SENSITIVITY TO POLLUTION OF THE UPPERMOST BEDROCK AQUIFERS

By

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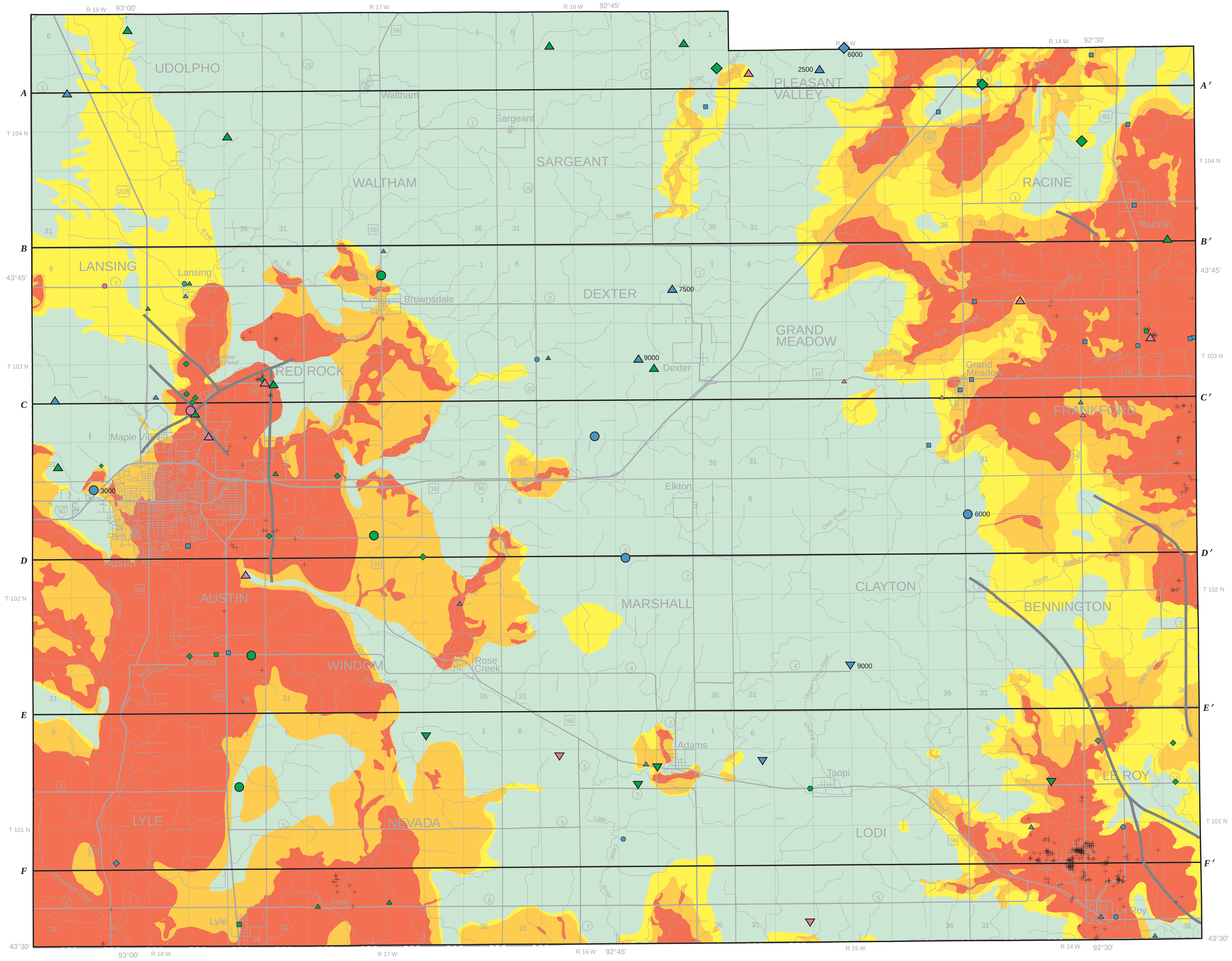


Digital base map composite:
Roads and county boundaries—Minnesota Department of Transportation GIS Statewide Base Map (source scale 1:24,000)
Hydrologic features—U.S. Geological Survey Digital Line Graphs (source scale 1:100,000)
Digital base map annotation—Minnesota Geological Survey.

