STATE OF MINNESOTA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATERS

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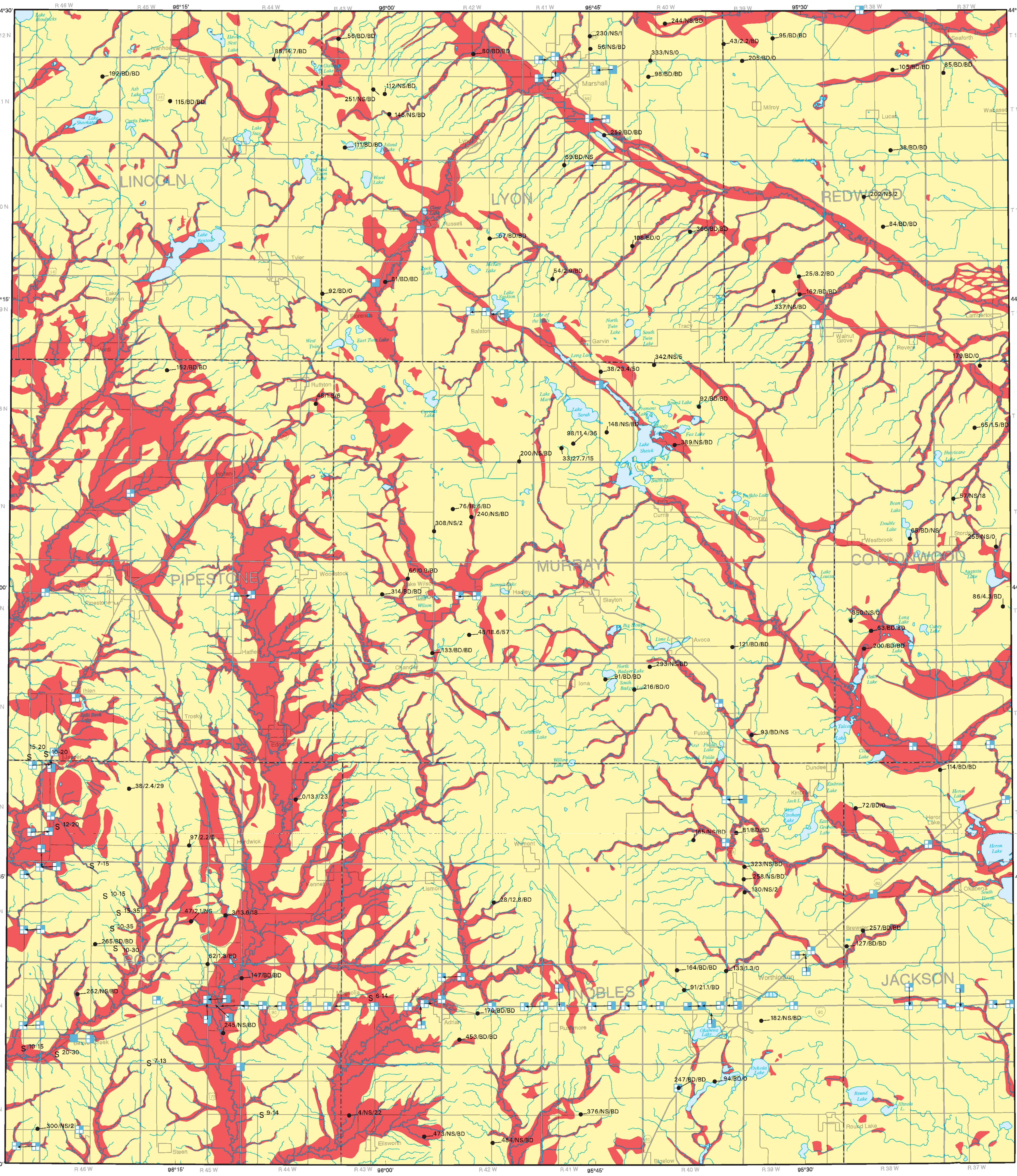


Digital roads data modified from 1990 Census TIGER/Line Files of the U.S. Bureau of the Census (source scale 1:100,000). Digital hydrology data modified from 1989 Digital Line Graph (DLG) files from the U.S. Geological Survey (source scale 1:100,000). Digital base annotation by the Minnesota Geological Survey and the Minnesota Department of Natural Resources.

