SENSITIVITY TO POLLUTION OF THE UPPERMOST AQUIFERS

By

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INTRODUCTION

This plate describes the relative sensitivity of the uppermost aquifers to the infiltration of a contaminant that moves conservatively with water. The uppermost bedrock aquifer in the upland areas of Wabasha County is usually the Prairie du Chien aquifer. In the western part of the county, significant bedrock faulting has elevated older bedrock formations to the bedrock surface. Because of this, the Jordan, St. Lawrence, and Franconia aquifers form the first bedrock aquifer in places in western Wabasha County. In the Mississippi River valley and the eastern Zumbro River valley, the Quaternary sediment fill is the uppermost and primary aquifer. The sensitivity to pollution of the Quaternary sand and gravel aquifer was evaluated separately and is shown in Figure 1.

The Zumbro River cut deeply into bedrock to form its river valley. In Mazeppa Township, the uppermost bedrock aquifer in the Zumbro River valley is the Franconia aquifer (Plate 2, Part A). From approximately Zumbro Falls to Millville in the Zumbro River valley, the Jordan aquifer is the uppermost bedrock aquifer. East of Millville, the valley cuts deeper and the St. Lawrence and Franconia aquifers become the uppermost bedrock aquifers. In Glasgow Township, the Eau Claire aquifer becomes the uppermost bedrock aquifer. In the Mississippi River valley, which typically has between 150 feet and 300 feet of sediment over bedrock (Plate 4, Part A), either the Eau Claire or the Mt. Simon aquifer is the uppermost bedrock aquifer.

Migration of liquid contaminants through unsaturated and saturated sediment and rock is a complex process. It is affected by biological degradation, oxidizing or reducing conditions, and contaminant density among other things. Countywide assessment of pollution sensitivity requires some generalizing assumptions. Flow paths from the land surface through the overlying cover are assumed to be vertical; horizontal flow paths may be important in sinkhole areas and in the major river valleys but have not been mapped and are not considered in the sensitivity model. Permeability is evaluated only qualitatively.

RATING MATRIX AND MAP DEVELOPMENT

The sensitivity assessment of the uppermost bedrock aquifer in Wabasha County is based on the vertical travel time of ground water from the surface to the sensitivity target as shown in Figure 2. The sensitivity map was constructed by combining the permeability characteristics interpreted from the surficial geology map (Plate 3, Part A) with the depth to bedrock map (Plate 4, Part A). About 41 percent of the county's land area has less than 5 feet of Quaternary sediment overlying bedrock, and another 31 percent of the land area has from 5 feet to 50 feet of Quaternary sediment overlying bedrock. Of the remaining 28 percent of the county that has at least 50 feet of cover over the bedrock, about one-third is in the upland area and two-thirds is in the river valleys.

The main factors in the sensitivity matrix (Figure 3) are the permeability and thickness of the geologic material that overlies the uppermost bedrock aquifer. In much of Wabasha County, weathered bedrock is at or near the surface with less than 5 feet of sediment cover. This lack of cover yields a very high sensitivity rating. Areas where 5 feet to 50 feet of Quaternary sediment overlie bedrock are rated as either high or very high depending on the type of sediment covering the bedrock. Areas with outwash (sand and gravel layers deposited by glacial meltwater) or colluvium (coarse debris eroded from nearby slopes) that is less than 50 feet thick are rated as very high because of the high permeability of these two sediments. Alluvium (low-energy stream deposits that contain sand with some silt and clay) is less permeable than outwash. Areas with alluvium less than 50 feet thick are rated high. Thin till (from 5 feet to 50 feet thick) is thin enough to be weathered and fractured throughout and provides less protection than thicker till units. Areas with thin till are rated high. Because increased sediment thickness slows ground-water travel time, all areas with glacial sediments greater than 50 feet thick are rated moderate.

Areas where the Shakopee Formation or the Oneota Dolomite is the uppermost bedrock and the bedrock is within 50 feet of the land surface are also prone to karst development (Plate 5, Part A). These areas often have many sinkholes. When sinkholes are present, the permeability of both the overlying sediment and the bedrock will be locally enhanced, and the sensitivity to pollution may be higher than indicated on the map.

