STATE OF MINNESOTA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATERS

POLLUTION SENSITIVITY OF THE BURIED AND SURFICIAL AQUIFERS

By

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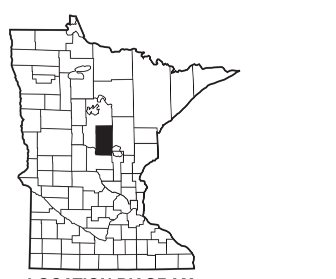
2007

Caution: The information on these maps is a generalized interpretation of the sensitivity of ground water to contamination. The maps are intended to be used for resource protection planning and to help focus the gathering of information for site-specific investigations.



LOCATION DIAGRAM

SCALE 1:200 000
COMPILATION SCALE 1:100 000
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 6 7 8 KILOMETERS

FIGURE 5. *Pollution sensitivity of five uppermost buried sand aquifers.* *This map shows the distribution and sensitivity of the uppermost buried aquifers in Crow Wing County: S1AT, S1MT, BGLS, BTN1, and BTS1. The aquifer sensitivity is based on the matrix in Figure 4. Locations and selected data of water samples collected from wells completed in these aquifers are shown.*

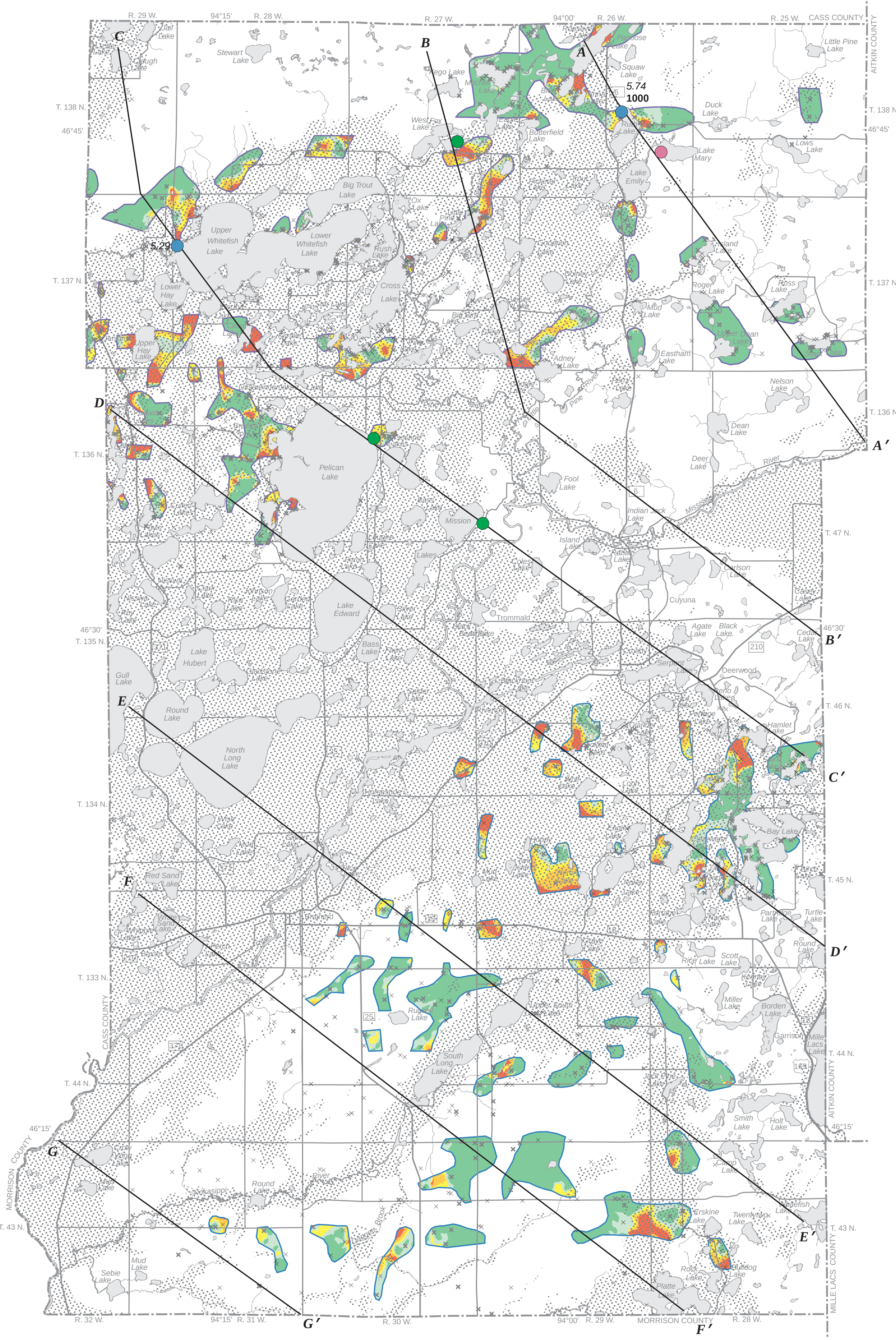


FIGURE 6. *Pollution sensitivity of two midlevel buried sand aquifers.* *This map shows the distribution and sensitivity of the BTN2 and BTS2 aquifers. The aquifer sensitivity is based on the matrix in Figure 4. Locations and selected data of water samples collected from wells completed in these aquifers are shown.*

