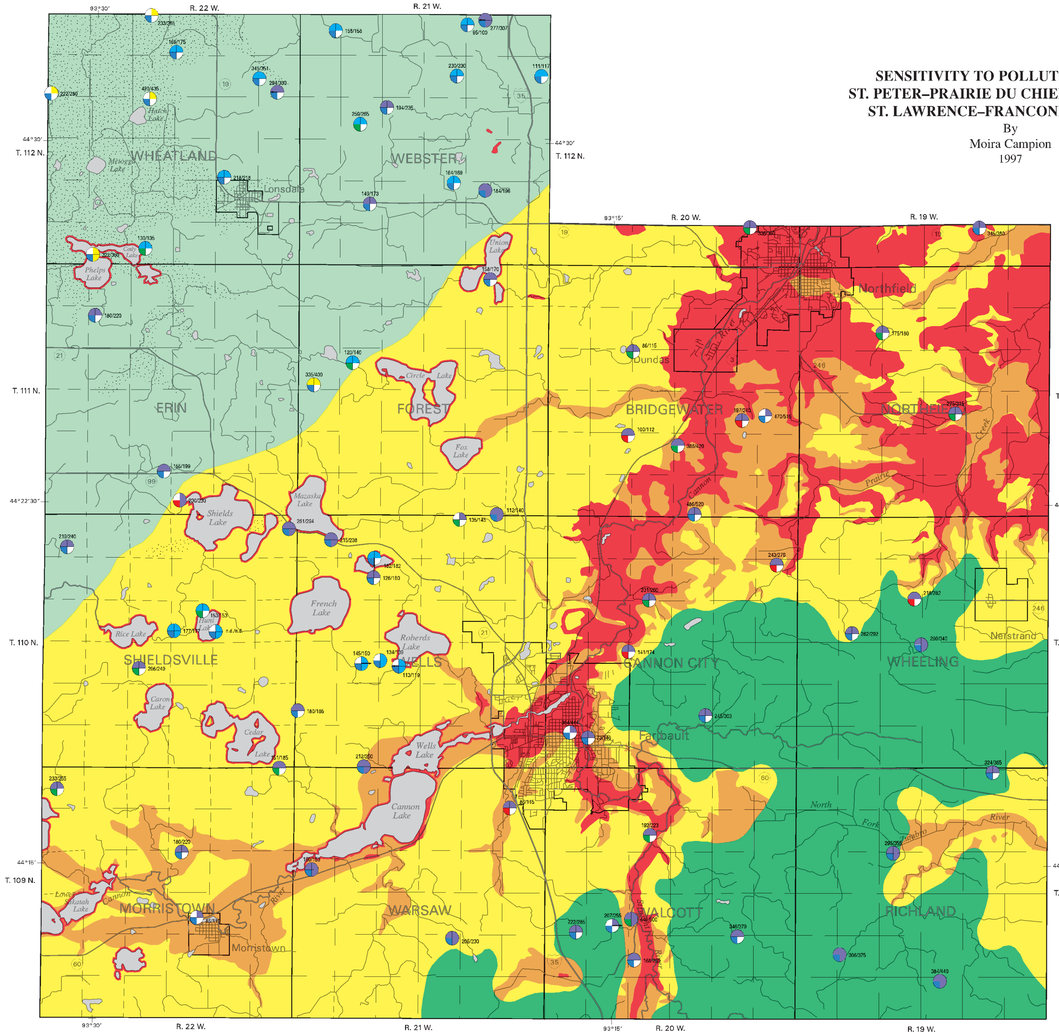
STATE OF MINNESOTA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATERS

Prepared and Published with the Support of
THE MINNESOTA ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

COUNTY ATLAS SERIES
ATLAS C-9 , PART B, PLATE 9 of 9
Sensitivity of Ground-Water Systems to Pollution

SENSITIVITY TO POLLUTION OF THE ST. PETER–PRAIRIE DU CHIEN–JORDAN AND ST. LAWRENCE–FRANCONIA AQUIFERS

By
Moira Campion
1997



EXPLANATION

Sensitivity Ratings

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

- **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**—More than a century
- **Lake**—Unrated, selected lakeshores rated Very High

Description of Map Symbols

- **Well measured for water level** — Depth in feet to bottom of well screen or open hole / Depth in feet to top of well screen or open hole
- **Well sampled for general chemistry**
- **Well sampled for tritium**—Color indicates age as shown below
- **Well sampled for ^{2}H, ^{18}O, or ^{14}C**
- **Data collection symbol moved to avoid overlap**—Arrow points to correct location

Aquifers[1]	*Tritium age of water samples*[2]
Quaternary	Recent
St. Peter-Prairie du Chien-Jordan	Mixed
St. Lawrence-Franconia	Vintage

[1] *No color indicates no data*
[2] *See Figure 1, Plate 8, for definition*

St. Lawrence-Franconia aquifer subcrop

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

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.

