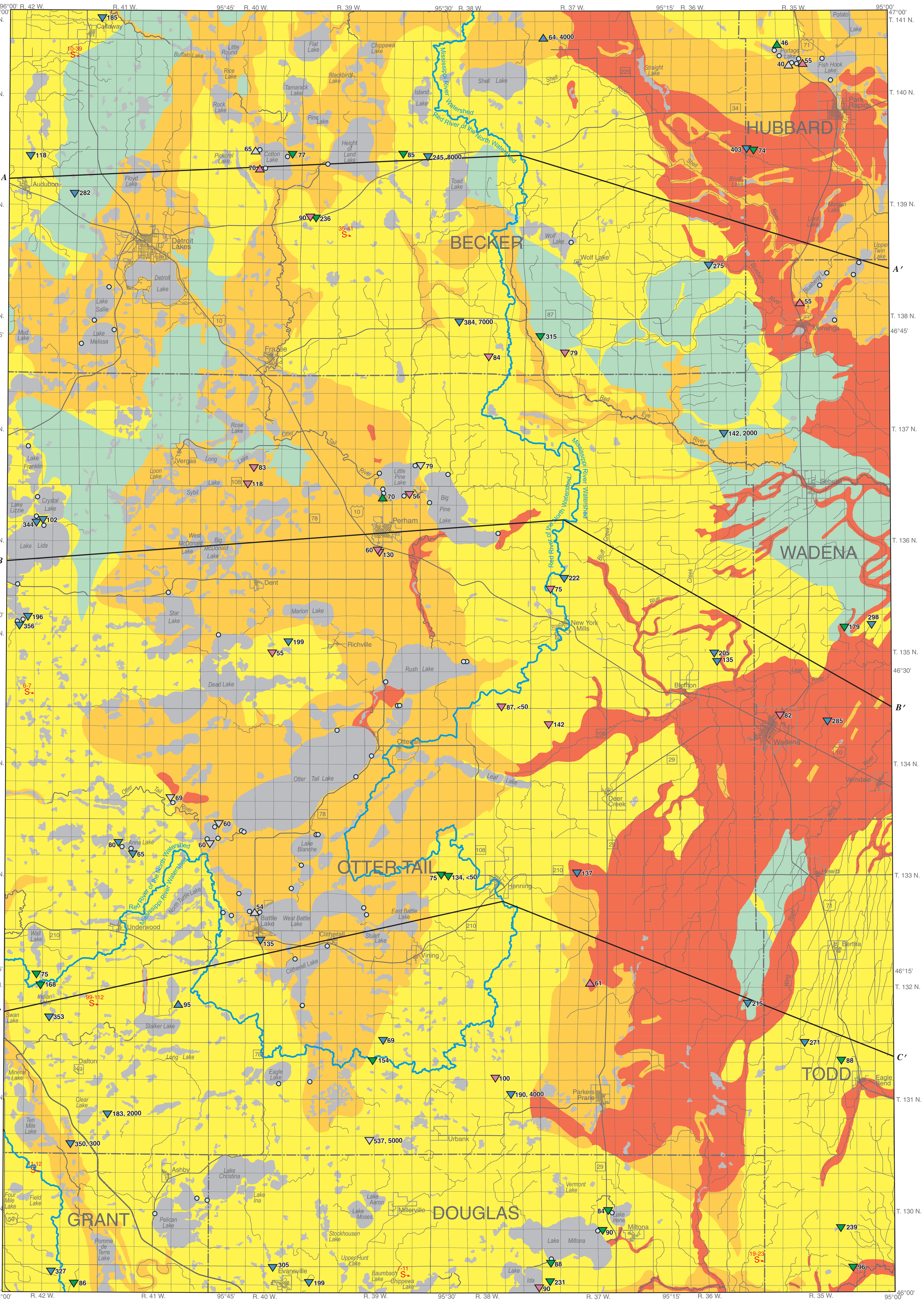

MAP EXPLANATION

Sensitivity Ratings

Estimated vertical travel time for water-borne surface contaminants to enter the target zone

VH	**Very High**—Hours to months
H	**High**—Weeks to years
M	**Moderate**—Years to decades
L	**Low**—Decades to a century
	Surface Water—Not rated

Sample Sites (number of samples)

- ▲ Quaternary water-table aquifer (11)
- ▼ Quaternary buried outwash aquifer (71)
- ○ Lake water (82)

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.
- Not tested for tritium.

