

# **Nitrate-Nitrogen Probability Map - Water Table Aquifer**

## **Dodge County**

**Minnesota Department of Health**  
Environmental Health Division  
Source Water Protection Unit

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# Nitrate-Nitrogen Probability Ranking Map for the Water Table Aquifer, Dodge County, Minnesota

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## Introduction

To assist with state and local water quality planning efforts and support a nitrate occurrence study (Southeast Minnesota Water Resources Board, 2009), the Minnesota Department of Health (MDH) Source Water Protection Unit developed nitrate-nitrogen (nitrate) probability ranking maps for the water table aquifer beneath eleven southeastern Minnesota counties, including Dodge (Figure 1). The nitrate probability ranking map identifies areas of the water table aquifer with relatively high, moderate, and low sensitivity to contaminant sources, including nitrate. Such maps are useful for wellhead protection and other water planning efforts.

According to the Guidance for Mapping Nitrates in Minnesota Groundwater (MDH, 1998), nitrate concentrations less than 1 mg-L<sup>-1</sup> are primarily due to natural processes. Nitrate concentrations in the range of 1-3 mg-L<sup>-1</sup> are transitional and may or may not represent anthropogenic (human-caused) nitrate sources. Nitrate concentrations in the range of 3 to less than 10 mg-L<sup>-1</sup> are elevated and may originate from human activities. Nitrate concentrations greater than 10 mg-L<sup>-1</sup> exceed the state and federal drinking water standards.

## Map Assembly

Map assembly followed Level 2 mapping methods outlined in the nitrate mapping guidance (MDH, 1998), combining nitrate loading estimated from land use data with hydrogeologic sensitivity to generate nitrate probability rankings. The MDH Source Water Protection Unit defines hydrogeologic sensitivity as the likelihood that an aquifer will remain isolated from contaminants due to intrinsic physical attributes of the geologic setting or geomorphology.

The mapping procedure is illustrated in Figure 2. Hydrogeologic sensitivity was ranked from low to very high based upon the permeability of geologic materials (surficial geology, soil parent material type and bedrock type) and land slope. Nitrate loading to the subsurface was estimated by reclassification of land use data. Adding the two derived maps in raster form simulated nitrate released to the water table aquifer, and produced the nitrate probability ranking map for the water table aquifer.

## Base Maps

Base maps contain the background data required for initiating derived (interpreted) maps. The base maps used to generate the nitrate probability ranking map for the water table aquifer in Dodge County are listed in Table 1.

**Table 1: Base Maps for Dodge County Nitrate Probability Ranking**

Figure No.	Map Name	Source	File Type	Comment
3	Land Use	2009 CDL, 2001 NLCD	Raster	
4	Land Slope	Dodge County Soil Survey	Vector	Minimum/maximum land slopes
5	Surficial Geology	MGS Miscellaneous Series Maps	Vector	Includes loess coverage from county soil survey
6	Bedrock Geology	K319 Mapping	Vector	

*Figure 3: Land Use.* The source for the land use base data was the 2009 Cropland Data Layer (National Agricultural Statistics Service, 2009), which contains the most recent information on over 40 crop types throughout Dodge County. In urban areas, this dataset incorporates the 2001 National Land Cover Dataset raster dataset (MRLC Regional Team, 2001) that the United States Geological Survey compiled from Landsat satellite thematic mapper imagery. Land use categories are listed in Appendix 1.

*Figure 4: Land Slope.* The Dodge County Soil Survey (Cowles, et al., 1961) shapefiles include a text field (MUNAME) indicating minimum and maximum land slope for each soil. MDH created two new numeric fields (MIN\_SLOPE and MAX\_SLOPE), extracted the slope information, and exported polygon shapefiles defining slopes in the following two categories: 1) moderate slopes of at least 6% and at most 12%; or 2) steep slopes greater than 12%.

*Figure 5: Surficial Geology.* The Minnesota Geological Survey prepared surficial geology base maps with the support of the United States Geological Survey as a part of the state geologic mapping program element (Statemap) of the National Geologic Mapping Program (Hobbs, 2000; Lusardi, Hobbs and Patterson, 2002; Hobbs, 2005). These base maps provide surficial geologic base data for all but the southwestern corner of Dodge County, where the Dodge County Soil Survey (Cowles, 1961; parent material group) provides surficial geologic base data. Figure 5 also shows the extent of wind-blown silt (loess), as mapped in the Dodge County Soil Survey (Cowles, 1961).

*Figure 6: Bedrock Geology.* The Minnesota Geological Survey generated the bedrock geology base map for the K319 coverage (Tipping and others, 2004). It was developed in support of the U.S. Environmental Protection Agency 319 Demonstration Project, “Contaminant Management in the Karst Region.” The dataset was generated in conjunction with the development of a state karst features database and enhanced the karst feature inventory of Steele, Dodge, Olmsted and Winona Counties.

## Derived Maps

The derived maps generated by MDH are potential nitrate loading estimated from land use (Figure 7), hydrogeologic sensitivity of the water table aquifer (Figure 8), and nitrate probability ranking for the water table aquifer (Figure 1); these maps are listed in Table 2.