WARNING: This map provides an overview of ground-water contamination potential as interpreted from 1:100,000-scale geologic map information. THIS MAP SHOULD NOT BE THE BASIS FOR EVALUATION OF SPECIFIC SITES.

Digital base composite of modified 1990 Census TIGER/Line files of the U.S. Bureau of the Census (source scale, 1:100,000), U.S. Geological Survey (USGS) Digital Line Graphs (source scale, 1:100,000), and Minnesota Department of Natural Resources (DNR)-developed Public Land Survey data (source scale, 1:24,000); digital base annotation by Minnesota Geological Survey and the DNR. Project data compiled 1997 at the scale of 1:100,000.

Universal Transverse Mercator Projection, grid zone 15, 1983 North American Datum.

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

MATRIX FOR RATING AQUIFER SENSITIVITY

		Decorah-Platteville-Glenwood Confining Unit		
		Absent	Eroded edge	Continuous
Rock, Sediment, or Other Feature	Bedrock at or near surface	VH	H	VL
	Alluvium	VH	VH	VL
	Lakeshore	VH		VL
	Alluvium over till	M[1]	H	VL
	Till: Pre-Wisconsinan	M	VL	VL
	Till: Des Moines lobe with lakes	M		
	Till: Des Moines lobe with few lakes	L		

[1] High in selected stream areas; Low in the northwestern part of the county where the Des Moines lobe till is thin and there are few lakes.

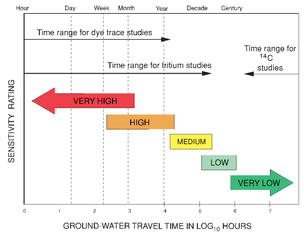


FIGURE 1. ***Geologic sensitivity ratings are based on the time required for water at or near the surface to travel vertically to the water table or other ground water of interest. Longer travel times imply a lower sensitivity to pollution. Dye trace, tritium, and ^{14}C studies can indicate the relative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

INTRODUCTION

This plate describes the factors influencing the sensitivity to pollution of the major bedrock aquifers in Rice County (see the plate supplement for sensitivity to pollution of near-surface ground-water systems). The sensitivity to pollution map describes the sensitivity of the bedrock aquifer using a model based on vertical ground-water flow behavior. The recharge conditions map shows how water may travel from the surface to the aquifer through both vertical and horizontal flow paths. The sensitivity of an aquifer to pollution is the relative ability of overlying geologic materials to restrict the downward migration of water and contaminants to an aquifer of interest. There are many ways to evaluate sensitivity to pollution (Geologic Sensitivity Workgroup, 1991). The Minnesota Groundwater Protection Act of 1989 states that a sensitive area is "a geographic area defined by natural features where there is a significant risk of groundwater degradation from activities conducted at or near the land surface." The "natural features" stated in the Act are the geologic conditions in an area, such as type of bedrock or surficial materials. This approach is called intrinsic or geologic sensitivity.

GROUND-WATER RESIDENCE TIME AND SENSITIVITY RATING

Sensitivity to pollution can be evaluated by relating it to the estimated age of the ground water. The age of the water, also called residence time, is the approximate time that elapses from the time a drop of water infiltrates the land surface to the time it is discharged or pumped from an aquifer. Radiometric dating using isotopes of carbon (^{14}C), hydrogen (^{3}H), and oxygen (^{18}O) can determine the residence time of ground water in an aquifer (Alexander and Alexander, 1989). Shorter residence times indicate recent recharge and higher sensitivity to pollution. Longer residence times may represent a greater travel time and an increased level of geologic protection to the aquifer. These sensitivity and travel-time relationships are shown in Figure 1.

The pollution sensitivity rating is classified into five categories in this report: Very High, High, Moderate, Low and Very Low. Very High sensitivity indicates that water moving vertically downward from the surface may reach the aquifer within hours to months. In these areas there is little time to respond to pollution incidents and prevent aquifer contamination. Conversely, a Low sensitivity rating indicates that a surface contamination source can likely be investigated, and possibly corrected, before serious ground-water pollution develops. However, High sensitivity does not mean that water quality has or will be degraded; nor does Low sensitivity guarantee that ground water is or will always remain uncontaminated.

