and the permeability (ability to transmit water) of the geologic material. A countywide assessment of sensitivity to a hypothetical contaminant requires some simplifying assumptions. For this assessment, the permeability factor was evaluated only qualitatively. Additionally, this analysis is based on the assumption of vertical ground-water transport, although horizontal flow dominates in many settings. Finally, the sensitivity ratings are based on vertical time of travel criteria (Figure 1), not the behavior of specific contaminants.

RATING MATRIX AND MAP DEVELOPMENT

The sensitivity assessment shown on the map is based on sensitivity classes of time of travel as interpreted in the rating matrix (Figure 2). A layer-by-layer development of the sensitivity map using conditions and ratings specified in the matrix is shown in Figures 3a through 3d. The first map of this series (Figure 3a) shows that without any overlying protective layers all the uppermost bedrock aquifers in the county would have a very high sensitivity rating.

A primary factor in the sensitivity interpretation is the permeability of geologic material overlying the uppermost bedrock aquifers. This appears in the matrix as the presence or absence of the Decorah-Platteville-Glenwood confining unit overlying any of the uppermost aquifers. The three conditions affecting permeability of this unit are shown in the first column of the matrix: absent, eroded edge, or continuous. The continuous condition is that portion of the unit that is approximately ¼ mile to 1 mile inside the unit edge. The permeability of this unit under continuous conditions is very low (see discussion on Plate 8); therefore, the sensitivity of the underlying bedrock aquifer under all the matrix combinations is very low. The dark green areas on Figure 3b represent this condition.

The Decorah-Platteville-Glenwood confining unit is expected to be eroded (fractured, thin, or both) and more permeable at some distance, possibly less than a mile, inside its edge (Lindgren, 2001). The sensitivity rating of this condition is also affected by the unique recharge mechanics of the underlying bedrock aquifer. This aquifer, under some portion of this eroded edge, receives additional recharge from the areally extensive perched Galena aquifer on the Decorah plateau. The combination of these factors contribute to a high sensitivity for this condition that is shown as the orange area on Figure 3b.

The other columns of the matrix list other factors affecting vertical flow, including overlying high-permeability materials, such as alluvium or outwash, or low-permeability materials such as glacial till. The fourth column of the matrix and Figure 3c show the estimated effects of a thin (5 feet to 50 feet) glacial till layer. A thin till layer without an underlying Decorah-Platteville-Glenwood confining unit may contribute to a high (orange patterned area) aquifer sensitivity, whereas a combination of a thin till layer over the eroded edge of the Decorah-Platteville-Glenwood confining unit may contribute to a moderate (yellow patterned area) sensitivity. A thicker till cover (greater than 50 feet) shown in the last column of the matrix and Figure 3d should result in low (nonpatterned light green) sensitivity rating where the Decorah-Platteville-Glenwood confining unit is eroded. Under the same thick till conditions, a moderate sensitivity (nonpatterned yellow) should result where the Decorah-Platteville-Glenwood confining unit is absent.

Matrix columns 2 and 3 list factors of the relatively permeable surficial elements. Outwash is very permeable sand and gravel deposited across the county by large glacial meltwater channels. Colluvium is coarse erosional debris left near the exposed bedrock bluff slopes that are typical of southeastern Minnesota. These materials have such a high permeability that they would not significantly slow the downward migration of many types of contaminants. Therefore, neither of these sediment types would provide much protection for the bedrock aquifer where they occur.

Alluvium is sediment deposited by low-energy rivers characteristic of the period since the end of the ice age. Layers of sand and fine-grained material such as silt and clay usually characterize this sediment. This mixture of sediment is expected to slow the vertical migration of contaminants. Therefore, a high sensitivity for alluvium is indicated on the map in the absence of the Decorah-Platteville-Glenwood confining unit, and a moderate sensitivity is shown in combination with the eroded edge of the Decorah-Platteville-Glenwood confining unit.