**Table 2: Derived Maps for Dodge County Nitrate Probability Ranking**

Figure No.	Map Name	File Type
1	Nitrate Probability Ranking, Water Table Aquifer	Raster
7	Nitrate Loading Estimated From Land Use	Raster
8	Hydrogeologic Sensitivity of the Water Table Aquifer	Vector converted to raster

*Figure 1: Nitrate Probability Ranking for the Water Table Aquifer.* The map was calculated by summing estimated nitrate loading (Figure 7) and hydrogeologic sensitivity (Figure 8). The resulting raster dataset was keyed as follows: low nitrate probability (2-4 points); moderate nitrate probability (5-6 points); high nitrate probability (7-9 points).

*Figure 7: Nitrate Loading Estimated From Land Use.* Cells of the rasterized land use base map (Figure 3) were reclassified according to minimum estimates of relative nitrate input for different land uses (Puckett and Cowdery, 2002; staff from MDH and MDA, per communication, 2011). The reclassified value of each cell was determined according to the base map land use category, as shown in Appendix 1.

Figure 8: *Hydrogeologic Sensitivity of the Water Table Aquifer*. Land slope (Figure 4), surficial geology and loess (Figure 5), and bedrock geology (Figure 6) were the datasets used to generate the hydrogeologic sensitivity of the water table aquifer (Figure 8). Areas were ranked as low, moderate, high, or very high hydrogeologic sensitivity based on permeability of near-surface geologic materials and land slope.

- **LOW** (1 point) was assigned to areas 1) covered by geologic materials primarily composed of clay or shale close to the surface, or 2) where land slopes were greater than 12% (regardless of underlying geologic materials).
- **MODERATE** (2 points) was assigned to areas not already assigned LOW, and underlain by modified clay till (clay plus a significant sand or gravel fraction). MODERATE was also assigned where land slopes were at least 6% and at most 12% (regardless of the rank of underlying geologic materials, except that material already ranked LOW remained LOW).
- **HIGH** (3 points) was assigned to areas not already assigned LOW or MODERATE, and underlain by unconsolidated sands and gravels. HIGH was also assigned to areas where limestone, dolomite, or sandstone were close to the surface and covered by loess.
- **VERY HIGH** (4 points) was assigned to areas not already assigned LOW, MODERATE or HIGH, where loess was absent, and shallow bedrock was limestone, dolomite, or sandstone.

## Discussion and Conclusions

*General Description of Nitrate Probability Rankings.* Estimated nitrate loading is moderately-high to high across Dodge County (Figure 7), leading to generally moderate nitrate probability rankings even where clay till is present (Figures 5 and 8). Along the western boundary, the southeastern corner, and the northwestern corner of the county, unconsolidated materials are more permeable (outwash or alluvium; Figure 5) or bedrock is close to the surface (Figure 6), leading to high nitrate probability rankings. The lowest nitrate probability rankings occur in wooded areas along rivers where nitrate loading is least.

**Table 3: Area and Percentage of Dodge County in Nitrate Probability Rank**

<i>Nitrate Probability Ranking</i>	<i>Area (mi<sup>2</sup>)</i>	<i>Percent of Total County Area</i>
High	73.1	16.8
Moderate	267.9	61.6
Low	94.0	21.6
<b>Totals</b>	<b>435</b>	<b>100.0</b>

*Comparing Results to Existing Nitrate Data.* The nitrate mapping guidance (MDH, 1998) uses point data (e.g., water level or nitrate concentration data from drinking water wells) to help evaluate the nitrate probability ranking maps. However, experience has shown that the distribution of data points (wells) is usually non-uniform and this prevents constructing consistent raster datasets of estimated water depth. Therefore, existing nitrate datasets were not used in map assembly but were used to check map accuracy.

The data sources with existing nitrate data in water table aquifer drinking water supply wells include 1) MDH (public water supply monitoring data and new well construction water quality data) and 2) the Volunteer Nitrate Monitoring Network. Generally, wells with the highest nitrate concentrations occur in areas of the map ranked high or moderate. Wells with lower nitrate concentrations tend to occur anywhere because acceptable water quality may still occur where the nitrate probability ranking is high, even though they pump from the water table aquifer system.

*Map Limitations.* There are several aspects associated with the mapping approach that may impact results. First, the method accounts only for vertical migration of nitrate to the aquifer, and does not address horizontal migration within the aquifer. It may be possible to represent the effect of horizontal nitrate migration within the aquifer using groundwater flow modeling, but that has not been attempted here. Also, the approach described in this report does not account for geochemical controls on nitrate occurrence and, therefore, the results are conservative. Furthermore, maps have been smoothed to eliminate areas of less than 10 acres. The nitrate probability ranking map was constructed using a grid cell size of 56 meters by 56 meters, and is intended for use at an approximate scale of 1:100,000 (county-scale). However, the methodology could be used at other scales if sufficient supporting data are available.

