# Pollution Sensitivity of the Bedrock Surface

**By Roberta Adams**

**Minnesota Hydrogeology Atlas Series HG-01, v.2**

***Report***

***Plate 1***

MNDNR

St. Paul

February 2016

Minnesota Department of Natural Resources

Ecological and Water Resources Division

County Geologic Atlas Program

This page intentionally left blank.

## Funding for this project was provided by the following:

The Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

The trust fund is a permanent fund constitutionally established by Minnesotans to assist in the protection, conservation, preservation and enhancement of the state's air, water, land, fish, wildlife and other natural resources.

The Clean Water Fund receives 33 percent of the sales tax revenue from the Clean Water, Land and Legacy Amendment, as approved by voters in November 2008. The Clean Water Fund's purpose is to protect, enhance and restore water quality in lakes, rivers, streams and groundwater.

At least 5 percent of the money is targeted for the protection of drinking water sources. The Legislature allocates funds for water quality work and drinking water protection based on recommendations from the Clean Water Council.

## Acknowledgements

I'd like to thank the following people for their comments on this report and contributions from staff of the Minnesota Department of Natural Resources: Jim Berg, Todd Petersen, Jan Falteisek, Ruth MacDonald, Carrie Jennings, Holly Johnson, John Barry, and Jeff Green. I would like to thank Jim Berg, Vanessa Baratta and Randy Bradt for their contributions from county geologic atlas reports in preparation. I would like to thank Janice Chezick and Terry Lee from Olmsted County for providing a digitized version of the 1988 Pollution Sensitivity from C-03, Plate 6.

## Recommended Citation

Adams, R., 2016, Pollution Sensitivity of the Bedrock Surface: St. Paul, Minnesota Department of Natural Resources, Minnesota Hydrogeology Atlas Series HG-01, v. 2, report and plate, accessible at http://www.dnr.state.mn.us/waters/programs/gw_section/mapping/platesum/mha_ps-bs.html.

# Contents


**Introduction** .......... 1

**Pollution Sensitivity of the Bedrock Surface** .......... 1

**County Geologic Atlas Map Development** .......... 4

**Tritium and Pollution Sensitivity Ratings** .......... 6

**Minnesota Hydrogeology Atlas Map Development** .......... 7

**County Analysis** .......... 9

**Legacy Matrix Method** .......... 9

Olmsted County, C-03 .......... 10

Dakota County, C-06 .......... 11

Ramsey County, C-07 .......... 12

Fillmore County, C-08 .......... 13

Rice County, C-09 .......... 14

Mower County, C-11 .......... 15

Goodhue County, C-12 .......... 16

Pine County, C-13 .......... 17

Wabasha County, C-14 .......... 18

**Recharge Surfaces Method** .......... 19

Scott County, C-17 .......... 19

Carlton County, C-19 .......... 19

McLeod County, C-20 .......... 20

Carver County, C-21 .......... 20

Chisago County, C-22 .......... 21

Blue Earth County, C-26 .......... 21

**Current Method: Cumulative Fine-Grained Sediment (CFGS) Thickness Method** .......... 22

Sibley County, C-24 .......... 22

Nicollet County, C-25 .......... 22

Anoka County, C-27 .......... 23

Renville County, C-28 .......... 23

**Cross-Border Discrepancies** .......... 24

Goodhue and Dakota Counties .......... 25

Scott and Dakota Counties .......... 25

Olmsted and Wabasha Counties .......... 26

Anoka and Ramsey Counties .......... 26

Scott and Rice Counties .......... 27

## Contents (continued)

**Summary and Conclusion** ........ **28**

**References** ........ **29**

**Glossary** ........ **30**

**Appendix A: Geographic Information System Analysis** ........ **32**

## Tables

Table 1. Methods used by 19 county geologic atlases ........ 3

Table 2. Geologic sensitivity rating descriptions ........ 3

Table 3. Tritium ages as defined in the DNR County Geologic Atlases ........ 6

Table 4. Pollution sensitivity maps for each County Geologic Atlas ........ 7

Table 5: Sensitivity ratings for the top of the bedrock surface in the Olmsted County Geologic Atlas ........ 10

Table 6. Sensitivity ratings for the Prairie du Chien–Jordan aquifer in the Dakota County Geologic Atlas ........ 11

Table 7. Original County Geologic Atlas' spatial data files for the bedrock surface pollution sensitivity ........ 32

Table 8. Field attributes assigned to CGA data in order to update atlases with a unified code ........ 32

Table 9. Sensitivity ratings for the top of bedrock surface in the Olmsted and Dakota County Geologic Atlases ........ 33

## Figures

Figure 1. Pollution sensitivity of the bedrock surface in the state of Minnesota....2

Figure 2. Geologic sensitivity rating for the bedrock surface as defined by vertical travel time....3

Figure 3. Pollution sensitivity rating matrix....4

Figure 4. Methods used to create bedrock-related pollution sensitivity maps....5

Figure 5. Bedrock map of Goodhue County....8

Figure 6. Bedrock cross section for Goodhue County....8

Figure 7. Pollution sensitivity of the uppermost bedrock aquifers in Goodhue County....8

Figure 8. Pollution sensitivity of the bedrock surface in Goodhue County....8

Figure 9. Pollution sensitivity of the groundwater systems in Olmsted County....10

Figure 10. Pollution sensitivity of the bedrock surface in Olmsted County....10

Figure 11. Pollution sensitivity of the Prairie du Chien–Jordan aquifer in Dakota County....11

Figure 12. Pollution sensitivity of the bedrock surface in Dakota County....11

Figure 13. Pollution sensitivity of the Prairie du Chien–Jordan aquifer in Ramsey County....12

Figure 14. Pollution sensitivity of the bedrock surface in Ramsey County....12

Figure 15. Pollution sensitivity of the St. Peter–Prairie du Chien–Jordan aquifer in Fillmore County....13

Figure 16. Pollution sensitivity of the bedrock surface in Fillmore County....13

Figure 17. Pollution sensitivity of the bedrock aquifer in Rice County....14

Figure 18. Pollution sensitivity of the bedrock surface in Rice County....14

Figure 19. Pollution sensitivity of the bedrock surface in Mower County....15

Figure 20. Pollution sensitivity of the bedrock aquifer in Goodhue County....16

Figure 21. Pollution sensitivity of the bedrock surface in Goodhue County....16

Figure 22. Pollution sensitivity of the bedrock surface in Pine County....17

Figure 23. Pollution sensitivity of the bedrock surface in Wabasha County....18

Figure 24. Pollution sensitivity of the bedrock surface in Scott County....19

Figure 25. Pollution sensitivity of the bedrock surface in Carlton County....19

Figure 26. Pollution sensitivity of the bedrock surface in McLeod County....20

Figure 27. Pollution sensitivity of the bedrock surface in Carver County....20

Figure 28. Pollution sensitivity of the bedrock surface in Chisago County....21

Figure 31. Pollution sensitivity of the bedrock surface in Blue Earth....21

Figure 29. Pollution sensitivity of the bedrock surface in Sibley County....22

Figure 30. Pollution sensitivity of the bedrock surface in Nicollet County....22

Figure 32. Pollution sensitivity of the bedrock surface in Anoka County....23

Figure 33. Pollution sensitivity of the bedrock surface in Renville County ........ 23
Figure 34. Pollution sensitivity of the bedrock surface in southeast Minnesota ........ 24
Figure 35. Cross-border discrepancies of pollution sensitivity ratings between Goodhue and Dakota counties ........ 25
Figure 36. Cross-border discrepancies of pollution sensitivity ratings between Scott and Dakota counties ........ 25
Figure 37. Cross-border discrepancies of pollution sensitivity ratings between Olmsted and Wabasha counties ........ 26
Figure 38. Cross-border discrepancies of pollution sensitivity ratings between Anoka and Ramsey counties ........ 26
Figure 39. Cross-border discrepancies of pollution sensitivity ratings between Scott and Rice counties ........ 27

# Technical Reference

Maps were compiled and generated in a geographic information system (GIS). Digital data products are available from the Department of Natural Resources (DNR), Ecological and Water Resources Division.

Maps were prepared from DNR and other publicly available information. Every reasonable effort has been made to ensure the accuracy of the factual data on which the report and map interpretations were based. However, the DNR does not warrant the accuracy, completeness, or any implied uses of these data. Users may wish to verify critical information. Sources include both the references here and information on file in the offices of the Minnesota Geological Survey (MGS) and the DNR. Every effort has been made to ensure the interpretations conform to sound geologic and cartographic principles. These maps should not be used to establish legal title, boundaries, locations of improvements, or other site specific decisions.

This report, Plate 1, the GIS files, and the metadata can be downloaded from:
http://www.dnr.state.mn.us/waters/programs/gw_section/mapping/platesum/mha_ps-bs.html

These maps were modified from the following County Geologic Atlas series. Each can be downloaded from:
http://www.dnr.state.mn.us/waters/groundwater_section/mapping/status.html

Olmsted County Geologic Atlas, Part A, 1988, Minnesota Geological Survey

Dakota County Geologic Atlas, Part A, 1990, Minnesota Geological Survey

Ramsey County Geologic Atlas, Part A, 1992, Minnesota Geological Survey

Fillmore County Geologic Atlas, Part B, 1996, Minnesota Department of Natural Resources

Rice County Geologic Atlas, Part B, 1997, Minnesota Department of Natural Resources

Mower County Geologic Atlas, Part B, 2002, Minnesota Department of Natural Resources

Goodhue County Geologic Atlas, Part B, 2003, Minnesota Department of Natural Resources

Pine County Geologic Atlas, Part B, 2004, Minnesota Department of Natural Resources

Wabasha County Geologic Atlas, Part B, 2005, Minnesota Department of Natural Resources

Scott County Geologic Atlas, Part A, 2006, Minnesota Geological Survey

Carlton County Geologic Atlas, Part B, 2011, Minnesota Department of Natural Resources

McLeod County Geologic Atlas, Part B, 2013, Minnesota Department of Natural Resources

Carver County Geologic Atlas, Part B, 2014, Minnesota Department of Natural Resources

Chisago County Geologic Atlas, Part B, 2014, Minnesota Department of Natural Resources

Sibley County Geologic Atlas, Part B, in preparation, Minnesota Department of Natural Resources

Nicollet County Geologic Atlas, Part B, in preparation, Minnesota Department of Natural Resources

Blue Earth County Geologic Atlas, Part B, in preparation, Minnesota Department of Natural Resources

Anoka County Geologic Atlas, Part B, in preparation, Minnesota Department of Natural Resources

Renville County Geologic Atlas, Part B, in preparation, Minnesota Department of Natural Resources

Project data was compiled in 2015 at a scale of 1:100,000. Universal Transverse Mercator projection, grid zone 15, North American Datum of 1983. Vertical datum is mean sea level. GIS and cartography by Roberta Adams and Holly Johnson. Edited by Carrie Jennings and Ruth MacDonald.

## Conversion Factors

| | |
|---|---|
| 1 foot | 0.3048 meters |
| 1 inch per hour | $7.06 \times 10^{-6}$ meters per second |

# Pollution Sensitivity of the Bedrock Surface

**By Roberta Adams**

# Introduction

The Minnesota Hydrogeology Atlas series (MHA) was created to provide a statewide format for groundwater information, building on maps and data originally published in the County Geologic Atlas (CGA) series. The MHA series will provide reports, maps, and digital data for selected information describing Minnesota groundwater, such as pollution sensitivity, water-table elevation, and other groundwater maps or data commonly published in the CGA reports. The digital data for use in geographic information systems (GIS) are provided in a statewide form that can be used by county, by watershed, or a specific area as defined by users.

The MHA series uses current data and methods and where possible incorporates information from reports in the CGA series. MHA reports that contain older published county data may not be completely consistent with the current standards for the CGA series. However, both the original published CGA series data and the MHA series data are useful to the public.

The Minnesota Hydrogeology Atlas will help users of the atlas manage and protect groundwater resources by providing more accessible, statewide groundwater data to citizens and all levels of government. This effort is part of the County Geologic Atlas program of the Minnesota Department of Natural Resources (DNR), Ecological and Water Resources Division.

## Pollution Sensitivity of the Bedrock Surface

This report of the pollution sensitivity of the bedrock surface describes the compilation of county maps from previously published maps and plates in the CGA series. The original CGA reports varied by how bedrock was mapped for pollution sensitivity. In some CGA reports the bedrock pollution sensitivity interpretation is of the bedrock surface, in others it is of the bedrock aquifer.

The map in this report combines 19 counties (Table 1) with published bedrock pollution sensitivity information into one statewide map (Figure 1 and Plate 1). This compilation respects the legacy of the previous maps with minimal alterations made to the original data. Future county geologic atlases that include mapping of the pollution sensitivity of the bedrock surface will be added to this HG-01 report.

Geologic sensitivity is defined by the physical properties and hydrologic controls that affect the ability of geologic materials to restrict the downward migration of pollutants to the groundwater of interest. The bedrock surface is defined as the shallowest bedrock below the surficial sediment cover. The shallowest bedrock may be an aquifer or an aquitard. It is assumed to have the highest pollution sensitivity of bedrock because it is closest to the surface.

The pollution sensitivity of the bedrock surface is portrayed by a map that characterizes the relative rate of vertical travel of a contaminant that moves conservatively with water from the land surface to the shallowest bedrock surface. Interpretation of pollution sensitivity of the bedrock surface is based on overlapping estimated time-of-travel ranges (Table 2 and Figure 2) (Geologic Sensitivity Workgroup, 1991). The travel time ranges vary: areas with relatively short travel times of 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 (Figure 2).

The method to map pollution sensitivity of the bedrock surface assumes downward vertical water movement. The method does not account for contaminants traveling with lateral water movement at the surface or in the subsurface. Lateral movement of a pollutant through an aquifer from an up gradient, high pollution sensitivity area to a down gradient, low pollution sensitivity area may be possible under certain hydrogeologic and land use settings.

Prior to 2006 the rating matrix used to interpret bedrock pollution sensitivity varied between counties and was largely dependent on conditions specific to a particular county (e.g., karst). This is referred to as the Legacy Matrix method. The Recharge Surfaces method (Berg, 2006) created a standard approach, and the Cumulative Fine-Grained Sediment (CFGS) Thickness method (Minnesota DNR, 2016) expanded on that (Table 1).

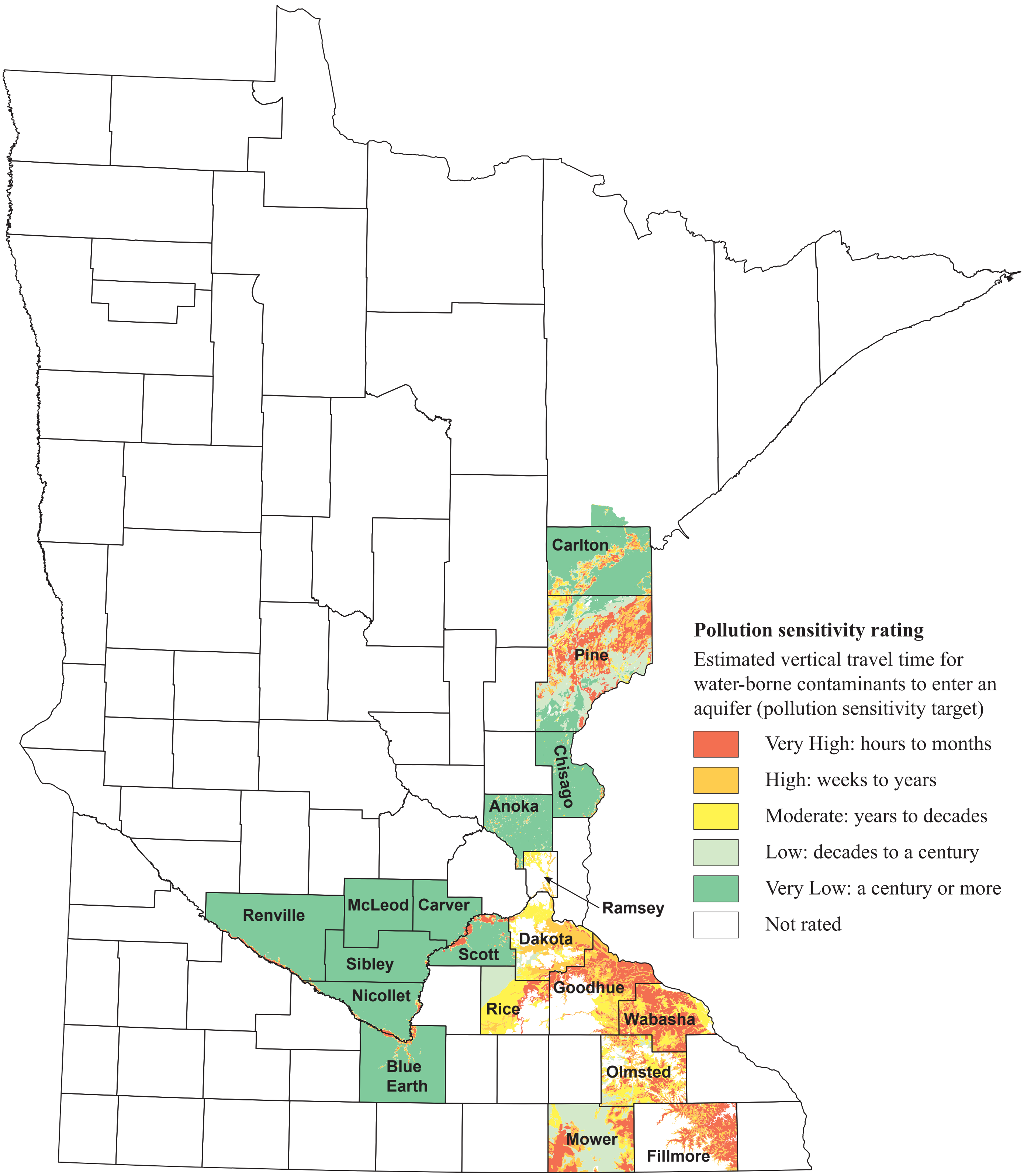



**Figure 1. Pollution sensitivity of the bedrock surface in the state of Minnesota**

This map depicts the current pollution sensitivity maps for the bedrock surface across Minnesota. Areas that are not rated have either not been completed, not been digitized, are currently being updated, or their pollution sensitivity maps depict particular bedrock units or bedrock aquifers that do not form the top of bedrock surface. Atlases created prior to 2006 used the Legacy Matrix method to calculate the pollution sensitivity of the bedrock surface, while between 2006 and 2015 the Recharge Surfaces method became standard. In 2016 the Cumulative Fine-Grained Sediment Thickness method was developed and implemented as the current method.