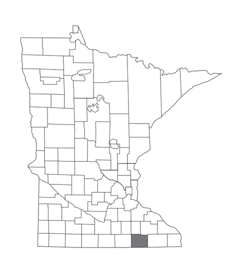
Project data compiled from 1997 to 2001 at the scale of 1:100,000. Universal Transverse Mercator projection, grid zone 15, 1983 North American datum. Vertical datum is mean sea level.

GIS data and metadata available through the DNR Waters website: http://www.dnr.state.mn.us/waters

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.

The DNR Information Center
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This information is available in an alternative format on request.

MAP EXPLANATION

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

Map Symbols

Mapped features influencing sensitivity

- \+ Sinkhole
- Fault

Well Symbols

Shape indicates aquifer type (Larger symbol ●, well in uppermost bedrock aquifer; smaller symbol ●, all other wells sampled)

- Quaternary
- Upper Cedar Valley
- Lower Cedar Valley
- Spillville-Maquoketa
- Galena
- St. Peter-Prairie du Chien-Jordan

Carbon-14 age of ground water

4000 If shown, ground-water age in years, estimated by carbon-14.

Tritium age of ground water

- Recent—Water with tritium concentration of 10 or more tritium units (TU) entered the ground water since 1953.
- Mixed—Water with 0.8 to less than 10 TU is a mixture of recent and vintage.
- Vintage—Water with tritium concentration of less than 0.8 TU entered the ground water before 1953.

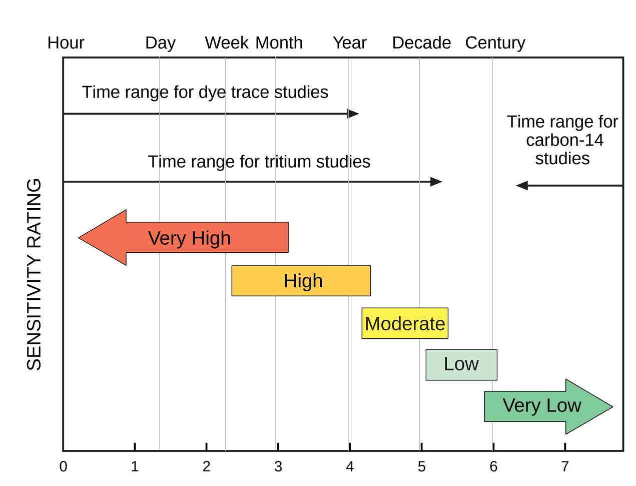
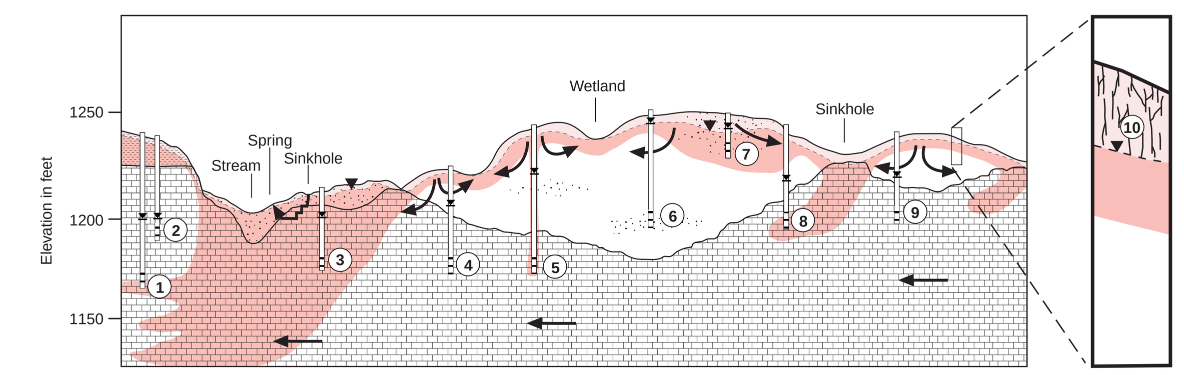