Universal Transverse Mercator projection, grid zone 15, 1983 North American Datum, map angle 1.987. Vertical datum is mean sea level. Compiled 1997.

GIS and cartography by Shawn Boeser, Malathi Bhattacharjee, Michael Scharber, Minnesota Department of Natural Resources, and Norman Anderson, Land Management Information Center, Minnesota Planning Office. Desktop publishing layout by Kim Anderson, Communications.Media, Minnesota Department of Administration. Digital assembly by Nordic Press.

SCALE 1:200 000

WARNING: This map provides an overview of ground-water contamination potential of the water-table system as interpreted from 1:200,000 scale geologic map information. THIS MAP SHOULD NOT BE THE BASIS FOR EVALUATION OF SPECIFIC SITES.

Partial funding for this project approved by the Minnesota Legislature M.L. 91, Ch. 254, Art. 1, Sec. 14, Subd. 4(f) and M.L. 93, Ch. 172, Sec. 14, Subd. 11(g) as recommended by the Legislative Commission on Minnesota Resources from the Minnesota Environment and Natural Resources Trust Fund. Base funding established by the 1989 Groundwater Protection Act, M.L. 89, c. 326, art. 10, sec. 1, subd.6, item a. and b.

EXPLANATION

Sensitivity Ratings

Estimated travel time for water-borne surface contaminants to reach the water table

Very High — Hours to months

Moderate — Years to decades

Key to Symbols

48/1.9/6 **Well sampled for general chemistry and/or tritium**
- Nitrate as nitrogen (milligrams per Liter, mg/L)*
- Tritium (tritium units, TU)*
- Depth to top of aquifer (feet)

** BD – below detection (<0.5 or <0.01 mg/L for nitrate, <0.8 TU for tritium)*
** NS – not sampled*

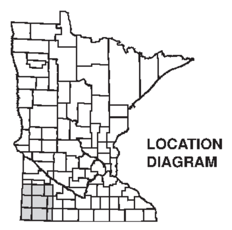
S^{15-20} **Seismic survey line** — numbers are range of depth in feet to the water table

Minnesota Department of Transportation boring

Depth to water table (feet)

0 to 10 | 10 to 20 | 20 to 30 | Greater than 30

Boring symbols were relocated to avoid overlap. Arrows point to correct boring location.



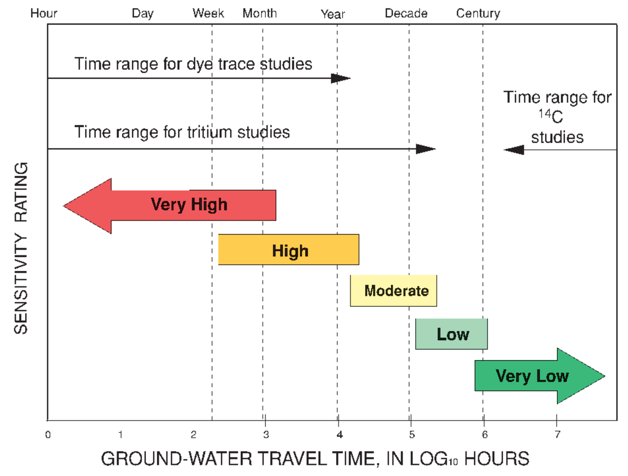


FIGURE 1. *Geologic sensitivity ratings are based on the time required for water at or near the surface to travel vertically to the water table. Longer travel times imply a lower sensitivity to pollution. Dye trace, tritium, and ^{14}C studies can indicate the relative ages of ground water.*