In hydrogeochemical studies, nitrate is commonly used as an indicator of environments susceptible to contamination. However, special conditions related to well construction and not overall aquifer geochemistry may also cause elevated nitrate, and the nitrate probability ranking maps do not address such localized well problems. The special conditions not addressed by the nitrate probability mapping are:

- Surface water drainage into the well;
- Improper well construction (does not meet State Well Code);
- Proximity to a pollution source, such as an old septic system, former outhouse, or a poorly constructed well that allows surface contamination to reach the water table.

The MDH mapping scheme differs from DNR (1991) in the following important ways:

- Water depth. The limitations of rasters generated from point datasets representing water table depth hinder sensitivity classifications based on water depth (e.g., DNR, 1991, page 55, Table VI-2).
- Nomenclature with respect to clay. The DNR scheme only assigns a “low” ranking if sediments are logged as “clay” or “shale” (no modifiers). In nitrate probability ranking, any logged “clay” is classified as clay (even if modified; e.g., “sandy clay,” “silty clay”). This is justified because waters in such low-permeability sediments are likely to be oxygen-depleted and denitrification in such settings is well documented.

*Map Applications.* Nitrate probability ranking maps have already been prepared for several Minnesota counties (<http://www.health.state.mn.us/divs/eh/water/swp/nitrate/nitratemaps.html>). The Dodge County nitrate probability map can help:

- Identify drinking water supply wells that may be at greatest risk to nitrate contamination.
- Prioritize community and nontransient/noncommunity public water supply systems for phasing into the wellhead protection program under state rule provisions.
- Inform communities about areas to avoid when siting new drinking water supply wells.
- Assist municipalities in managing potential nitrate sources.

- Identify areas susceptible to other contaminants commonly indicated by the presence of nitrate, such as volatile organic chemicals, pesticides, or pathogens.
- Identify where local wellhead protection plans or local efforts to evaluate water quality in private water supply wells must include monitoring groundwater for nitrate.
- Target educational programs for the owners of domestic drinking water wells.
- Select drinking water wells for use in evaluating trend analysis of nitrate levels.
- Assist in defining and prioritizing areas for implementing nitrate remediation practices.

## **Bibliography**

Cowles, D.A., et al., 1961, *Soil Survey of Dodge County, Minnesota*, Soil Survey, United States Department of Agriculture, Soil Conservation Service, Washington, D.C., 113 p., 24 sheets, scale 1:20,000.

Hobbs, Howard C., 2000, *Surficial Geology of the Rochester 30 X 60 Minute Quadrangle, Minnesota*, Miscellaneous Map series M-107, Minnesota Geological Survey, St. Paul, Minn., 1 plate, scale 1:100,000.

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MRLC Regional Team, 2001, *Minnesota National Land Cover Dataset (NLCD)*, United States Geological Survey, EROS Data Center.

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Puckett, Larry J., and Cowdery, Timothy K., 2002, *Transport and Fate of Nitrate in a Glacial Outwash Aquifer in Relation to Ground Water Age, Land Use Practices, and Redox Processes*, J. Environ. Qual. 31:782-796.

Southeast Minnesota Water Resources Board, 2009, *Section 319 Nonpoint Source Pollution Program Volunteer Nitrate Monitoring Network Final Report*, grant contract CFMS #B05788, Attachment 8b, MDH contribution to final report.

Tipping, R.G., J.H. Mossler, E.C. Alexander, Jr., Y. Gao, J. Green, and S.C. Alexander, 2004, *Bedrock Geology, Topography and Karst Feature Inventory of Steele, Dodge, Olmsted and Winona Counties*, Produced as part of a U.S. Environmental Protection Agency 319 Karst Demonstration Project. Minnesota Geological Survey Open File Report 07-07, <ftp://mgssun6.mngs.umn.edu/pub3/karst/karst319/>.