Well Labels

113, 4000 — If shown, ground-water age in years, estimated by carbon-14. Samples labeled "< 50" were used to calibrate the carbon-14 model.

Well depth in feet.

Seismic Refraction

9-10 S→ Numbers indicate range of depth in feet to the water table; arrow points to location of the midpoint of transect.

Hydrologic Symbol

Surface watershed divide between Mississippi River and Red River of the North watersheds

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 regional resource protection planning and to help focus the gathering of information for site-specific investigations.*

SCALE 1:200 000

5 0 5 10 Miles

5 0 5 10 Kilometers

GEOLOGIC SENSITIVITY TO POLLUTION OF NEAR-SURFACE GROUND WATER

by

Julie C. Ekman

2002

INTRODUCTION

Prevention of ground-water contamination is an important part of water resource management. The first step 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 the geologic conditions in the area. The sensitivity of ground water to pollution is related to the ability of 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 describes the geologic sensitivity to pollution of the near-surface ground-water systems, including surficial aquifers. The sensitivity map depicts the potential for ground-water contamination by using categories of travel time (Figure 1). The map shows that areas mapped as outwash are more sensitive to rapid vertical transport of water that may contain contaminants from the land surface than are areas mapped as moraine. Decision makers, planners, and citizens can use this plate with other planning tools to help make ground-water management decisions. The pollution sensitivity map is also useful for directing fiscal resources to areas with greater potential for water-resource contamination.

GEOLOGIC SENSITIVITY

Minnesota DNR interprets relative geologic sensitivity as the relative rate of travel for water at the surface to travel vertically downward to the ground water of interest (Geologic Sensitivity Workgroup, 1991). Estimating the time for water to move from the land surface to the near-surface ground water depends on many factors, including precipitation, depth to the water table, hydrogeologic setting, sediment texture, and the potential for focused recharge in depressions and wetlands and along lakeshores.

This interpretation of geologic sensitivity to pollution of the near-surface portion of the shallow ground-water system is based primarily on what is known about the sediments within 50 feet of the surface. The target of geologic sensitivity interpretation is a 30-foot-thick layer beginning at 20 feet below the land surface (Figure 2). This zone encompasses the water table and a saturated thickness beneath it for most of the study area. Although this target does not represent an aquifer in all areas, it is important for understanding water systems at depth and the movement and characteristics of regional ground water.

GEOLOGIC SENSITIVITY MAP

Approach. For this assessment, the pollution sensitivity interpretation focuses on the sediments 20 to 50 feet below the surface (the target zone) and assumes downward movement of ground water. Hydraulic conductivity values from literature were assigned to the surficial sediments in this study area to estimate the time of travel for water to reach depths of 20 to 50 feet. Well logs were assumed to provide a reasonably accurate description of the sediments at depth. This assessment is applicable to contaminants that are released at or near the surface, are chemically inert, and move with water.

Summary of Assessment Process. Figure 3 depicts the process used in developing the geologic sensitivity map. Four main hydrogeologic and geologic factors were identified that influence downward travel time of water: hydrogeologic setting, surficial sediment, unsaturated thickness, and target zone lithology. Two factors are based on spatial information from Plate 3 and from Plate 1 of Part A (hydrogeologic setting and surficial sediment, respectively), and two are based on point data from field measurements and well logs (unsaturated thickness and target zone lithology). Each factor was subdivided into categories. The factors and their associated categories (in parentheses) are hydrogeologic setting (outwash plain, collapsed outwash, hummocky moraine, ground moraine), surficial sediment (sand and gravel, sandy loam, loam, loam to clay loam), unsaturated thickness (0 to 20 feet, 21 to 50 feet, greater than 50 feet), and target zone lithology (no clay, some clay, all clay). A number representing a vertical time of travel for water to reach a depth of 20 to 50 feet (the target zone) was assigned to each of the categories.