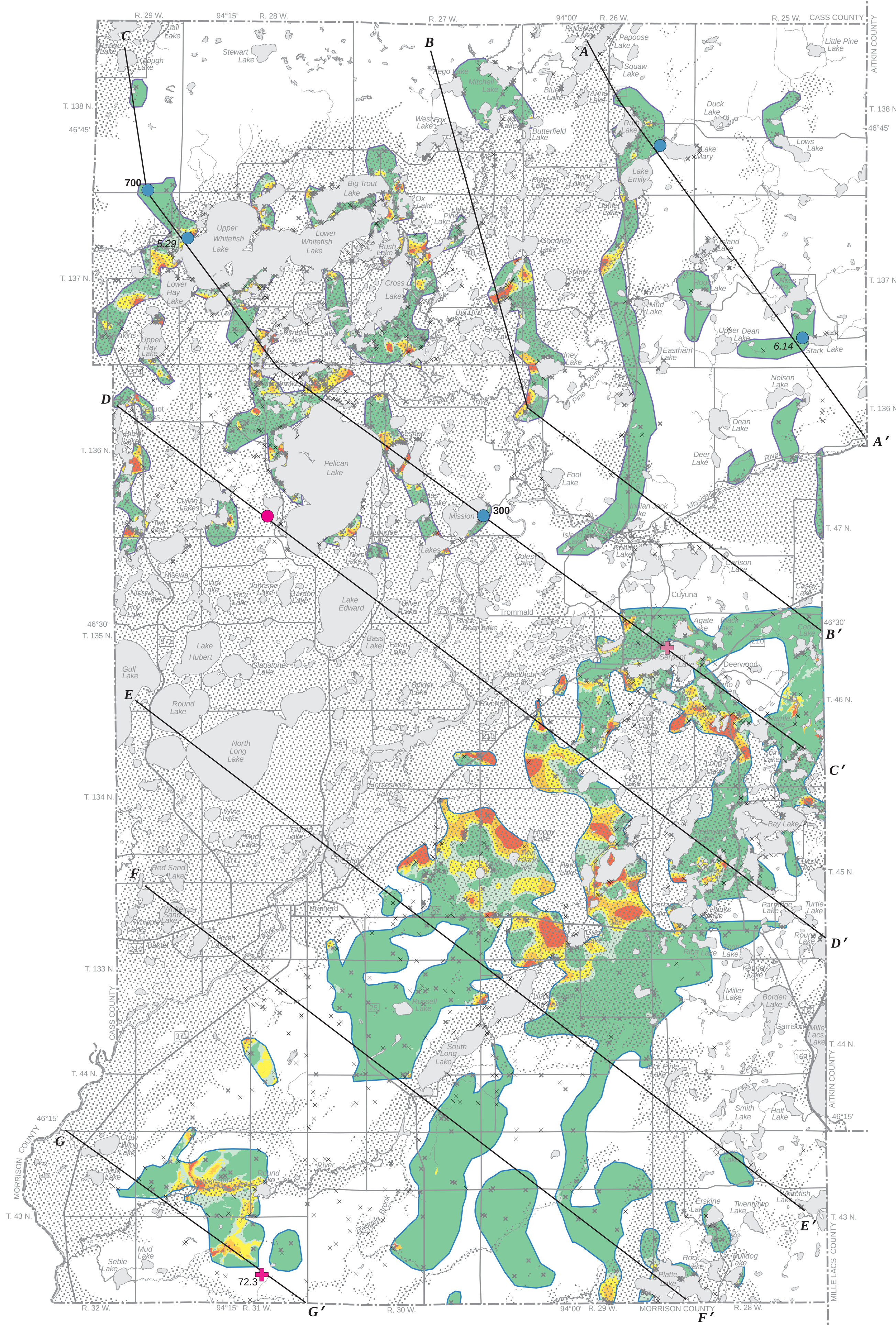


FIGURE 7. *Pollution sensitivity of two lowest buried sand aquifers.* *This map shows the distribution and sensitivity of the BTN3 and BTS3 aquifers. The aquifer sensitivity is based on the matrix in Figure 4. Locations and selected data of water samples collected from wells completed in these aquifers are shown.*

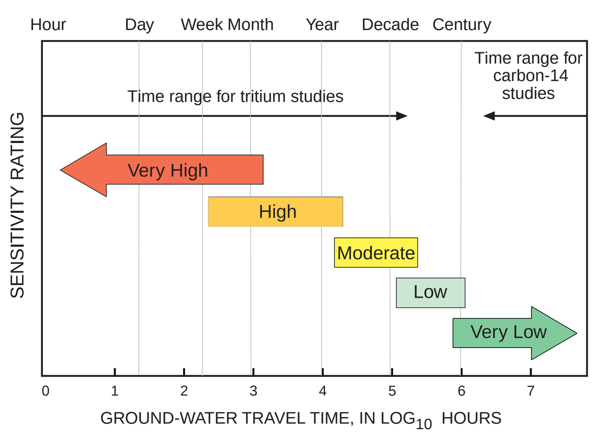


FIGURE 1. *Geologic sensitivity rating as defined by vertical travel time* *(Geologic Sensitivity Workgroup, 1991). Ratings are based on the time range required for water at or near the surface to travel vertically into the ground water of interest or a pollution sensitivity target. Tritium and carbon-14 studies indicate the relative ages of ground water.*

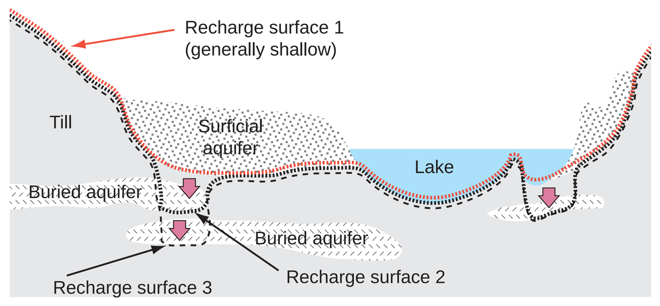


FIGURE 3. *Generalized cross section showing recharge concepts for buried aquifers considered in the sensitivity evaluations.* *In this model, all recent recharge enters the buried aquifer system at recharge surface 1 (red dotted line). Recharge surface 1 is considered to be at the land surface where till is present, at the bottom of surficial sand deposits, and at the bottom of lakes where surficial sand is not present. If less than 10 feet of fine-grained sediment (clay or till) exists between recharge surface 1 and the shallowest underlying buried aquifer, then recent recharge is assumed to reach and move to the bottom of that aquifer to form recharge surface 2. A second deeper buried aquifer that has less than 10 feet of clay or till between it and the overlying buried aquifer is also assumed to allow further penetration of recent recharge. In that case, recharge surface 3 is calculated at the bottom of this next deeper aquifer. The pink arrows indicate ground-water recharge of recent tritium age through a recharge surface.*

Thickness of protective layer between the aquifer and the nearest overlying recharge surface (in feet)				
0 to 10	10 to 20	20 to 30	30 to 40	Greater than 40
VH	H	M	L	VL