FIGURE 1. ***Geologic sensitivity rating as defined by ground-water travel time. Ratings are based on the time range required for water at or near the surface to travel vertically into the uppermost bedrock aquifers (target zone) (see Figure 2). Longer travel times imply a lower sensitivity to pollution. The sensitivity ratings overlap because of uncertainty in estimating travel times, which can vary significantly because of local variations in geologic and hydrologic conditions. Dye trace, tritium, and carbon-14 studies indicate the relative ages of ground water.***



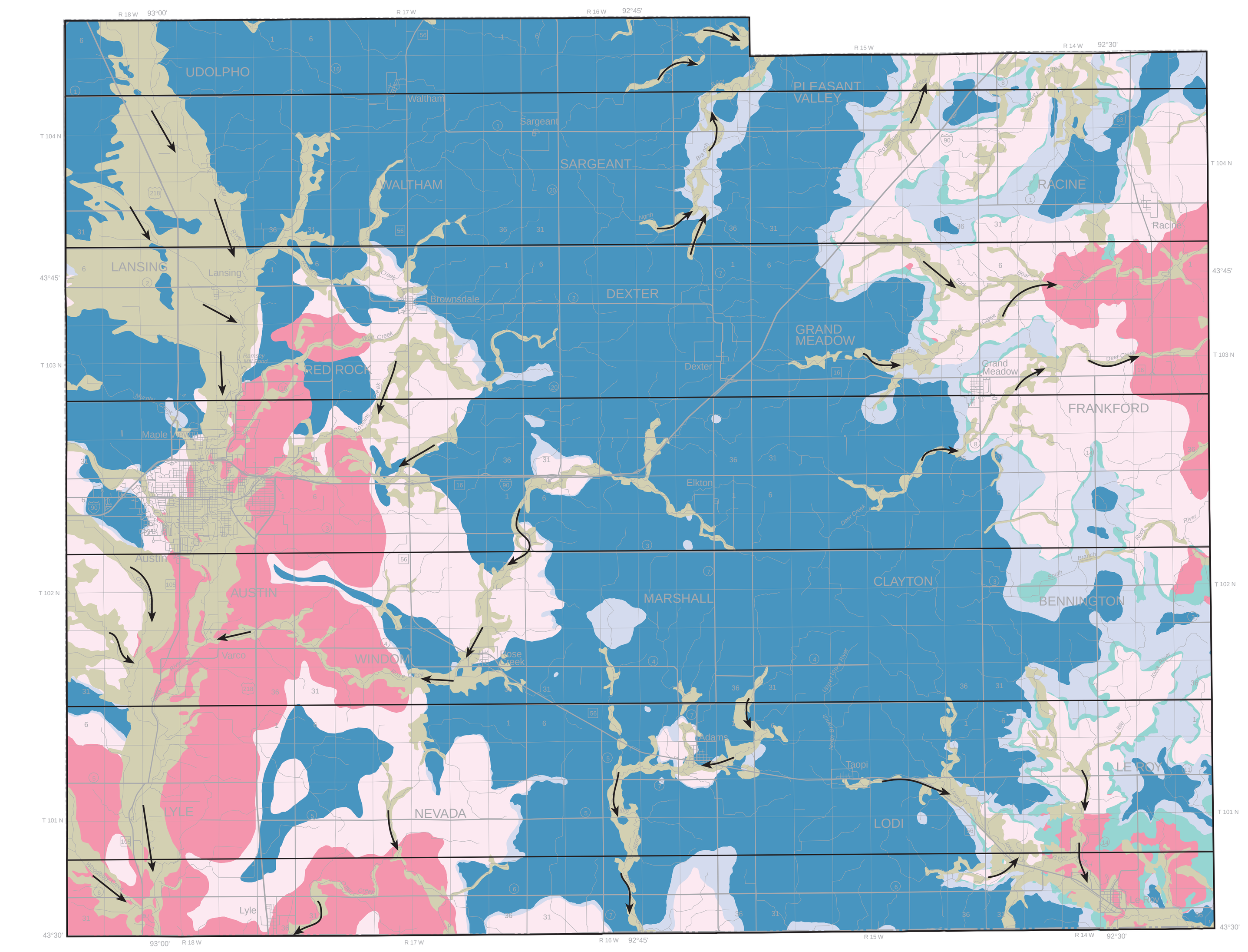
EXPLANATION

- Tritium present—Water entered subsurface less than 50 years ago. Lighter shade indicates the unsaturated zone above the water table.
- Arrow point and dashed line indicate water table
- Elevation of water in well
- Well screen
- Till
- Sand and gravel
- Shale
- Carbonate bedrock aquifer
- Direction of ground-water flow
- Bedrock surface

Subsurface Conditions

1. Lateral flow from unprotected area to bedrock well under shale cover
2. Bedrock well, protected by shale cover
3. Vertical flow to bedrock well from area without till cover
4. Bedrock well, buried under till cover
5. Bedrock well, poorly constructed, conducting water along well casing
6. Well in sandy glacial deposit, deeply buried under till cover
7. Shallow well in sandy glacial deposit without till cover
8. Lateral flow to bedrock well from sinkhole
9. Bedrock well, protected by some till cover
10. Fractures in till that can reduce travel time for water

FIGURE 2. ***Schematic illustration of typical subsurface conditions in the study area. The illustration shows the vertical distribution of tritium and the factors that may influence ground-water travel time and contribute to lateral flow. Illustration not drawn to scale.***



SCALE 1:200 000

EXPLANATION

Fast vertical recharge, horizontal transport

- Surficial sandy deposits*
- Direction of ground-water movement

Fast, direct recharge to bedrock

- Karst units with sinkholes**
- Limestone plain karst unit

Slow, less direct recharge to bedrock

- Greater than 25 feet but less than 50 feet of till
- Greater than 50 feet but less than 75 feet of till
- Greater than 75 feet of till

*Outwash, stratified sediments, and alluvium.