The County Analysis section summarizes the factors used to determine the pollution sensitivity to bedrock ratings in each county. These factors vary with local conditions. However, the geological sensitivity rating applied to each county is standard and represents the same travel time no matter the bedrock unit, method, or county. Border discontinuities appear where authors did not consistently use the criteria for assessing geologic sensitivity as determined by the Geologic Sensitivity Workgroup (1991) (e.g., Olmsted and Dakota counties), or in areas where the Recharge Surfaces method and CFGS Thickness methods were originally not used.

**Table 1. Methods used by 19 county geologic atlases**

Highlighted counties depict the pollution sensitivity of a particular bedrock unit or aquifer in their original CGA data. These counties were modified for HG-01 to depict pollution sensitivity of the bedrock surface.

| Legacy Matrix Method | | Recharge Surfaces Method | | CFSG Thickness Method | |
|---|---|---|---|---|---|
| County | Date | County | Date | County | Date |
| Olmsted[1] | 1988 | Scott[1] | 2006 | Sibley[3] | in preparation |
| Dakota[1] | 1990 | Carlton[3] | 2011 | Nicollet[3] | in preparation |
| Ramsey[2] | 1992 | McLeod[3] | 2013 | Anoka[3] | in preparation |
| Fillmore[3] | 1996 | Carver[3] | 2014 | Renville[3] | in preparation |
| Rice[3] | 1997 | Chisago[3] | 2014 | | |
| Mower[3] | 2002 | Blue Earth[3] | in preparation | | |
| Goodhue[3] | 2003 | | | | |
| Pine[3] | 2004 | | | | |
| Wabasha[3] | 2005 | | | | |

[1]Authored by the Minnesota Geological Survey

[2]Authored by Minnesota Geological Survey and the Ramsey Soil and Water Conservation District

[3]Authored by Minnesota Department of Natural Resources

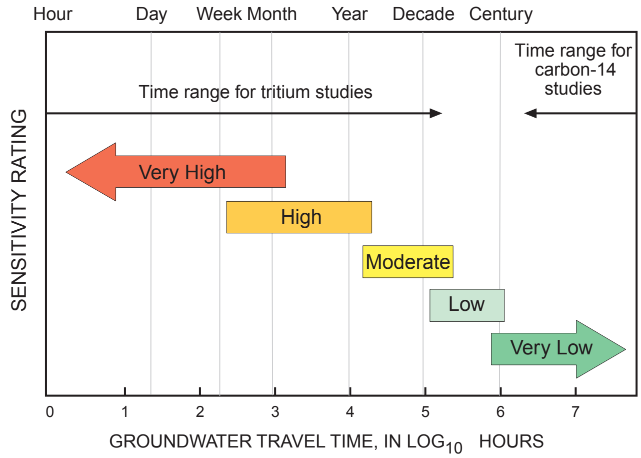



**Figure 2. Geologic sensitivity rating for the bedrock surface as defined by vertical travel time**

Ratings are based on the time range required for water at or near the surface to travel vertically into the aquifer of interest.

**Table 2. Geologic sensitivity rating descriptions**

The Code column shows the abbreviation used in the spatial data to represent the sensitivity rating.

| Color | Code | Description |
|---|---|---|
| Red | VH | Very High: Hours to months |
| Orange | H | High: Weeks to years |
| Yellow | M | Moderate: Years to decades |
| Light Green | L | Low: Decades to a century |
| Dark Green | VL | Very Low: A century or more |

# County Geologic Atlas Map Development

Currently there are 19 counties with pollution sensitivity maps for the bedrock (Table 1). These maps were created by various authors using different methods and geologic factors through the years. The assumptions that relate the geologic factors to travel time were evaluated using groundwater chemistry data (e.g., presence of tritium and carbon-14 age). Chemistry data were compared to the generated map for general consistency. Differences between the map and the chemistry data were explained in that county's atlas.

County atlases created before 2006 used a matrix with author-assigned sensitivity ratings for bedrock surface pollution sensitivity (Legacy Matrix). After 2006 the Recharge Surfaces method was used, followed in 2016 with the CFGS Thickness method (Table 1 and Figure 4).

The Recharge Surfaces method takes into account surface infiltration and subsurface recharge as demonstrated in Pope County (Berg, 2006) and was first applied to the bedrock surface in Scott County (Tipping, 2006).

The Recharge Surfaces method predicts how water from precipitation first infiltrates at the surfice, next recharges portions of the first underlying aquifer, then portions of deeper aquifers, and finally the bedrock surface. The central concept of the method is focused recharge, or relatively rapid recharge where portions of aquifers overlap and are connected by complex three-dimensional pathways that allow surface water to penetrate to even the deepest mapped aquifers in some areas. The Recharge Surfaces method simplified the focused recharge concept by considering only direct vertical recharge. Groundwater from an aquifer will recharge the next deepest aquifer if the intervening protective layer of fine-grained material is less than 10 feet thick. In this method, recharge is assumed to penetrate vertically until it is stopped by fine-grained material that is 10 or more feet thick, or it reaches the bedrock surface. The step-wise downward process of defining recharge surfaces through a sequence of buried sand and gravel aquifers to the bedrock surface is shown in Plate 6, Figure 5 (Tipping 2006).

Starting in 2016, the DNR began calculating pollution sensitivity based on the Cumulative Fine-grained Sediment (CFGS) Thickness method (Minnesota DNR, 2016). This method is similar to the Recharge Surfaces method, taking into account surface infiltration and subsurface recharge. However, instead of using the distance from a recharge surface to assign a pollution sensitivity rating, the CFGS Thickness method uses the total thickness of fine-grained sediments overlying the bedrock surface to determine the sensitivity rating and assumes that deep unmapped Quaternary sediments are fine-grained materials. The CFGS Thickness method is the current method used to determine the pollution sensitivity of the bedrock surface by the DNR at the time of publication. A detailed procedure of the methods used to make pollution sensitivity maps with the CFGS Thickness method is available on the DNR County Geologic Atlas website (Minnesota DNR, 2016).

The pollution sensitivity rating matrix seen in Figure 3 is used in all three methods, and the values are applicable across all pollution sensitivity maps for the bedrock surface. The method in which the value is derived is the difference, as can be seen in the Figure 3 definition.

| 0-10 | > 10–20 | > 20–30 | > 30–40 | > 40 |
|---|---|---|---|---|
| VH | H | M | L | VL |

**Figure 3. Pollution sensitivity rating matrix**

Legacy Matrix (pre 2006): relative permiability, texture, and thickness of glacial material (in feet)

Recharge Surfaces (2006-2015): Distance between bedrock surface and recharge surface (in feet)

CFGS Thickness (current): Cumulative thickness of fine-grained sediment overlying the bedrock surface (in feet)

For the Recharge Surfaces method the pollution sensitivity is inversely proportional to the distance between the bedrock surface and the nearest overlying recharge surface. For the CFGS Thickness method the pollution sensitivity of an aquifer is inversely proportional to the cumulative thickness of fine-grained sediment overlying the bedrock surface. Where the distance or thickness between the bedrock surface and the nearest overlying recharge surface is 10 feet or less, the sensitivity is rated very high. Distances or thicknesses greater than 40 feet are rated very low. The rating is defined as intermediate where the distance or thickness is greater than 10 feet and less than or equal to 40 feet.

The legacy data of Hennepin and Washington counties are not available in a GIS format; however their atlases are currently being updated. The Winona and Benton county atlases did not include a bedrock surface pollution sensitivity or equivalent map. The Winona County atlas is currently being updated.

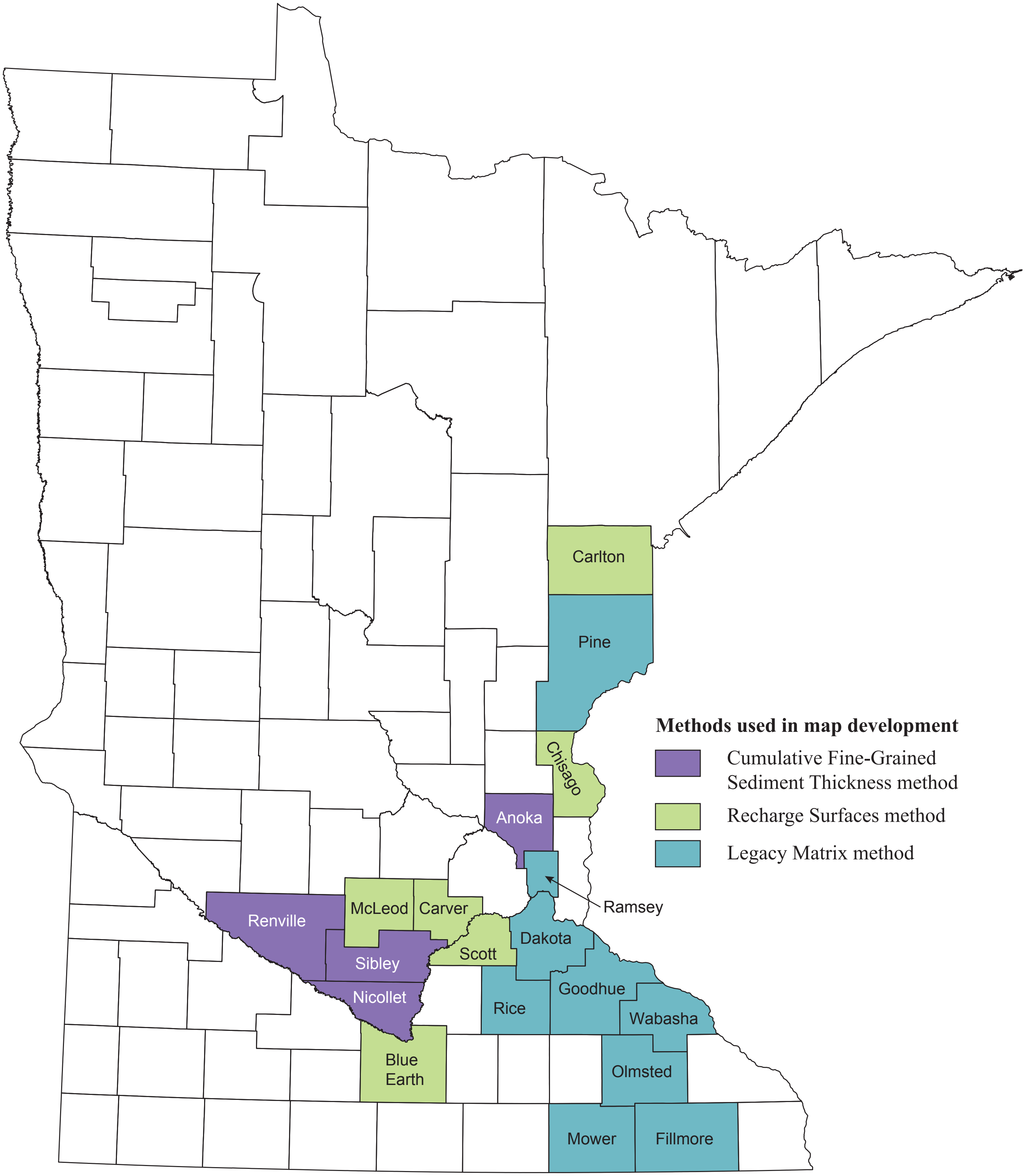



**Figure 4. Methods used to create bedrock-related pollution sensitivity maps**

Green counties were completed after 2006 and used the Recharge Surfaces method. Blue counties were completed prior to 2006 and used the Legacy Matrix method that emphasized different factors. Purple counties use the Cumulative Fine-Grained Sediment thickness method, the current methodology used by the DNR at time of this publication.

# Tritium and Pollution Sensitivity Ratings

Tritium is a naturally occurring radioactive isotope whose concentration was greatly increased by atmospheric nuclear weapons testing in the 1950s and 1960s. Tritium concentrations are used to indicate the relative residence time of groundwater and are also used to affirm the sensitivity ratings. Tritium has a relatively short half-life of 12.32 years (Lucas and Unterweger, 2000). Because of the short half-life, the meaning of the absolute tritium concentration in a groundwater sample changes over time. For atlases produced from 2013 to 2015, the following definitions for tritium age are used:

**Cold War era**: Water entered the ground during the peak period of atmospheric tritium concentration from nuclear bomb testing, 1958–1959 and 1961–1972 (greater than 15 tritium units [TU]).

**Recent**: Water entered the ground since about1953 (8 to 15 TU).

**Mixed**: Water is a mixture of recent and vintage waters (greater than 1 TU to less than 8 TU). Mixed tritium-age results indicate that at least a portion of the groundwater has been recharged since the 1950s.

**Vintage**: Water entered the ground before 1953 (less than or equal to 1 TU). Vintage tritium ages are consistent with predominantly very low pollution sensitivity ratings.

Some counties included in this compilation did not use tritium age as a check of bedrock pollution sensitivity ratings. Those atlases were authored by agencies outside of the DNR (Olmsted, Dakota, Ramsey, and Scott counties).

**Table 3. Tritium ages as defined in the DNR County Geologic Atlases**

Tritium age ratings have changed over time due to the decay of tritium in the environment. However, the ratings are still comparable between the atlases.

| | | Tritium Ages | | | |
|---|---|---|---|---|---|
| **County** | **Atlas** | **Cold War Era** | **Recent** | **Mixed** | **Vintage** |
| Fillmore (1996) | C-08 | N/A | ≥10 TU | >1 to <10 TU | ≤ 1 TU |
| Rice (1997) | C-09 | N/A | ≥10 TU | >1 to <10 TU | ≤ 1 TU |
| Mower (2002) | C-11 | N/A | ≥10 TU | 0.8 to 10 TU | < 0.8 TU |
| Goodhue (2003) | C-12 | N/A | ≥10 TU | 0.8 to 10 TU | < 0.8 TU |
| Pine (2004) | C-13 | N/A | ≥10 TU | 0.8 < 10 TU | < 0.8 TU |
| Wabasha (2005) | C-14 | N/A | ≥10 TU | >1 to <10 TU | ≤ 1 TU |
| Carlton (2011) | C-19 | N/A | ≥10 TU | >1 to <10 TU | ≤ 1 TU |
| McLeod (2013) | C-20 | N/A | ≥8 TU | >1 to < 8 TU | ≤ 1 TU |
| Carver (2014) | C-21 | > 15 TU | 8 to 15 TU | >1 to < 8 TU | ≤ 1 TU |
| Chisago (2014) | C-22 | >15 TU | 8 to 15 TU | >1 to < 8 TU | ≤ 1 TU |
| Sibley (in preparation) | C-24 | N/A | 8 to 15 TU | >1 to < 8 TU | ≤ 1 TU |
| Nicollet (in preparation) | C-25 | >15 TU | 8 to 15 TU | >1 to < 8 TU | ≤ 1 TU |
| Blue Earth (in preparation) | C-26 | N/A | 8 to 15 TU | >1 to < 8 TU | ≤ 1 TU |
| Anoka (in preparation) | C-27 | N/A | 8 to 15 TU | >1 to < 8 TU | ≤ 1 TU |
| Renville (in preparation) | C-28 | N/A | 8 to 15 TU | >1 to < 8 TU | ≤ 1 TU |

TU are Tritium Units

# Minnesota Hydrogeology Atlas Map Development

When compiling different atlases for the map of the pollution sensitivity of the bedrock surface, the original map product was taken into consideration. Atlases prior to 2006 evaluate a variety of bedrock pollution sensitivity scenarios, from maps showing the sensitivity of the entire top of bedrock surface to maps showing the sensitivity of only the most significant bedrock aquifers, such as the Prairie du Chien and Jordan (Table 4). Starting in 2006 the bedrock pollution sensitivity maps have only shown the pollution sensitivity for the entire top of bedrock surface.

**Table 4. Pollution sensitivity maps for each County Geologic Atlas**

| County | Atlas | Plate | Date | Title |
|---|---|---|---|---|
| Olmsted | C-03 | 6 | 1988 | Sensitivity of the Ground-Water System to Pollution |
| Dakota | C-06 | 7 | 1990 | Sensitivity of the Prairie du Chien–Jordan Aquifer to Pollution |
| Ramsey | C-07 | 9 | 1992 | Sensitivity of the Prairie du Chien–Jordan Aquifer |
| Fillmore | C-08 | 7 | 1996 | Sensitivity of the St. Peter–Prairie du Chien–Jordan aquifer system to pollution |
| Rice | C-09 | 9 | 1997 | Sensitivity of Bedrock Aquifer Systems to Pollution |
| Mower | C-11 | 9 | 2002 | Sensitivity to Pollution of the Uppermost Bedrock Aquifers |
| Goodhue | C-12 | 9 | 2003 | Sensitivity to Pollution of the Uppermost Bedrock Aquifers |
| Pine | C-13 | 10 | 2004 | Sensitivity to Pollution of the Uppermost Bedrock Aquifers |
| Wabasha | C-14 | 10 | 2005 | Sensitivity to Pollution of the Uppermost Bedrock Aquifers |
| Scott | C-17 | 6 | 2006 | Subsurface Recharge and Surface Infiltration |
| Carlton | C-19 | 10 | 2011 | Sensitivity of Groundwater Systems to Pollution |
| McLeod | C-20 | 9 | 2013 | Pollution Sensitivity of the Near-Surface Materials, Buried Sand and Gravel Aquifers, and the Bedrock Surface |
| Carver | C-21 | 9 | 2014 | Pollution Sensitivity of the Near-Surface Materials, Buried Sand and Gravel Aquifers, and the Bedrock Surface |
| Chisago | C-22 | 10 | 2014 | Pollution Sensitivity of the Near-Surface Materials, Buried Sand and Gravel Aquifers, and the Bedrock Surface |
| Sibley | C-24 | N/A | in preparation | Found in the pollution sensitivity section of the report |
| Nicollet | C-25 | N/A | in preparation | Found in the pollution sensitivity section of the report |
| Blue Earth | C-26 | N/A | in preparation | Found in the pollution sensitivity section of the report |
| Anoka | C-27 | N/A | in preparation | Found in the pollution sensitivity section of the report |
| Renville | C-28 | N/A | in preparation | Found in the pollution sensitivity section of the report |

To compile the pollution sensitivity of the bedrock surface layer, maps that did not originally depict that surface had to be modified. The most recent bedrock map for each county was used to determine where the mapped sensitivity of the bedrock correlated to the bedrock surface. These areas were then shown as part of this compilation. The areas that did not reflect the bedrock surface were left blank because they were removed from the dataset.

