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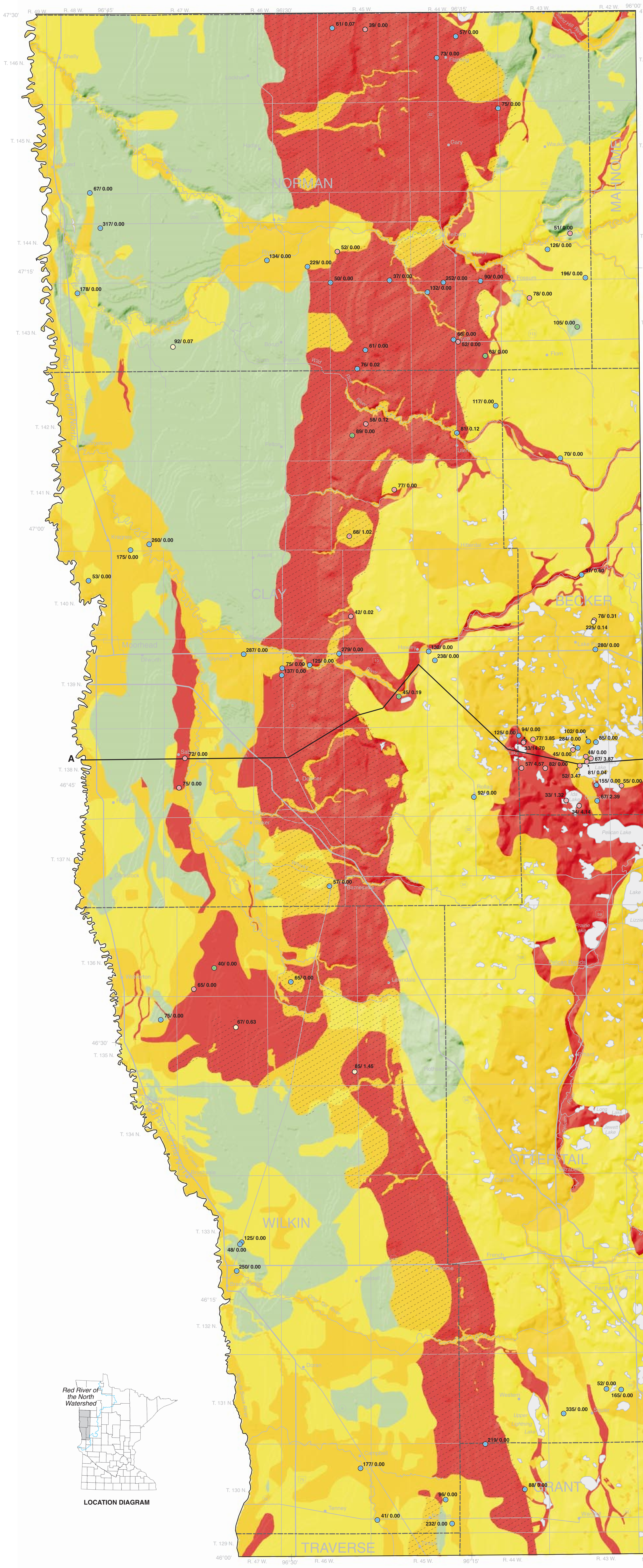

SCALE 1:200 000

5 0 5 10 15 Miles

5 0 5 10 15 Kilometers

MAP EXPLANATION

Sensitivity Ratings

Estimated vertical travel time for water-borne surface contaminants to enter the upper part of the near-surface ground-water systems

- VH — **Very High**—Hours to months
- H — **High**—Weeks to years
- M — **Moderate**—Years to decades
- L — **Low**—Decades to a century
- **Water** (not rated)

Description of Map Symbols

51/ 0.00 — **Tritium or nitrate-nitrogen sample**—Color indicates residence time based on tritium age, as shown below.
Nitrate-nitrogen concentration, in milligrams per liter (mg/L)
Well depth, in feet

Tritium age of water samples

- **Recent**—Entered the subsurface since 1953
- **Mixed**—Mixture of recent and vintage
- **Vintage**—Entered the subsurface before 1954
- **No tritium sampled**

Area of shallow, lateral flow

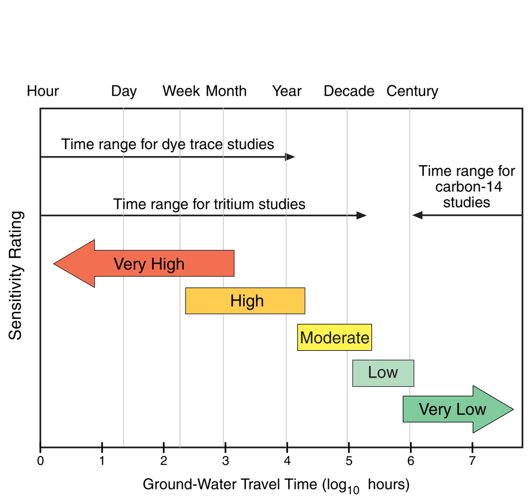

FIGURE 1. *Geologic sensitivity ratings are based on the time required for water at or near the land surface to travel vertically to the water table or other ground water of interest. Longer travel times imply a lower sensitivity to pollution. Dye trace, tritium, and carbon-14 studies can indicate the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