The study area was divided into 83 map polygons with similar characteristics. Within the boundaries of a map polygon are one hydrogeologic setting and one surficial sediment, as well as the overall similarity of unsaturated thickness and target zone lithology. The time of travel values attributed to these categories were averaged for each map polygon. Applying this calculation to each map polygon ensured that a consistent method for assessing time of travel was used throughout the study area. The resultant travel time values provided an initial geologic sensitivity rating for each map polygon (Figure 3, matrix). Qualifying information about the physical and chemical environments was then considered for each map polygon to validate or adjust these initial results and assign the final geologic sensitivity ratings.

Refer to Sensitivity Map Preparation in the Technical Appendix for details of how sensitivity ratings were calculated and assigned to map polygons.

Results. The target zone in outwash settings has a very high to high sensitivity rating, indicating there is little time to respond to pollution incidents and prevent aquifer contamination. Nearly all wells less than 100 feet deep (approximately the maximum thickness of these sediments) had detectable tritium (Figure 4). This observation supports a very high to high rating. Sensitivity ratings of very high or high do not mean that ground-water quality is or will be degraded. If there are no contaminant sources, pollution will not occur. Additionally, surface water in these settings actively interacts with ground water. Consequently, surface water should be considered sensitive to contamination from ground water. Refer to Figure 3 on Plate 3 for more information on interactions of lakes and ground water.

The sensitivity of the target zone in moraine settings is rated moderate to low, indicating that a pollution incident can likely be investigated and possibly corrected before serious ground-water contamination develops. The presence of clay in these sediments has a major influence on primary hydraulic conductivity, reducing the travel time of ground water. Secondary hydraulic conductivity from fractures or connected buried sand units, however, can result in more rapid infiltration of ground water, possibly explaining the presence of tritium in some wells in the moraine settings (Figure 4). Low sensitivity does not guarantee that ground water in moraine settings is or will always remain uncontaminated. Leakage from abandoned or poorly constructed wells could bypass the natural protection of clay-rich sediments (condition 4 of Figure 5). Surface-water contamination is a concern in the moraine settings due to the increased likelihood that runoff from precipitation may carry contaminants to lakes and streams rather than infiltrate the ground.

Most of the wells in this study area are completed below the target zone. Vertical travel time to deeper aquifers is assumed to be longer; therefore, these aquifers will have the same or a lower sensitivity rating than that shown for the target zone above them. Wells shown on the map with vintage water indicate a low to very low sensitivity at the well depth indicated.

The map shows that areas with very high sensitivity and areas with low sensitivity can be adjacent to each other. Abrupt changes in sensitivity result where there are distinct changes in hydrogeologic setting or sediment texture. An example of this is the low sensitivity area where Todd County borders with Wadena and Otter Tail counties. Here, the sand and gravel sediments of an outwash plain that have a very high sensitivity rating surround an area of ground moraine that has a low sensitivity rating. In some areas, the sediments between lakes and along rivers are also rated very high while the adjacent sediments may range from low to high (for example, between Rush and Otter Tail lakes and near Sebeka).

Map Limitations. Lateral movement of water can transport contaminants from a place on the surface to a location at depth that is not directly below it (conditions 3 and 5 of Figure 5). In all settings, heterogeneities, some of which may be connected deposits of buried sand and gravel (for example, on Plate 2 of Part A and on Plate 3), result in preferred flow paths where the rate of ground-water movement in these coarse-textured sediments can be greater than in surrounding fine-textured sediments. This geologic sensitivity assessment is limited to vertical movement of water from the surface to the target zone and does not address geologic sensitivity based on lateral flow of ground water.

It is generally accepted that the water table throughout Minnesota, except where it is very deep, is recharged each spring following snowmelt. A geologic sensitivity assessment of the water table based on annual recharge would result in a high sensitivity rating for most of the state. At the other extreme, all precipitation can be intercepted by evapotranspiration during the peak growing season in some areas (Figure 6). The sensitivity ratings shown on the map do not reflect such annual or seasonal conditions.

Locally, sediments may differ from those shown on the sensitivity map. More detailed geologic and hydrogeologic information must be evaluated for site-specific investigations. This map gives a regional perspective of pollution sensitivity that can serve as a screening tool to estimate the potential impacts of certain activities and land uses on the ground-water quality in the study area.