For example, in Part B of the Goodhue County Geologic Atlas, the Pollution Sensitivity of the Uppermost Bedrock Aquifer map considers the St. Peter–Shakopee–Oneota, Jordan, and the St. Lawrence–Franconia–Ironton–Galesville aquifers (now referred to as the St. Lawrence–Tunnel City–Wonewoc aquifer). However, large areas of the aquifer are covered by the Decorah–Platteville–Glenwood aquitard, which is the top of bedrock surface for a portion of the county (Figure 5). This can be seen in a cross section of Goodhue County (Figure 6). In order to correctly show the pollution sensitivity of the bedrock surface, areas were omitted where the bedrock aquifer (Figure 7) is not the top of bedrock surface (Figure 8). This results in partial coverage in Dakota, Fillmore, Ramsey, Rice, Goodhue, and Olmsted counties. However, this does not mean that the bedrock surface may not be sensitive to pollution in these omitted areas. The compiled map reflects the lack of a current countywide map of the pollution sensitivity for the bedrock surface in these counties.

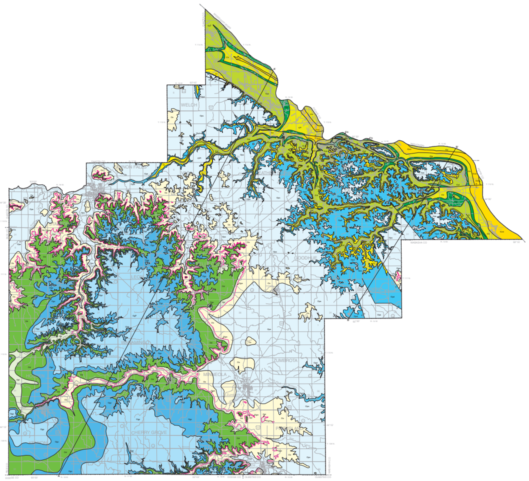


**Figure 5. Bedrock map of Goodhue County**

This map shows the bedrock units at the bedrock surface, not the subsurface distribution of deeper bedrock units. See C-12, Plate 2 for a full description of the bedrock units.

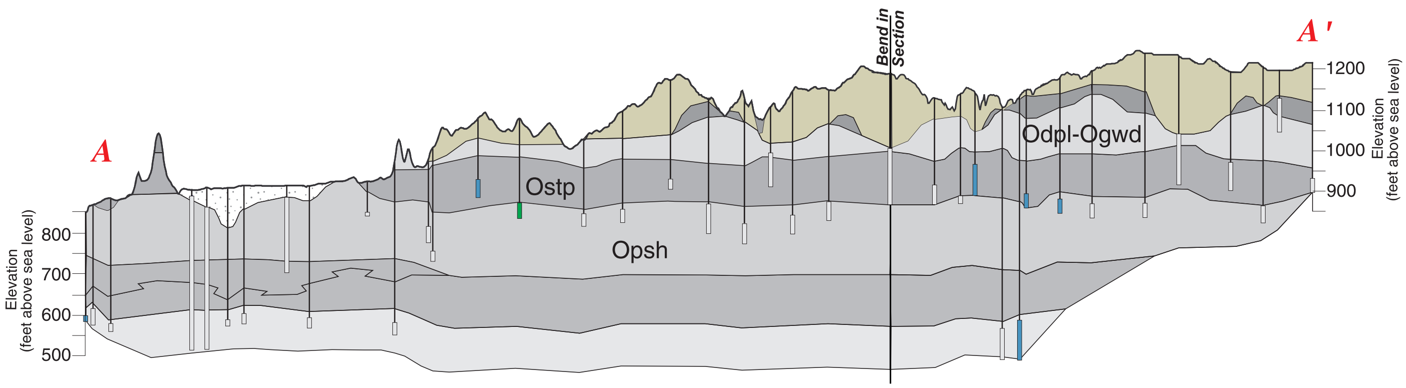



**Figure 6. Bedrock cross section for Goodhue County**

From C-12, Plate 8. Layers labeled Ostp (St. Peter) and Opsh (Shakopee) represent the top of bedrock aquifers. These aquifers were considered in the pollution sensitivity analysis presented in Plate 9 (Figure 7). However, the unit Odpl + Ogwd (Decorah–Platteville–Glenwood) represents the top of bedrock for large areas of the county, as seen on Plate 2 (Figure 5).

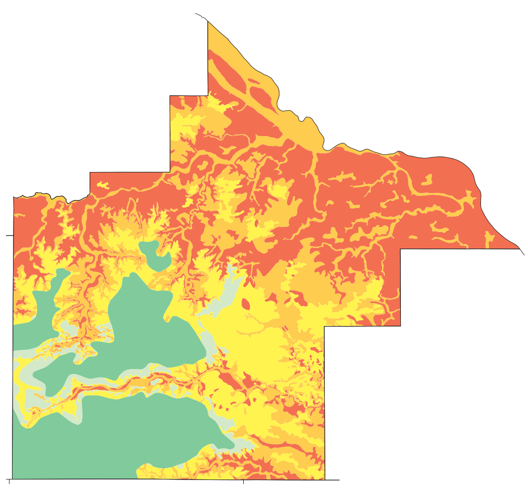


**Figure 7. Pollution sensitivity of the uppermost bedrock aquifers in Goodhue County**

This map portrays the pollution sensitivity of the uppermost bedrock aquifers. The Goodhue County map includes areas where the bedrock aquifers are not the bedrock surface (indicated primarily as green). From C-12, Plate 9.

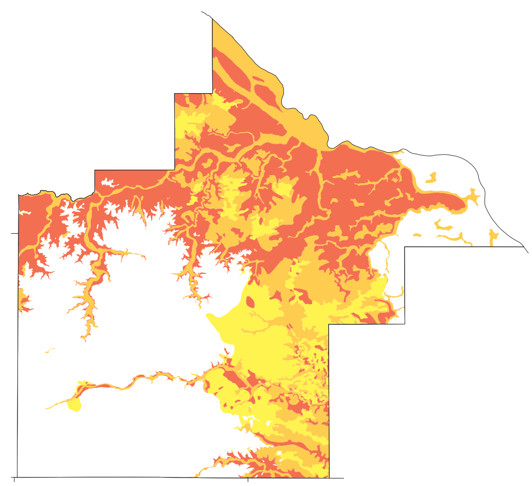


**Figure 8. Pollution sensitivity of the bedrock surface in Goodhue County**

The adjusted pollution sensitivity map of Goodhue County has areas where the bedrock surface pollution sensitivity was not originally rated because the bedrock surface was not an aquifer.

# County Analysis

Bedrock surface pollution sensitivity ratings are based on vertical travel times defined by the Geologic Sensitivity Workgroup (1991). Currently there are 19 counties with existing pollution sensitivity maps for bedrock units or aquifers (Table 1). As mentioned previously, atlases created before 2006 used the Legacy Matrix method at the discretion of the author. After 2006 a standardized Recharge Surfaces method was used to map the bedrock surface pollution sensitivity, taking into account subsurface recharge and surface infiltration. This was further developed into the CFGS Thickness method in 2016. At the time of this publication, the CFGS Thickness method is the current method employed by the DNR as standard for bedrock surface and buried aquifer pollution sensitivity.

Six counties were modified from their original atlas to show only the bedrock surface pollution sensitivity (highlighted in Table 1). These counties were created using the Legacy Matrix method and originally depicted the pollution sensitivity of either a particular bedrock aquifer or groundwater system. For this compilation of bedrock surface pollution sensitivity, areas were omitted that were originally mapped but did not reflect the bedrock surface. The result is a map that reflects only the top of bedrock surface pollution sensitivity (Figure 1). This depiction results in a partial map of the pollution sensitivity of the bedrock surface in those counties where units other than the bedrock surface were originally evaluated.

The following section is a summation of the map development for each county. This summary is not meant to substitute for the original county atlas. It is highly recommended that the user refer to the county geologic atlas for a more in-depth understanding of how each atlas map was created. County atlases will also include chemical data, well and sample locations, and symbolized local geological factors, which are not included in this map compilation of pollution sensitivity of the bedrock surface.

## Legacy Matrix Method

The Legacy Matrix method consisted of a matrix of factors that estimated the pollution sensitivity of a target aquifer based on the thickness of the overlying glacial sediment and the relative permeability and texture of those glacial materials. The matrix created for each county was unique to that county and did not necessarily take the same factors into account as surrounding areas. Other geologic and hydrogeologic factors, such as karst, were also considered on a county by county basis. Therefore two counties that may border each other may not be directly comparable, even though the resulting pollution sensitivity rating may be similar. These cross-border discrepancies are discussed in a later section.

## Olmsted County, C-03

The Olmsted County Geologic Atlas was completed by the Minnesota Geological Survey (MGS) in 1988. Compilation information is derived from Plate 6, the *Sensitivity of the Ground-Water System to Pollution* (Olsen and Hobbs, 1988). "Geologic sensitivity was assigned on the basis of the estimated ability of the sequence of geologic materials to retard the downward movement…into the water table. The major consideration for these geologic materials is their estimated permeability relative to their composition and thickness" (Olsen and Hobbs, 1988).

Sensitivity was rated by combining attributes of the bedrock and surficial geologic units including sediment texture, fractures in the bedrock, thickness of material, and depth to water table. In general, areas rated very high have karst limestone or dolomite occurring within 5 feet of the land surface or are in terrace deposits along river valleys (Figure 9). Areas of moderate or low sensitivity were limited to thick sequences of till or thin till over a confining bedrock unit. Nitrate-nitrogen data in the County Well Index were used to check the mapping, with concentrations between 1 and 9 ppm considered elevated.

It should be noted that, unlike DNR maps, the sensitivity ratings for Olmsted County include a high-moderate and a low-moderate rating. A conversion was made for the purposes of this compilation (Table 5). The adjusted pollution sensitivity map of Olmsted County has areas where the bedrock surface pollution sensitivity was not originally modelled (Figure 10). Differences between Olmsted and surrounding counties are discussed in the Cross-Border Discrepancies section.

**Table 5: Sensitivity ratings for the top of the bedrock surface in the Olmsted County Geologic Atlas**

The updates for the statewide atlas compilation series definition of sensitivity ratings are highlighted.

| Olmsted CGA, 1988 | Bedrock Surface Pollution Sensitivity, 2015 |
|---|---|
| Very High: Hours to months | Very High: Hours to months |
| High: Weeks to years | High: Weeks to years |
| High-Moderate: Years to decade | Moderate: Years to decades |
| Moderate: Several years to decades | Moderate: Years to decades |
| Low-Moderate: Several decades | Low: Decades to a century |
| Low: Several decades to a century | Low: Decades to a century |
| Very Low: More than a century | Very Low: A century or more |

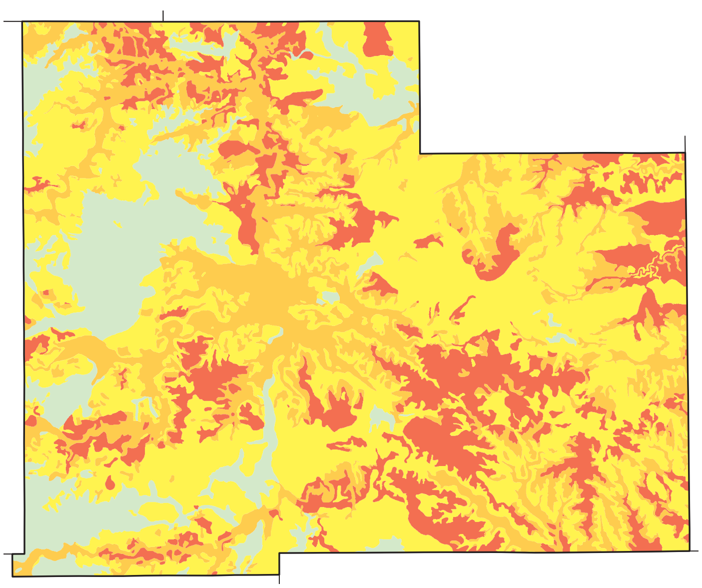


**Figure 9. Pollution sensitivity of the groundwater systems in Olmsted County**

From C-03, Plate 6.

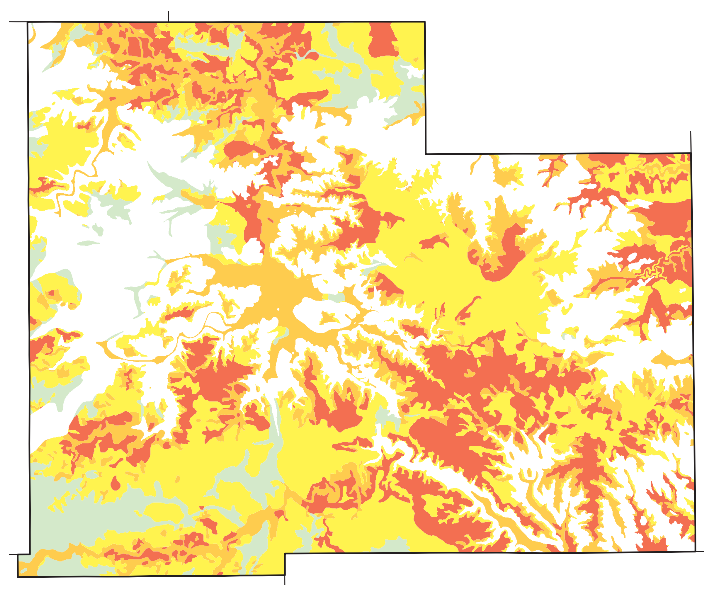


**Figure 10. Pollution sensitivity of the bedrock surface in Olmsted County**

The adjusted pollution sensitivity map of Olmsted County has areas where the bedrock surface pollution sensitivity was not originally rated.

## Dakota County, C-06

The Dakota County Geologic Atlas was completed by the MGS in 1990. Compilation information is derived from Plate 7, *Sensitivity of the Prairie du Chien–Jordan Aquifer to Pollution* (Hobbs, 1990). "The [sensitivity] ratings are based on characteristics of rock and sediment known to overlie the Prairie du Chien–Jordan bedrock aquifer. This aquifer underlies almost all of the country, and is the most heavily used source of groundwater in the county" (Hobbs, 1990). The ratings on the map were based on the estimated time for water-soluble, geologically inert contaminants to travel from the surface to the aquifer (Figure 11).

The Decorah Shale is considered the best confining unit in the county. It overlies the Prairie du Chien in small areas in the northern part of the county. The Glenwood Formation is a good confining unit and covers the majority of the county. Very small areas of St. Peter Sandstone with discontinuous, overlapping shale beds occur in the county as described in select water well records.

The thickness and nature of sediment that overlies the bedrock surface is highly variable and this has a large effect on the sensitivity rating. The Legacy Matrix (referred to as the ratings matrix in the atlas) divided sediment thickness into three increments: less than 50 feet, 50–100 feet, and greater than 100 feet. Materials were rated on their ability to offer protection (i.e., greatest, moderate, minimal, and no protection).

It should be noted that, as in Olmsted County, the sensitivity ratings for Dakota County included a high-moderate and a low-moderate rating. Conversions were applied for this compilation (Table 6). Areas were omitted where the Prairie du Chien–Jordan aquifer was not the top of the bedrock surface (Figure 12). Differences between Dakota and surrounding counties are discussed in the section on Cross-Border Discrepancies.

**Table 6. Sensitivity ratings for the Prairie du Chien–Jordan aquifer in the Dakota County Geologic Atlas**

The updates for the statewide atlas compilation series are highlighted.

| Dakota CGA, 1990 | Bedrock Surface Pollution Sensitivity, 2015 |
|---|---|
| Very High: Hours to months | Very High: Hours to months |
| High: Weeks to years | High: Weeks to years |
| High-Moderate: Years to decade | Moderate: Years to decades |
| Moderate: Several years to decades | Moderate: Years to decades |
| Low-Moderate: Several decades | Low: Decades to a century |
| Low: Several decades to a century | Low: Decades to a century |
| Very Low: More than a century | Very Low: A century or more |

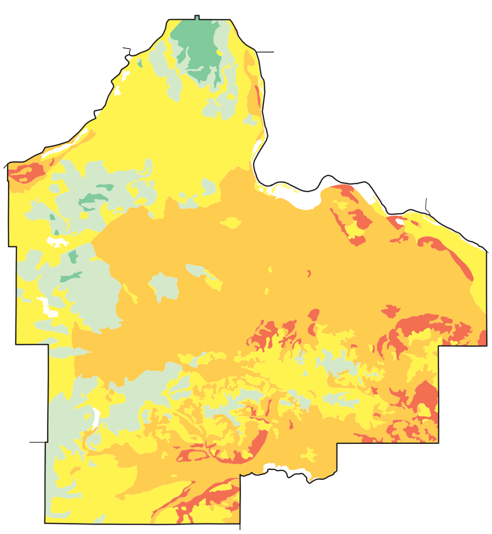


**Figure 11. Pollution sensitivity of the Prairie du Chien–Jordan aquifer in Dakota County**

From C-06, Plate 7.