	Sediment Group	Depth to Water Table (feet)			
		0 to 10	10 to 20	20 to 40	More than 40
Decreasing estimated permeability ↓	Sand and gravel	VH	VH	H	M
	Mixed clayey sand	H	H	M	L
	Mixed sandy clay	M	M	L	L
	Lake silt and clay	M	L	L	L

FIGURE 2. *Matrix for rating pollution sensitivity of the upper part of the near-surface ground-water systems for a mixed assessment zone, extending from the water table to 30 feet below the water table.*

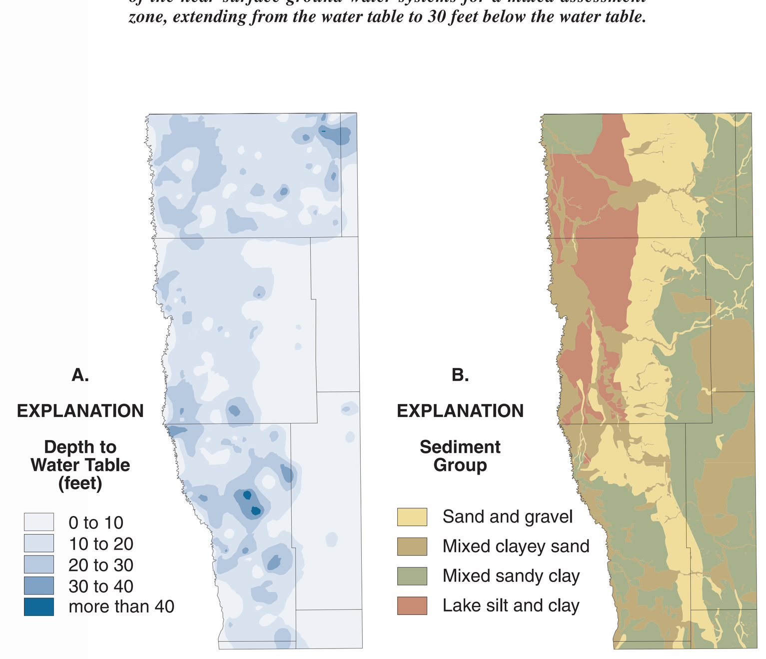

FIGURE 3. *The two primary information layers used to prepare the pollution sensitivity map. Figure 3a shows the depth to the water table created from point data as described in the text. Figure 3b shows sediment groups based on the surficial geologic map units on Plate 1. The information layers were combined as described in the text.*

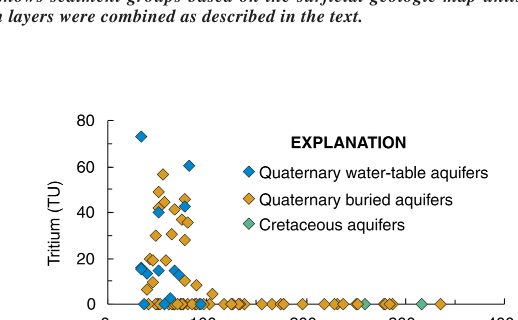

FIGURE 4. *Tritium concentration by well depth and aquifer in 87 sampled wells. No well deeper than 105 feet had detectable tritium.*

SENSITIVITY TO POLLUTION OF NEAR-SURFACE GROUND-WATER SYSTEMS

By
Jan D. Falteisek
2000

INTRODUCTION

This plate presents the sensitivity to pollution interpretation for the southern part of the Red River of the North valley in Minnesota. The map portrays the pollution sensitivity of the upper part of the near-surface ground-water systems within 30 feet below the water table, based on several geologic and hydrogeologic factors that can affect the time of travel of water. The map shows areas particularly sensitive to pollution from sources or activities at the land surface. They include the Buffalo and Pelican River Sand Plain aquifers and Beach Ridge Complex region (Figure 2, Plate 3). Except where the Buffalo aquifer occurs in it, the Lake Agassiz Plain region is generally less sensitive than elsewhere in the study area.

This pollution sensitivity assessment can assist a variety of water-resource protection efforts. Elected officials, administrators, agency environmental staff, and the public can use the assessment to evaluate the potential impacts of land-use decisions; more effectively identify and prioritize problem areas; and, as a result, better protect the region's ground-water resources.