REFERENCES 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.

ACKNOWLEDGMENTS

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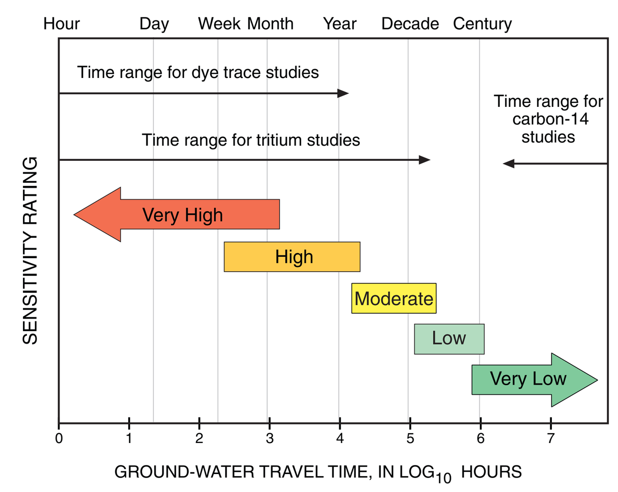


FIGURE 1. *Geologic sensitivity rating as defined by ground-water travel time.* *Ratings are based on the time range required for water at or near the surface to travel vertically into the target zone (see Figure 2). Longer travel times imply a lower sensitivity to pollution. The sensitivity ratings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

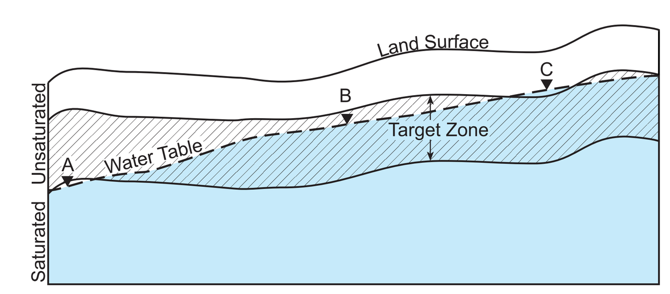
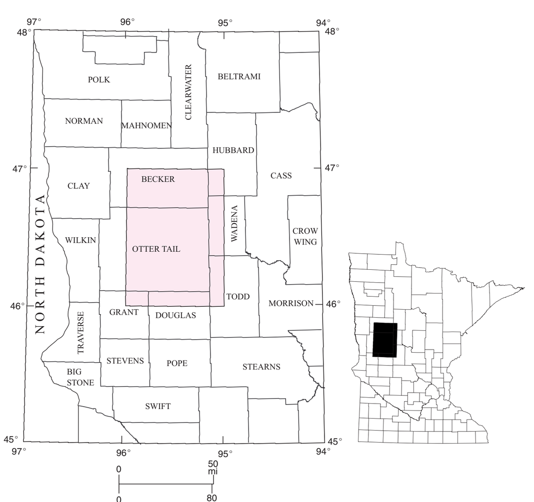


FIGURE 2. *Illustration of the geologic sensitivity target zone and water table. The target zone is a 30-foot-thick layer beginning at 20 feet below the land surface and includes both aquifer and nonaquifer materials. Throughout most of this study area, the water table is found within the target zone. In a few areas (A), the water table is deep, below the target zone, and all of the target zone material is unsaturated. In most of the study area (B), the water table lies within the target zone and some of the target zone material is saturated. In some areas (C), the water table is shallow, above the target zone, and all of the target zone material is saturated. Illustration not drawn to scale.*



LOCATION OF STUDY AREA

Initial Sensitivity Rating Matrix

Spatial Data Factors: Hydrogeologic setting	Surficial sediment	0–20 feet: No clay	0–20 feet: Some clay	0–20 feet: All clay	21–50 feet: No clay	21–50 feet: Some clay	21–50 feet: All clay	Greater than 50 feet: No clay	Greater than 50 feet: Some clay	Greater than 50 feet: All clay
Outwash plain	Sand and gravel	V	H	H	H	H	M	H	H	M
Collapsed outwash	Sand and gravel	V	H	H	H	H	M	H	M	M
Hummocky moraine	Sandy loam	H	H	M	H	M	M	M	M	L
Ground moraine	Sandy loam	H	M	M	M	M	M	M	L	L
Hummocky moraine	Loam	H	M	M	M	M	L	M	L	VL
Hummocky moraine	Loam to clay loam	M	M	M	M	M	L	M	L	VL