MATRIX FOR RATING THE SENSITIVITY OF THE WATER-TABLE SYSTEM

Geologic materials in the unsaturated zone[1]	Permeability	Depth to water table (feet): Less than 20 feet	Greater than 20 feet — Low permeability units in the unsaturated zone between 10 feet below the surface and the water table: No low permeability units at least 10 feet thick	Greater than 20 feet — One or more low permeability units at least 10 feet thick
Unconsolidated sediments				
Sand and gravel; organics	High	VH	H	L[4]
Loam to clay loam till; lake sediments[2]	Low	M	M[4]	L
Consolidated sediments				
Sioux Quartzite[3]	High	VH	VH	L[4]

Notes: [1] Geologic materials mapped at the surface are assumed to extend to the water table; [2] Depth to the water table in these sediments assumed to be less than 20 feet; locally, depth to water may exceed 20 feet; [3] Sioux Quartzite is assumed to be fractured and fractures extend to the water table; [4] Requires additional site-specific information. Matrix boxes with gray pattern indicates this condition was not found.

SENSITIVITY OF SURFICIAL AQUIFERS TO POLLUTION

By
Randy Bradt
1997

INTRODUCTION

Prevention of ground-water contamination is a major component of wise resource management. One approach to prevent ground-water pollution is to recognize where ground water is particularly sensitive to pollution. The Minnesota Legislature, in 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. This plate shows a water-table pollution sensitivity map for southwestern Minnesota prepared according to criteria developed by the DNR. The sensitivity map will enable planners to include ground-water concerns in land-use decisions and to direct policy and fiscal resources to areas where there is a greater ground-water contamination potential.

GEOLOGIC SENSITIVITY

The procedure used to construct the sensitivity map follows the guidelines published by the DNR (Geologic Sensitivity Workgroup, 1991) in which geologic sensitivity defines pollution potential. Geologic sensitivity is defined by the time it takes water-borne contaminants to travel vertically from the surface through the unsaturated zone to the water table. Travel time depends on the permeability and thickness of geologic materials between the land surface and the water table. Geologic materials with the lowest vertical permeability are assumed to have the greatest ability to retard the vertical movement of contaminants, resulting in longer travel times. Conversely, geologic materials with the highest vertical permeability are assumed to have the least ability to retard the vertical movement of contaminants, resulting in shorter travel times. However, shorter travel times do not mean that the water table is or will be contaminated, and longer travel times do not ensure that the water table in these areas is or will remain pristine.

The five overlapping classes of travel time that define geologic sensitivity are shown in Figure 1. Each class is assigned a relative geologic sensitivity rating from Very High to Very Low. The ranges of travel time for each class overlap because of the uncertainty of travel-time estimates. The sensitivity map was developed by applying the rating matrix which assigns sensitivity ratings according to the estimated permeability of surficial geologic materials and depth to the water table. In areas where depth to the water table is greater than 20 feet the presence or absence of a confining unit is also considered. A confining unit is at least 10 feet of low permeability material. In accordance with the guidelines, the top 10 feet of the unsaturated zone is not evaluated for confining material because infiltrating water could move rapidly downward through direct pathways such as animal burrows, root casts, fractures, or joints.

Assessing geologic sensitivity according to the guidelines requires several simplifying assumptions: 1) contaminants are inert and move with the water; 2) contaminants are released at or near the land surface and move vertically downward; 3) estimates of permeability can be made based on general knowledge of saturated permeabilities for broad groups of geologic materials; 4) use of saturated permeabilities of geologic materials in the unsaturated zone will provide shorter, or more conservative, estimates of travel time; 5) surficial geologic map units from Plate 1 in Part A are representative of the geologic materials from the surface to the water table.