SENSITIVITY MAP EVALUATION

The Wabasha County sensitivity model was created by combining permeability factors from geologic map layers. The model indicates that in most of the county the uppermost bedrock aquifer is very sensitive to pollution. Limited till and sediment cover reduce the sensitivity in a few areas.

The sensitivity model can be tested by using ground-water age data (tritium and carbon-14) to evaluate the geologic sensitivity ratings. Most wells are not completed in the uppermost bedrock aquifer; therefore, direct comparison of age data with the mapped sensitivity ratings generally is not possible. Wells that are completed in the uppermost bedrock aquifer and are not located in ground-water discharge zones have mixed and recent tritium ages. Many wells completed below the uppermost bedrock aquifer also have recent and mixed tritium ages (Plate 9), giving further evidence of the high geologic sensitivity of Wabasha County.

The concentration of commonly occurring contaminants like chloride and nitrate can be used to indirectly evaluate the sensitivity map. The data include all water samples that have both a general chemistry and tritium analysis. All of the data are useful because even if the samples are not from the uppermost bedrock aquifer, they help define the relationship of chloride and nitrate concentrations to tritium values in the county. Figure 4 is a scatter plot of chloride in parts per million (ppm) versus tritium units (TU). Elevated chloride is a good indicator of relatively young water. Water samples from wells with chloride content greater than 5 ppm are mostly associated with young water (greater than 7 TU). Natural chloride levels in Wabasha County are mostly below 5 ppm. Samples with low chloride and recent tritium imply recent recharge, but without anthropogenic chloride. Therefore, high chloride (greater than 5 ppm) is generally correlated with recent ground water, but low chloride can occur in young or old ground water.

Two of the samples in Figure 4 are anomalous because they have high chloride concentrations but low tritium concentrations. The sample from Plainview municipal well number 3, completed in the Jordan aquifer (Figure 4, sample a), contained 18.1 ppm chloride but only 2.2 tritium units. The water sample from the 1025-foot-deep Elgin municipal well number 4 completed mostly in the Mt. Simon Sandstone (the top 24 feet of open hole is located in the Eau Claire Formation) contained 45.4 ppm chloride and no detectable tritium (Figure 4, sample b).

The elevated chloride in the sample from Plainview number 3 may be due to local mixing with younger water. A water sample from Plainview number 2 (also completed in the Jordan aquifer and approximately 0.8 mile west-southwest of Plainview number 3) contained 86 ppm chloride and 14.6 tritium units (Figure 4, sample c; Plate 9, cross-sections C–C′ and H–H′).

The water from the Elgin municipal well completed in the Mt. Simon Sandstone has an estimated age of 20,000 years based on carbon-14 analysis. However, an equally old sample (again based on carbon-14 analysis), from a domestic well in Minneiska that was also completed in the Mt. Simon Sandstone, has a much lower chloride value (Figure 4, sample d). Water from the Elgin city well has 45 ppm chloride, but water from the Minneiska well has only 4.3 ppm chloride. Water from the Elgin well is likely mixing with deep saline water entering the well near the bottom of the open hole. This deep water is very salty, and only a small amount is necessary to greatly increase the chloride concentration. A water sample from the deep Mt. Simon-Fond du Lac well in Lake City has a chloride concentration of 1470 ppm. The Minneiska domestic well is not drilled as deep as the Elgin municipal well and it has a much shorter open-hole interval, so it has less contact with deep saline water.

Most of the chemistry data on the plate are representative of the chemistry of the aquifer water. The water sample from a well completed in the St. Lawrence Formation in Mt. Pleasant Township is probably an exception. It has higher than expected nitrate and chloride concentrations compared to nearby wells. These data may indicate a problem with well construction and not reflect actual aquifer conditions.

MAP EVALUATION BY AREA

Upland Area

Most of the upland area has little or no till cover; consequently, the uppermost bedrock aquifers in this area are very sensitive to pollution. Unlike neighboring counties, Wabasha County has very little Decorah Shale; it only occurs in a few small patches (Plate 3, Part A). Where the Decorah Shale exists over large areas, it acts as a protective blanket (Berg, 2003). Because of its very limited distribution in Wabasha County, however, it is not an important protection unit. Additionally, lateral flow may be an important pollution sensitivity factor in areas of karst (see Karst Features, Plate 5, Part A).