GEOLOGIC SENSITIVITY

The Minnesota Department of Natural Resources (DNR) identifies sensitive areas as geographic areas defined by natural features where there is significant risk of ground-water degradation from activities conducted at or near the surface (MS § 103H.005). The natural features are the geologic conditions in the area. This approach is called intrinsic or geologic sensitivity.

DNR guidelines for preparing maps of geologic sensitivity define it as the time needed for water at the surface to travel vertically downward to the ground water of interest (Geologic Sensitivity Workgroup, 1991). As applied to this study area, the estimated travel times (Figure 1) are based on the vertical path length to the water table and into the upper part of the near-surface ground-water systems (described on Plate 3) and the estimated vertical permeability of the geologic materials through which the water travels. The travel time ranges and sensitivity ratings overlap because of uncertainty in estimating travel times, which can vary significantly due to local-scale variations in geologic and hydrologic conditions.

The water table exists throughout the study area and typically occurs within 20 feet below the land surface. Surficial (water table) aquifers occur in about 30 percent of the area. Buried aquifers are present in near-surface sediments in most places and often underlie surficial aquifers, but some parts of the study area may lack both surficial and shallow buried aquifers. The map presents the interpretation of pollution sensitivity for the upper part of the near-surface ground-water systems, whether a surficial or shallow buried aquifer is present or not.

This interpretation of geologic sensitivity required a number of simplifying assumptions. Water, often called the "universal solvent," was used as a surrogate for potential ground-water contaminants, which were assumed to be released at the land surface. Water was assumed to move vertically downward, and thus shallow portions of the system were assumed to be more sensitive than deep portions. The interpretation assumes, on a regional scale, that the sediment identified at the surface represents the sediment from the water table to 30 feet below it. Above the water table, sediments are more affected by physical, chemical, and biological processes that may result in enhanced permeability.

MAP PREPARATION

The map was developed by applying the travel-time criteria and following the general procedures in the DNR guidelines for the unsaturated zone and water table, although with modifications. Factors considered were depth to the water table and sediment texture. In selected areas, additional geologic and hydrogeologic data supplemented those factors.

Modified Procedure

The map portrays the result of applying a modified Level 2 assessment procedure. A Level 2 assessment procedure is an evaluation of the combined effects on pollution sensitivity of the water table position and the interpreted properties of geologic materials between the land surface and the water table (Geologic Sensitivity Workgroup, 1991). The water table is an example of an assessment boundary and represents a continuous planar feature in the subsurface. The modified Level 2 procedure on which the map is based uses a mixed assessment boundary (Pfannkuch, 1998), which is a thickened planar zone. Its upper surface is the water table and its lower surface is 30 feet below the water table. The mixed assessment boundary was chosen because it represents the native sediment less affected by surface processes such as animal burrows, root casts, and till fractures. These features are most common above the water table and may allow contaminants to enter the subsurface more quickly.

Factors Considered

Depth to the water table and sediment texture were the two primary factors considered in assessing pollution sensitivity for the study area. Described below are the factors used to assign sensitivity ratings. Figure 2 shows how these factors were combined.

Depth to water table. A map showing the vertical distance that infiltrating water must travel to reach the water table was prepared from point data that were computer contoured (Figure 3a). The point data included both data compiled for Plate 3 and supplemental surface-water control points. The 815 data points used 407 surface-water points (zero depth to water), depth to water values from 16 water-table well records, and 392 locations with interpreted depth to the water table based on the depth of the oxidation-reduction interface as identified from sediment color change noted in well records. The values from the 815 data points were kriged (linear option) using a 1000-meter grid interval and then contoured with a 10-foot contour interval. The types of data were not distributed evenly throughout the area. Depth to water table values determined from the oxidation-reduction interface predominated in the western half and northern eighth of the study area; surface water values predominated in the remaining portion of the area. The relatively few depth to water table values from water wells were mainly scattered in the central part of the study area.

Sediment group. As described on Plate 3, the near-surface ground-water systems occur in Quaternary glacial, lacustrine, aeolian, and alluvial deposits of sand and gravel, silt and clay, and till. The 15 surficial geologic map units described on Plate 1 of Part A were separated into four sediment permeability groups based on sediment texture. Map units Qrc, Qwh, Qwl, Qls, Ql/g, and Pgr are sediments of mostly sand, gravel, and some silt and were estimated to have relatively high permeability. These map units were assigned to the sand and gravel group. The map units Hro, Qro, Qln, Qlb, and Pgh are units of mostly sand, silt, and clay; these units have somewhat lower estimated permeability than the sand and gravel group. These sediments were included in the mixed clayey sand group. Map units Pgl, Pgm, and Pgw are unsorted sand, silt, and clay sediments and were estimated to be less permeable than the mixed clayey sand group. These map units were assigned to the mixed sandy clay group. Finally, map unit Qlo, lacustrine clay sediment, was estimated to be the least permeable and is the only map unit assigned to the lake silt and clay group. Figure 3b shows the distribution of these groups in the study area.