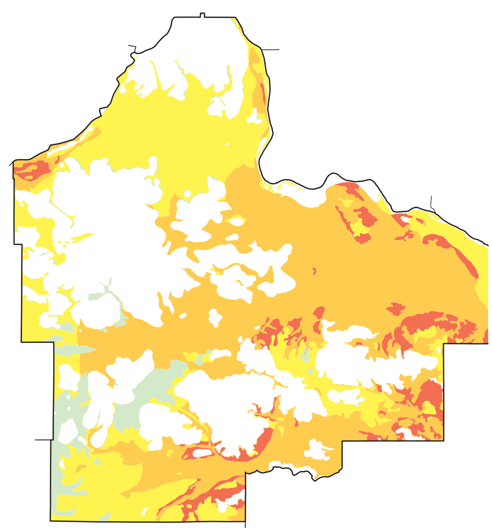


**Figure 12. Pollution sensitivity of the bedrock surface in Dakota County**

The adjusted pollution sensitivity map of Dakota County has areas where the bedrock surface pollution sensitivity was not originally rated.

## Ramsey County, C-07

The Ramsey County Geologic Atlas was completed by the MGS and the Ramsey Soil and Water Conservation District (SWCD) in 1992. Compilation information is derived from the SWCD's Plate 9, *Sensitivity of the Prairie du Chien–Jordan Aquifer to Pollution* (Twiss, 1992). A rating matrix was developed to relate depth to bedrock, a confining unit's distribution and ability to restrict flow, and the composition of overlying unconsolidated deposits.

Areas of high sensitivity are primarily located within valleys eroded into the bedrock and through the protective confining layer that were subsequently filled with highly permeable sands and gravels (Figure 13). Lower ratings are located where bedrock confining units are intact and where there is a thick layer of till of the Twin Cities Member of the New Ulm Formation (formerly referred to as Grantsburg till). Decorah Shale is the most effective bedrock confining unit but is only present in southeastern and southwestern Ramsey County. The shale of the Glenwood Formation extends through the southwest, east-central, and central parts of the county. There are a series of overlapping shale and siltstone beds of the St. Peter Sandstone within the county, but they are not effective confining units due to a series of ancient and recent valleys that cut through the unit, as well as some faulting across units. Quaternary geologic sediment such as till and glaciolacustrine layers can act as confining units, especially where uniform from the surface to the bedrock. Areas where the Prairie du Chien–Jordan aquifer was not the top of the bedrock surface were omitted (Figure 14).

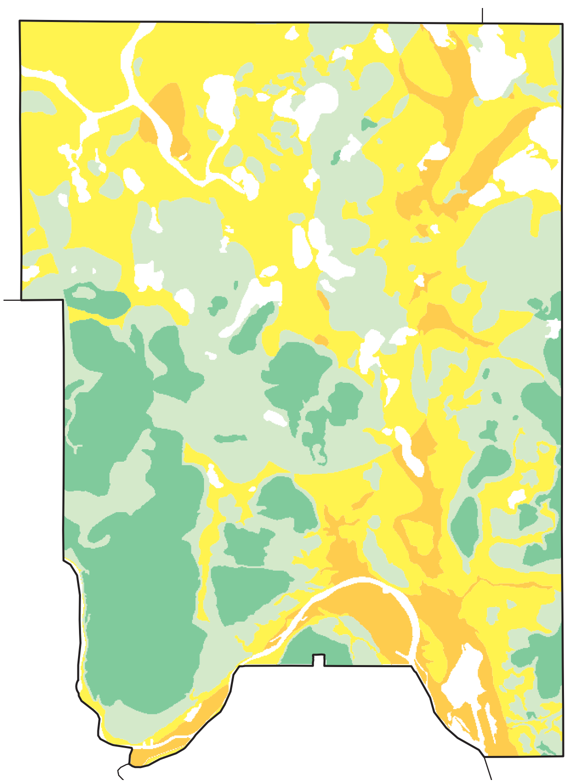


**Figure 13. Pollution sensitivity of the Prairie du Chien–Jordan aquifer in Ramsey County**

From C-07, Plate 9.

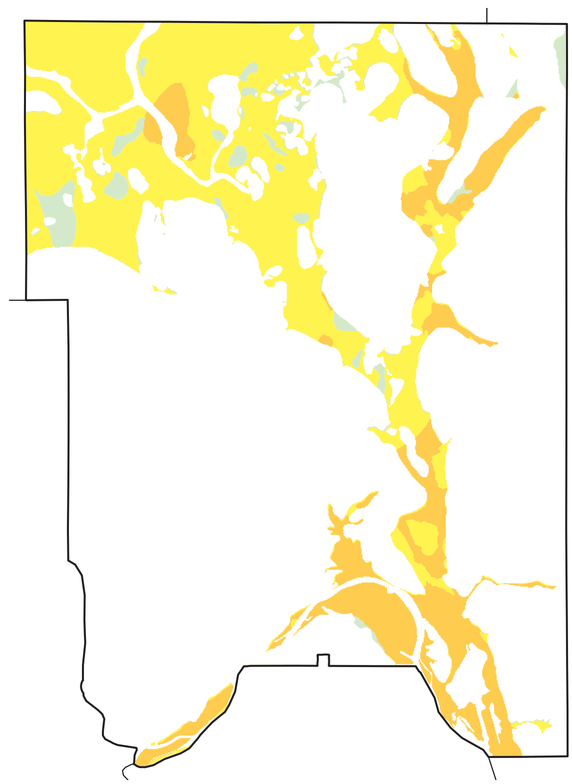


**Figure 14. Pollution sensitivity of the bedrock surface in Ramsey County**

The adjusted pollution sensitivity map of Ramsey County has blank areas where the bedrock surface pollution sensitivity was not originally rated.

## Fillmore County, C-08

The Fillmore County Geologic Atlas Part B was completed by the DNR in 1996. It was the first county atlas with a Part B, and included a bedrock pollution sensitivity map authored by the DNR. Compilation information was derived from Plate 7, *Sensitivity of the St. Peter–Prairie du Chien–Jordan aquifer to pollution* (Zhang and Falteisek, 1996). Six geologic and hydrogeologic factors were considered when making this map: 1) depth to water, 2) presence of a confining unit, 3) bedrock geology, 4) surficial geology, 5) sinkholes, and 6) drift (glacial sediment) thickness.

The "matrix assumes that the presence of the Decorah–Platteville–Glenwood confining unit and till at the surface [as] the major controls on the pollution sensitivity of the St. Peter–Prairie du Chien–Jordan aquifer. In the northeast half of the county, where the confining unit has been completely removed by erosion, the area has…a rating of [high] or [very high]…However, [where] the confining unit is not completely eroded, [the area] received Moderate pollution sensitivity ratings" (Zhang and Falteisek, 1996).

Most of the St. Peter–Prairie du Chien–Jordan (a karst unit) is overlain by the protective Decorah–Platteville–Glenwood confining unit in the southwest, resulting in a lower sensitivity rating for the aquifer being given at the time of publication (Figure 15). Since the original map was not completely representative of the pollution sensitivity of the bedrock surface, areas not originally modeled have been omitted from this compilation (Figure 16). However, based on field observations and continuous work in this area, it is agreed by regional hydrogeologists at the DNR that western Fillmore has the best developed surface karst features in Minnesota, which would result in a very high sensitivity to pollution (J. Green, written communication, 2015).

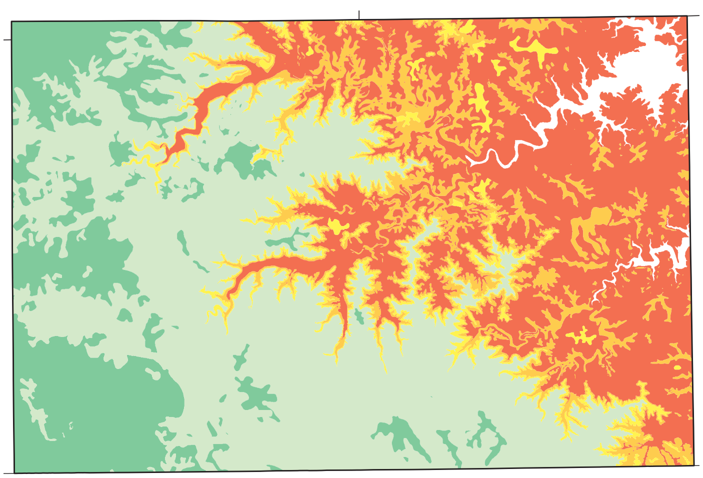


**Figure 15. Pollution sensitivity of the St. Peter–Prairie du Chien–Jordan aquifer in Fillmore County**

From C-08, Plate 7.

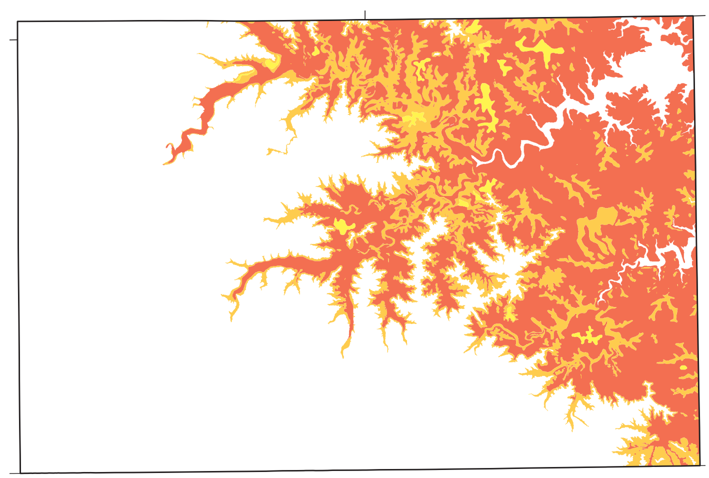


**Figure 16. Pollution sensitivity of the bedrock surface in Fillmore County**

The adjusted pollution sensitivity map of Fillmore County has areas where the bedrock surface pollution sensitivity was not originally rated.

## Rice County, C-09

The Rice County Geologic Atlas Part B was completed by the DNR in 1997. Compilation information was derived from Plate 9, *Sensitivity of bedrock aquifer systems to pollution* (Campion, 1997). It shows distinctive hydrogeologic conditions that influence recharge and aquifer sensitivity (Figure 17). Key factors considered were the nature of the geologic material and geomorphic setting (till, alluvium, lakeshore or bedrock at or near surface), the condition of the Decorah–Platteville–Glenwood confining unit (absent, eroded edge, or continuous), and the overall thickness of the geologic material. "The thickness and hydrogeologic character of tills and the uneroded Decorah–Platteville–Glenwood confining unit are the most significant factors for interpreting sensitivity to the pollution in Rice County" (Campion, 1997). Unweathered and unfractured shale is a good confining unit, but the eroded edge allows groundwater to move easily through fractures. In areas where the confining unit is buried by more than 100 feet of saturated till, the hydrologic influence is less clear.

The most direct pathway to the bedrock aquifer is in the northeastern Rice County where the St. Peter Sandstone or the Prairie du Chien Group is at or near the land surface. Water then moves through pore spaces and fractures in the rock (Campion, 1997). "The county can be broadly divided into four sensitivity regions: [high] and [very high] where the [bedrock] aquifer or the edge of Decorah–Platteville–Glenwood confining unit has less than 50 feet of sedimentary cover or is covered by alluvium or outwash; moderate where the [bedrock] aquifer or the edge of the Decorah–Platteville–Glenwood confining unit has greater than 50 feet of sedimentary cover; Low where the [bedrock] aquifer is under thick New Ulm Formation till without many lakes; and [very low] where the [bedrock] aquifer is beneath the continuous Decorah–Platteville–Glenwood confining unit [and lakeshores] for larger lakes" (Campion, 1997). Areas in the county where the bedrock aquifer was not the top of the bedrock surface have been omitted to reflect only ratings for the bedrock surface (Figure 18).

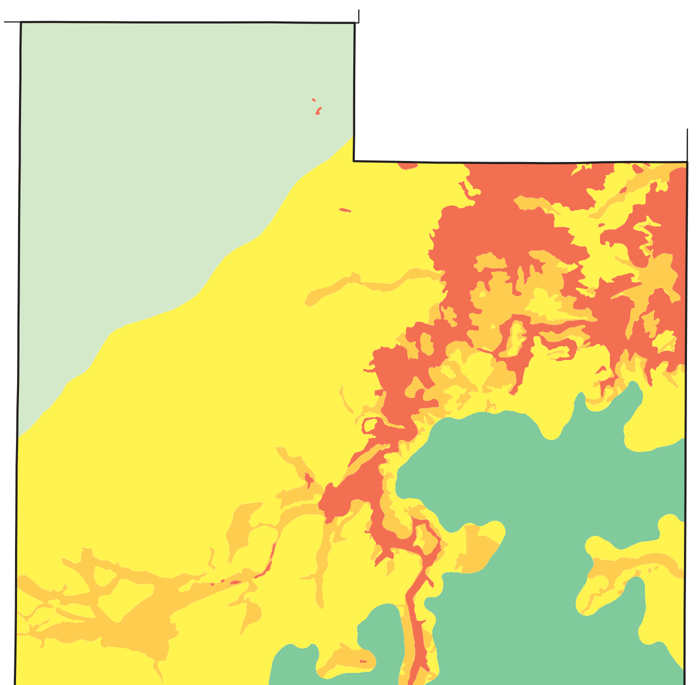


**Figure 17. Pollution sensitivity of the bedrock aquifer in Rice County**

From C-09, Plate 9.

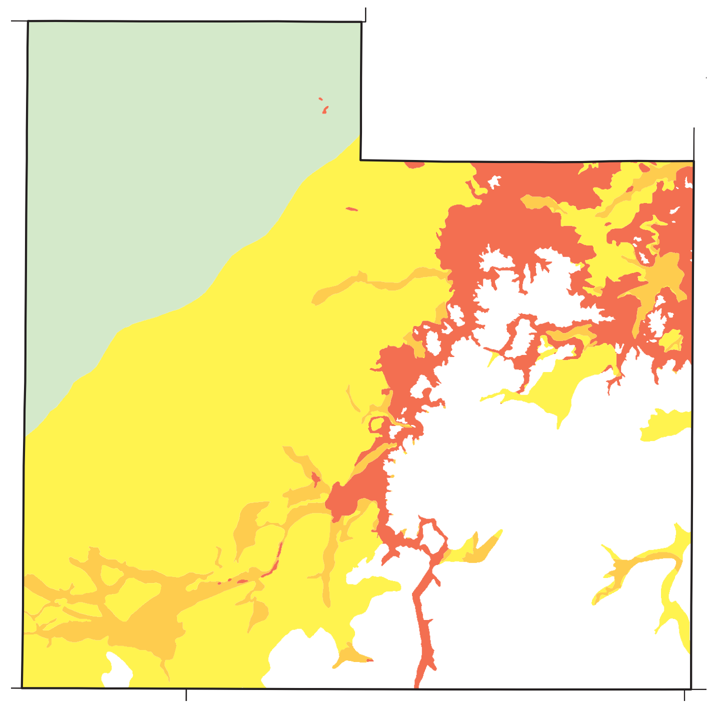


**Figure 18. Pollution sensitivity of the bedrock surface in Rice County**

The adjusted pollution sensitivity map of Rice County has areas where the bedrock surface pollution sensitivity was not originally rated.

## Mower County, C-11

The Mower County Geologic Atlas Part B was completed by the DNR in 2002. Compilation information was derived from Plate 9, *Sensitivity to pollution of the uppermost bedrock aquifers* (Campion, 2002). This map does not omit any areas in the county because the aquifers reflect the top of bedrock (Figure 19). The map used a sensitivity Legacy Matrix based on a combination of factors related to the information provided throughout the atlas: bedrock at or near land surface, karst hydrogeomorphic units, presence of outwash deposits, and thickness of till cover. The areas rated very high tend to be where there is bedrock at or near surface and where shallow karst units with identifiable sinkholes are present. High sensitivity areas also occur in the karst hydrogeomorphic unit where the surficial cover is less than 25 feet or the surficial sand units overlying other glacial material is less than 75 feet thick. Two major areas of moderate sensitivity are karst areas with less than 75 feet of cover and the large sandy outwash area in western Mower County. The rest of the county has low sensitivity with more than 75 feet of glacial sediment and no sand at the surface.

"The dominant factors influencing travel time and controlling the ability of geologic material to transmit water are the flow characteristics to the aquifer and the thickness and texture of the material between the land surface and the aquifer. Bedrock aquifers in southeastern Minnesota are typically fractured and very porous. Water is transmitted into the aquifer directly if there is no cover material at the land surface. Materials deposited by glaciers, lakes, and streams cover most of the bedrock in Minnesota in varying thicknesses" (Campion, 2002).

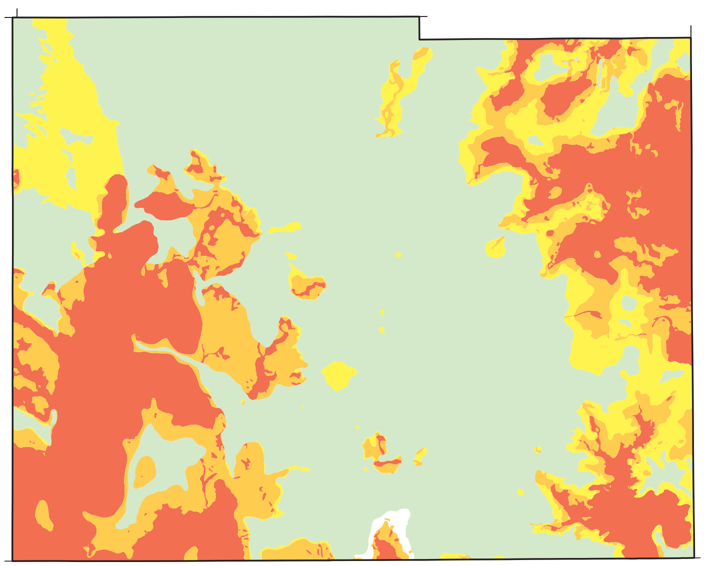


**Figure 19. Pollution sensitivity of the bedrock surface in Mower County**

From C-11, Plate 9. No modifications were made to the original map for this series.