SENSITIVITY MAP EVALUATION

Evaluation Data

After all the sensitivity conditions and layers are combined, three general areas discussed on Plate 8 emerge. These three general areas of sensitivity are the very low to low sensitivity of the Decorah plateau, the low to moderate sensitivity of the till-covered Zumbrota-Goodhue area, and the high to very high sensitivity of the northeastern area and major river valleys. The sensitivity map and associated matrix (Figure 2) represent a conceptual model that can be tested with chemical data from water well samples. The model should be able to predict generally the age of the ground water and the distribution of some common, widespread contaminants in these three areas. For evaluation purposes, the data associated with the target aquifer and the Galena aquifer are shown.

Ground-water age data (tritium and carbon-14) are used in this and other pollution sensitivity studies because these data relate directly to the sensitivity criteria. These criteria attempt to predict the time required for infiltrating contaminants to travel through various protective layers. Therefore, if the age of the ground water in the target aquifer is known, the travel time can be estimated and the sensitivity can be interpreted.

The concentrations of commonly occurring contaminants, nitrate and chloride, in ground-water samples can be used to indirectly evaluate the sensitivity model. Anhydrous ammonia and other nitrogen fertilizers may raise nitrate concentrations in ground water above background levels and indicate sensitive conditions. However, nitrate is not a very good travel-time indicator because the general timing of large-scale applications is mostly unknown. Furthermore, the distribution of these substances is uneven and rate of degradation can vary considerably.

The presence of chloride from human activities (road salt, fertilizer, septic tank effluent, or water softening salt) may indicate recent recharge of ground water (Ekman and Alexander, 2002). Salt derived from halite deposits typically has chloride to bromide ratios greater than 10,000 to 1. The chloride to bromide ratios derived from water samples collected from the sensitivity target (uppermost bedrock) aquifers discussed on this plate ranged from 26 to 1 to 784 to 1, with most of the values below 200 to 1. Therefore, chloride contamination from halite is not evident in the county. However, a comparison of tritium unit (TU) values versus chloride concentrations (Figure 4) suggests chloride concentrations above approximately 12 parts per million (ppm) may be partly attributable to human activities from sources other than halite. This graph shows that most of the samples with vintage and mixed tritium characteristics (less than 10 TU) also have low chloride concentrations. One carbon-14 age value is shown for reference indicating natural chloride values may be at least as high as 7 ppm. This natural chloride population is the cluster of data points in the lower left portion of the graph. Most of the water samples with recent tritium characteristics (greater than 10 TU) also have higher chloride values. The line between the two populations appears to be at about 12 ppm.

Evaluation by Area

Decorah Plateau. In the Decorah plateau area, 16 ground-water samples were collected from the St. Peter-Shakopee aquifer for analysis of tritium concentrations. As predicted by the model, all of the samples had tritium concentrations indicating vintage water (greater than 50 years old). Two samples analyzed for carbon-14 age yielded values of 3000 years and 40,000 years before present; these values indicate the presence of very old water in this setting. In addition, none of the sampled wells contained elevated concentrations of chloride (values greater than 12 ppm).

Zumbrota-Goodhue. A large area of moderate to high sensitivity is shown in the southeastern part of the county surrounding the towns of Goodhue and Zumbrota. Smaller moderate to high sensitivity areas are also located in the north-central portion of the county mostly in the Vasa, Welch, and Featherstone townships. The main protection for the uppermost bedrock aquifer in these areas is the overlying clayey till that can be greater than 200 feet thick in some locations. In the Zumbrota-Goodhue area, 14 well water samples were collected for tritium analysis. As predicted by the model, most (11 of 14) of these samples contained mixed water indicating some infiltration of recent water. In addition, seven of these samples contained elevated nitrate concentrations ranging from 1.2 ppm to 5 ppm, and three had elevated chloride concentrations from 15 ppm to 24 ppm. Although some of the nitrate values may represent naturally occurring concentrations, some infiltration of nitrate-contaminated water since presettlement times is indicated.

As explained above, tritium, nitrate, and chloride values in water samples from this area suggest a moderate to high sensitivity. Since the main protective layer in this area is glacial till, the area sensitivity is largely related to the till permeability. Extensive fractures within till sediments may have caused this higher than expected sensitivity. Other chemical evidence collected from the underlying aquifers suggests that ground-water residence time within these till units is not long compared to ground-water residence times in thick till regions elsewhere in Minnesota.