FIGURE 4. *Pollution sensitivity rating matrix.* *Pollution sensitivity is inversely proportional to the thickness of a protective layer between the top of the aquifer and the nearest overlying recharge surface as defined in Figure 3. Any buried aquifer with less than a 10-foot-thick protective layer between it and an overlying recharge surface is rated very high sensitivity because there is little fine-grained material to slow the time of travel. A thicker overlying protective layer provides additional protection to the aquifer, and sensitivity ratings are determined based on the thickness of this layer.*

MAP EXPLANATION
Figures 2, 5, 6, and 7

Sensitivity ratings

Estimated vertical travel time for water-borne contaminants to enter an aquifer (pollution sensitivity target).

- 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—A century or more

Tritium age

Color indicates tritium age of water sampled in well.

- Cold war era—Water entered the ground during the peak period of atmospheric bomb testing, 1958–1959 and 1961–1972 (20 or more tritium units [TU]).
- Recent—Water entered the ground since about 1953 (10 TU to less than 20 TU).
- Mixed—Water is a mixture of recent and vintage waters (greater than 1 TU to less than 10 TU).
- Vintage—Water entered the ground before 1953 (less than or equal to 1 TU).
- Well not sampled for tritium.

Well and aquifer symbols

- Surficial sand aquifers.
- Buried sand aquifer beneath the Nelson Lake till (S1AT).
- Buried sand aquifer beneath the Mille Lacs deposits (S1MT).
- Buried sand aquifer associated with Glacial Lake Brainerd (BGLS).
- Buried sand aquifer associated with Brainerd assemblage, north (BTN1, BTN2, BTN3).
- Buried sand aquifer associated with Brainerd assemblage, south (BTS1, BTS2, BTS3).

Map symbols and labels

- 5.25 If shown, arsenic concentration equals or exceeds 5 parts per billion.
- 14.5 If shown, chloride concentration equals or exceeds 5 parts per million.
- 2000 If shown, ground-water age in years, estimated by carbon-14 isotope analysis.
- × Static (nonpumping) water-level data from County Well Index database.
- × Well log listed in County Well Index database.
- F F′ Line of cross section.
- Body of water.

Aquifer pattern and colors

- Surficial sand aquifer.

Buried sand aquifers—Colored border identifies aquifer.

- S1AT
- S1MT
- BGLS
- BTN1, BTN2, BTN3
- BTS1, BTS2, BTS3

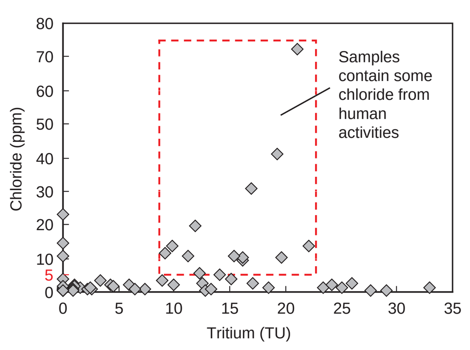


FIGURE 8. *Comparison of tritium concentration to chloride concentration in water samples from 70 wells.* *Chloride concentrations above 5 parts per million (ppm) appear to be largely attributable to human activities. The box outlined by the dashed red line indicates samples with chloride concentrations above 5 ppm and chloride to bromide ratios greater than 400. Three other samples with chloride concentrations above 5 ppm have low chloride to bromide ratios and vintage tritium values. The elevated chloride concentration in these three samples is probably of natural origin and not related to human activities.*