**Karst units CRp; DCp; Op; and units LRp, SVp, and LRu with less than 25 feet of glacial cover.

FIGURE 3. ***Six areas with different recharge characteristics. Some correspond to units found on the karst unit map (Plate 10). Generally, the pink areas have rapid recharge with relatively direct flow from the surface to the aquifer. The green and blue areas have slower recharge and may have more lateral flow depending the heterogeneities in the glacial deposits and the flow gradient. The tan areas may transport large quantities of water laterally because of their associations with streams, as well as vertically because of their high porosity and permeability.***

	Thickness of Till Cover (in feet)			
Geologic Feature	Less than 25	25–50	50–75	Greater than 75
Bedrock at or near land surface	VH	n.a.	n.a.	n.a.
Shallow karst	VH	n.a.	n.a.	n.a.
Limestone plain	VH	VH* / H	H* / M	n.a.
Outwash deposit in western Mower County	VH	H	M	M
Covered karst	n.a.	n.a.	M	L

n.a., not applicable
*Sandy deposits: outwash, stratified sediments, and alluvium found deposited over geologic feature

FIGURE 4. ***Sensitivity matrix for sensitivity ratings. The first column lists geologic features (Plates 2, 3, and 5, Part A; Plate 10, Part B) relevant to sensitivity in Mower County. Column headings indicate thickness of till cover (modified from Plates 3 and 5, Part A). Sensitivity ratings show the influence of till cover and sandy deposits on geologic features.***

INTRODUCTION

Prevention of ground-water contamination is an important part of water resource management. The first step to preventing contamination is to recognize where ground water is particularly sensitive to pollution. The 1989 Minnesota Groundwater Protection Act requires the Minnesota Department of Natural Resources (DNR) to map geographic areas defined by natural features where there is a significant risk of ground-water degradation from activities conducted at or near the land surface (MS § 103H.005). The natural features are defined as the geologic conditions in the area. The sensitivity of ground water to pollution is related to the ability of rocks and sediments to restrict the downward migration of contaminants that move with water. The sensitivity of ground water to pollution based on geologic conditions is called geologic sensitivity.