The interaction of water with various geologic materials as it infiltrates can alter the chemistry of the water. These chemistry changes can reveal information about ground-water residence times and recharge sources. Table 1 shows the proportion of barium and strontium from rocks in the Prairie du Chien Group and from glacial sediment (till and loess) samples; barium and strontium are much higher in the glacial sediments than in the Prairie du Chien rocks. If the till was an effective confining unit, water might move so slowly through the till that it could leach elevated concentrations of barium and strontium into the underlying Prairie du Chien units. Ekman and Alexander (2002) show elevated (greater than 0.2 ppm) concentrations of these constituents associated with mostly mixed and vintage water samples from till areas of northwestern Minnesota. Figure 5 shows relatively low (approximately 0.1 ppm) mean concentrations of these constituents in water samples from area wells completed in the Prairie du Chien and St. Peter aquifers. These relationships also suggest that accumulation of barium and strontium ions in the recharge water infiltrating through the till probably requires a residence time longer than the maximum residence time measurable by tritium (approximately 50 years).

Northeastern Goodhue County and Major River Valleys. Little or no glacial sediment cover and no bedrock confining units at the surface characterize these areas. Eleven of the 26 samples from these areas were located in major river valleys and contain concentrations of tritium indicating vintage or mixed water. As shown on Plates 7 and 8, these valleys are important discharge areas for bedrock aquifers. Strong upward and lateral flow may have brought older and deeper water near the surface in these areas. In some places, mixing of waters with recent and vintage concentrations of tritium probably occurs where local shallow flow systems converge with the deeper systems creating mixed water (see Plate 8, left portion of D–D′ and right portion of E–E′). In other places, all or most of the water intercepted by the wells is vintage water discharging to the river systems. Recent water (six samples) was detected where the wells are too shallow or far from the deep discharging flow systems. Elevated nitrate values (1.1 ppm to 5.1 ppm) were detected in seven of the recent and mixed water samples.

The common occurrences of vintage and mixed concentrations of tritium in these two areas may seem inconsistent with the high to very high sensitivity rating. However, the data distribution seemed somewhat biased toward sampling in the major river valleys. Furthermore, ample evidence exists in the data set of mixing occurring in the shallow local flow systems that can be affected by contamination. Therefore, the high to very high rating is justified based on the sensitivity of the shallow flow systems.

GALENA AQUIFER SENSITIVITY

The sensitivity of the Galena aquifer is considered separately for two reasons: it is an areally extensive perched aquifer above the Decorah-Platteville-Glenwood confining unit and the extent of the Galena Group and associated aquifer is limited to erosional remnants on the Decorah plateau. Therefore, the dynamics of deep and shallow flow systems discussed in the previous section mostly do not apply to the Galena aquifer.

Measured water levels from wells completed in the Galena aquifer range from about 20 feet to 70 feet below the land surface. At these shallow depths, the Galena aquifer is probably the water table or is connected with the water table in many places. Five water samples were collected from the Galena aquifer for tritium analysis. Three samples contained recent water, one contained mixed water, and one contained vintage water. Two of the samples contained elevated nitrate concentrations (8.4 ppm and 17 ppm). Four of the five samples also contained elevated concentrations of chloride. These data suggest a high sensitivity rating for the Galena aquifer. However, all of the samples were collected near the edges of the thick (greater than 50 feet) till cover. These sample locations may have biased the sample set toward the high sensitivity range. Some portions of the Galena aquifer farther inward from the edge of the thick till cover may have a lower sensitivity as suggested by the vintage water sample with a carbon-14 age date of 10,000 years old that was drawn from a well east of Kenyon.

Of the 14 water samples that contained elevated chloride concentrations within the county, nine of them were from well locations on or near the Decorah plateau. This relationship suggests that the Galena aquifer and associated glacial till on the Decorah plateau are an important reservoir of ground water containing elevated chloride concentrations. Since much of this chloride probably results from human activities, this high chloride area may be due to a higher production of water effluent with high chloride concentrations on the plateau. A more likely explanation is the longer residence time of ground water on the plateau. As discussed on Plates 7 and 8, vertical recharge of ground water is impeded in this area by the low vertical hydraulic conductivity of the Decorah-Platteville-Glenwood confining unit, which forces infiltrating ground water to travel a longer and slower route through the Galena or till toward the edges of the plateau. In other portions of the county where the upper aquifer is relatively free of chloride, ground-water residence times may be much shorter and essentially flush the chloride to the stream discharge areas.