Point Data Factor: Unsaturated thickness (0–20 feet; 21–50 feet; Greater than 50 feet). Point Data Factor: Target zone lithology (No clay; Some clay; All clay). ← Generally Decreasing Permeability

Qualifying Information

Physical environment
- Lakes, wetlands in low areas
- Developed stream network
- Ground-water gradient in topographic high

Chemical environment
- Presence of tritium
- Evidence of human impact

Final Sensitivity Rating

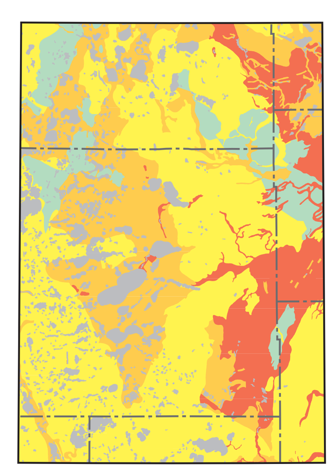


FIGURE 3. *Development of the geologic sensitivity map. Initial sensitivity ratings were assigned by combining time of travel values from two spatial factors (hydrogeologic setting and surficial sediment) and from two point factors (unsaturated thickness and target zone lithology), and calculating an average value for each map polygon in the study area. Information about the physical and chemical environment (summarized under Qualifying Information) was used to validate or adjust the initial sensitivity ratings. Cells with the pattern in the rating matrix indicate conditions that are possible but were not found in the study area.*

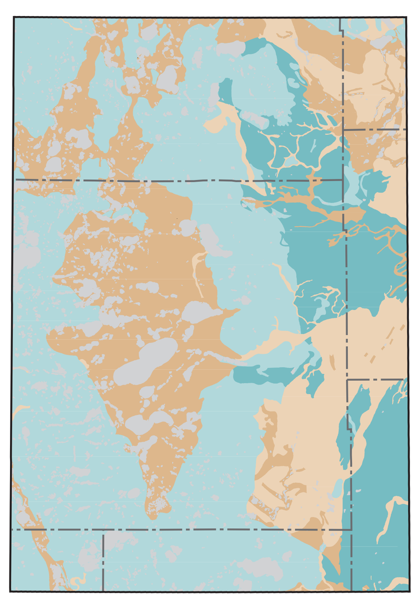
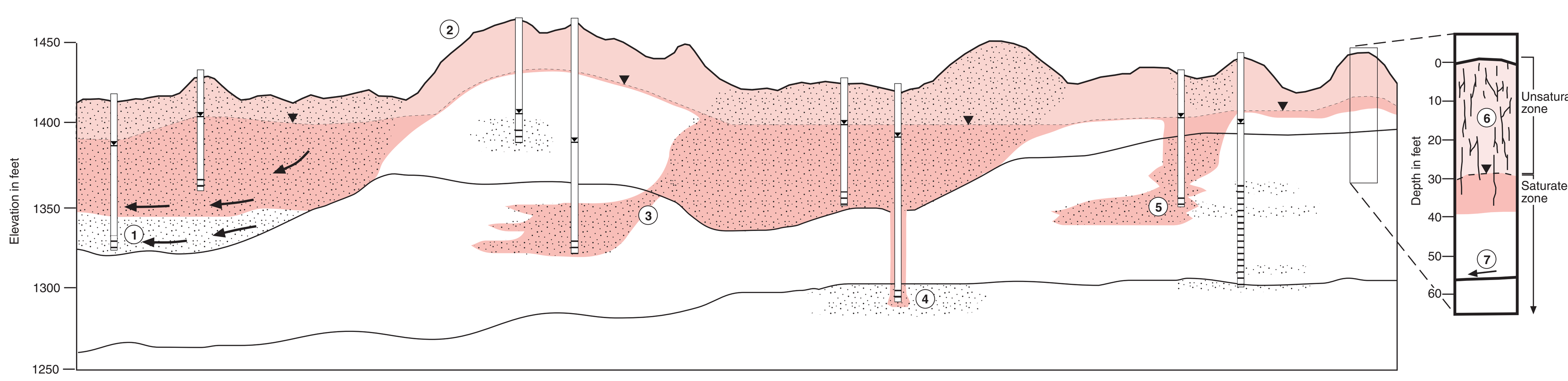