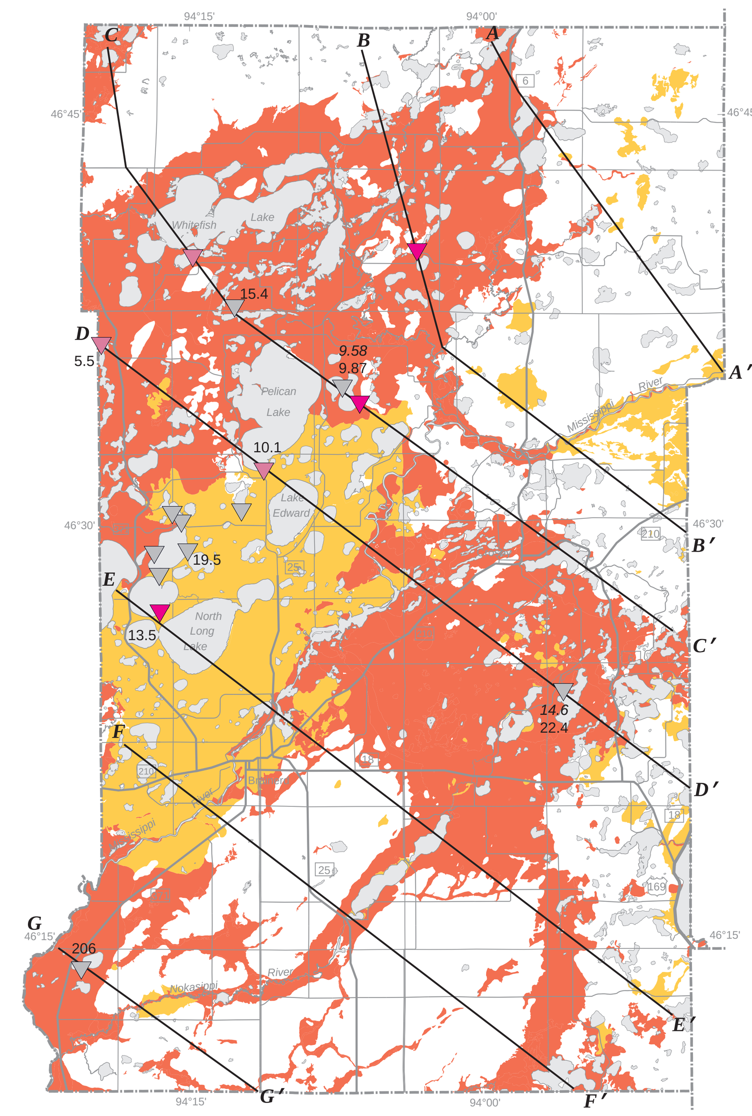


FIGURE 2. *Pollution sensitivity of the surficial aquifer in Crow Wing County.* *All areas of the surficial sand aquifer are relatively sensitive to pollution. The sensitivity of the surficial aquifer was based on the simplified material map in Figure 1, Plate 3, Part A. The sensitivity of the sand and gravel portion of the aquifer is rated very high; however, the sensitivity of the lacustrine fine-grained sands portion of the aquifer is rated high because ground-water travel time through these finer grained sediments will be slower than it is through the coarser grained sand and gravel.*

MAP EXPLANATION
See explanation for Figures 5, 6, and 7 in upper right

SCALE 1:350 000
COMPILATION SCALE 1:100 000
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 6 7 KILOMETERS

INTRODUCTION

This plate describes the sensitivity to pollution of surficial and buried aquifers in Crow Wing County by infiltration of a contaminant that moves conservatively with water.

Migration of contaminants dissolved in water through unsaturated and saturated sediments is a complex process. It is affected by biological degradation, oxidizing or reducing conditions, and contaminant density among other things. Countywide assessment of pollution sensitivity requires some generalizing assumptions. Flow paths from the land surface through the overlying cover to an aquifer are assumed to be vertical; horizontal flow paths may be important in specific instances, but they have not been adequately mapped and are not considered in the sensitivity model. Permeability is evaluated only qualitatively.

The sensitivity assessment estimates the time of travel for water from infiltration at the land surface to the pollution sensitivity target (Figure 1). Areas with relatively short travel times (less than a few years) are rated high or very high. Areas with estimated travel times of decades or longer are rated low or very low.

SENSITIVITY TO POLLUTION OF THE SURFICIAL AQUIFER

The surficial sand aquifer has very little protective cover and the water table is generally shallow, so sensitivity to pollution of the surficial aquifer is very high to high (Figure 2). The sensitivity model is based on the simplified surficial sediment material, as mapped in Figure 1, Plate 3, Part A. The surficial sand aquifer comprises lacustrine sand of glacial lakes Brainerd and Aitkin, outwash of the Brainerd assemblage and of the Mille Lacs deposits of the Cromwell Formation, and terrace sediments. The lacustrine sand is fine grained and has very little gravel, while the outwash and terrace sediments are coarser grained sand and gravel. The outwash contains 15–20 percent gravel (Gary Meyer, written commun., Oct. 2007). The time of travel is estimated to be fairly rapid through the sand and gravel of both the outwash and the terrace sediments. Time of travel through the lacustrine sand, which is less permeable, is estimated to be longer than the time of travel through the sand and gravel. Thus, the sensitivity to pollution of the sand and gravel is estimated as very high, and the sensitivity to pollution of the lacustrine sand is estimated as high.