The sensitivity map does not account for changes in sensitivity as a result of human activities, such as improperly constructed or abandoned wells, that may accelerate transport of contaminants to the water table. Users of the sensitivity map should be aware that information displayed on the map is generalized according to the scale at which it is portrayed. Enlarging this map could result in a false indication of precision. Additionally, map unit boundaries are a product of the geological sensitivity assessment model and do not represent absolute differences in sensitivity. Each map unit represents a predominant sensitivity rating, therefore this map should not be considered a substitute for site-specific information.

SENSITIVITY MAP PREPARATION

Sensitivity of the water-table system to pollution was assessed on the basis of estimated vertical permeability of geologic materials in the unsaturated zone and depth to the water table. The rating matrix shows how the geologic sensitivity ratings are defined. The surficial geology map units from Plate 1 in Part A are the source of geologic information for the unsaturated zone. The rating matrix first separates the geologic materials into consolidated or unconsolidated sediments and then subdivides them based on their relative permeabilities. The result is that surficial geologic map units are grouped into one of three categories. Each of these categories is again subdivided on the basis of depth to the water table and whether a confining unit is present in the unsaturated zone. The rating matrix thus represents a decision tree with nine possible outcomes. Each outcome is assigned a geologic sensitivity rating based on criteria in the DNR guidelines. Five of the outcomes, shown with a gray pattern in the rating matrix, are not identified on the map. Three of the outcomes (see note 4) are not identified because they contradict the previously stated assumption that material above the water table is entirely composed of the mapped surficial geology as shown on Plate 1 in Part A. The contradiction occurs because each of the three outcomes requires the identification of two or more geologic materials of differing permeability in the unsaturated zone. This level of detail was not feasible at the scale of this project. Where more site-specific information is available, ratings as shown in the matrix should be applied.

The first category of geologic materials in the rating matrix is unconsolidated Quaternary sediments with high permeability. The category includes the six map units on Plate 1 in Part A interpreted as stream deposits (*sb, sbd, sd, sld, so*, and *sv*) and organic deposits (*oh*). Water can move quickly from the land surface through these sediments to the water table, which commonly has a depth of less than 20 feet. Vertical travel times are estimated in the range of hours to months, so a Very High sensitivity is assigned to these deposits. There may be areas where map units *sbd, sld, so,* and *sv* are overlain with locally thick lower-permeability sediments. However, information was not available to delineate where the overlying sediments were sufficiently thick to modify the sensitivity rating. As a result, map units *sbd, sld, so*, and *sv* were rated conservatively in favor of higher sensitivity.

The second category of geologic materials in the rating matrix includes low-permeability Quaternary sediments. These include the 11 mapped till units (*tbd, tfd, tfo, thd, tld, tlo, tmd, to, tsd, tv,* and *two*) interpreted as ice deposits and two map units (*gl* and *lh*) interpreted as lake deposits. These deposits tend to have relatively low permeabilities as a result of their fine-grained and poorly sorted textures. Data posted on the map, which include Minnesota Department of Transportation borings and DNR seismic lines, show that depth to the water table is predominately less than 20 feet. Vertical travel times through these sediments are estimated to be on the order of several years to a few decades so a Moderate sensitivity rating is assigned to these deposits. Locally, such as in high-relief areas, these deposits may have water-table depths exceeding 20 feet and if confirmed their geologic sensitivity rating would be modified to a Low rating.

The third category of geologic materials in the rating matrix is the Sioux Quartzite map unit (*pq*). Sioux Quartzite is a metamorphosed quartzose sandstone of mostly silica-cemented quartz sand that has very little primary pore space. Locally, fracturing or dissolution of silica cement has created secondary porosity. Where the Sioux Quartzite occurs at the land surface in parts of Pipestone and Rock counties, water is assumed to be rapidly transmitted to the water table via secondary porosity. A Very High sensitivity rating is assigned to these areas.