Table of Tritium Penetration

Hydrogeologic Setting	Expected Maximum Depth of Tritium (feet)	Deepest Recent Water (feet)	Shallowest Vintage Water (feet)	Wells: Number Sampled	Wells: Depth Range (feet)
Collapsed outwash	130	130	64	11	56–350
Outwash plain	130	82	137	9	55–403
Ground moraine	130	88	135	8	79–298
Hummocky moraine	170	168	65	41	55–384

FIGURE 4. *Tritium penetration by hydrogeologic setting.* *Sample results for this study showed that tritium concentrations greater than 0.8 tritium units can be expected to a maximum depth of 130 feet in the outwash and ground moraine settings, and somewhat deeper (170 feet) in the hummocky moraine setting. Table data show that recent water penetrated deeper in the hummocky moraine setting (168 feet) than in the other hydrogeologic settings, possibly because of connected sand and gravel deposits in the subsurface that provide pathways for ground-water movement. Buried sand and gravel deposits tend to be smaller and more isolated in the ground moraine than in the hummocky moraine, and ground moraine sediments have been compacted by overriding glaciers limiting ground-water movement; consequently, recent water has not migrated as deeply (88 feet). In the outwash settings, recent water penetration is also limited (82-130 feet) because low-permeability till underlying the relatively thin outwash restricts downward movement. In addition, the contrast in permeability between outwash and till may induce lateral flow (see Figure 5, condition 7) and further limit downward movement.*



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
- Direction of ground-water flow
- Till sheet boundary

Subsurface Conditions

1. Strong lateral flow has prevented recent water from infiltrating to the deeper portion of a surficial aquifer.
2. High-relief areas can have reduced infiltration due to runoff.
3. Coarse, permeable materials provide a preferential pathway for the water to enter into the subsurface.
4. A poorly constructed well conducts water from the surface to aquifers or between aquifers.
5. Buried aquifers overlain by thin, low-permeabilty sediments may be recharged by recent water.
6. Fractures and joints can reduce travel time for water through till and fine-grained sediments.
7. Boundaries between glacial units can induce lateral flow where a lower unit has a different permeability.

FIGURE 5. *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.*

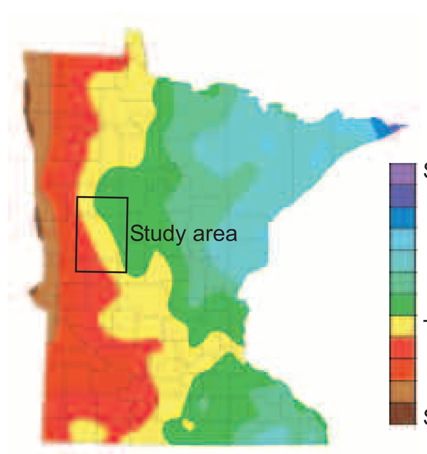


FIGURE 6. *Average annual precipitation minus average annual evapotranspiration. The transition zone between the semihumid and the semiarid climate regimes covers a wide swath diagonally through the study area. In this zone and to the southwest, evapotranspiration equals or nearly equals precipitation. Furthermore, during the growing season, infiltration of water and water-borne contaminants to the water table is very limited. During spring and fall, however, when transpiration is reduced, infiltrating water replenishes ground water and can carry contaminants with it. The sensitivity method described on this plate is based on geologic conditions, not seasonal fluctuations of precipitation and evapotranspiration. This figure is an adaptation of an illustration from the Minnesota State Climatology Office.*

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 1997 to 1999 at the scale of 1:200,000. Universal Transverse Mercator projection, grid zone 15, 1983 North American datum. Vertical datum is mean sea level.

GIS and cartography modified from Minnesota Geological Survey RHA-5, Part A, Plate 1 (Surficial Geology).