Supplementary information sources. In addition to the factors shown in Figure 2, the initial pollution sensitivity ratings of selected locations in the eastern half of the study area were modified based on information from other sources. In some areas where map unit Pgh occurs, primarily near Pelican and Cormorant lakes, the 1:100,000-scale Geomorphology of Minnesota (Minnesota Department of Natural Resources, 1997) identifies surficial outwash (landform assemblage VBs3I) and ice contact (landform assemblage VBs3O) deposits. If these areas were not already rated Very High, the rating was modified to High. Finally, the U.S. Geological Survey had previously mapped two surficial aquifers in the eastern half of the study area. In the mapped extent of the Pelican River Sand Plain aquifer (Miller, 1981, 1982), the initial sensitivity rating of the area was increased by one rating classification or at least to High. The same adjustment was applied to the mapped surficial aquifer near Fergus Falls (Winter and others, 1969; Lorenz and Stoner, 1996).

Result of Applying the Modified Assessment Procedure

The map shows the interpreted sensitivity to pollution of the upper part of the near-surface ground-water systems based on the factors described above. The factors were combined and the sensitivity ratings, based on estimated time of travel, were assigned as shown in Figure 2. The map shows five distinct regions of sensitivity. The distribution of pollution sensitivity ratings within the study area generally comprises three north-south strips roughly corresponding to the Moraine, Beach Ridge Complex, and Lake Agassiz Plain geomorphic regions (Figure 2, Plate 3). The Moraine geomorphic region to the east was mostly rated Moderate, the Beach Ridge Complex region in the middle was mostly rated Very High, and the Lake Agassiz Plain region to the west was mostly rated Low. Within the Moraine and Lake Agassiz Plain regions are significant areas of Very High sensitivity associated with important surficial aquifers.

East of the sensitive Beach Ridge Complex is an area of mostly Moderate sensitivity primarily in the Moraine geomorphic region. The more sensitive area from north of Cormorant and Pelican lakes and south almost to Fergus Falls is discussed separately below. Generally underlying this Moderate sensitivity area are moderate- to somewhat low-permeability deposits of glacial sediment, primarily till, that can provide some protection to any near-surface aquifers buried within these sediments. In this area, lower permeability sediments limit deep, downward movement of ground water. Instead, ground water is more likely to move laterally over time to surface water.

The Beach Ridge Complex region was rated mostly Very High sensitivity. Much of this area has relatively thin sands and gravels of former beach deposits at or near the land surface. These high-permeability sediments can allow water and potential contaminants to move quickly downward and then laterally, flowing mostly westward. As a result, ground water infiltrating within the Beach Ridge Complex tends not to penetrate very deeply. Wells are more likely to be completed in buried aquifers within lower permeability sediments that may have better protection from surface contamination than the surficial aquifers. The pattern on the map shows the extent of the Beach Ridge Complex and where rapid infiltration followed by shallow lateral ground-water flow, instead of ground-water movement into deeper aquifers, would be expected.

West of the Beach Ridge Complex to the Red River of the North is the Lake Agassiz Plain region, which is generally Low sensitivity. The sensitive Buffalo aquifer, contained within this region, is discussed separately below. In the southern part of this region, Moderate sensitivity was applied to areas underlain by glacial till instead of lake silt and clay. Elsewhere, low-permeability lake silts and clays are present that restrict downward movement of water and potential contaminants. However, that restriction increases the potential that pollutants would instead be carried by surface water runoff into the region's rivers and streams.

The area surrounding Cormorant and Pelican lakes and south to Fergus Falls was generally rated High or Very High. The near-surface glacial deposits of this area are characterized by sand and gravel deposits. This area includes the Pelican River Sand Plain aquifer, a surficial glacial outwash aquifer that is an important regional water resource.

The Buffalo aquifer, east of Moorhead and south to northern Wilkin County, was rated mostly Very High and High sensitivity. The thick sand and gravel deposits of the Buffalo aquifer are exposed at the land surface or overlain by thin silts and clays. The aquifer is readily recharged by precipitation but also has limited natural protection from contaminants introduced at the land surface. The Buffalo aquifer is one of the most important ground-water resources in the study area.

Validation of Interpretation

After development of the pollution sensitivity interpretation, two independent validation checks were applied to evaluate the assessment's predictive quality. Isotopic and chemical data were each considered in relation to sensitivity ratings. The isotopic and chemical data collected as part of this study are independent, direct measures of travel time (the hydrogen isotope tritium [^{3}H]) and transmittal of contaminants (the chemical constituent nitrate [as NO_3-N]).