The surficial sand aquifer is an important source of water in Crow Wing County. Water chemistry samples were collected from 16 wells in this aquifer (Figure 2). Seven of these wells were completed in lacustrine sand deposits of Glacial Lake Brainerd, and nine of the wells were completed in sand and gravel. The water samples from two of the seven wells completed in the lacustrine sand had tritium values indicating recent water. Another sample, which was not analyzed for tritium, showed anthropogenic influence with 19.5 parts per million (ppm) chloride (Cl), which indirectly indicates recently recharged water. The other four well samples were not analyzed for tritium, and those samples contained only low levels of chloride and nitrate; therefore, estimating the residence time of that ground water was impossible. The nine surficial aquifer wells completed in sand and gravel also generally confirmed the estimated sensitivity rating. Four of the wells were sampled for tritium and had either recent or cold war era water. Of the five wells not analyzed for tritium, four had elevated chloride values.

SENSITIVITY TO POLLUTION OF BURIED AQUIFERS

Development of Sensitivity Model and Maps

The first step in creating a sensitivity model for buried aquifers was to map the subsurface geology. A map was made of the bottom elevation and thickness of the surficial sand and then of buried sand units (aquifers) (see Plate 7). By using geographic information system (GIS) software, 30-meter grids were calculated for the base of the surficial sand and the top and bottom of buried sand units that could be mapped. The fine-grained material between the sand bodies (e.g., clay or till) is considered during mapping, but it does not have its own grid surface. The volume of sediment between the bottom of one sand body and the top of the next lower sand body is assumed to consist of fine-grained material that acts as an aquitard, restricting the ground-water movement to the sand below.

Next, creation of pollution sensitivity maps for buried aquifers was based on the method of vertical recharge surfaces of Berg (2006). Recharge surfaces were derived from the distribution and thickness of sand (and intervening low-permeability) layers mapped on Figure 4, Plate 7.

The uppermost recharge surface (RS1) starts at the land surface (Figure 3). Where surficial sand or a lake is present, RS1 extends to the base of this sand unit or lake. The assumption is that precipitation can quickly reach this shallow recharge surface.

If less than 10 feet of fine-grained sediment such as clay or till is present between RS1 and the top of a buried sand below, then the assumption is that a buried sand is probably recharged vertically from water at RS1. Thus, water will travel vertically to the bottom of this buried sand body, which is labeled recharge surface 2 (RS2). RS2 is the same as RS1 where more than 10 feet of fine-grained sediment exists immediately below RS1.

Deeper recharge surfaces (below RS2) are calculated similarly. If a deeper buried sand has less than 10 feet of clay between RS2 and the top of a deeper sand, then a third recharge surface (RS3) will be defined as the bottom of this sand. This model assumes that clay layers that are less than 10 feet thick are fairly leaky and will allow relatively rapid recharge to the next deeper layer.

Horizontal movement of ground water is not accounted for in this method although it is often important.

Finally, the sensitivity estimates for the buried aquifers are calculated by comparing the elevation of the upper surface of each buried aquifer with the nearest overlying recharge surface (Figure 4). The distance between the top of the aquifer and the overlying recharge surface is used to determine the sensitivity to pollution.

Comparison of Sensitivity Model to Ground-Water Chemistry Data

Chemistry data can be used to check the accuracy of the sensitivity model. Samples from aquifers rated low to very low should have little tritium. Samples from aquifers rated moderate to very high should contain tritium if the aquifer is recharged vertically. Figure 5 shows the sensitivity to pollution for buried sand aquifers S1AT, S1MT, BGLS, BTN1, and BTS1. They are shown together for convenience because they are the shallowest buried aquifers and have little geographic overlap. Water samples were collected from all mapped aquifers except BTN1.