GROUND-WATER RESIDENCE TIME

The pollution sensitivity map divides the study area into regions that portray a range of estimated travel times for contaminants to move from the surface to the water table. It is difficult to verify directly the mapped sensitivity ratings, so measurements of ground-water residence time and water quality were used as indirect tests. Residence time is the approximate time from when water infiltrates the land surface to when it is discharged or pumped from an aquifer. Radiometric dating utilizing isotopes of hydrogen or carbon is used to estimate ground-water residence times (Alexander and Alexander, 1989). Tritium, as discussed on Plate 3, is an isotope of hydrogen that is an indicator of more recently recharged precipitation. Tritium results are expressed in tritium units (TU) where one tritium unit means one atom in 10^{18} hydrogen atoms. The laboratory detection limit of the samples collected for this study is 0.8 tritium units. If a ground-water sample has no detectable tritium, it can be assumed that the sample is dominated by precipitation that entered the subsurface prior to 1953. Conversely, samples containing detectable tritium have some component of post-1953 recharge. Nitrate can also be an indicator of more recently recharged precipitation. Unlike tritium, however, sources of nitrate are not always present where recharge to ground water occurs. In addition, nitrate can be removed by natural processes such as denitrification.

Mapped surficial sand and gravel deposits in the study area have been interpreted as Very High sensitivity. Some residents with wells located within these deposits have reported rapid water-level changes that are occasionally associated with muddied water soon after a rain event. Water samples from these surficial aquifers generally have concentrations of dissolved solids less than 1000 milligrams per Liter (mg/L) and detectable tritium. Additionally, some samples also have elevated concentrations of either dissoved oxygen, nitrate, or both. All of these observations indicate rapid infiltration and support the Very High sensitivity rating.

Areas where Sioux Quartzite is mapped at or near the land surface have also been interpreted as Very High sensitivity. Water samples from wells completed in Sioux Quartzite at these locations commonly have relatively low concentrations of dissolved solids and detectable tritium. Elevated concentrations of either dissolved oxygen or nitrate are also present in some samples. All of these observations suggest recent recharge and support the Very High sensitivity rating.

Till and lacustrine deposits are rated as Moderate sensitivity. No water samples for age dating or general chemistry analysis are available because very few, if any, water-table wells are screened in these low permeability sediments. However, chemical analysis results from wells completed in aquifers below the water table were used to estimate vertical recharge rates. Detectable tritium in all sampled wells less than 60 feet deep and the absence of detectable tritium in most sampled wells more than 100 feet deep, suggests average vertical penetration rates from one to two and one half feet per year. This interpretation is based on the assumption that vertical recharge velocities are uniform with depth and no horizontal flow occurs. These results support the rating matrix criteria, which uses a depth to water of 20 feet as the boundary between Moderate and Low sensitivity. The assumption of constant vertical flow rates with depth may be suitable for shallow ground water, but this assumption fails at greater depths. Water from eight of the nine sampled wells completed in Quaternary or Cretaceous deposits ranging from 180 to 496 feet deep had ^{14}C age dates of several thousand years before present. One explanation for this discrepancy may be that lateral flow becomes increasingly important with depth. Additionally, shallow aquifers may be part of local or intermediate flow systems that have shorter ground-water residence times because recharge and discharge occur over relatively short distances. Deeper wells are probably located within regional ground-water flow systems that have a much longer residence time due to slower movement and longer flow paths from recharge to discharge areas.

Results of nitrate and tritium analysis of ground-water samples collected from 113 wells are plotted on the map. The thickness of geologic material from the land surface to the top of the aquifer is also plotted at each sample location. Figure 2 is a schematic illustration showing the relationship between the vertical distribution of tritium and representative geologic conditions for southwestern Minnesota. Detectable tritium in till extends from the land surface to an average depth of approximately 50 feet. Between depths of 50 and 100 feet is a transition zone representing the maximum depth that post-1953 water has penetrated. Below 100 feet tritium was rarely detected in samples. The maximum depth that tritium is detected is an indicator of the degree of protection that geology can provide to an aquifer.