REFERENCES CITED

Ekman, J., and Alexander, S., 2002, Water chemistry and residence time, technical appendix to Part B *in* Regional Hydrologic Assessment Otter Tail Area, West-Central Minnesota: Minnesota Department of Natural Resources Regional Hydrogeologic Assessment Series RHA-5, Part B.

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

Lindgren, R.L., 2001 Ground-water recharge and flowpaths near the edge of the Decorah-Platteville-Glenwood confining unit, Rochester, Minnesota: U.S. Geological Survey Water-Resources Investigations Report 00-4215.

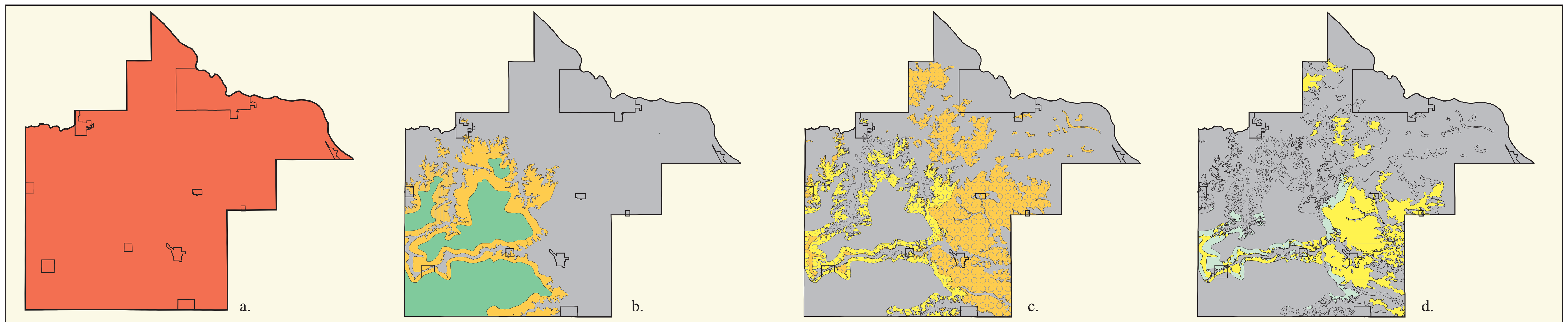


FIGURE 3. ***Components of the Sensitivity Map.*** This series of maps show how the various protective geologic layers affect the sensitivity of the uppermost bedrock aquifers (excluding the Galena aquifer).
a. Without any overlying protective layers, all the uppermost bedrock aquifers in the county would be rated very high sensitivity.
b. The continuous Decorah-Platteville-Glenwood confining unit provides an effective protective barrier. The dark green indicates very low pollution sensitivity. The orange border indicates high sensitivity along the eroded and fractured edge of this unit.
c. This map indicates moderate (yellow patterned area) aquifer sensitivity where a thin (5 feet to 50 feet) glacial till layer overlies the eroded and fractured edge of the Decorah-Platteville-Glenwood confining unit. Thin till cover beyond the edge of the Decorah-Platteville-Glenwood confining unit should result in a high (orange patterned) sensitivity.
d. The presence of a thicker till cover (greater than 50 feet) should result in a moderate (yellow) aquifer sensitivity rating where the Decorah-Platteville-Glenwood confining unit is absent. Aquifer sensitivity should be rated low (light green) where a thick till layer overlies the eroded edge of the Decorah-Platteville-Glenwood confining unit.
Sensitivity Map. On the sensitivity map above, outwash and colluvium (dotted pattern) have such high permeability that they would not significantly slow the downward migration of contaminants. Alluvium (diagonal line pattern) contains layers of fine-grained sediment that should help slow the vertical migration of contaminants. Therefore, a high sensitivity for alluvium (compared to very high for outwash and colluvium) is indicated on the map where the Decorah-Platteville-Glenwood confining unit is absent. Moderate sensitivity is shown if alluvium overlies the eroded edge of the Decorah-Platteville-Glenwood confining unit.