One well completed in the S1AT aquifer was sampled for chemistry, which had 6.5 tritium units (TU) (mixed water). The immediate area around the well is mapped as low sensitivity, but moderate and high sensitivity zones are nearby. Horizontal flow could account for the presence of tritium.

Two sampled wells are completed just outside the mapped area of the S1MT aquifer but in the same stratigraphic position. One sample had 9.2 TU and 11.6 ppm Cl. The adjacent S1MT aquifer has very low sensitivity, but less than 1000 feet away the S1MT sensitivity is mapped as high (horizontal flow paths probably carry recent water toward this well). The second sample from the S1MT aquifer had 2.6 TU. In this area, the aquifer has about 50 feet of clay overlying it.

Six wells completed in the BGLS aquifer were sampled for chemistry. Two of these wells were completed in an area where the aquifer was mapped; the other four wells are adjacent to the mapped areas and, because of their elevation, were assumed to be completed in the BGLS. The water sample for the well just north of Lake Edward indicated a good correlation between chemistry and mapping: it contained recent water with 15.4 TU and was rated high sensitivity. The water sample for the well just north of Mission Lake had a poor correlation. It occurred in an area rated as very high sensitivity, but the well water had no detectable tritium. It had 14.5 ppm Cl and a chloride to bromide (Cl/Br) ratio of 223, which indicates it probably is natural chloride (not anthropogenic or attributed to human activities). At this well location, the BGLS aquifer is upgradient from Upper Mission Lake. Thus, older ground water is flowing toward this high sensitivity area and Upper Mission Lake (see cross-section C–C′, Plate 8). The two water samples from the BGLS aquifer near Gilbert Lake had elevated tritium values (9.8 TU and 16.1 TU). Although there were not enough data to map the BGLS aquifer at this location, it appears to be locally connected to Gilbert Lake (see cross-section E–E′, Plate 8).

Only one well from the BTS1 aquifer was sampled, which had recent water with 11.9 TU and 19.5 ppm Cl. The mapped sensitivity of the BTS1 aquifer in the immediate vicinity is very low, but high sensitivity areas are only 1000 feet away. Again, horizontal transport inside aquifers is likely and could account for the discrepancy between the sensitivity model and the ground-water chemistry data.

Figure 6 shows the sensitivity to pollution for buried sand aquifers BTN2 and BTS2. Six wells completed in the BTN2 aquifer were sampled for chemistry, but no water samples were collected from the BTS2 aquifer.

Three of the six wells completed in the BTN2 aquifer showed fair to good correlation between the mapped sensitivity and the water chemistry. The sample from the well north of Ruth Lake, mapped as very low sensitivity, had no detectable tritium, 0.48 ppm Cl, and a carbon-14 age of 1000 years. The map indicates that this aquifer may have low to moderate sensitivity nearby, but the South Long Lake till in this area may provide more protection than is suggested by thickness alone. The water sample from a well just south of East Fox Lake had 7.4 TU, which is consistent with the high sensitivity mapped in this area. The water sample from the well just northeast of Pelican Lake, an area mapped as high sensitivity, had 4.5 TU and 1.64 ppm Cl, which is only a fair correlation.

The sample from the well just west of Upper Whitefish Lake, near where the aquifer was mapped as high sensitivity, had no detectable tritium and 0.52 ppm Cl. This does not correlate with the chemistry results. This well appears to be located at a ground-water discharge area where the BTN2 aquifer is fed from the deeper BTN3 aquifer (see well C-1, cross-section C–C′, Plate 8). Samples from wells in both the BTN2 and BTN3 aquifers at this location had vintage water. The other two samples were collected from locations where there were not enough data to map the aquifer beyond those particular wells.

Figure 7 shows the sensitivity to pollution for the buried sand aquifers BTN3 and BTS3. Six wells completed in the BTN3 aquifer were sampled for chemistry. Samples from five of these wells had vintage water, and the other sample had 25 TU indicating cold war era water. All samples had low chloride values. Four wells were mapped as very low sensitivity, one well was mapped as low sensitivity, and one well (with cold war era water) was outside a mapped area.