This plate presents the geologic sensitivity to pollution map for the uppermost bedrock aquifers throughout Mower County. The sensitivity map depicts the potential for ground-water contamination by using categories of travel time for water from the land surface to reach the uppermost aquifers (Figure 1). The map shows that areas with thin or no till cover and visible karst features such as sinkholes are rated as very high sensitivity. Areas with till cover more than 75 feet thick are rated as low sensitivity and mostly protected from downward migration of contaminants. Although lateral flow and focused recharge have the potential to transport contaminants and adversely affect the ground-water system, they were not included in the geologic sensitivity interpretation. The conceptual illustration (Figure 2), the recharge map (Figure 3), and "Additional Sensitivity Information" are presented, however, to show that lateral flow can affect nearby and distant ground-water resources.

GEOLOGIC SENSITIVITY APPROACH

The purpose of geologic sensitivity mapping by the Minnesota DNR is to assess the ability of the geologic materials to transmit water from the land surface to the uppermost bedrock aquifers (sensitivity target) in Mower County and estimate the time required for water to travel (travel time) to that resource (Geologic Sensitivity Workgroup, 1991). Figure 1 shows the categories of travel time for assessing sensitivity for an area. The time of travel is the basis for the sensitivity rating. A thorough presentation of the lateral flow characteristics of ground water throughout the county was beyond the scope of this project. Therefore, this geologic sensitivity interpretation considers only a theoretical vertical pathway taken by water from the land surface to the aquifer. This approach simplifies the range of sensitivity characteristics considered. Contaminant transport is not evaluated in this geologic sensitivity assessment because contaminants behave differently according to their density, viscosity, and solubility. Evaluation of contaminant behavior under various geologic settings presented too many factors for the scope of this study.

The dominant factors influencing travel time and controlling the ability of geologic material to transmit water are the flow characteristics to the aquifer and the thickness and texture of the material between the land surface and the aquifer. Bedrock aquifers in southeastern Minnesota are typically fractured and very porous. Water is transmitted into the aquifer directly if there is no cover material at the land surface. Materials deposited by glaciers, lakes, and streams cover most of the bedrock in Minnesota in varying thicknesses. Tills and lake sediments contain fine-grained clay minerals and do not transmit water quickly unless they are fractured (Figure 2, condition 10). Sandy materials, whether deposited on or near a glacier or deposited by stream processes, transmit water readily.

The target for this sensitivity study is the uppermost bedrock aquifers. As shown on Plates 7 and 8, four bedrock aquifers were mapped in Mower County. These uppermost bedrock aquifers were chosen as the geologic sensitivity target because it is the most relevant to the county residents. Most wells are drilled to the first reliable ground-water supply allowed under the well code. If there is adequate low-permeability cover, the well will be completed in the first bedrock aquifer encountered. Although several municipalities and industrial facilities use one of several deeper aquifers, most wells in the county are completed in the uppermost bedrock aquifers.

GEOLOGIC SENSITIVITY MAP

The sensitivity ratings in Mower County range from very high to low. The information on the other plates of this publication provides the framework for the geologic sensitivity interpretation. Plate 8 describes the effect of faulting near Austin on ground-water movement and the ground-water behavior of the multiple-porosity aquifers of Mower County. Karst features, karst hydrogeomorphic units, and the ground-water system created within karst aquifers in the sensitivity target zone are explained on Plate 10. Plates 2, 3, and 5 in Part A show the distribution of bedrock units, surficial units, and the depth to bedrock, respectively. Plate 7 illustrates the depth and heterogeneity of the glacial materials overlying the bedrock aquifers. The cross sections show the distribution of ground-water residence time. The sensitivity matrix (Figure 4) was developed using a combination of factors from Plates 2, 3, and 5 in Part A and Plate 10 in Part B.