RECHARGE CONDITIONS

The recharge conditions map displays areas with different recharge characteristics for the St. Peter-Prairie du Chien-Jordan and the St. Lawrence-Franconia aquifers. This map shows eight distinctive hydrogeological conditions that influence recharge to these aquifers. These conditions account for both vertical and horizontal ground-water flow behavior and are directly related to the geological deposits which overlie the aquifers. The recharge conditions map was developed from the geologic maps on Plates 2, 3, and 5 of Part A, as well as hydrogeological information collected during this study. Although horizontal flow of ground water is not a factor in the Department of Natural Resources model of pollution sensitivity, horizontal flow has a significant role in understanding the entire ground-water system in Rice County.

The area with the most direct recharge to the aquifer is in northeastern Rice County where the St. Peter Sandstone or the Prairie du Chien Group is at or near land surface. In this area (map unit **aqs**), water enters the aquifer readily from the land surface through the unsaturated zone, moving through pore spaces and fractures in the rock.

Three map units show areas that are characterized by strong horizontal flow: the exposed and buried subcrop edge of the Decorah-Platteville-Glenwood confining unit (maps units **ecu** and **bcu**, respectively) and alluvium and outwash deposits (**alo**), particularly where they occur over less permeable sediments. The ground water in these deposits does not recharge the underlying aquifer in a direct vertical manner over a large area. Instead, horizontal flow through these units can deliver large volumes of ground water to limited areas in the underlying bedrock aquifer.

The edge of the Decorah-Platteville-Glenwood confining unit near Rochester has been identified by Delin (1991) and Delin and Almendinger (1991) as an area of high recharge into the underlying St. Peter-Prairie du Chien-Jordan aquifer. However, the bedrock units above the St. Peter Sandstone (the Cummingsville Formation, Decorah Shale, Platteville Formation, and Glenwood Formation), which all consist of limestone or dolostone interlayered with shale, are hydrogeologically more complex than depicted in the focused recharge model of Delin (1991).

Where the shales are unweathered and unfractured, away from the subcrop edge, ground water moves easily through the fractures in the carbonate layers but is impeded from downward migration by the shaly layers. However, in other places away from the subcrop edge these shales are fractured. It is therefore possible that the focused recharge to the St. Peter Sandstone occurs through concentrated areas of fractures that may be located miles behind the subcrop edge of the Glenwood-St. Peter contact (Runkel, A.C., 1997, personal communication). Although identifying the specific location of this focused recharge boundary is prohibitive in an area this large and geologically complex, it is clear that the eroded edge of this confining unit is an important hydrologic feature in Rice County (see cross section E-E', Plate 8). The significance of this feature is most evident where it is at or near the surface and creates a perched aquifer system (see Plate 7). Where the edge of the confining unit is buried by more than 100 feet of saturated till, its hydrologic influence is less clear. On this map this edge is shown by the smoothed subcrop boundary of the Glenwood Shale from Plate 2, with a buffer strip of approximately one-third mile inward from that edge. This buffer strip was then divided into two map units. Map unit **ecu** indicates the portion of this area with depth to bedrock of less than 50 feet. Map unit **bcu** shows the portion of this unit with a depth to bedrock greater than 50 feet. The short arrows shown in these two map units indicate the general direction of horizontal ground-water flow from the Decorah-Platteville-Glenwood confining unit and overlying sediments into the St. Peter-Prairie du Chien-Jordan aquifer.

The third area with strong horizontal flow behavior includes the alluvial and outwash deposits described on the Surficial Geology map on Plate 3. These sand and gravel deposits (map unit **alo**) have high porosity and permeability. Long arrows indicate the general horizontal direction that ground water is likely to move within these units until more direct access to the bedrock aquifer is encountered. Throughout the county, where streams and the associated sediments are in close contact with the bedrock aquifer, the bedrock aquifer is generally discharging into the stream. However, this relationship could be reversed under drier climatic conditions.

The tills in Rice County have been divided into three recharge map units. Areas of pre-Wisconsinan till are shown as map unit **tpw**. The areas with late Wisconsinan till at or near the surface have been divided into two recharge map units. Map unit **twl** indicates areas in central Rice County that have thinner till and many large lakes. Map unit **tfl** shows areas in northwestern Rice County that have thicker till and very few lakes.

Depth to bedrock in till-covered areas is often the only factor used when interpreting how well till will protect an aquifer. This approach assumes that all material between the surface and bedrock is till and that all tills are equivalent. In Rice County, as in most places, both of these assumptions are false. Although recharge map unit **twl** can include areas with depths to bedrock of more than 300 feet, well logs show that much of the subsurface sediment in these deep areas include buried sand and gravel deposits. These deposits offer no protection and provide potential pathways to the underlying bedrock aquifer. Conversely, in the area indicated by map unit **tfl** the subsurface sediment contains fewer sand bodies and would be expected to offer more protection.