Tritium. Tritium concentrations in water samples obtained from wells can be used to estimate ground-water travel time or "age" of younger ground waters (Alexander and Alexander, 1989). The tritium data were compared to sensitivity ratings to evaluate the correspondence between the travel time of water in the subsurface measured by tritium and the estimated ground-water travel times of the sensitivity assessment ratings. The locations of the 87 tritium samples obtained as part of this study are plotted on the map and are color coded for tritium age. The well depth at each location is also shown. Tritium was not detected deeper than 105 feet anywhere in the study area (Figure 4). Water from wells with no detectable tritium must have entered the subsurface prior to 1954. Of the 87 tritium samples, 38 were obtained from wells less than 75 feet deep, which is about the maximum depth of the base of the mixed assessment boundary. Of the 38 samples, 17 had no detectable tritium and were vintage age, three samples had detectable tritium concentrations less than 10 tritium units (TU) and were mixed age, and 18 samples had tritium concentrations greater than 10 TU and were recent age.

Figure 5 shows the distribution of the 38 tritium samples from wells less than 75 feet deep by geomorphic region and aquifer. Except for the Lake Agassiz Plain, which did not have any water-table aquifer wells, buried aquifer wells less than 75 feet deep in the study area had a greater proportion of samples with no detectable tritium than water-table wells, indicating generally longer travel times to buried aquifers. In the Very High to Moderate sensitivity Moraine region, 13 of 17 tritium samples from wells less than 75 feet deep had detectable tritium. Of 17 wells, 10 are buried aquifer wells. Most of these wells are in the vicinity of Cormorant Lake or in the northern part of the Pelican River Sand Plain aquifer (Very High and High sensitivity), which has significant sand and gravel in the surrounding and underlying glacial sediments. In the Moraine region, six of seven water table and seven of 10 buried aquifer samples from wells less than 75 feet deep had detectable tritium. These results indicate buried aquifers in this region may be nearly as prone to surface contamination impacts as are the water-table aquifers. In the Beach Ridge Complex region (mostly Very High sensitivity), nine of 13 wells less than 75 feet deep had no detectable tritium. Of the 13 tritium samples in this region from wells less than 75 feet deep, nine are from buried aquifer wells. The large proportion of wells with no detectable tritium reflects the thin surficial sands; lower permeability sediments underlying the surficial sands; and the resulting shallow, lateral ground-water movement after infiltration. In the mostly Low sensitivity, low-permeability silts and clays of the Lake Agassiz Plain region (except the Buffalo aquifer), four of five wells less than 75 feet deep did not have detectable tritium. All five of these wells are buried aquifer wells. However, of three wells in the Very High sensitivity Buffalo aquifer within the Lake Agassiz Plain region, all samples had detectable tritium. Of these wells, one is a water-table well and two are buried aquifer wells. The tritium results for samples from Buffalo aquifer wells indicated that recharge since 1953 has moved deeply into the aquifer, partly due to the influence of municipal-well pumping within the aquifer. In comparison, wells in buried sands and gravels in the surrounding lake plain are little affected by recharge since 1953, being protected by lower permeability sediments and by being located within a regional ground-water discharge zone (see Plate 3).

As shown in Figure 6, the tritium analysis results for 38 wells less than 75 feet deep are generally consistent with sensitivity ratings by geomorphic region, except for the Beach Ridge Complex. If the sensitivity rating assignments in Figure 2 are reasonable, the tritium analysis results should show a greater proportion of samples with detectable tritium in areas rated more sensitive compared with areas rated less sensitive. Each region in the study area, except for the Beach Ridge Complex, generally shows a greater proportion of samples with detectable tritium when comparing region results for higher sensitivity ratings to lower sensitivity ratings. In the Moraine region, 12 of 14 samples with detectable tritium are from wells in areas rated Very High or High sensitivity. In the Moderate sensitivity area of the region, only one of three samples had detectable tritium. The lower proportion of detectable tritium in samples in Moderate areas suggests the generally finer textured sediments in this area are more protective. The 13 wells less than 75 feet deep in the Beach Ridge Complex are all in areas of Very High or High sensitivity. However, only four of these wells had detectable tritium. In this area, the surficial sands allow rapid infiltration, but the movement of ground water downward to buried aquifers is limited. In the Lake Agassiz Plain region (except for the Buffalo aquifer), one of five tritium samples had detectable tritium and that sample was from an area rated High. However, both samples from an area rated Low did not have detectable tritium. The silts and clays in the lake plain provide good protection to ground water. All three samples from the Buffalo aquifer had detectable tritium and they were all from areas rated Very High. The coarse-textured sediments of the aquifer, which are more than 100 feet thick in places, provide poor natural protection from surface contamination. These results show the sensitivity ratings are consistent with tritium results in wells less than 75 feet deep, except for the Beach Ridge Complex region.