**Appendix 1:**

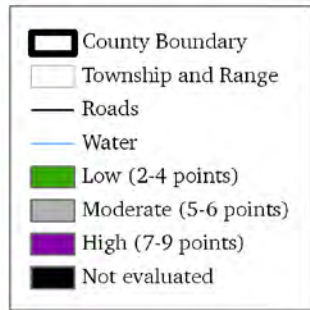
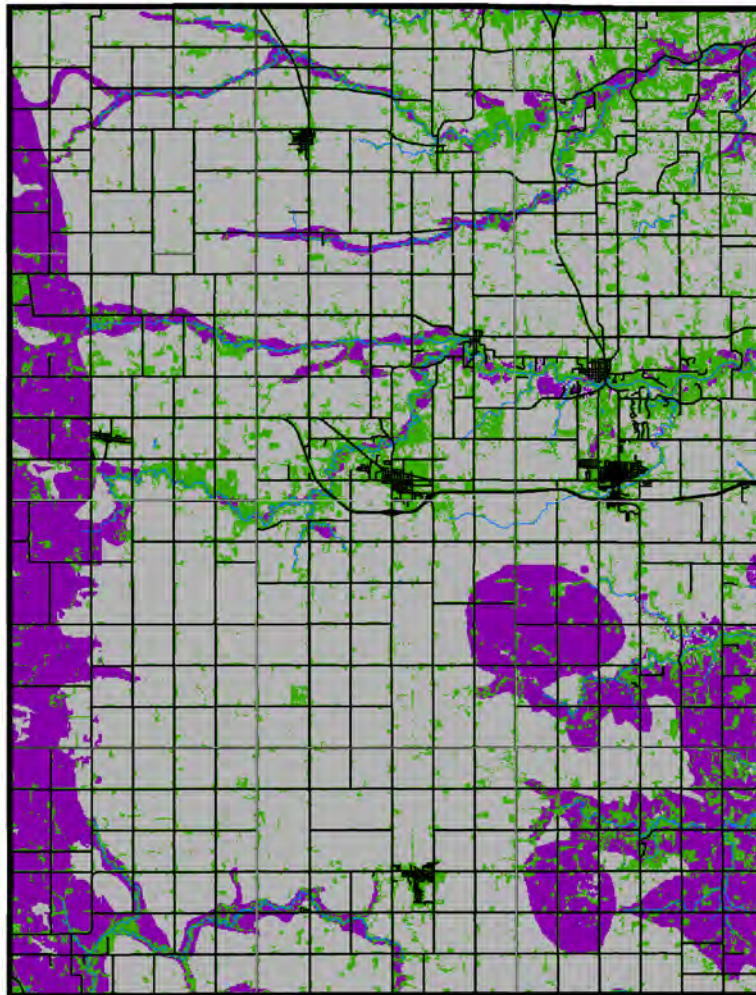
**Relative Nitrate Loading for 2009 CDL and 2001 NLCD Land Use Classifications**

<i>Relative Nitrate Loading (this report)</i>	<i>Land Use Class (this report)</i>	<i>Original 2001 NLCD Land Use Class</i>	<i>Includes 2009 CDL Land Use Classes</i>
1	Water	Open Water (11) Perennial ice/snow (12) Woody wetlands (90) Emergent herbaceous wetlands (95)	
	Forested	Deciduous (41) Evergreen (42) Mixed (43) Dwarf scrub (51) Scrub/shrub (52)	
	Perennial Developed	Grassland/herbaceous (71) Open space (21) Low intensity (22) Barren (31)	
2	Urban	Medium intensity (23) High intensity (24)	
4	Pasture/hay	Pasture/hay (81)	Alfalfa Clover/wildflowers Fallow/idle cropland Grass/pasture Herbs Other crops Other hays Rye Seed/sod grass
5	Row crops	Cultivated crops (82)	Barley Canola Corn Dry beans Durum wheat Flaxseed Millet Misc. vegetables/fruit Oats Other small grains Peas Potatoes Sorghum Soybeans Spring wheat Sugar beets Sunflowers Sweet corn Winter wheat

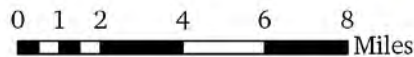


# Figure 1: Nitrate Probability Ranking Water Table Aquifer, Dodge County

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Nitrate probability ranking was determined by map addition (estimated nitrate loading from land use plus hydrogeologic sensitivity of the water table aquifer),

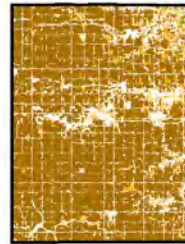


## Figure 2: Map Assembly

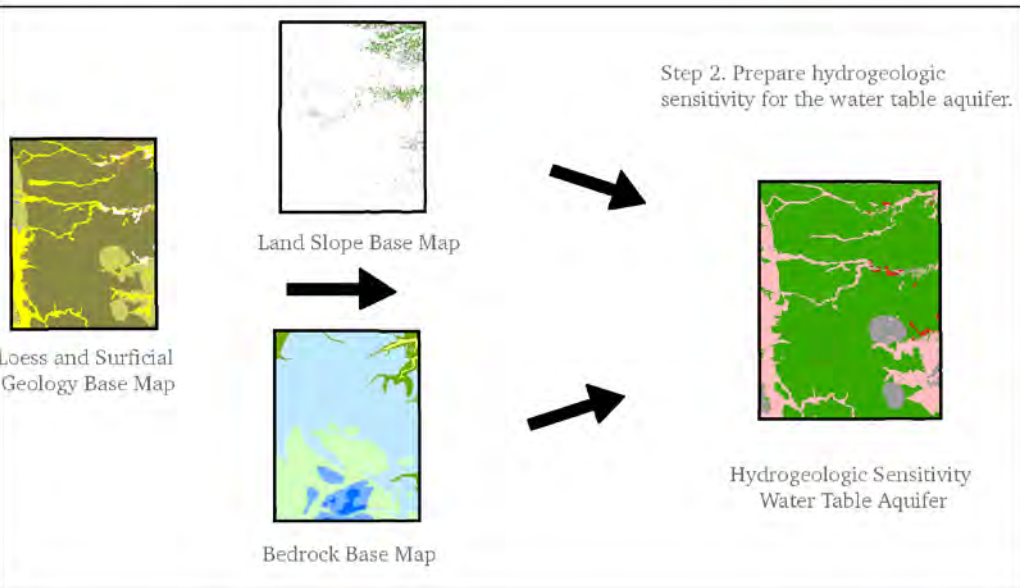
Step 1. Prepare nitrate loading estimate. Land use base map (left) shows 45 crop types and land uses. The reclassified land use map (right) supports the calculation of nitrate probability ranking (Step 3).