Very High

The characteristics of areas rated as very high are bedrock at or near the land surface and shallow karst units with identified sinkholes. The areas with bedrock at the land surface are shown on Plate 3, Part A. The areas with cover less than 25 feet thick are shown on Plate 5, Part A. Both of these bedrock characteristics mostly occur within the shallow karst hydrogeomorphic units described on Plate 10: Cedar River plain, Deer Creek plain, Le Roy plain, Ostrander plain, Spring Valley plain, and Le Roy upland. These karst units have sinkholes as shown on the sensitivity map on this plate. In these areas where bedrock aquifers are at or near the land surface, water is transported directly from the surface into the fractured carbonate aquifers.

The faults shown on the sensitivity map indicate the areas of vertical displacement of the low-permeability bedrock units (see cross sections on Plate 2, Part A, and Plate 7). Recent and mixed waters have been found very deep in the aquifers near the faults. These are the only faults identified, but there may be more unidentified faults in the area (see the western portions of cross-sections C–C′, D–D′, E–E′, and F–F′ on Plate 7).

High

Areas of high sensitivity include the Limestone plain karst unit (see Plate 10), except where cover is less than 25 feet thick, which is rated as very high. The Limestone plain is a relatively large karst unit that occurs in eastern and western Mower County surrounding the shallow karst units. Some sinkholes have been mapped in this karst unit in eastern Mower County, but these occur in the very high sensitivity area where cover is less than 25 feet thick. Also rated as high sensitivity are areas of glacial sediments from 25 feet to 75 feet thick with overlying surficial sandy deposits. These sandy deposits can transmit water quickly.

Moderate

Areas of moderate sensitivity in Mower County occur in two situations. A large deposit of sandy outwash in western Mower County allows water to travel from the land surface through the sandy material into the fractured carbonate aquifer more quickly than through till in the surrounding area. Areas in the Covered karst unit with till less than 75 feet thick are also rated as moderate. These areas are found in central and eastern Mower County.

Low

Areas mapped as till on Plate 3 with more than 75 feet to bedrock (Plate 5) are rated as low sensitivity. These low-sensitivity areas with thick till cover differ from the areas on Plate 5 with depth to bedrock more than 75 feet and the Covered karst unit on Plate 10 because they do not include thick and extensive sandy deposits on the land surface.

Some water samples were taken from the uppermost aquifers (sensitivity target) for carbon-14 age dating. The modeled ages ranged from 2500 years to 9000 years. Although their carbon-14 age dates are in the very low sensitivity range, the samples were taken from areas where the knowledge of the subsurface materials and ground-water flow conditions is insufficient to justify rating the target aquifer as very low sensitivity.

Map Limitations

The sensitivity interpretation presented on the map was affected by limitations of data and the sensitivity model. In some areas of the county, data were very sparse. Furthermore, the sensitivity interpretation is based on a vertical pathway model, which does not include the influence of lateral ground-water flow. Some limitations of the sensitivity model were qualitatively resolved by the map (Figure 3) showing recharge characteristics, but this map is also limited by lack of information. Lateral flow is an important part of ground-water flow behavior but is difficult to characterize without quantitative aquifer parameters. Additionally, a thorough understanding of aquifer characteristics on a countywide scale was unrealistic for this project. Information on hydraulic conductivity, lateral and vertical flow gradients, and distribution of sediment textures in the unconsolidated materials overlying the uppermost aquifers would be needed to assess recharge and sensitivity more thoroughly.