Two sampled wells are completed in the BTS3 aquifer. The water sample from a well near Serpent Lake had 17.1 TU. The aquifer is not directly mapped here, but the nearby mapped area was rated as very low sensitivity, so the sample and the sensitivity estimate do not correlate well. One possible explanation for this discrepancy is that Serpent Lake is fairly deep, and the lake bottom is only about 15 feet above the top of the aquifer (see cross-section C–C′, Plate 8). Water may penetrate from the bottom of the lake into the BTS3 aquifer and then move laterally toward the sampled well. The other BTS3 water sample was collected from a well in the southwest corner of Crow Wing County on cross-section G–G′. The aquifer is buried beneath approximately 50 feet to 60 feet of South Long Lake till; the stratigraphy is shown on the cross section (Plate 8). This BTS3 water sample had 21 TU, 72.3 ppm Cl, and a Cl/Br ratio of 629. This sample may indicate an unmapped lateral or vertical connection with other aquifers.

The sensitivity model provides a reasonable estimate of the pollution sensitivity of the buried aquifers at county scale. Because the geology is very complex, however, unmapped sand units probably form permeable pathways between some of these aquifers, which cannot be accounted for in this model. Also, the model does not account for lateral or upward ground-water flow. Therefore, some aquifers may be more or less sensitive to pollution than shown, depending on local conditions.

GEOCHEMICAL INDICATORS OF LAND USE CHANGE OVER TIME

Most well water samples that were collected for this project were sampled for both chloride and bromide. Chloride is a good indicator of local anthropogenic effects on the ground water because it moves conservatively with the infiltrating water.

Figure 8 is a scatter plot of tritium concentrations in TU compared to chloride concentrations in ppm based on water samples from 70 wells. Chloride values greater than 5 ppm, where the Cl/Br ratio is greater than 400, appear to be largely attributable to human activities. Anthropogenic sources of chloride usually contain little bromide. Three well samples have chloride concentrations greater than 5 ppm and low Cl/Br ratios. All three of these samples had no detectable tritium, indicating that the elevated chloride is natural and not anthropogenic. All of the other samples with elevated chloride had tritium values between 9.2 TU and 22.1 TU. Samples with higher tritium values (cold war era) all had low chloride concentrations. This indicates that ground water that infiltrated from the surface during the 1960s was less affected by local anthropogenic influences than ground water that infiltrated in the 1970s or later. This result implies that the use of fertilizer, road salt, water softener salt, and possibly other sources of chloride began to rise in the 1970s. Sampling for chloride, especially when combined with bromide, may be an acceptable, less expensive substitute for the more expensive tritium analysis.

REFERENCES CITED

Berg, J.A., 2006, Sensitivity to pollution of the buried aquifers [Plate 9], *in* Geologic Atlas of Pope County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series, C-15, Part B, Scale 1:150,000.

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.

ACKNOWLEDGEMENTS

I received much help from my colleagues at DNR. Jan Falteisek provided assistance and guidance throughout the project. Nick Kroska and Greg Massaro made the plates much more understandable through their editing, GIS, and layout work. Jim Berg provided his geologic insight. Jennie Leete did much of the water sampling and reviewed the final product. Julie Ekman and Suzanne Jiwani provided technical peer reviews. Special thanks are due to the Thirty Lakes Watershed District for funding extra chemistry and isotope sample analyses. Alan Cibuzar of A.W. Research Laboratories provided remote sensing information. Thanks are also due to my colleagues from other agencies who provided excellent suggestions during peer review: Alan Knaeble, Gary Meyer, Bob Tipping, and Dale Setterholm of the Minnesota Geological Survey; Mike Trojan and Sharon Kroening of the Minnesota Pollution Control Agency; and Jim Walsh of the Minnesota Department of Health. Scott Alexander of the University of Minnesota, Department of Geology and Geophysics collected the carbon-14 water samples for analysis and interpreted the results.

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 2005 to 2007 at a scale of 1:100,000. Universal Transverse Mercator projection, grid zone 15, 1983 North American datum. Vertical datum is mean sea level.
GIS and cartography by Todd Petersen and Greg Massaro. Edited by Nick Kroska.