## Goodhue County, C-12

The Goodhue County Geologic Atlas Part B was completed by the DNR in 2003. Compilation information was derived from Plate 9, *Sensitivity to pollution of the uppermost bedrock aquifers* (Berg, 2003). "Which bedrock is upper [most] varies across [the] county because of erosion as described [in the Plate 7, Bedrock and Water Table Hydrogeology]. In general, the upper aquifer is the St. Peter–Shakopee in the southwestern portion of the county, the Jordan aquifer in the central and northeastern portions, and the St. Lawrence–Franconia–Ironton–Galesville aquifer in the far northeastern portion of the county" (Berg, 2003), now referred to as the St. Lawrence–Upper Tunnel City–Wonewoc aquifer (Figure 20). These bedrock aquifers are considered the sensitivity target for most of the evaluations. "Sensitivity of the Galena aquifer in the southwestern Goodhue County is… considered separately because it is an aerially extensive perched aquifer above the Decorah–Platteville–Glenwood confining unit and the extent of the Galena Group and associated aquifer is limited to erosional remnants on the Decorah plateau" (Berg, 2003). Geologic factors include the presence, absence, and erosional state of the Decorah–Platteville–Glenwood confining unit, thickness of till and other glacial materials over the confining unit, and permeability of the glacial material. Areas in the county where the bedrock aquifer was not the top of the bedrock surface have been omitted to reflect only ratings for the bedrock surface (Figure 21).

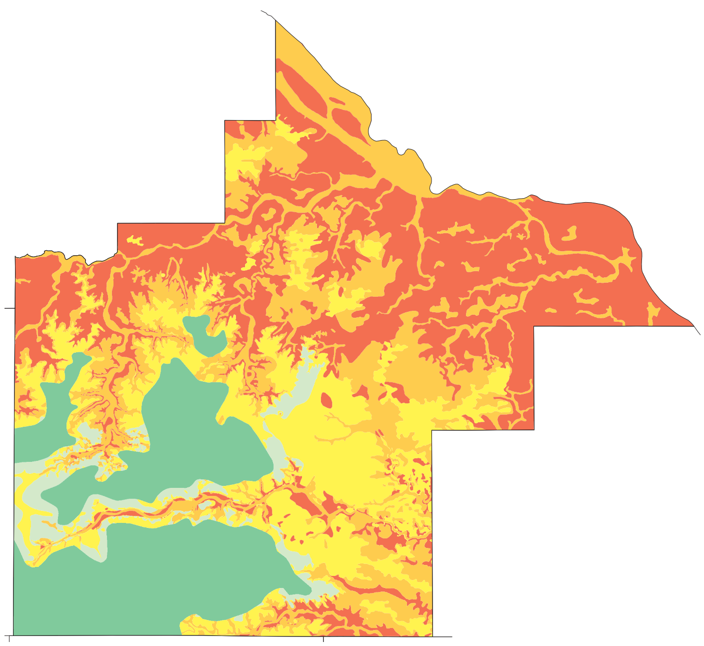


**Figure 20. Pollution sensitivity of the bedrock aquifer in Goodhue County**

From C-12, Plate 9.

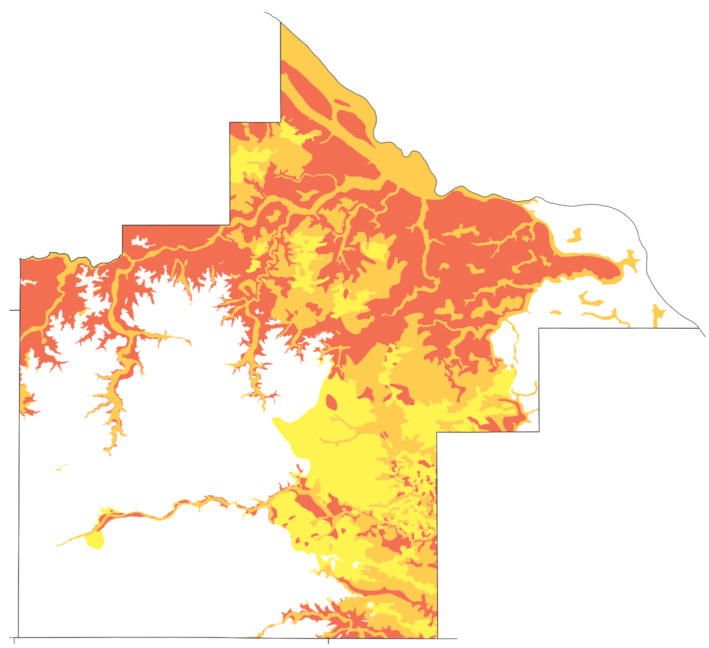


**Figure 21. Pollution sensitivity of the bedrock surface in Goodhue County**

The adjusted pollution sensitivity map of Goodhue County has areas where the bedrock surface pollution sensitivity was not originally rated.

## Pine County, C-13

The Pine County Geologic Atlas Part B was completed by the DNR in 2004. Compilation information was derived from Plate 10, *Sensitivity to pollution of the uppermost bedrock aquifers* (Berg, 2004). A combination of geologic factors such as permeability of surface materials and the glacial sediment thickness were considered. Local geologic factors were also important in some areas such as the presence of buried sand and gravel, fine-grained sediment of glacial Lake Lind, and unsaturated Hinckley Sandstone.

The model assumes that in areas of equal glacial sediment thickness, the overall permeability increases as sand and gravel thicknesses increase at the expense of till thickness. Areas of thin glacial sediment are found in the central and northeastern portions of the county, with most of the material consisting of till units; whereas the northeastern, southern, and eastern portions of the county have relatively thick glacial sediment cover. One of the geologic factors considered is whether there are buried valleys filled with permeable sediment that breach a confining layer. The pollution sensitivity classification was very high where unsaturated Hinckley Sandstone is overlain by less than 50 feet of till because of the high potential for sinkholes in the Hinckley Sandstone (Berg, 2004).

This map does not omit any areas in the county because the map reflects the bedrock surface in Pine County (Figure 22).

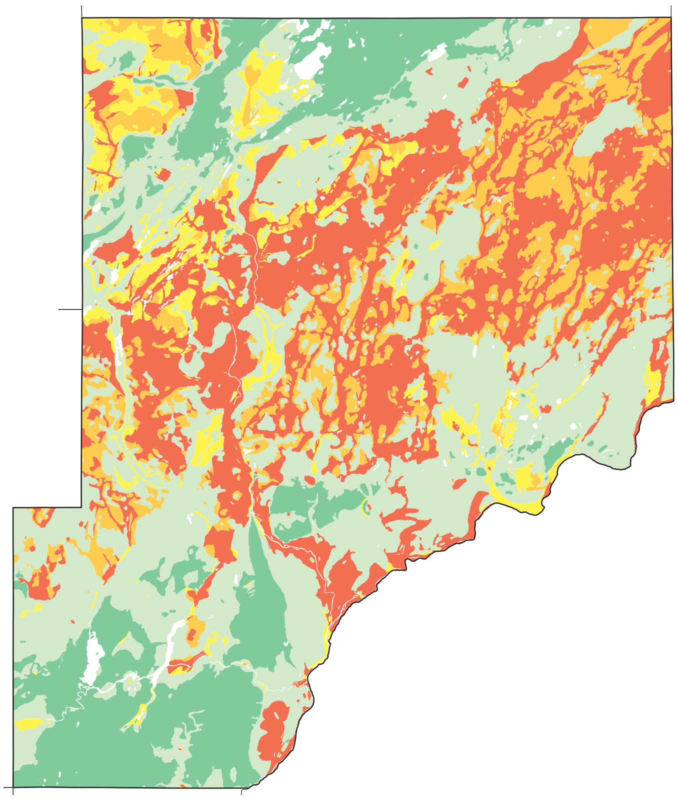


**Figure 22. Pollution sensitivity of the bedrock surface in Pine County**

From C-13, Plate 10. No modifications were made to the original map for this series.

## Wabasha County, C-14

The Wabasha County Geologic Atlas Part B was completed by the DNR in 2005. Compilation information was derived from Plate 10, *Sensitivity to pollution of the uppermost bedrock aquifers* (Petersen, 2005). This map does not omit any areas in the county because the map reflects the top of bedrock in Wabasha (Figure 23). The sensitivity to pollution of the upper aquifers describes multiple bedrock aquifers. "The upper bedrock aquifer in the upland areas of Wabasha County is usually the Prairie du Chien aquifer. In the western part of the county, significant bedrock faulting has elevated older bedrock formations to the bedrock surface" (Petersen, 2005). The Jordan, St. Lawrence, and Franconia (now called Upper Tunnel City) aquifers form the first bedrock surface in western Wabasha County.

In the Mississippi River valley and the Zumbro River valley, the Quaternary sediment is the upper and primary aquifer. "The sensitivity to pollution of the Quaternary sand and gravel aquifer was evaluated separately and is shown [on Plate 10 as another figure]" (Petersen, 2005). The Zumbro River cut deeply into bedrock to form its valley. Along the valley the upper bedrock aquifer is Jordan in the west, Franconia in the east, and St. Lawrence–Franconia farther east. "In the Mississippi River valley, which typically has between 150 feet and 300 feet of sediment over bedrock… either the Eau Claire or the Mt. Simon aquifer is the upper bedrock aquifer" (Petersen, 2005).

The sensitivity map combined surficial geology and depth-to-bedrock maps because the main factors in the matrix were permeability and thickness of the overlying material.

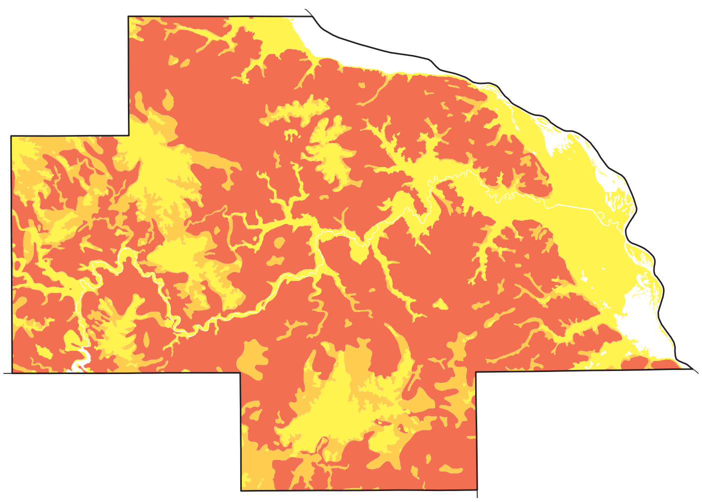


**Figure 23. Pollution sensitivity of the bedrock surface in Wabasha County**

From C-14, Plate 10. No modifications were made to the original map for this series.

# Recharge Surfaces Method

Starting in 2006, the DNR began calculating pollution sensitivity based on the Recharge Surfaces method (Berg, 2006). Recharge is used to describe downward movement of water through the unsaturated to the saturated zone.

The Recharge Surfaces method (Berg, 2006) was extended by Tipping (2006) to calculate the pollution sensitivity of the bedrock surface since it only evaluated buried sand and gravel aquifers at the time. The maps shown in this compilation show the estimated rate of recharge for the top of the bedrock surface.

## Scott County, C-17

The Scott County Geologic Atlas was updated by the Minnesota Geological Survey in 2006. Compilation information was derived from Plate 6, *Subsurface Recharge and Surface Infiltration* (Tipping, 2006). These maps show the estimated rate of recharge for three buried sand units and the bedrock surface using the Recharge Surfaces method (Berg, 2006). He rated each of the buried sand units for recharge rate based on the "thickness of the confining layer between the top of a buried aquifer and the next overlying recharge surface". He also mapped the estimated rate of recharge for the bedrock surface. His rating scheme of very fast to very slow is directly comparable to the pollution sensitivity ratings of very high to very low used by DNR for pollution sensitivity ratings. Thus the recharge rate rating can be directly translated to a pollution sensitivity rating. Most of the bedrock surface of Scott County is rated very low pollution sensitivity. Areas rated very high pollution sensitivity along the river valley are where bedrock is at or close to the land surface or in direct contact with surficial sand and gravel deposits (Figure 24).

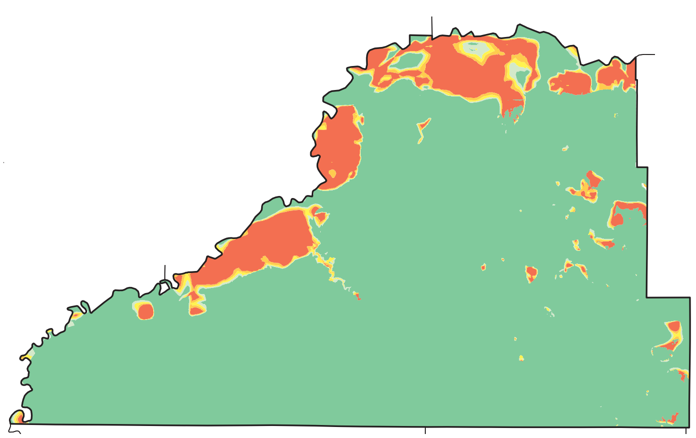


**Figure 24. Pollution sensitivity of the bedrock surface in Scott County**

No modifications were made to the original map for this series.

## Carlton County, C-19

The Carlton County Geologic Atlas Part B was completed by the DNR in 2011. Compilation information was derived from Plate 10, *Sensitivity of Groundwater Systems to Pollution* (Berg, 2011). It is common in Carlton County for bedrock to be within 150 feet of the surface with thin overlying protective layers of glacial sediment, with the exception of parallel deep bedrock valleys in the southeast and northwest corners of the county. The areas of the county rated very high to moderate pollution sensitivity are generally where shallow bedrock conditions occur and consequently provide limited overlying protection (see the northeast trending moderate to very high ratings in Figure 25).

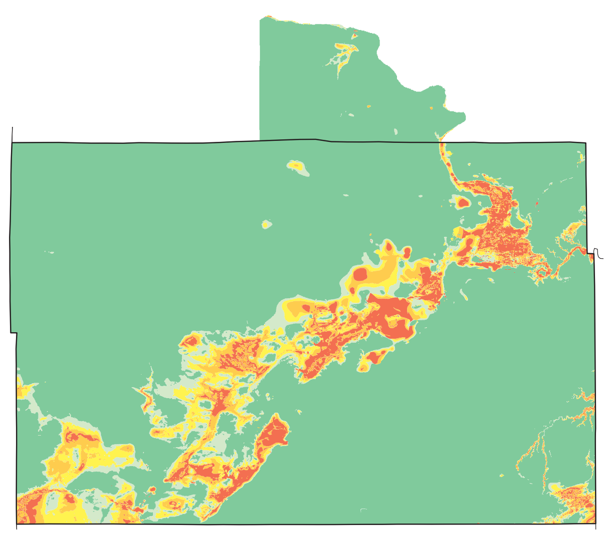


**Figure 25. Pollution sensitivity of the bedrock surface in Carlton County**

No modifications were made to the original map for this series.

## McLeod County, C-20

The McLeod County Geologic Atlas Part B was completed by the DNR in 2013. Compilation information was derived from Plate 9, *Pollution sensitivity of the near-surface materials, buried sand and gravel aquifers, and the bedrock surface* (Petersen, 2013). The entire bedrock surface is rated as very low pollution sensitivity because the overlying material is over 40 feet thick and consists mainly of till (Figure 26).

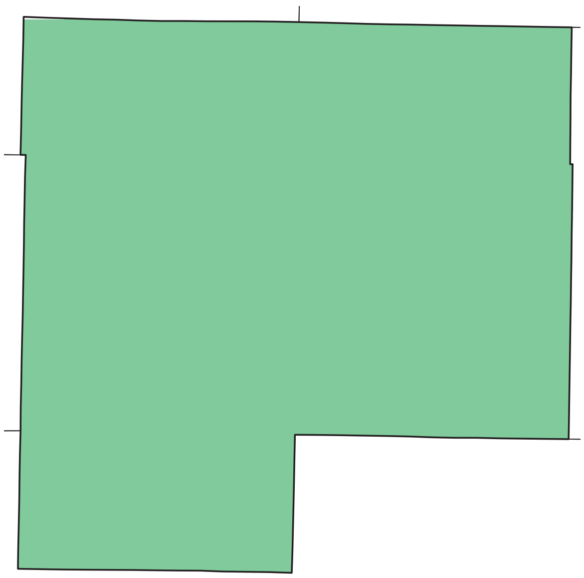


**Figure 26. Pollution sensitivity of the bedrock surface in McLeod County**

No modifications were made to the original map for this series.

## Carver County, C-21

The Carver County Geologic Atlas Part B was completed by the DNR in 2014. Compilation information was derived from Plate 9, *Pollution sensitivity of the near-surface materials, buried sand and gravel aquifers, and the bedrock surface* (Petersen, 2014). The bedrock surface in southeast Carver County is rated high to very high pollution sensitivity owing to the presence of overlying permeable sand and gravel aquifers in that area. Elsewhere in the county the pollution sensitivity of the bedrock surface is rated very low because the overlying protective layer of mainly clay loam and loam tills is more than 40 feet thick (Figure 27).