In southeastern Rice County, the continuous subcrop of the Decorah-Platteville-Glenwood confining unit (map unit **ecu**) inhibits recharge to the underlying St. Peter-Prairie du Chien-Jordan aquifer more effectively than any other geologic unit in the county. This unit is less than 100 feet thick, whereas till is western Rice County often exceeds 300 feet thick. Delin (1991) estimated that the recharge rate through this unit is approximately 0.5 inch per year.

SENSITIVITY INTERPRETATION

The sensitivity to pollution of the St. Peter-Prairie du Chien-Jordan and the St. Lawrence-Franconia aquifers map was developed based on information from Plates 2, 3, and 5 of Part A and the maps and cross sections from Plates 6 and 7. The recharge conditions map was also used to construct this map. The factors considered are illustrated in the sensitivity rating matrix. This map shows the estimated travel time of water from the land surface vertically downward to the bedrock aquifers, with no consideration of horizontal flow. The thickness and hydrogeologic character of tills and the unroofed Decorah-Platteville-Glenwood confining unit are the most significant factors for interpreting sensitivity to pollution in Rice County. This interpretation simplifies the hydrogeological conditions that affect these aquifers and should be applied in conjunction with the recharge conditions map.

The county can be broadly divided into four sensitivity regions: High and Very High where the aquifer or the edge Decorah-Platteville-Glenwood confining unit has less than 50 feet of sedimentary cover or is covered by alluvium or outwash; Moderate where the aquifer or the edge of Decorah-Platteville-Glenwood confining unit has greater than 50 feet of sedimentary cover; Low where the aquifer is under thick Des Moines lobe till without many lakes; and Very Low where the aquifer is beneath the continuous Decorah-Platteville-Glenwood confining unit. Lakeshore for larger lakes has been rated Very High. As discussed on Plate 7, lakeshore is considered a likely area of recharge to the underlying aquifer.

ISOTOPIC AGE-DATING RESULTS

The results of tritium analyses may be used to evaluate the sensitivity map as a predictor of the ground-water time of travel from the surface to the sampled well. The tritium data are generally consistent with the location of the four broad sensitivity regions mentioned above.

Figure 2 shows the distribution of tritium ages of 81 samples collected during this study, and summarizes the tritium results of the analyses listed in Table 1, Plate 7. Sixty-five percent of the samples had no detectable tritium (vintage water) and thus infiltrated the land surface before 1953. More than ten tritium units (TU) were detected in 14 percent of the samples and these are considered recent waters. Twenty-one percent of the samples had tritium concentrations between the detection limit (0.8 TU) and ten TU and are referred to as mixed. These tritium results were compared to the average concentration of nitrate (expressed as nitrogen) and chloride in the samples. Elevated amounts of nitrate or chloride in well samples are considered an indication of human activity. Recent waters have the highest concentration of nitrate and chloride, and the vintage waters have the lowest.

The symbols show the location of the 77 ground-water samples taken from wells greater than 100 feet deep that were analyzed for general chemistry and isotopes. Seven samples have tritium concentrations greater than ten TU. Five of these samples are located in areas with High or Very High sensitivity. The other two recent samples are from areas with a Moderate rating. Sixteen samples had tritium concentrations less than ten TU but greater than the detection limit. Nine of these mixed-age samples are located in or near areas rated High or Very High and seven are from areas rated Moderate. Fifty-four of the samples have no detectable tritium. Thirty of these are from areas with ratings of Low or Very Low. Seven vintage samples are from areas with a Moderate sensitivity rating. Seventeen vintage samples were collected in areas rated High or Very High (including near lakes in western Rice County). Figure 2 illustrates that tritium may be detected in wells whose sensitivity ratings could range from Very High to Low.

Only one sample with detectable tritium was collected in the Low sensitivity area despite the wide range of depths sampled. This sample was taken from a Quaternary well, located near a lake. Tritium results indicate the alluvial and outwash deposits identified on the recharge conditions map have no direct influence on the deeper ground water in this area.

In the Moderate sensitivity area, tritium results vary. In eastern Rice County, several samples with mixed or recent waters were collected along the edge of the Decorah-Platteville-Glenwood confining unit, close to High and Very High sensitivity areas. Vintage samples in this area are generally from wells that are deeper or further from the edge of the Decorah-Platteville-Glenwood confining unit. In the lakes region of western Rice County, the tritium results also vary. Only two samples have recent water, one is on a lake, and both are from bedrock wells. Six samples from the lakes region have mixed water, and are widely distributed both spatially and with depth. Most of the samples in this area have vintage water, and were taken from a variety of depths. The wide distribution of tritium ages at various depths in the area covered by the thin, supraglacial deposits of the Des Moines lobe attests to the complexity of ground-water flow in this area, as discussed in Plate 6. All but one of the ^{14}C samples from this area were too young for the range of ^{14}C dating, which indicates that water is getting from the surface to even the deepest wells within a few centuries.