Eleven of the water samples collected for this study were taken from the uppermost bedrock aquifer; 10 of these samples were analyzed for tritium. Five of these wells were drilled on the upland area and completed in the Prairie du Chien Group. The other six wells were in or near the ground-water discharge zones along the Zumbro and Mississippi River valleys.

All water samples from the Prairie du Chien aquifer indicate that it is very sensitive to pollution. The samples were either recent or mixed age based on tritium, and four out of five had elevated chloride and nitrate concentrations. One sample collected where the bedrock is covered by less than 5 feet of sediment was recent age based on tritium. A second sample collected under colluvium less than 50 feet thick had 8.6 TU (mixed age). A third sample collected under thin (less than 50 feet) sandy alluvium had only 3.6 TU (mixed age) and is the one sample with little chloride or nitrate. A fourth sample, which is on the edge of thin till and more than 50 feet of till, was recent age based on tritium content. The fifth Prairie du Chien sample was collected in an area with more than 100 feet of till cover. It had a mixed ground-water age based on tritium and elevated chloride and nitrate concentrations.

Water samples from the Jordan aquifer near Plainview also indicate that the vertical flow model for sensitivity to pollution is not completely adequate. Two of the three wells sampled in this area have recent age water based on tritium and either elevated chloride or nitrate values (see Plate 9, cross-section C–C′, for a more complete explanation).

Areas of thicker till (greater than 50 feet thick) are found in Gillford, Hyde Park, West Albany, Elgin, and Plainview townships. Unfortunately, they constitute a relatively small area, and underlying karst or paleokarst conditions in the Prairie du Chien Group and local faulting may allow lateral flow. As illustrated by the fifth Prairie du Chien sample mentioned above and in the samples from the Jordan aquifer near Plainview, younger ground water with elevated chloride and nitrate concentrations may penetrate to the uppermost bedrock aquifer and to deeper aquifers. Lateral flow may help explain the discrepancies between the sensitivity rating and the chemistry data.

Bluff Edges

The bluff edges are a very complex hydrologic zone at the edge of the upland area where it meets the river valley areas. Fracturing and weathering allow greater vertical movement of water through confining beds than in more deeply buried bedrock. Springs, usually found at the base of bluffs, contain a mixture of older ground water and recently recharged water (Plate 5, Part A). Thus, bluff edges are geologically sensitive areas.

Zumbro and Mississippi River Valleys

The sensitivity to pollution of the uppermost bedrock aquifer in the Mississippi River valley and the eastern Zumbro River valley is rated moderate because the overlying Quaternary sediments are very thick (between 100 feet and 200 feet in the Zumbro River valley and up to 300 feet in the Mississippi River valley). These river valleys are also ground-water discharge zones of bedrock aquifers. Five wells that draw water from the uppermost bedrock aquifer in or near the ground-water discharge zones along the Zumbro and Mississippi River valleys were sampled for chemistry and tritium. Three of these wells had vintage age water based on tritium and two had mixed age water. The two mixed tritium samples had only 1.2 TU and 1.3 TU, indicating that the sample was mostly vintage water with only a small amount of recent water. This is consistent with the moderate sensitivity to pollution rating.

Because most wells in the eastern Zumbro River valley and in the Mississippi River valley are completed in Quaternary sediments, a separate near-surface Quaternary sensitivity map has been constructed (Figure 1). The near-surface sensitivity is high to very high over most of this area. Areas of outwash or colluvium have a very high sensitivity rating. Areas of alluvium have a high rating. Four Quaternary wells were sampled for tritium (see data shown on map to right). All four samples had either mixed or recent ages based on tritium content: 11.1, 9.9, 9, and 7.3 TU. All had a significant component of recent age water.

REFERENCES CITED

Berg, J.A., 2003, Sensitivity to pollution of the uppermost bedrock aquifers (Plate 9) *in* Geologic Atlas of Goodhue County, Minnesota: Minnesota Department of Natural Resources County Atlas Series C-12, Part B, scale 1:100,000.