Land Use Base Map



Reclassified Land Use



Step 3. Determine nitrate probability ranking by adding estimated nitrate loading (Step 1) to hydrogeologic sensitivity of the water table (Step 2). The resulting map indicates areas of the water table aquifer most likely to receive nitrate (purple), and other areas (green) where elevated nitrate is unexpected.

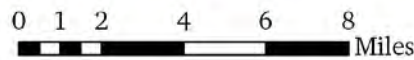
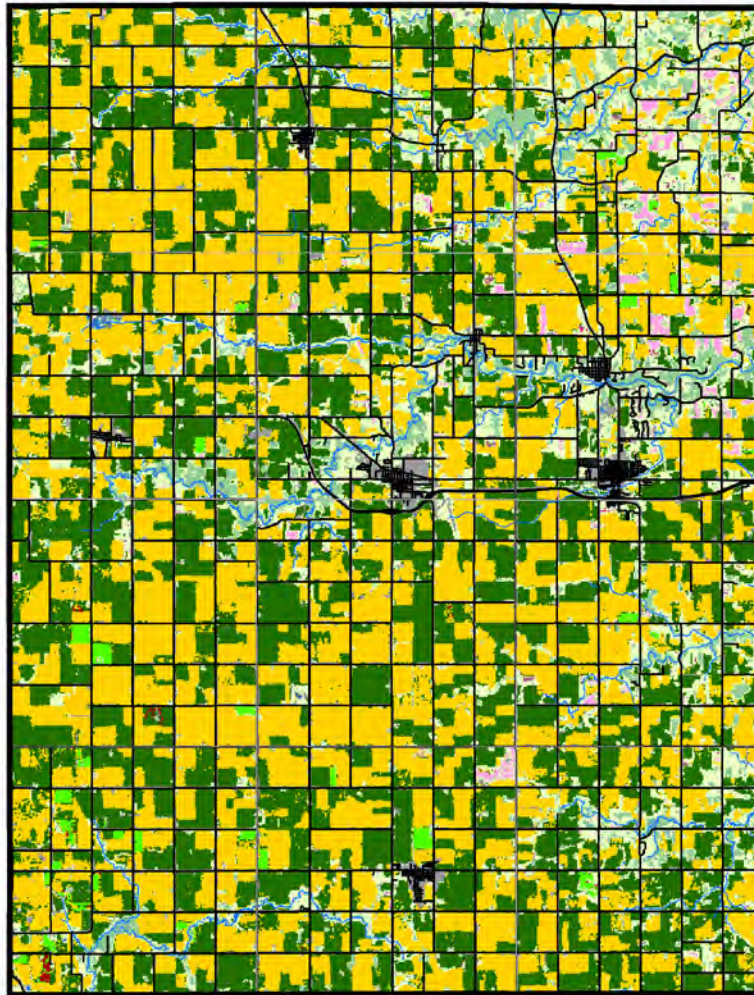


Nitrate Probability Ranking Water Table Aquifer



# Figure 3: Land Use Base Map, Dodge County

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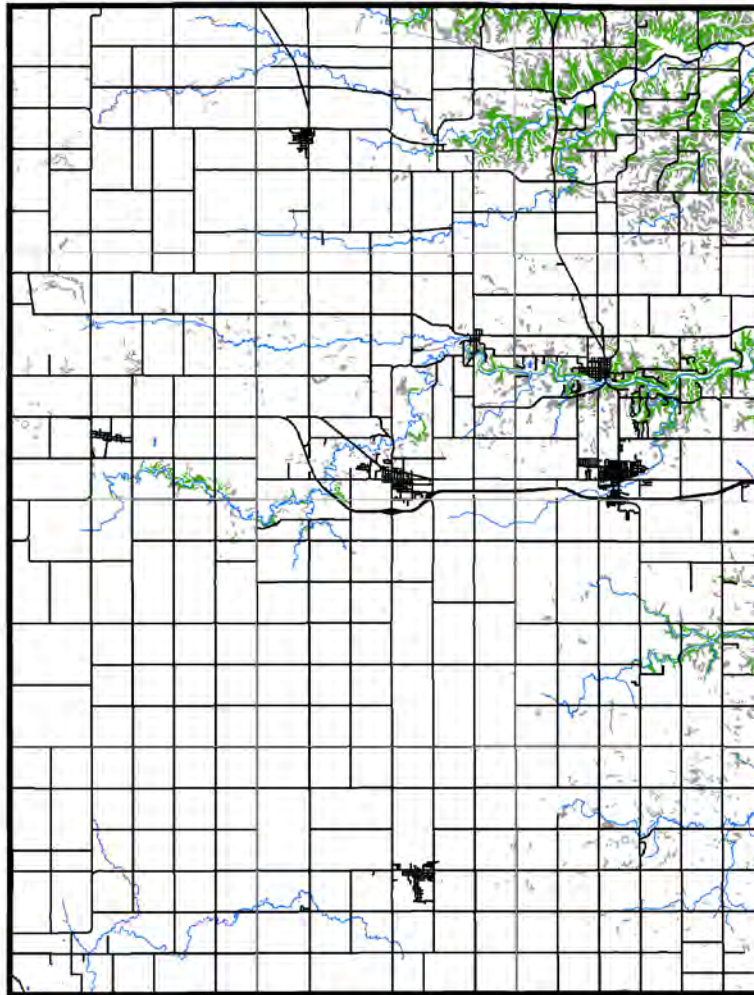