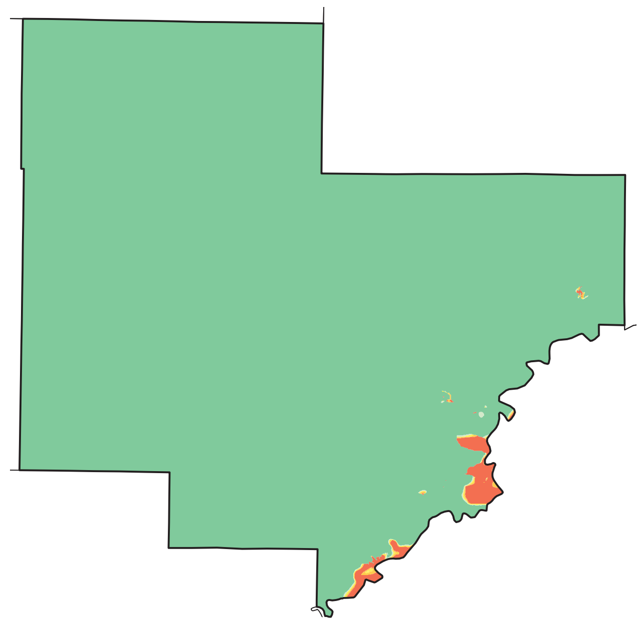


**Figure 27. Pollution sensitivity of the bedrock surface in Carver County**

No modifications were made to the original map for this series.

## Chisago County, C-22

The Chisago County Geologic Atlas Part B was completed by the DNR in 2014. Compilation information was derived from Plate 10, *Pollution sensitivity of the near-surface materials, buried sand and gravel aquifers, and the bedrock surface* (Barry, 2014). The pollution sensitivity rating of the bedrock surface is primarily very low, but there are scattered areas of the county with very high to moderate pollution sensitivity rating where the depth to bedrock is less than 50 feet (Figure 28). On the eastern border of Chisago County the bluffs of basalt along the St. Croix River in the Taylor Falls area have a very high pollution sensitivity rating, although the physical properties of basalt may lower the actual sensitivity to pollution.

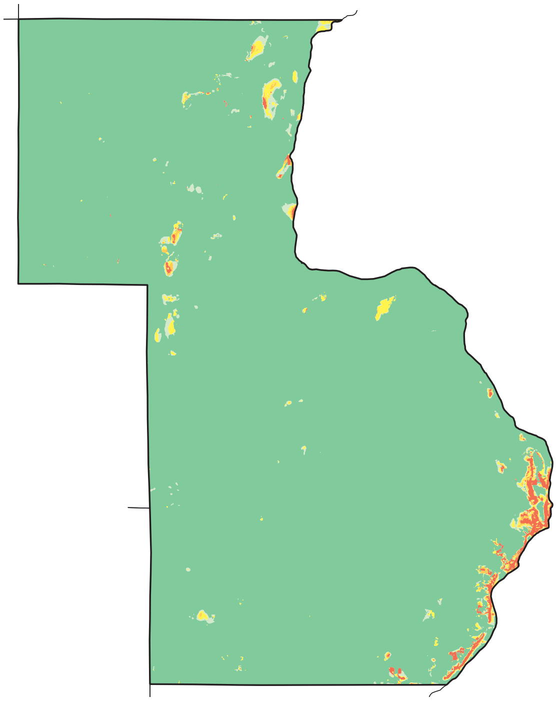


**Figure 28. Pollution sensitivity of the bedrock surface in Chisago County**

No modifications were made to the original map for this series.

## Blue Earth County, C-26

The Blue Earth County Geologic Atlas Part B is in preparation at the DNR at the time of this report. Compilation information was derived from the pollution sensitivity report sections and figures (Berg, in preparation). The pollution sensitivity map for the bedrock surface is based on the Recharge Surfaces method (Berg, 2006) used in previous County Geologic Atlas reports.

The bedrock surface of most of Blue Earth County is rated very low pollution sensitivity (Figure 31) (Berg, in preparation). The northern border of the county along the Minnesota River Valley and the downstream portions of major rivers are rated very high to moderate pollution sensitivity. In these areas bedrock is shallow and sandy alluvium overlies the bedrock surface.

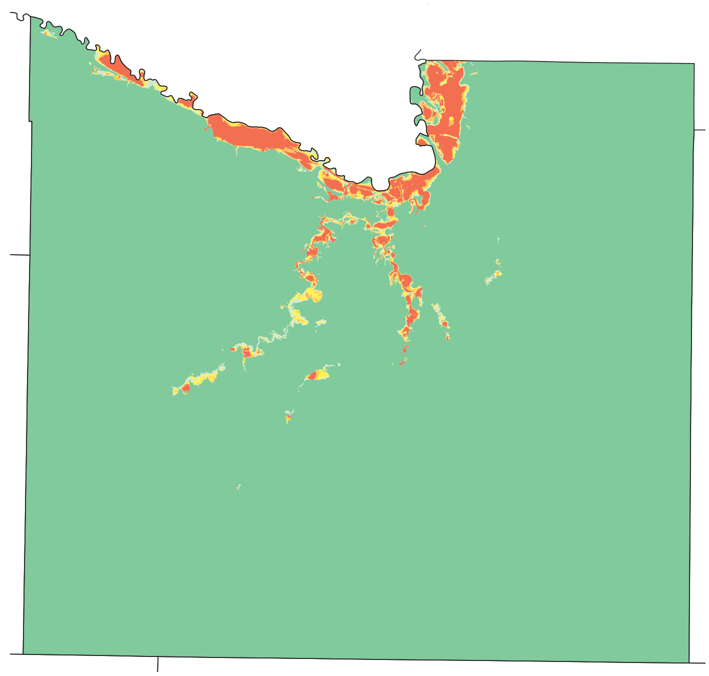


**Figure 31. Pollution sensitivity of the bedrock surface in Blue Earth**

No modifications were made to the original map for this series.

# Current Method: Cumulative Fine-Grained Sediment (CFGS) Thickness Method

Starting in 2016, the DNR began calculating pollution sensitivity based on the CFGS Thickness method (Minnesota DNR, 2016). This method is similar to the Recharge Surfaces method, taking into account surface infiltration and subsurface recharge, however it uses the cumulative thickness of fine-grained sediments overlying an aquifer or the bedrock surface to determine the sensitivity rating. At the time of this publication, it is the current method used by the DNR to determine the pollution sensitivity of the bedrock surface.

## Sibley County, C-24

The Sibley County Geologic Atlas Part B is in preparation by the DNR at the time of this report. Compilation information was derived from the pollution sensitivity report sections and figures (Baratta and Petersen, in preparation). The pollution sensitivity map for the bedrock surface is based on the CFGS Thickness method (Minnesota DNR, 2016).

The bedrock surface of Sibley County is mostly rated as very low pollution sensitivity with the exception of along the eastern border of the county in the Minnesota River valley (Figure 29). Within the valley, limited areas are rated high pollution sensitivity because bedrock is within 50 feet of the land surface (Part A, Plate 6) (Baratta and Petersen, in preparation).

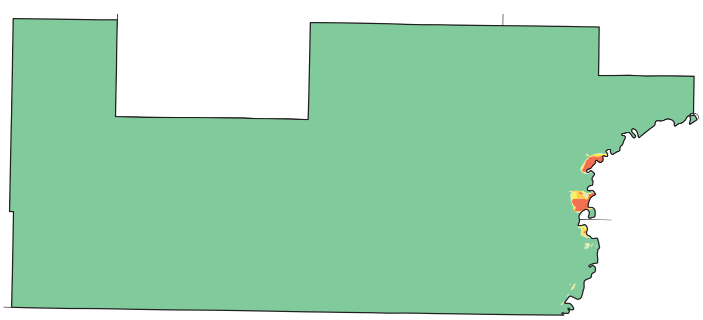


**Figure 29. Pollution sensitivity of the bedrock surface in Sibley County**

No modifications were made to the original map for this series.

## Nicollet County, C-25

The Nicollet County Geologic Atlas Part B is in preparation at the DNR at the time of this report. Compilation information was derived from the pollution sensitivity report sections and figures (Baratta and Petersen, in preparation). The pollution sensitivity map for the bedrock surface is based on the CFGS Thickness method (Minnesota DNR, 2016).

The bedrock surface of Nicollet County is rated mostly very low pollution sensitivity, with the exception where the county is bordered on the southwest and east by the Minnesota River valley (Figure 30). Within the valley, limited areas are rated high pollution sensitivity because bedrock is within 50 feet of the land surface (Part A, Plate 6).

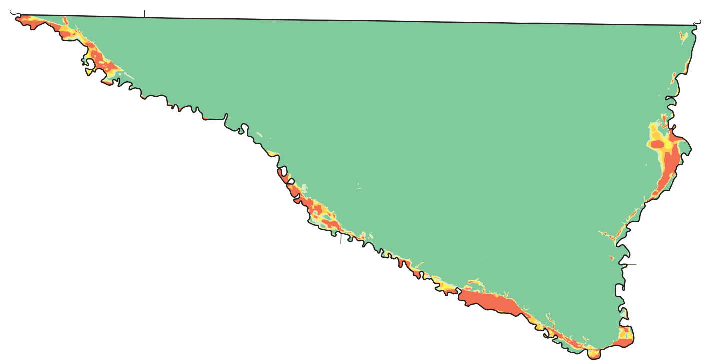


**Figure 30. Pollution sensitivity of the bedrock surface in Nicollet County**

No modifications were made to the original map for this series.

## Anoka County, C-27

The Anoka County Geologic Atlas Part B is in preparation at the DNR at the time of this report. Compilation information was derived from the pollution sensitivity report sections and figures (Berg, in preparation). The pollution sensitivity map for the bedrock surface is based on the CFGS Thickness method (Minnesota DNR, 2016).

The bedrock surface of much of Anoka County is rated very low pollution sensitivity (Figure 32). However, numerous, relatively small areas throughout the central western and southern portions of the county are rated moderate to very high pollution sensitivity. These small scattered areas represent conditions where water moves downward through the surficial sand layer and passes through multiple buried sand and gravel aquifers to the bedrock surface without encountering cumulative thicknesses of greater than 40 feet of fine-grained sediments such as lake clay.

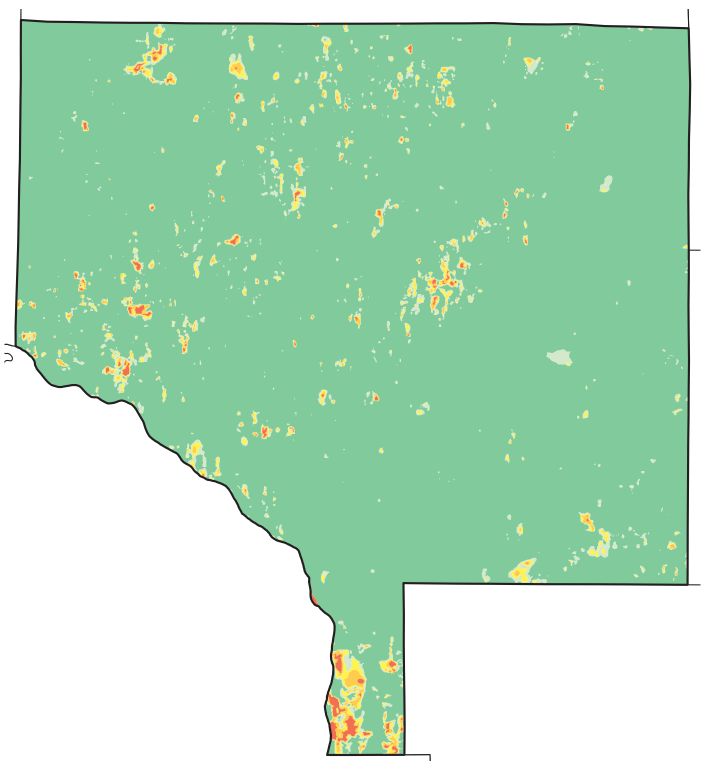


**Figure 32. Pollution sensitivity of the bedrock surface in Anoka County**

No modifications were made to the original map for this series.

## Renville County, C-28

The Renville County Geologic Atlas Part B is in preparation at the DNR at the time of this report. Compilation information was derived from the pollution sensitivity report sections and figures (Bradt, in preparation). The pollution sensitivity map for the bedrock surface is based on the CFGS Thickness method (Minnesota DNR, 2016).

The pollution sensitivity of the bedrock surface is rated primarily very low, except along the southwestern border of the county in the Minnesota River valley (Figure 33). In these areas the pollution sensitivity rating is very high to moderate sensitivity because the depth to bedrock is less than 50 feet (Part A, Plate 5).

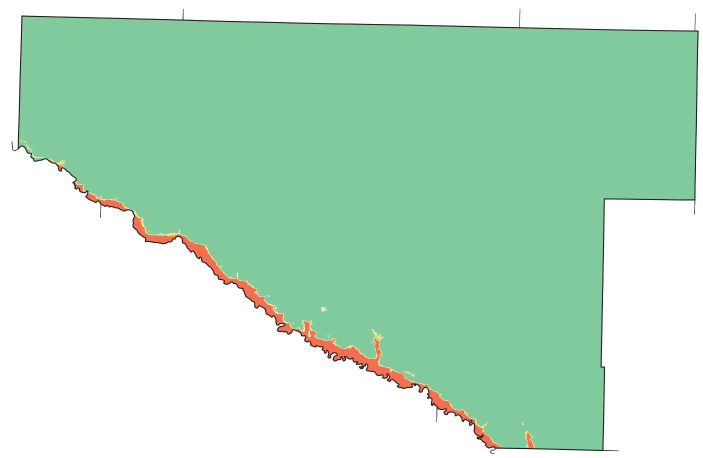


**Figure 33. Pollution sensitivity of the bedrock surface in Renville County**

No modifications were made to the original map for this series.

# Cross-Border Discrepancies

The pollution sensitivity ratings of the bedrock surface are not always consistent across county boundaries due to the breadth of data sets used and the varied methods of the authors (Figure 34). Four of the 19 maps were produced by groups other than the DNR, each using different methods and rating matrix structures. Of the 15 DNR-authored maps, the 4 most recent used the CFGS Thickness method, and the 5 previous to that used the the Recharge Surfaces method (Berg, 2006).

Differences across borders can be related to multiple factors. The most commonly used data across all counties are the surficial geology map and cross sections produced in the Part A of each county's geologic atlas. The majority of the discrepancies result from the varied methods used and the differences in surficial units mapped across county boundaries. These reflect differences in publication date, author, and available data. The stratigraphy of bedrock and erosional contacts vary regionally and may be widely present in one county but not present at a mappable scale in another. Cross-border discrepancies due to unmapped areas are not discussed. Omission of data in some counties represents situations where available data was not strictly defined as the pollution sensitivity of the bedrock surface and therefore could not be used in the compilation consistently with other data. These discrepancies were not modified because it was not within the scope of the project and would require a complete reanalysis of the older published atlases.

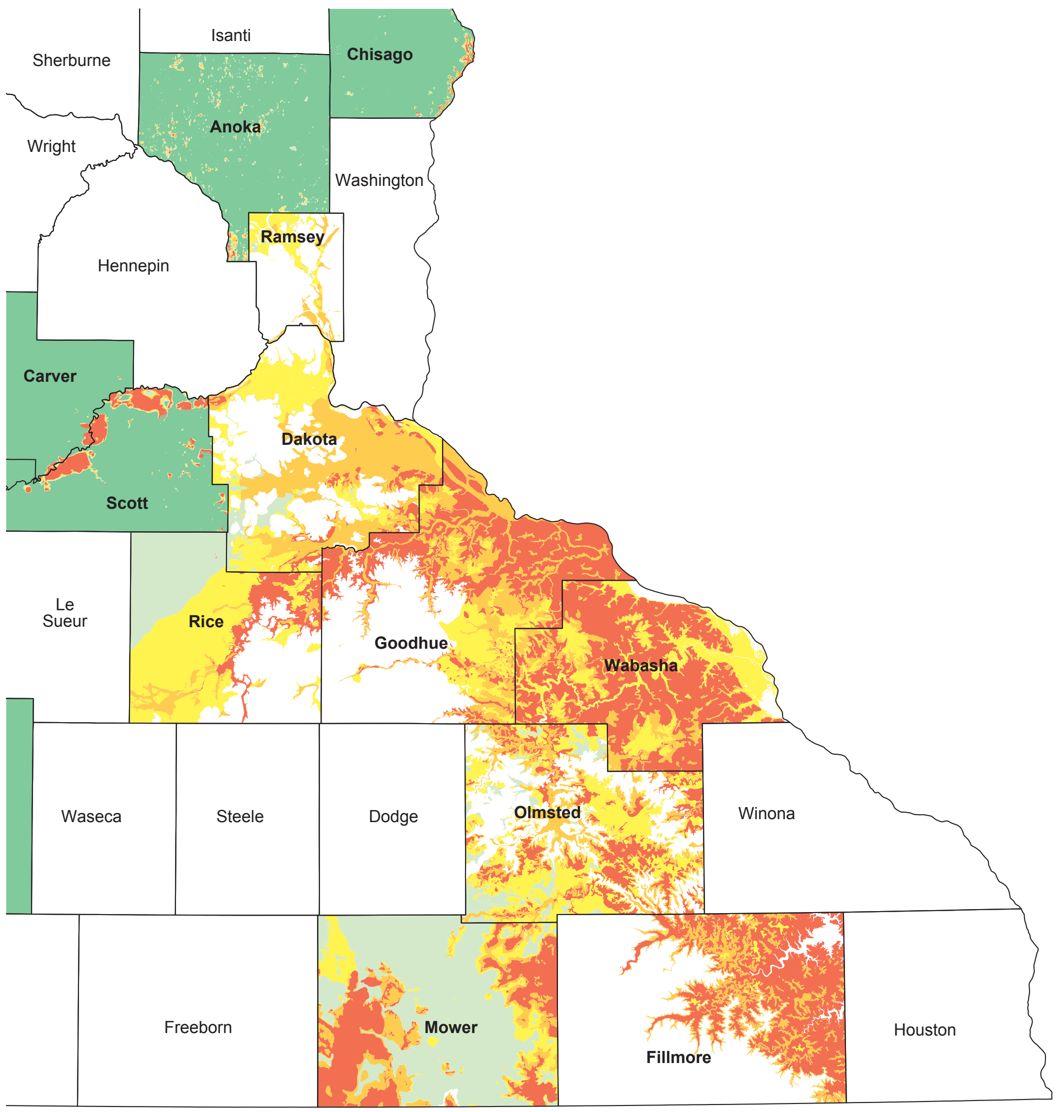



**Figure 34. Pollution sensitivity of the bedrock surface in southeast Minnesota**

Pollution sensitivity ratings of the bedrock surface are not always consistent across county boundaries due to the breadth of data sets used and the varied methods of the authors. White areas represent areas where no bedrock surface pollution sensitivity data are available.