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

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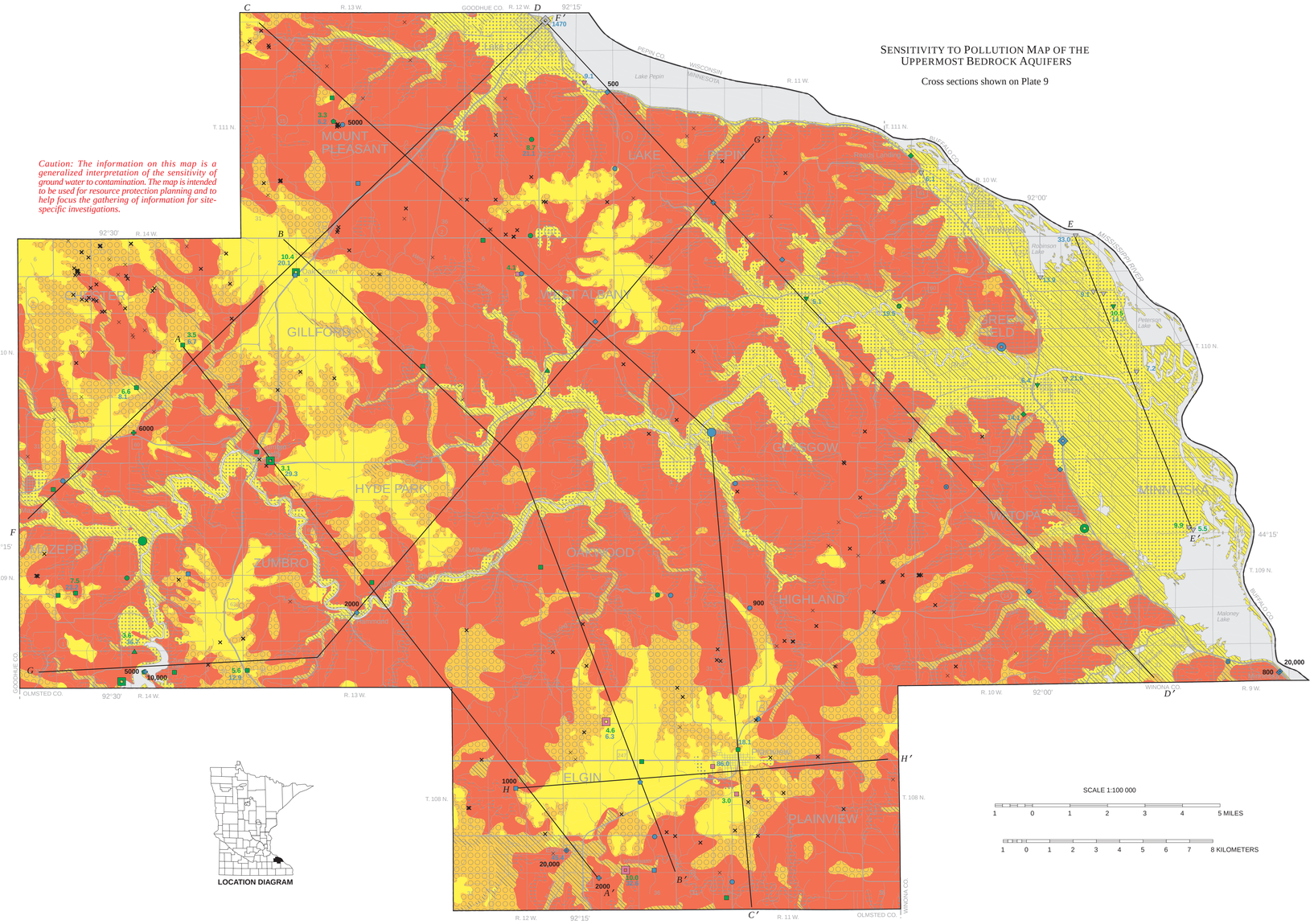

MAP EXPLANATION

Sensitivity ratings

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

- VH — Very High—Hours to months
- H — High—Weeks to years
- M — Moderate—Years to decades

Overlying sediments

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

Well symbols by aquifer

Shape indicates aquifer. Larger symbol, well in uppermost bedrock aquifer; smaller symbol, all other wells sampled.

- Quaternary sand and gravel
- Prairie du Chien
- Jordan
- St. Lawrence
- St. Lawrence-Franconia
- Franconia
- Franconia-Ironton-Galesville
- Ironton-Galesville
- Eau Claire
- Mount Simon

Tritium age

Color indicates tritium age.

- Recent—Water entered the ground since about 1953 (10 or more tritium units).
- Mixed—Water is a mixture of recent and vintage waters (greater than 1 tritium unit to less than 10 tritium units).
- Vintage—Water entered the ground before 1953 (less than or equal to 1 tritium unit).
- Well not sampled for tritium.