Tritium was detected in wells at varying depths depending on geologic and hydrogeologic conditions. Figure 7 shows the tritium results for wells along cross section A-A' (see also Figure 3, Plate 3) and the depth to which tritium is likely to be detected. The cross section shows tritium was not detected in the deep regional system and in most places was only detected within about 50 feet below the water table. In the Lake Agassiz Plain, tritium was not detected very deeply, except within the Buffalo aquifer. In the vicinity of Turtle and Big Cormorant lakes, tritium was detected as deep as 100 feet below the water table because of the presence of both surficial and subsurface sands and gravels and the downward gradients of this regional recharge area.

Nitrate. In addition to evaluation of isotopic data, the relationship of nitrate concentrations to sensitivity ratings was considered as a further check of sensitivity rating validity. Nitrate (and dissolved oxygen) concentrations in sampled wells were typically low; however, elevated values were generally not observed deeper than about 85 feet. As shown in Table 1 on Plate 3, the mean nitrate concentration for the entire study area was only 0.34 milligram per liter (mg/L) for all samples and only one sample exceeded 10 mg/L. According to Table 1, mean nitrate concentrations were highest in the Moraine geomorphic region, the central geographic area, and surficial aquifers.

Nitrate in 45 wells less than 75 feet deep was tabulated by geomorphic region and sensitivity rating for three nitrate concentration classes, 0.1 mg/L or less, more than 0.1 and less than 10 mg/L, and 10 mg/L or more (Figure 8). Of 19 wells less than 75 feet deep in the Moraine geomorphic region sampled for nitrate, 12 wells are buried aquifer wells. None of the four nitrate samples from wells in the Moderate sensitivity area had a concentration greater that 0.1 mg/L and two of three samples from wells in this area sampled for tritium were of vintage age. Of 15 wells in Moraine areas rated Very High and High, six wells had nitrate concentrations of 0.1 mg/L or less, eight wells had nitrate between 0.1 and 10 mg/L, and one well had nitrate greater than 10 mg/L. Compared to Very High and High sensitivity areas in the Moraine region, these results suggest greater protection for shallow ground water in Moderate sensitivity areas. In the Beach Ridge Complex region, of 16 wells less than 75 feet deep, 12 were buried aquifer wells. Of four water-table wells in this area rated Very High and High, three had nitrate concentrations of 0.1 mg/L or less, and one had nitrate between 0.1 and 10 mg/L. Two of the three wells with nitrate of 0.1 mg/L or less were less than 50 feet deep, both in areas rated Very High. A sample from one of these wells was vintage tritium age and the other was recent tritium age. In the Beach Ridge Complex region, low nitrate concentrations, even in high sensitivity areas, may be due to limited introduction of nitrate to shallow ground water; wells completed in zones with older, vintage-age water, and thus unlikely affected by nitrate; or completion of wells in buried aquifers with some protection from surface contamination. In addition, some western portions of the Beach Ridge Complex are ground-water discharge areas (see Plate 3). The Lake Agassiz Plain region, including the Buffalo aquifer, had 10 wells less than 75 feet deep; all were buried aquifer wells, except for one water-table well 72 feet deep in the Buffalo aquifer. None of these wells had nitrate concentrations greater than 0.1 mg/L, regardless of sensitivity rating. However, all three tritium samples in the Buffalo aquifer were of recent age, indicating a potential for nitrate contamination. In contrast, only one of five tritium samples in the Lake Agassiz Plain region (excluding the Buffalo aquifer) had detectable tritium, suggesting the fine-textured sediments of the area provide protection to shallow buried aquifers. As a whole, the nitrate data compared reasonably well to the sensitivity ratings for the study area.

CONCLUSION

The evaluation of geologic sensitivity to pollution for the southern Red River valley study area is shown on this plate. The map shows sensitivity to pollution for the upper part of the near-surface ground-water systems to a depth of 30 feet below the water table. Factors considered included depth to the water table and surficial sediment permeability. Factors were combined and sensitivity ratings applied as shown in Figure 2. In the east-central portion of the study area, supplementary information from other sources was included in the evaluation.

The Very High sensitivity areas include much of the Beach Ridge Complex geomorphic region and two important surficial aquifers: the Pelican River Sand Plain aquifer in the east-central part of the study area and the Buffalo aquifer in the west-central part of the study area. High sensitivity areas occur mostly in the east-central and south-central portions of the study area, generally adjacent to Very High sensitivity areas. Much of the eastern third of the study area was rated Moderate sensitivity, reflecting the somewhat lower permeability of the surficial sediments that underlie much of this sensitivity area. A Low sensitivity rating was applied to much of the western part of the study area, which is underlain by extensive areas of silts and clays.