Most areas rated as High or Very High sensitivity are in northeastern Rice County, and through the Cannon and Straight River valleys, similar to the sensitivity of the near-surface ground-water system map on the plate supplement. Most of the samples with detectable tritium came from wells located in the northeastern part of the county. However, there are also several deeper wells in this area with vintage water. The boundary between recent and vintage waters in northeastern Rice County can be seen on cross section E-E' on Plate 8.

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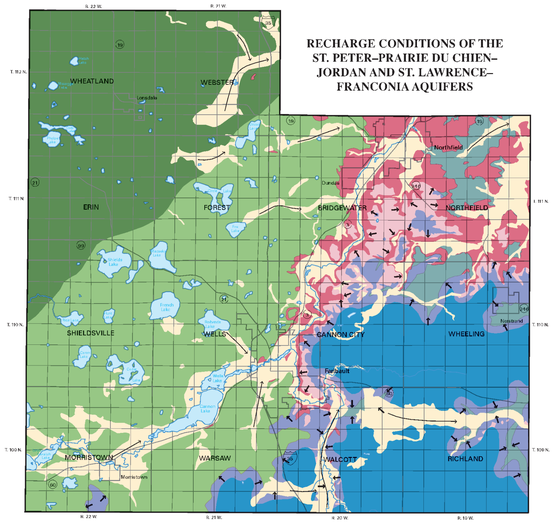
ACKNOWLEDGMENTS

I would like to thank Dr. E. Calvin Alexander, Jr., and Dr. H.-O. Pfannkuch for professional guidance through the entire development of this plate. Robert Tipping, Anthony Runkel, Geoffrey Delin and Michael Trojan gave important suggestions on the development of the Recharge Conditions map, as well as review of this plate. Jeffrey Green, Barbara Palen, Carrie Patterson, and Bruce Olsen also offered valuable review and criticism. James MacArthur gave critical and timely consideration to the text. Jan Falteisek provided important editorial direction. The Ground Water Unit Staff was very helpful throughout this project. Paul Bulger offered the perspective of a consulting hydrogeologist along with invaluable support.



RECHARGE CONDITIONS OF THE ST. PETER–PRAIRIE DU CHIEN–JORDAN AND ST. LAWRENCE–FRANCONIA AQUIFERS

SCALE 1:200 000
2 0 2 4 6 8 MILES
2 0 2 4 6 8 KILOMETERS

EXPLANATION

Description of Map Units

- **aqs** — **Aquifer at or near the surface, water infiltrates directly into the aquifer**

Areas with significant horizontal ground-water flow

- **alo** — **Alluvium or outwash**
- **ecu** — **Decorah-Platteville-Glenwood confining unit edge with less than 50 feet cover**
- **bcu** — **Decorah-Platteville-Glenwood confining unit edge with greater than 50 feet cover**

Areas with both vertical and horizontal ground-water flow

- **tpw** — **Pre-Wisconsinan till**
- **twl** — **Thin late Wisonsinan Des Moines lobe till with lakes**
- **tfl** — **Thick late Wisonsinan Des Moines lobe till with few lakes**

Area of bedrock confining unit

- **ecu** — **Continuous Decorah-Platteville-Glenwood confining unit**

Description of Map Symbols

- **Probable horizontal ground-water flow over eroded edge of the Decorah-Platteville-Glenwood confining unit to underlying aquifer**
- **Probable horizontal ground-water flow in alluvium or outwash**

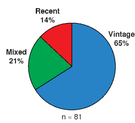


FIGURE 2. The pie diagram shows the percentage of ground-water samples by tritium age for this study. The mean concentration of chloride and nitrate (shown as NO_3-N) in samples with recent tritium ages are elevated compared to samples with vintage and mixed-age water, suggesting that human activity is affecting ground-water quality in Rice County. Analytical results of one Galena well sample are not included.

Chloride and Nitrate Concentration by Tritium Age, in Milligrams per Liter

	Chloride	Nitrate
Recent		
Mean	19.48	0.33
Standard deviation	21.25	0.75
Mixed		
Mean	3.17	0.13
Standard deviation	6.03	0.19
Vintage		
Mean	1.23	0.08
Standard deviation	1.80	0.04

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