ADDITIONAL SENSITIVITY INFORMATION

Lateral Flow

Lateral movement of ground water has relevance for protecting ground-water resources from land use practices that could introduce contaminants. Ground water infiltrates the land surface under saturated conditions and flows from higher areas to lower areas on the potentiometric surface. Plate 7 shows the potentiometric surfaces of bedrock aquifers based on available water-level information. Ground water often travels laterally for two reasons. First, the discharge point is far from the point where water is introduced into the ground-water system. Second, ground-water flow is influenced by heterogeneities in the aquifer material and secondary porosity.

Figure 2 shows some examples of lateral ground-water flow in shallow, unconsolidated glacial sediments and in underlying bedrock. The enlargement in Figure 2 (condition 10) shows secondary porosity in shallow till resulting from fractures. Fractures become less abundant with depth but are important to water movement in the shallow surface environment. In the glacial sediments, sandy deposits are more porous and permeable than the surrounding till. In well 7, recent ground water is traveling in a local flow system downgradient to the right. The vintage ground water in well 6 is less influenced by the local ground-water systems near the surface. It is more likely to be traveling to the left with the regional ground-water system dominated by the bedrock aquifer.

Ground water in the karst system of carbonate bedrock aquifers in Mower County shows evidence of lateral flow, which is described in detail on Plate 8. The influence of lateral ground-water flow is shown schematically in wells 1 and 8 in Figure 2. Recent ground water has traveled to the left through solution-enhanced fractures and conduits in the carbonate bedrock aquifer under the less permeable materials at the surface. Wells 2, 4, and 9 are completed in areas where lateral flow is present, but recent water has not yet reached the wells.

Recharge to Uppermost Bedrock Aquifers

Some recharge characteristics of aquifers are important to a sensitivity assessment. Recharge is defined here as the process that allows water to enter an aquifer. The meaning of the term recharge varies. For example, recharge can be described as water traveling from the land surface to the water table, which is water-table recharge. Some recharge areas shown on Figure 3 were used in this sensitivity assessment.

Most ground water in Mower County is contained within a karst system of carbonate bedrock aquifers with solution-enhanced fractures and conduits (see description of multiple-porosity aquifers, Plate 8). Generally, ground water flows from the topographically high areas in a north-south trending ridge in the eastern part of the county in the Covered karst unit (Plate 10) to the surrounding, topographically low areas. The high areas largely coincide with areas having the thickest tills, and the low areas occur where there are major streams. Regional potentiometric highs, however, should not be confused with the primary source of recharge.

Typically, ground-water recharge occurs where downward gradients are present over the entire surface of an aquifer or ground-water resource, but it occurs at different rates. Figure 3 shows a map with six recharge characteristics. The bright pink areas have little or no cover material on the surface of the carbonate bedrock aquifer. These areas are a combination of all the shallow karst units (Cedar River plain, Deer Creek plain, Le Roy plain, Ostrander plain, Spring Valley plain, and Le Roy upland), and all have sinkholes. Water recharges directly into the aquifer and can quickly move great distances from the surface. The area in pale pink corresponds to the Limestone plain karst unit. There is limited cover here, and recharge is enhanced because karst features are close to the land surface. The green areas occur in eastern Mower County between the Limestone plain unit and the area with till cover greater than 50 feet thick. These areas have slower recharge than the pink areas but still allow large quantities of water from the surface to enter the aquifer. The light blue areas have till cover from 50 feet to 75 feet thick, and recharge also is slower than in the pink areas. The extent of the dark blue recharge area is similar to the extent of the Covered karst unit. Ground water recharges bedrock aquifers slowly here and can be thousands of years old.

The areas in pink have rather direct flow from the land surface to the aquifer, whereas the areas in green and blue may have more lateral flow depending on the heterogeneities in the glacial deposits and the flow gradient. The tan area shows sandy deposits. Water can easily enter the subsurface through this porous material and may also be transported laterally by a stream. A stream in the area with thick till could transport a contaminant downstream to an area with focused recharge. Because lateral flow is not part of the sensitivity evaluation, these areas might be overlooked but still have an impact on ground-water quality in the county.

REFERENCE CITED

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.

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