The predictive quality of the sensitivity interpretation was evaluated using tritium and nitrate concentrations in well samples. Each set of data was compared to sensitivity ratings and showed the pollution sensitivity interpretation to be reasonable and consistent.

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ACKNOWLEDGMENTS

This interpretation relied to a great extent on field data collected and other project files assembled by Michael Trojan for the development of Plate 3. The assistance of Julie Ekman in the preparation of modified maps of water-table elevation and depth is gratefully acknowledged. Many thanks are due to current and former staff at DNR Waters, but especially Randy McGregor, GIS specialist, and Nick Kroska, technical editor. Special thanks are owed to Randy Bradt, Julie Ekman, Ken Harris, Roman Kanivetsky, Cliff McClain, Barbara Palen, H.O. Pfannkuch, Michael Trojan, and James Walsh for reviewing the draft plate and providing many thoughtful comments and suggestions.

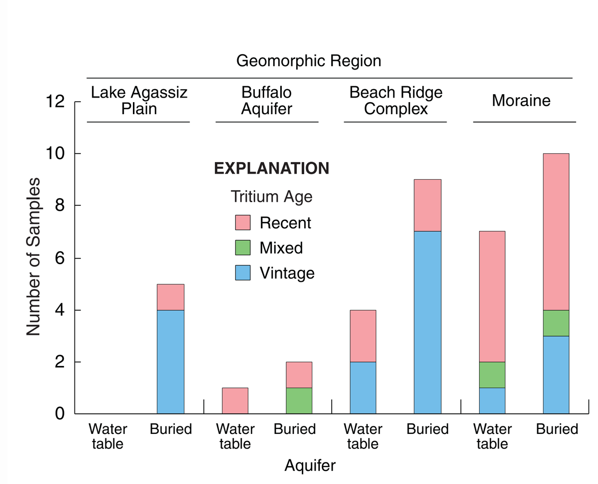

FIGURE 5. *Number of samples by tritium age and aquifer within geomorphic regions for 38 sampled wells less than 75 feet deep.*

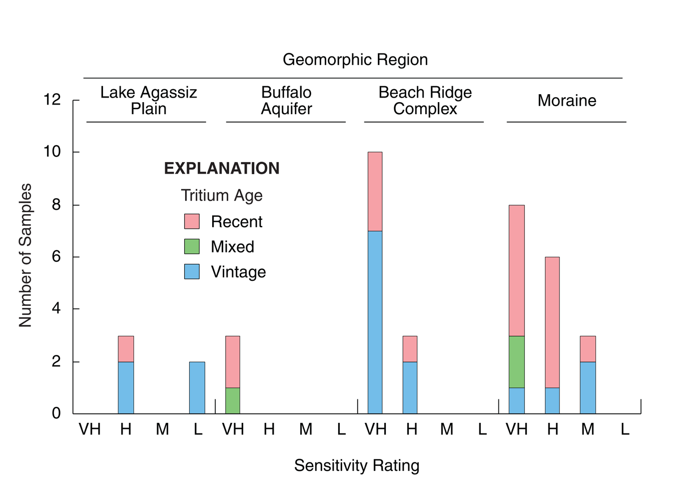

FIGURE 6. *Number of samples by tritium age and sensitivity rating within geomorphic regions for 38 sampled wells less than 75 feet deep.*

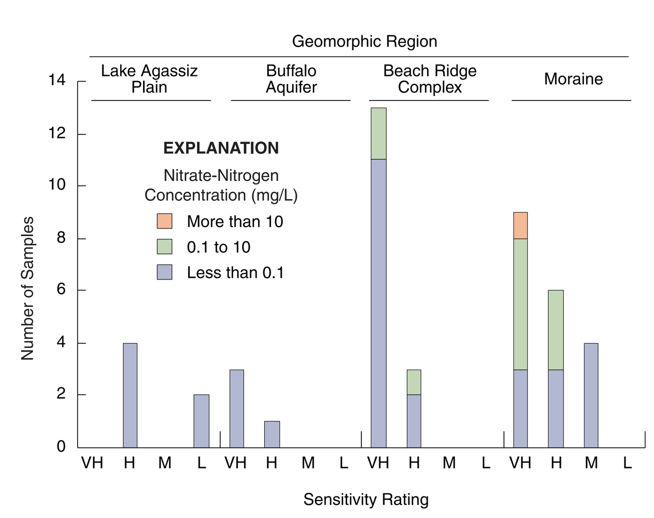

FIGURE 8. *Number of samples by nitrate class and sensitivity rating within geomorphic regions for 45 sampled wells less than 75 feet deep.*