Figure 2 shows five conditions where local geologic factors in southwestern Minnesota may enhance water's ability to travel to the water table or to an aquifer. Condition 1 shows water with detectable tritium penetrating to a greater depth where more permeable geologic material is present. Condition 2 shows a situation where a portion of an aquifer is overlain by relatively thin till, thus allowing more rapid recharge at that location. Following recharge, horizontal ground-water movement transports tritium to other locations in the aquifer. Condition 3 shows how fractures in the Sioux Quartzite could preferentially transmit water to the water table or to an aquifer at depth. Condition 4 shows how an improperly constructed well can act as a conduit for water to enter from the surface or move from one aquifer to another. Condition 5 is an example of fractures which may be present in till. The inset in Figure 2 is a cross-section sketch of a fractured till showing an upper oxidized zone and a lower unweathered zone (modified from Ruland and others, 1991). Most fractures are found in the upper oxidized portion of the till. A study by Grisak and others (1976) found that fractures could increase a till's ability to transmit water by approximately two orders of magnitude.

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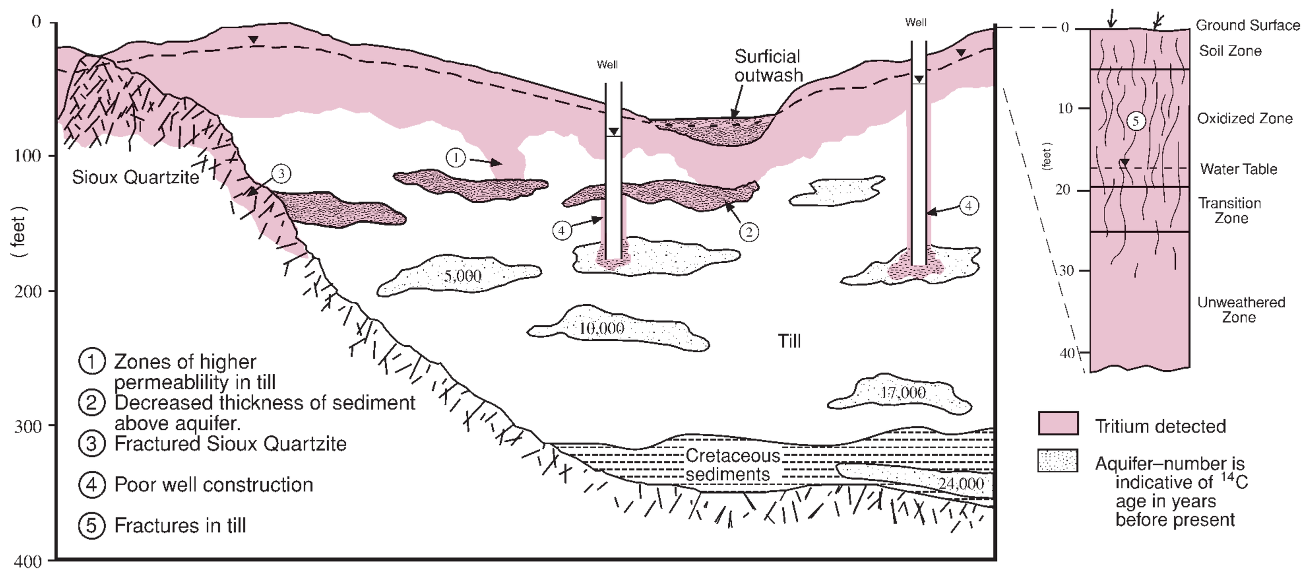

FIGURE 2. *Schematic illustration of subsurface conditions in southwestern Minnesota that may reduce travel times of potential surface contaminants. Inset modified from Ruland and others (1991). Not drawn to scale.*

The DNR Information Center
Twin Cities: (612) 296-6157
MN Toll Free: 1-800-766-6000
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REGIONAL HYDROGEOLOGIC ASSESSMENT
SOUTHWESTERN MINNESOTA