Data source: 2009 Cropland Data Layer (2001 NLCD data for urban areas).



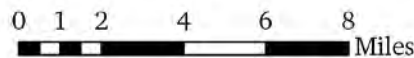
# Figure 4: Land Slope Base Map, Dodge County

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- County Boundary
- Township and Range
- Roads
- Water
- Steep slope ( $\geq 12\%$ )
- Moderate slope (6% to 12%)

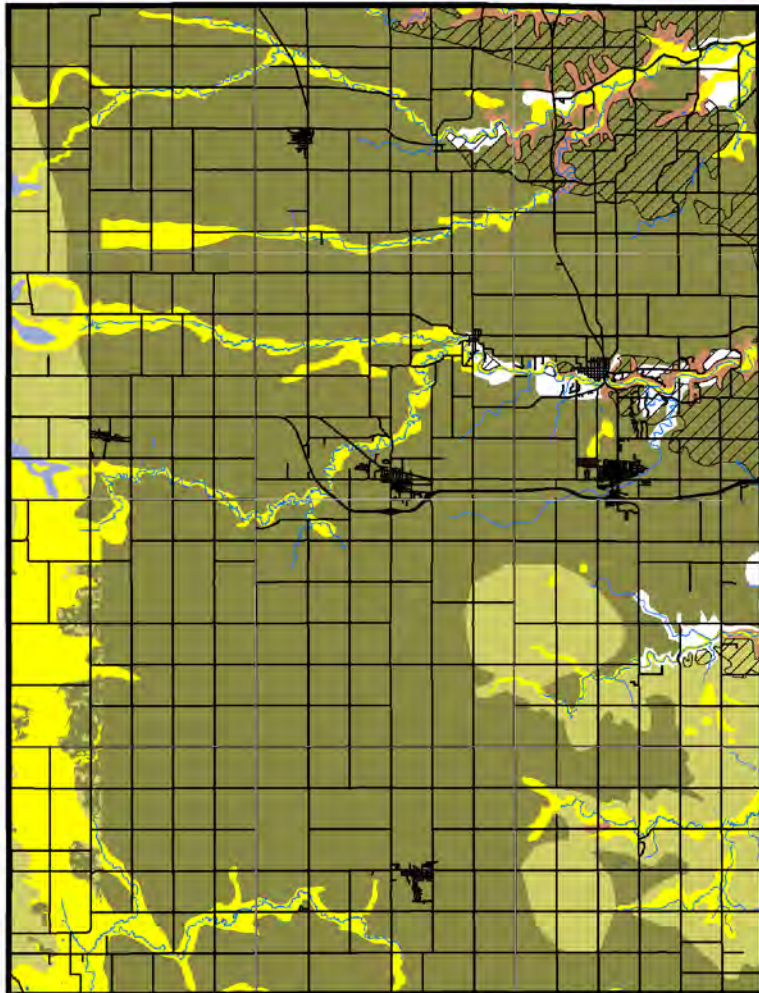
Information from Dodge County soil survey (field name = MUNAME). Areas with steepest slopes (minimum slope of 12%) receive a "LOW" hydrogeologic sensitivity rating. Areas with moderate slopes (minimum slope of 6%, maximum of 12%) receive a "MODERATE" hydrogeologic sensitivity rating (except if underlying geologic materials are already rated "LOW").
















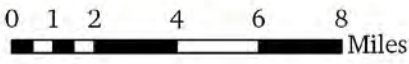
# Figure 5: Surficial Geology Base Map, Dodge County