## Goodhue and Dakota Counties

There is an obvious step down in pollution sensitivity ratings from the very high ratings in northwest Goodhue County to the high ratings in southern Dakota County (Figure 35). The underlying bedrock is the Shakopee Formation of the Prairie du Chien Group, and the surficial material is New Ulm Formation glacial stream sediment (formerly called Des Moines Lobe outwash). The explanation for the differences in pollution sensitivity rating is that Dakota County's pollution sensitivity map was authored by the MGS in 1990. The scale of seven sensitivity ratings was adjusted for the purposes of this compilation to match the scale of five sensitivity ratings currently used by the DNR (Table 6). Goodhue County (2003) was mapped using the Legacy Matrix method that was first used by the DNR in Fillmore County in 1996.

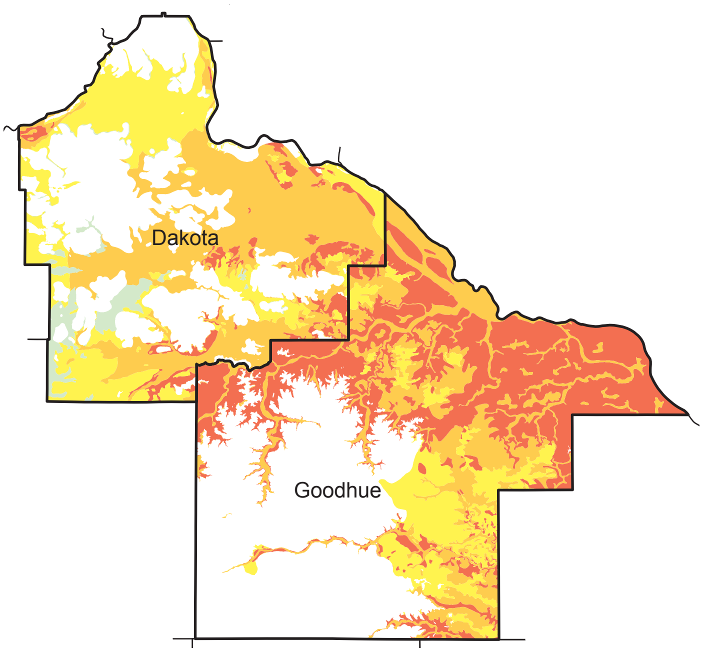



**Figure 35. Cross-border discrepancies of pollution sensitivity ratings between Goodhue and Dakota counties**

Differences across the county boundary are due to the different methods. Dakota County used seven sensitivity ratings while Goodhue County used five ratings. Both were a variation of the Legacy Matrix method.

## Scott and Dakota Counties

There is a large discrepancy of pollution sensitivity ratings along the border between Scott and Dakota counties owing to the different methods used in each atlas (Figure 36). The Scott County map was created with the Recharge Surfaces method which considers only focused recharge, whereas the Dakota County map was created with the Legacy Matrix method using unit thicknesses in increments of 50 feet (a different scale than other surrounding counties) and seven sensitivity ratings.

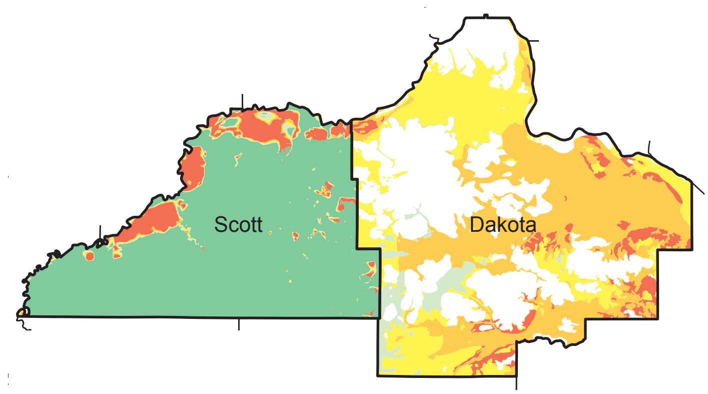



**Figure 36. Cross-border discrepancies of pollution sensitivity ratings between Scott and Dakota counties**

Differences across the county boundary are due to the different methods. The Dakota County atlas used a scale of seven sensitivity ratings and unit thicknesses in increments of 50 feet (a different scale and method than other surrounding counties) while the Scott County atlas used the Recharge Surfaces method.

## Olmsted and Wabasha Counties

The primary difference of pollution sensitivity ratings between Olmsted and Wabasha counties is the differences in methods. Olmsted County's sensitivity map was calculated by the MGS and used a scale of seven ratings (Table 5) whereas Wabasha was completed by the DNR and used the standard five ratings. Both used the Legacy Matrix method; however, the methods varied in their matrix composition. The geology is relatively similar along the border between the counties and the difference equates to one step down in sensitivity from Wabasha to Olmsted (Figure 37).

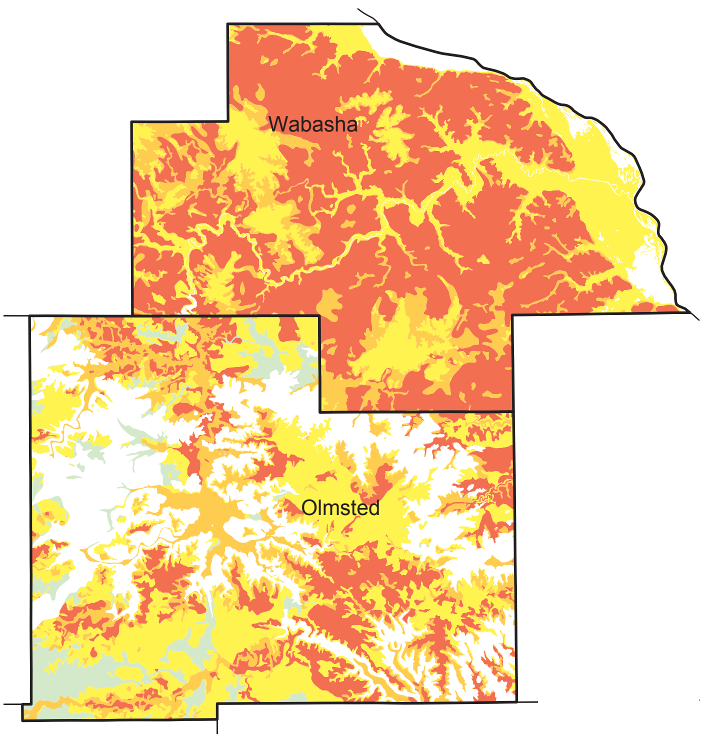



**Figure 37. Cross-border discrepancies of pollution sensitivity ratings between Olmsted and Wabasha counties**

Differences across the county boundary are due to the different Legacy Matrix methods. The Olmsted County atlas used a scale of seven ratings while the Wabasha County atlas used a scale of five ratings.

## Anoka and Ramsey Counties

The primary difference between the pollution sensitivity ratings of Anoka and Ramsey counties is the difference in methods. Ramsey County's sensitivity map was created by the Ramsey SWCD and used five ratings with a Legacy Matrix method, whereas the Anoka map was completed by the DNR and used the standard five ratings using the CFGS Thickness method (Figure 38).

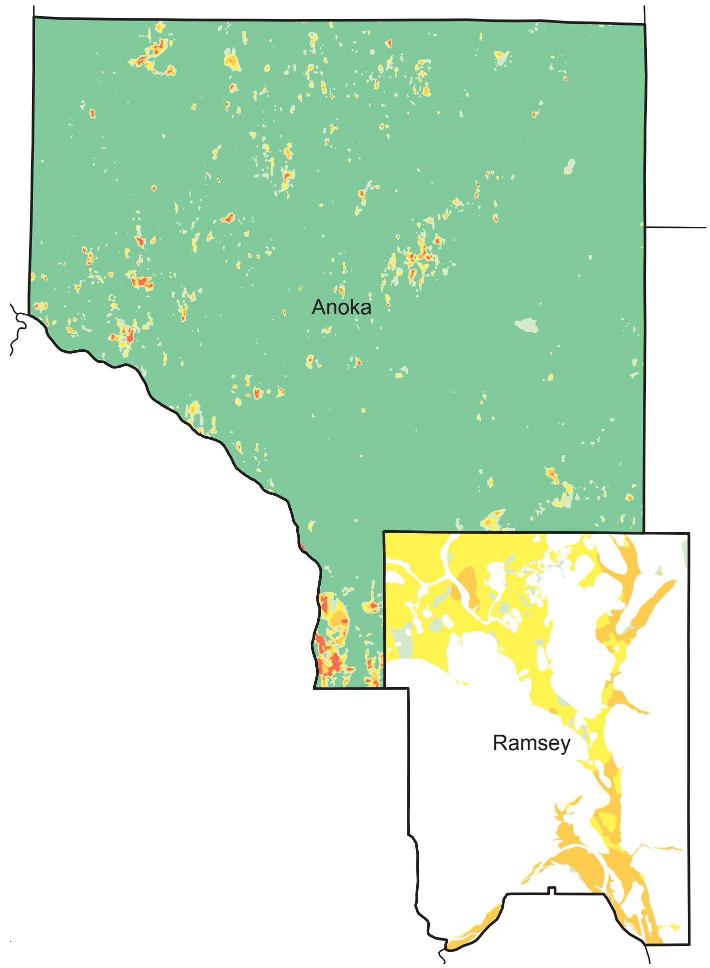



**Figure 38. Cross-border discrepancies of pollution sensitivity ratings between Anoka and Ramsey counties**

Differences across the county boundaries are due to the different methods. The Ramsey County atlas used the Legacy Matrix method while the Anoka County atlas used the Recharge Surfaces method.

## Scott and Rice Counties

As with the other discrepancies, the differences between the pollution sensitivity ratings of Scott and Rice counties is related to the method employed (Figure 39). The Rice County atlas used the Legacy Matrix method, whereas the Scott County atlas used the Recharge Surfaces method. The difference in method resulted in a low sensitivity rating in northwest Rice County and a very low rating in southeast Scott County. Differences in geology along the border may also play a role.

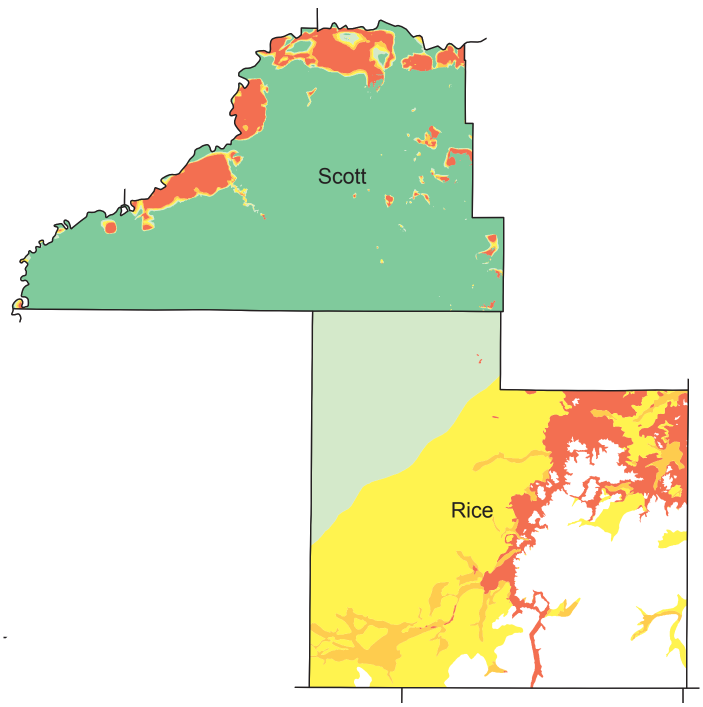



**Figure 39. Cross-border discrepancies of pollution sensitivity ratings between Scott and Rice counties**

Differences across the county boundary are due to the different methods, resulting in a very obvious difference of low to very low sensitivity rating from Rice to Scott County.

# Summary and Conclusion

The migration of contaminants with or within water as it moves through geologic material is a complex process, dependent upon many physical, chemical, and geologic factors. The hydrogeologic maps of the county atlases have taken geological factors into consideration, though the factors and methods employed have not remained consistent.

The pollution sensitivity of the bedrock surface for the state of Minnesota (Figure 1) reflects an estimation of vertical flow of a contaminant with or within water to the bedrock surface. This map and report are a broad perspective and serve as a base for contaminant modelling and pollution sensitivity investigations. They should be used in conjunction with more detailed geologic and hydrogeologic information when assessing site-specific investigations.

Contaminants are assumed to originate at or near the land surface and move downward, travelling at the same rate as infiltrating water. Therefore the assessment does not consider any specific contaminant and lateral movement is ignored. The main variable that affects the sensitivity of aquifers to pollution is the rate that water travels from the surface to the aquifer. The sensitivity to pollution for specific pollutants is beyond the scope of this map compilation. Additional analysis is required for pollutants that travel at a different rate than groundwater, or are chemically changed by interacting with soil and geologic materials.

Relatively high sensitivity does not mean that water quality has been or will be degraded. For example, if there are no contaminant sources, pollution will not occur. This also means that relatively low sensitivity does not guarantee that groundwater is or will remain uncontaminated. For instance, leakage from an unsealed well may bypass the natural protection of geologic materials, allowing contaminated water from one aquifer to directly enter another aquifer (Berg, 2006).

This map and report are meant to supplement the previous and ongoing work done by the County Geologic Atlas program. Other sources of data in an atlas are available in the metadata of the atlas for each county, such as well locations, tritium ages, and geochemistry.

Regardless of these limitations, the map can serve as a screening tool to estimate the potential impacts of specific activities and land uses on groundwater quality at a general county scale, as well as guide resource-protection decisions.

# References

Baratta, V.M. and Petersen, T.A., in preparation, Geologic atlas of Sibley County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-24, Part B, accessed December 2015.

Baratta, V.M. and Petersen, T.A., in preparation, Geologic atlas of Nicollet County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-25, Part B, accessed December 2015.

Barry, J., 2014, Pollution sensitivity of the near-surface materials, buried sand and gravel aquifers, and the bedrock surface, pl. 10 *in* Geologic atlas of Chisago County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-22, Part B, 4 pls., scale 1:100,000.

Berg, J.A., 2003, Sensitivity to pollution of the uppermost bedrock aquifers, pl. 9 *in* Geologic atlas of Goodhue County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-12, Part B, 4 pls., scale 1:100,000.

Berg, J.A., 2004, Sensitivity to pollution of the uppermost bedrock aquifers, pl. 10 *in* Geologic atlas of Pine County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-13, Part B, 3 pls., scale 1:100,000.

Berg, J.A., 2006, Sensitivity to pollution of the buried aquifers, pl. 9 *in* Geologic atlas of Pope County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-15, Part B, 4 pls., scale 1:100,000.

Berg, J.A., 2011, Sensitivity of Groundwater Systems to Pollution, pl. 10 *in* Geologic atlas of Carlton County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-19, Part B, 4 pls., scale 1:100,000.

Berg, J.A., in preparation, Geologic atlas of Blue Earth County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-26, Part B, accessed April 2015.

Berg, J.A., in preparation, Geologic atlas of Anoka County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-27, Part B, accessed December 2015.

Bradt, R., in preparation, Geologic atlas of Renville County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-28, Part B, accessed December 2015.

Campion, M., 1997, Sensitivity of bedrock aquifer systems to pollution, pl. 9 *in* Geologic atlas of Rice County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-09, Part B, 3 pls., scale 1:100,000.

Campion, M., 2002, Sensitivity to pollution of the uppermost bedrock aquifers, pl. 9 *in* Geologic atlas of Mower County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-11, Part B, 4 pls., scale 1:100,000.

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.

Hobbs, H.C., 1990, Sensitivity of the Prairie du Chien–Jordan aquifer to pollution, pl. 7 *in* Geologic atlas of Dakota County, Minnesota: St. Paul, Minnesota Geologic Survey County Atlas Series C-06, 9 pls., scale 1:100,000.

Lucas, L.L., and Unterweger, M.P., 2000, Comprehensive review and critical evaluation of the half-life of tritium: Journal of Research of the National Institute of Standards and Technology, v. 105, no. 4, p. 541.

Minnesota DNR, 2016, Procedure for determining buried aquifer and bedrock surface pollution sensitivity based on cumulative fine-grained sediment (CFGS) thickness: St. Paul, Minnesota Department of Natural Resources, Procedure GW-02, accessible at http://files.dnr.state.mn.us/waters/groundwater_section/mapping/gw/gw02_report.pdf.

Olsen, B.M., and Hobbs, H.C., 1988, Sensitivity of the ground-water system to pollution, pl. 6 *in* Geologic atlas of Olmsted County, Minnesota: St. Paul, Minnesota, Minnesota Geologic Survey County Atlas Series C-03, 9 pls., scale 1:100,000.

Petersen, T.A., 2005, Sensitivity to pollution of the uppermost aquifers, pl. 10 *in* Geologic atlas of Wabasha County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-14, Part B, 3 pls., scale 1:100,000.

Petersen, T.A., 2013, Pollution sensitivity of the near-surface materials, buried sand and gravel aquifers, and the bedrock surface, pl. 9 *in* Geologic atlas of McLeod County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-20, Part B, 3 pls., scale 1:100,000.

Petersen, T.A., 2014, Pollution sensitivity of the near-surface materials, buried sand and gravel aquifers, and the bedrock surface, pl. 9 *in* Geologic atlas of Carver County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-21, Part B, 4 pls., scale 1:100,000.