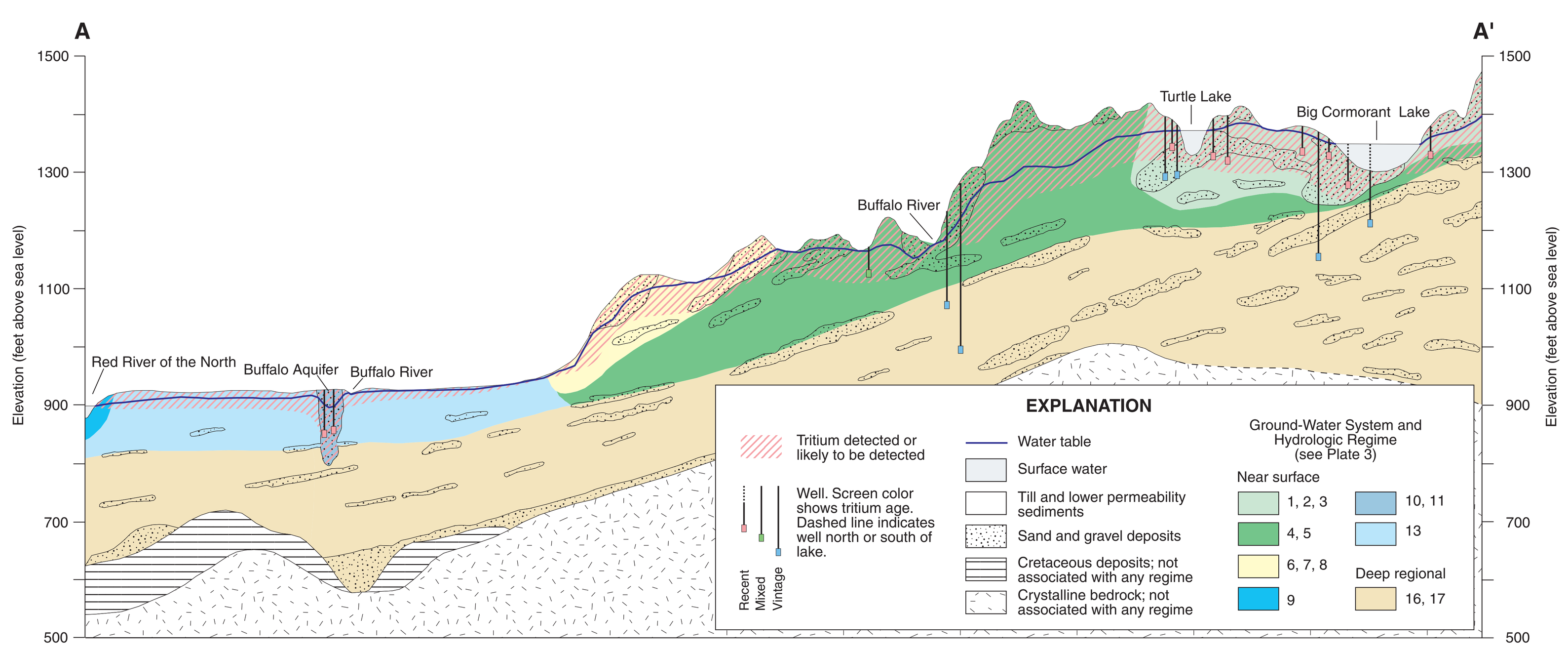

FIGURE 7. *Schematic cross section A-A' based on Figure 3, Plate 3, shows the depth below land surface that tritium was detected or is likely to be detected. The presence of tritium indicates at least some portion of the ground water entered the subsurface since 1953. Wells shown may be projected up to 3 miles either side of line A-A'. Not drawn to scale.*

Digital base data modified from 1984 and 1985 Digital Line Graph (DLG) files from the U.S. Geological Survey (source scale, 1:100,000). Shaded topographic relief derived from the 90-meter digital elevation model from the U.S. Geological Survey (source scale 1:250,000, presented with relief exaggerated x 30). Base annotation by the Minnesota Geological Survey. Compiled at a scale of 1:200,000.

GIS data and metadata available through the Ground Water Mapping Program website: http://www.dnr.state.mn.us/waters/programs/gw_section/cgarha/index.html

Projection:	Albers Equal Area Conic
Spheroid:	Clarke, 1866
Standard Parallels:	29°30'N and 45°30'N
Origin Latitude:	23°N
Origin Longitude	97°W

1927 North American Datum. Vertical datum is mean sea level.

GIS and cartography by Randy McGregor. Edited by Nick Kroska. Digital assembly by Nordic Press.

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WARNING: This map provides an overview of ground-water contamination potential as interpreted from 1:200,000-scale geologic map information.

THIS MAP SHOULD NOT BE THE BASIS FOR EVALUATION OF SPECIFIC SITES.