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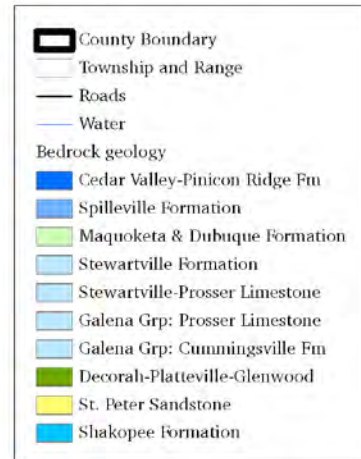
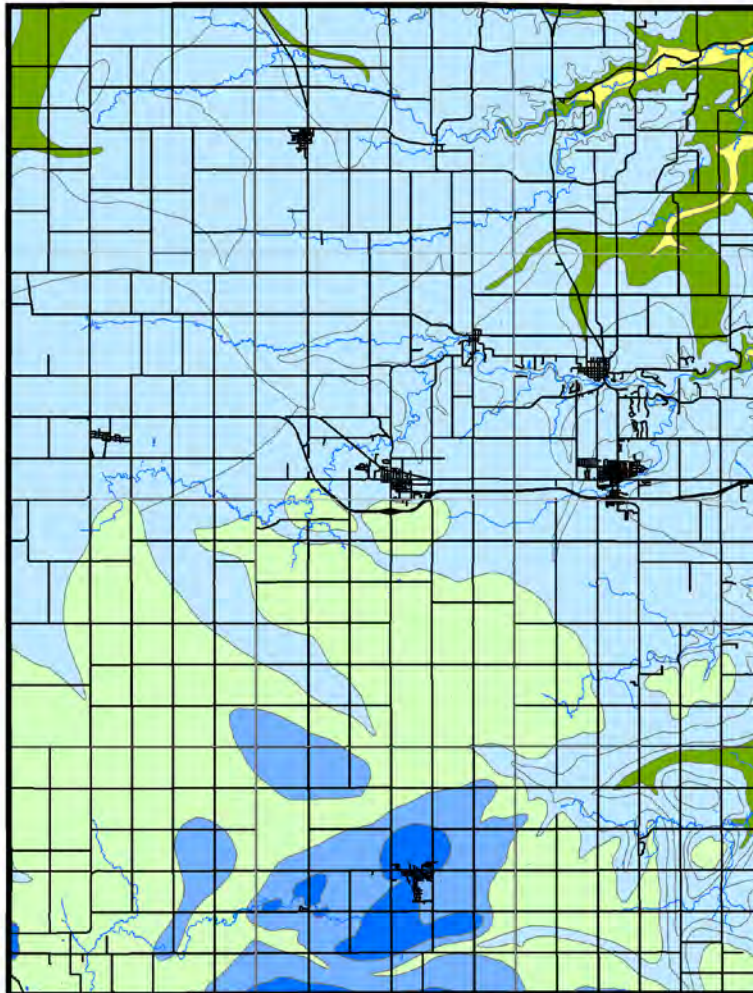
-  County Boundary
-  Township and Range
-  Roads
-  Water
-  Loess
-  Clay till
-  Mixed till
-  Organic desposit
-  Sands, gravel
-  Colluvium
-  Bedrock near surface

Information from Minnesota Geological Survey (Hobbs, 2000; Hobbs, 2005; Lusardi, Hobbs and Patterson, 2002; and Hobbs, 2005) and the Dodge County Soil Survey (Cowles, et al., 1961).

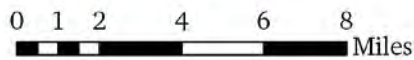


# Figure 6: Bedrock Geology Base Map, Dodge County

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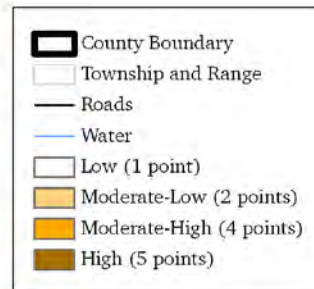
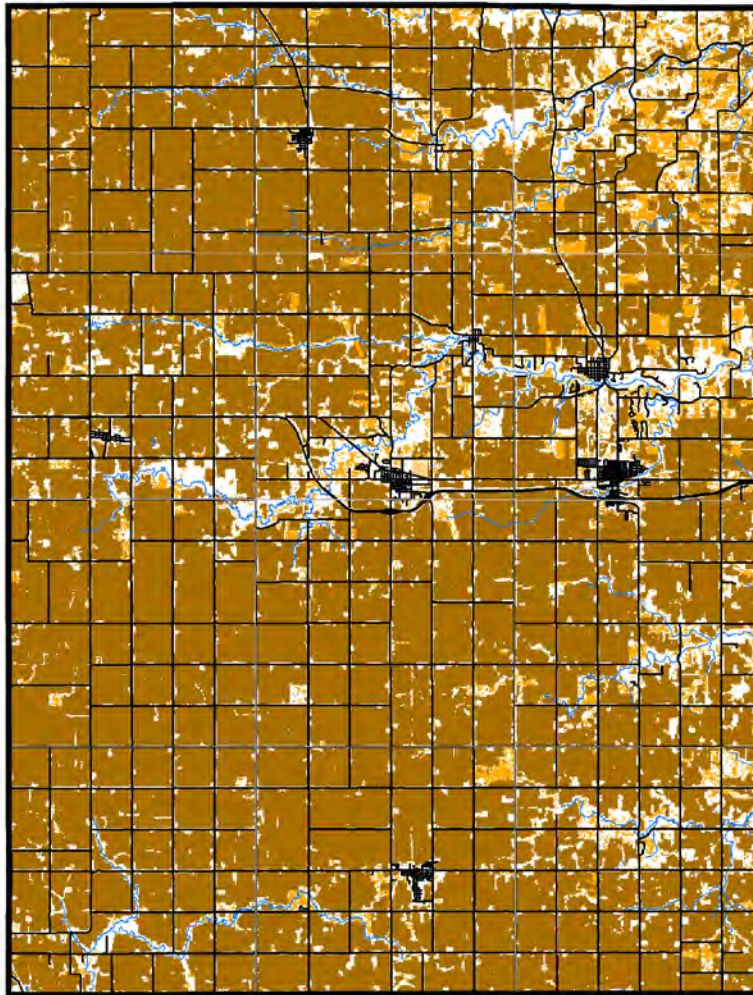
Information from Minnesota Geological Survey (K319 Bedrock Geology).