Tipping, R.G., 2006, Subsurface recharge and surface infiltration, pl. 6 *in* Geologic atlas of Scott County, Minnesota: St. Paul, Minnesota Geologic Survey County Atlas Series C-17, 6 pls., scale 1:100,000.

Twiss, W.P., 1992, Sensitivity of the Prairie du Chien–Jordan aquifer to pollution, pl. 9 *in* Geologic atlas of Ramsey County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-7, Part A, 10 pls., scale 1:48,000.

Zhang, H. and Falteisek, J., 1996, Sensitivity of the St. Peter–Prairie du Chien–Jordan aquifer to pollution, pl. 7 *in* Geologic atlas of Fillmore County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-08, Part B, 4 pls., scale 1:100,000.

# Glossary

**aquifer—**an underground layer of water-bearing permeable rock or unconsolidated materials (gravel and sand) from which groundwater can be extracted using a water well.

**aquitard (or confining layers)—**made up of materials with low permeability, such as layers of clay and shale, which prevent any rapid or significant movement of water.

**basalt—**a dark, fine-grained volcanic rock that sometimes displays a columnar structure. It is typically composed largely of the minerals plagioclase with pyroxene and olivine.

**bedrock—**the consolidated rock underlying unconsolidated surface materials such as soil or glacial sediment.

**buried aquifer—**a volume of porous and permeable sediment, either sand or gravel or a mixture of sand and gravel, which is buried beneath the ground surface by an impermeable or low permeable layer. Buried aquifers are typically, but not always, under confined conditions.

**carbon-14 ($^{14}C$)—**a radioactive isot¬¬ope of carbon with a nucleus containing 6 protons and 8 neutrons. Its presence and gradual decay in organic materials is the basis of the radiocarbon dating method (half-life of 5,730 years).

**confining unit—**hydrogeologic unit of impermeable or distinctly less permeable material bounding one or more other units.

**County Well Index (CWI) / Minnesota Well Index (MWI)** —a database developed and maintained by the Minnesota Department of Health and Minnesota Geological Survey containing basic information, such as location, depth, and static water level, for wells drilled in Minnesota. The database contains construction and geological information from the well record (well log) for many wells. The website also provides mapping of wells onto aerial photos, allowing users to visually identify well locations (http://www.health.state.mn.us/divs/eh/cwi/index.html). The name was changed to Minnesota Well Index in 2015.

**dolostone, or dolomite rock—**a sedimentary carbonate rock that contains a high percentage of the mineral dolomite. Most dolostone formed as a magnesium replacement of limestone or lime mud prior to lithification. It is resistant to erosion and can either contain bedded layers or be unbedded. It is less soluble than limestone in weakly acidic groundwater, but it can still develop solution features over time.

**formation—**formally defined and fundamental unit of lithostratigraphy. A formation consists of a certain number of rock strata that have a comparable lithology, facies or other similar properties.

**glacial—**of, relating to, or derived from a glacier.

**groundwater—**water that collects or flows beneath the earth's surface, filling the porous spaces in soil, sediment, and rocks.

**hydrogeology—**the study of subsurface water, including its physical and chemical properties, geologic environment, role in geologic processes, natural movement, recovery, contamination, and utilization.

**infiltration—**the movement of water from the surface of the land into the subsurface under unsaturated conditions in the vadose zone.

**karst—**a landscape-scale hydrologic system formed in soluble bedrock. Water chemically and mechanically enlarges passages resulting in integrated conduits through which it can then travel rapidly, at speeds of up to several miles per day. Certain bedrock layers are more prone to karst formation and the resulting aquifers are called karst systems.

**limestone—**a hard sedimentary rock, composed mainly of the mineral calcium carbonate.

**nitrate—**a polyatomic ion with the molecular formula $NO_3^-$. Nitrates are primarily derived from fertilizer. Humans are subject to nitrate toxicity, with infants being especially vulnerable to methemoglobinemia, also known as blue baby syndrome. Excess nitrate concentrations in aquatic systems from agricultural runoff may lead to increased algae blooms. When excess algae die they use up oxygen as they decompose depleting oxygen and creating dead zones.

**Quaternary—**denoting the most recent period in the Cenozoic era, comprising the Pleistocene and Holocene epochs (and thus including the present).

**recharge—**the process by which water enters the groundwater system.

**sandstone—**sedimentary rock consisting of sand or quartz grains cemented together, typically red, yellow, white, or brown in color.

**sensitivity, sensitive area—**a geographic area characterized by natural features where there is significant risk of groundwater degradation from activities conducted at or near the land surface.

**shale—**soft, finely stratified sedimentary rock that formed from consolidated mud or clay and can be split easily into fragile slabs.

**sinkhole—** a closed depression with internal drainage underlain by soluble bedrock, ranging in diameter from a few meters to a kilometer and in depth from a less than one to several hundred meters.

**stratigraphy—**a branch of geology which studies rock layers and layering (stratification). It is primarily used in the study of sedimentary and layered volcanic rocks, the order and relative position of strata and their relationship to the geological time scale. Also used to refer to the sequence of rock layers in a region.

**till—**unsorted glacial sediment derived from the subglacial erosion and entrainment of rock and sediment over which the glacier has passed and deposited directly by ice. It is no longer till if it has been modified or redeposited.

**tritium ($^3$H)—**a radioactive isotope of hydrogen. The nucleus of tritium contains one proton and two neutrons.

**unconfined—**refers to an aquifer which has a water table and implies direct contact of the water table with the atmosphere through an unsaturated layer.

**vadose zone—**also termed the unsaturated zone, the layer between the land surface and the top of the water table. Water in the vadose zone has a pressure head less than atmospheric pressure, and is retained by a combination of adhesion and capillary action.

**water table—**a surface at or near the top of the phreatic zone (zone of saturation) where the fluid pressure is equal to atmospheric pressure.

# Appendix A: Geographic Information System Analysis

The file geodatabase, *BedrockSurface_PollutionSensitivity.gdb*, contains the statewide feature class of the pollution sensitivity of the bedrock surface. The counties used to create the statewide feature class can be found on their respective County Geologic Atlas Program page (http://www.dnr.state.mn.us/waters/groundwater_section/mapping/status.html).

**Table 7. Original County Geologic Atlas' spatial data files for the bedrock surface pollution sensitivity**

The legacy data of Hennepin and Washington counties is not available in a GIS format; however, their atlases are currently being updated. Counties that are in progress will be added once they are published.

| County | Atlas | Original CGA shapefile | Author Agency |
|---|---|---|---|
| Olmsted | C-03 | sensitivity | MGS; digitized by Olmsted County |
| Dakota | C-06 | sensitiv | MGS |
| Ramsey | C-07 | psopcj83 | MGS and Ramsey Soil and Water Conservation District |
| Fillmore | C-08 | gwsl3py | DNR |
| Rice | C-09 | gwsl3py | DNR |
| Mower | C-11 | gwslpy | DNR |
| Goodhue | C-12 | gwslpy | DNR |
| Pine | C-13 | gwslpy | DNR |
| Wabasha | C-14 | gwslpy | DNR |
| Scott | C-17 | bdr_ttrv1 | MGS |
| Carlton | C-19 | aqbdsnpy | DNR |
| McLeod | C-20 | aqbdsnpy | DNR |
| Carver | C-21 | aqbdsnpy | DNR |
| Chisago | C-22 | aqbdsnpy | DNR |
| Sibley | C-24 | aqbdsnpy | DNR |
| Nicollet | C-25 | aqbdsnpy | DNR |
| Blue Earth | C-26 | aqbdsnpy | DNR |
| Anoka | C-27 | aqbdsnpy | DNR |
| Renville | C-28 | aqbdsnpy | DNR |

All maps were kept at their original 1:100,000 scale and unioned after applying a standardized rating system (Table 8). The original fields that held the value of the sensitivity rating (i.e., SENS in Mower, SENSRATING in Fillmore, and DESCRIPTIO in Goodhue) had the value transferred into the ORG_RATING field, preserving it for cross referencing while presenting a simplified end product.

The RATING field was populated using the Select by Attribute function from ORG_RATING field and converting the values into the unified code (Table 8). An example of the process for Goodhue is the transfer of the original data from field DESCRIPTIO= high to a new standard field ORG_RATING= high and then converting to the new unified field RATING= H.

**Table 8. Field attributes assigned to CGA data in order to update atlases with a unified code**

| Name | Type | Definition | Length | Example |
|---|---|---|---|---|
| ATLAS | Text | CGA series identifier | 6 | C-12 |
| COUN | Short Integer | County number | n/a | 25 |
| CTY_NAME | Text | County name | 20 | Goodhue |
| ORG_RATING | Text | Rating given in the original map and spatial data | 6 | High |
| RATING | Text | Sensitivity rating created to unify the compilation | 2 | H |

The only exception to this procedure was for Olmsted and Dakota counties, where the original authors at the Minnesota Geological Survey created seven rating classes. These classes were converted to the new sensitivity values (Table 9).

**Table 9. Sensitivity ratings for the top of bedrock surface in the Olmsted and Dakota County Geologic Atlases**
The updates for the statewide atlas compilation series definition of sensitivity ratings are highlighted in the table.

| Olmsted CGA (1988) and Dakota CGA (1990) | Pollution Sensitivity of the Bedrock Surface (2015) |
|---|---|
| Very High: Hours to months | Very High: Hours to months |
| High: Weeks to years | High: Weeks to years |
| High-Moderate: Years to decade | Moderate: Years to decades |
| Moderate: Several years to decades | Moderate: Years to decades |
| Low-Moderate: Several decades | Low: Decades to a century |
| Low: Several decades to a century | Low: Decades to a century |
| Very Low: More than a century | Very Low: A century or more |

Values like “water”, “none”, and “NR” in the original rating field were transferred into the field ORG_RATING, but they represent nonstandard attribute values. When converting to the unified code the field was kept blank, resulting in a Null value and therefore no assigned sensitivity rating in the MHA.

Areas where the pollution sensitivity was not representative of the bedrock surface were omitted from the map. For example, in Goodhue County a pollution sensitivity map was prepared for the uppermost bedrock aquifer. However, there are areas of the county where the top of the bedrock surface is not the bedrock aquifer. To account for this, the bedrock units of the original map that were not the bedrock surface were selected and used to remove portions of the original pollution bedrock sensitivity map to show only the pollution sensitivity of the bedrock surface.

Once the values for RATING were assigned under the unified coding, the *Union* function was used to create the final feature class *bedrocksurface_pollutionsensitivity*. A layer file (bsPS_final.lyr) of the rating codes was created with uniform symbology that can be used for either the individual county or the state scale.

The *bedrocksurface_pollutionsensitivity* feature class and layer file (bsPS_final.lyr), along with the metadata can be found online at http://www.dnr.state.mn.us/waters/programs/gw_section/mapping/platesum/mha_ps-bs.html.

This page intentionally left blank.

This page intentionally left blank.

**Recommended Citation**

Adams, R., 2015, Pollution Sensitivity of the Bedrock Surface: Minnesota Department of Natural Resources, Minnesota Hydrogeology Atlas Series HG-01, report, plate, gis, http://www.dnr.state.mn.us/waters/programs/gw_section/mapping/platesum/mha_ps-bs.html

**Link to supporting atlases:**

County Geologic Atlas Series
http://www.dnr.state.mn.us/waters/groundwater_section/mapping/status.html

MNDNR

**The DNR Information Center**

Minnesota Department of Natural Resources
Ecological and Water Resources Division
500 Lafayette Road
St. Paul, MN 55155-4025
For more information call 651-296-6157 or 888-646-6367
http://www.mndnr.gov/waters

This information is available in alternative format on request.

STATE OF MINNESOTA
DEPARTMENT OF NATURAL RESOURCES
ECOLOGICAL AND WATER RESOURCES DIVISION

Prepared and Published with the Support of the
MINNESOTA ENVIRONMENT AND NATURAL RESOURCES TRUST FUND and the CLEAN WATER, LAND AND LEGACY AMENDMENT



# Pollution Sensitivity of the Bedrock Surface

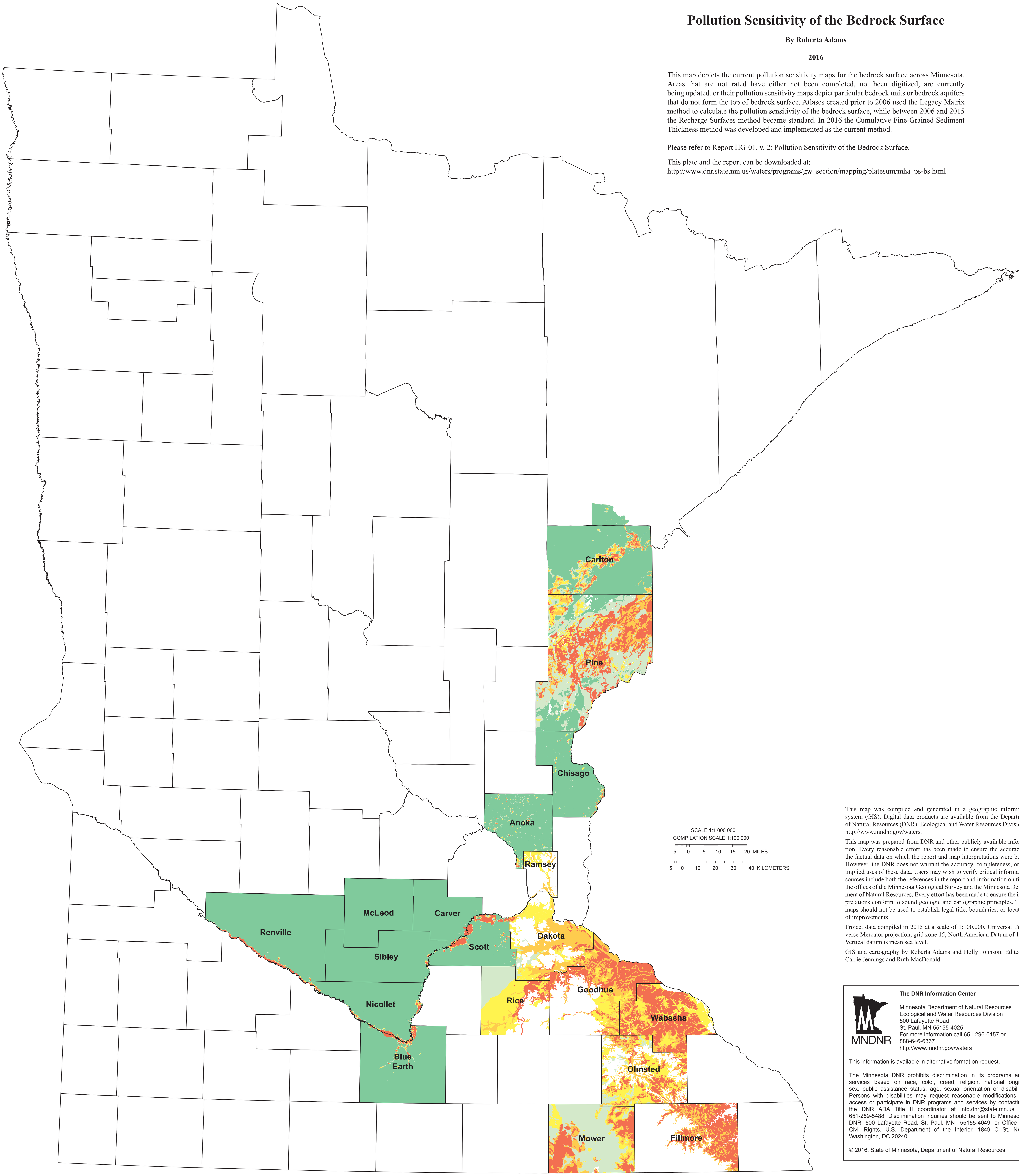
By Roberta Adams

2016

This map depicts the current pollution sensitivity maps for the bedrock surface across Minnesota. Areas that are not rated have either not been completed, not been digitized, are currently being updated, or their pollution sensitivity maps depict particular bedrock units or bedrock aquifers that do not form the top of bedrock surface. Atlases created prior to 2006 used the Legacy Matrix method to calculate the pollution sensitivity of the bedrock surface, while between 2006 and 2015 the Recharge Surfaces method became standard. In 2016 the Cumulative Fine-Grained Sediment Thickness method was developed and implemented as the current method.

Please refer to Report HG-01, v. 2: Pollution Sensitivity of the Bedrock Surface.

This plate and the report can be downloaded at:
http://www.dnr.state.mn.us/waters/programs/gw_section/mapping/platesum/mha_ps-bs.html




SCALE 1:1 000 000
COMPILATION SCALE 1:100 000
5 0 5 10 15 20 MILES
5 0 10 20 30 40 KILOMETERS

This map was compiled and generated in a geographic information system (GIS). Digital data products are available from the Department of Natural Resources (DNR), Ecological and Water Resources Division at http://www.mndnr.gov/waters.

This map was prepared from DNR and other publicly available information. Every reasonable effort has been made to ensure the accuracy of the factual data on which the report and map interpretations were based. However, the DNR does not warrant the accuracy, completeness, or any implied uses of these data. Users may wish to verify critical information; sources include both the references in the report and information on file in the offices of the Minnesota Geological Survey and the Minnesota Department of Natural Resources. Every effort has been made to ensure the interpretations conform to sound geologic and cartographic principles. These maps should not be used to establish legal title, boundaries, or locations of improvements.

Project data compiled in 2015 at a scale of 1:100,000. Universal Transverse Mercator projection, grid zone 15, North American Datum of 1983. Vertical datum is mean sea level.

GIS and cartography by Roberta Adams and Holly Johnson. Edited by Carrie Jennings and Ruth MacDonald.

**The DNR Information Center**

MNDNR

Minnesota Department of Natural Resources
Ecological and Water Resources Division
500 Lafayette Road
St. Paul, MN 55155-4025
For more information call 651-296-6157 or 888-646-6367
http://www.mndnr.gov/waters