Well labels

- 5.5 — If shown, nitrate concentration equals or exceeds 3 parts per million.
- 9.1 — If shown, chloride concentration equals or exceeds 5 parts per million.
- 2000 — If shown, ground-water age in years, estimated by carbon-14 isotope analysis.

Map symbols

- × — Sinkhole, location verified
- × — Sinkhole, location not verified
- F — F′ — Line of cross section

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Project data compiled from 2003 to 2004 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 Nick Kroska.

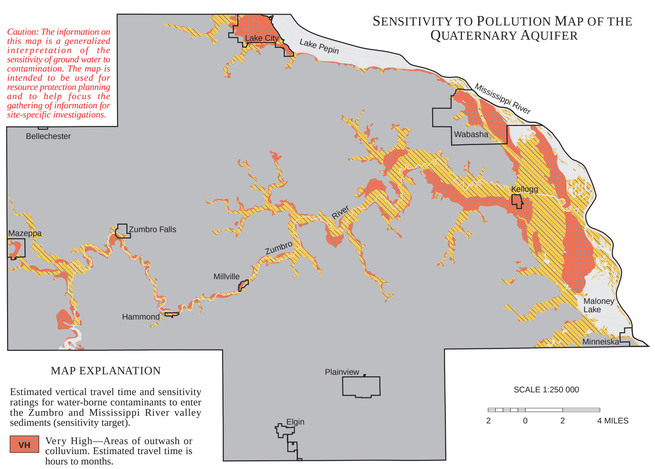


FIGURE 1. *Sensitivity to pollution of the Quaternary aquifer in the Zumbro and Mississippi River valleys. Quaternary sands and gravels are an important aquifer in the Zumbro and Mississippi River valleys. See Figure 2 for time of travel criteria. The pollution sensitivity of the uppermost bedrock beneath the Quaternary aquifer in these river valleys is shown on the larger map above.*

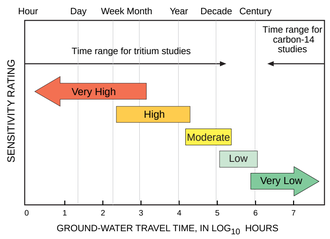
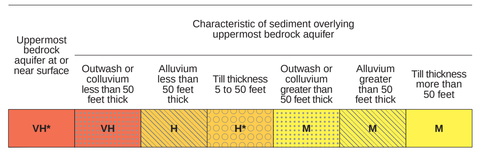


FIGURE 2. *Geologic sensitivity rating as defined by vertical travel time (Geologic Sensitivity Workgroup, 1991). Ratings are based on the time range required for water at or near the surface to travel vertically into the uppermost aquifers (sensitivity target). Tritium and carbon-14 studies indicate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



*Very high locally where sinkholes are present; may imply increased sensitivity over a large area where sinkholes occur in clusters. See Plate 5, Part A.

FIGURE 3. *Sensitivity matrix for sensitivity ratings. The ratings show the influence of various surficial sediments on the sensitivity of the uppermost bedrock aquifers. (See Figure 2 for time of travel criteria.)*

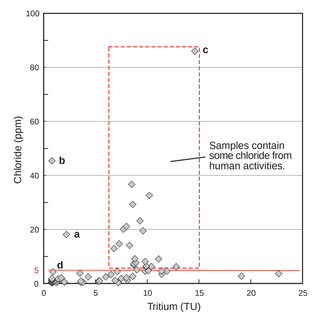


FIGURE 4. *Comparison of tritium concentrations to chloride concentrations in water samples from 87 wells and springs. Chloride concentrations above 5 parts per million appear to be largely attributable to human activities. The City of Plainview well number 3 (Jordan aquifer, label a) and the City of Elgin well number 4 (Mt. Simon aquifer, label b) have high chloride but low tritium concentration. Plainview well number 2 (Jordan aquifer, label c) has a very high chloride value and recent tritium age. This suggests that Plainview well number 3 contains a mixture of recent, human-influenced water and vintage water. The high chloride in Elgin well number 4 is due to mixing with saline water from a deeper source. Other shallower Mt. Simon wells, such as a domestic well near Minneiska (label d), have low chloride values because they pump less deep saline water.*