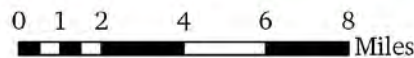


# Figure 7: Nitrate Loading Estimated From Land Use, Dodge County

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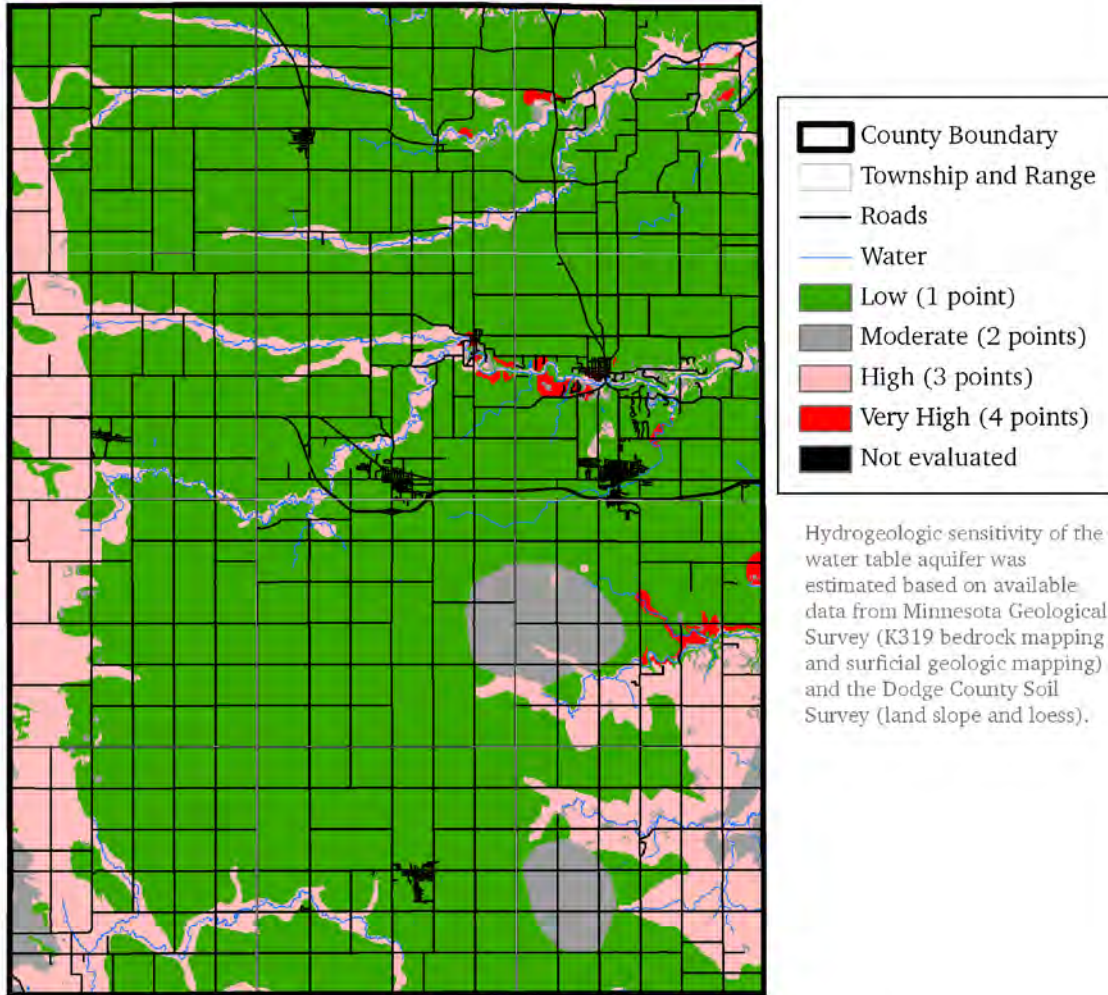


Nitrate loading was estimated for each land use, using Puckett and Cowdery (1999) and discussions with Minnesota Department of Agriculture as guidelines. General nitrate loading/land use categories included water, forested, developed land, pasture, and row crops. See Appendix 1 of the report for the detailed reclassification scheme.



# Figure 8: Hydrogeologic Sensitivity of the Water Table Aquifer, Dodge County

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0 1 2 4 6 8 Miles

