Nitrate-Nitrogen Risk Ranking Methods and Results

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Minnesota Department of Health
DRINKING WATER PROTECTION

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Contents

Introduction

To assist with state and local water quality planning efforts, the Minnesota Department of Health (MDH) Source Water Protection Unit developed a nitrate-nitrogen (nitrate) risk ranking raster dataset for the water table aquifer beneath central, south-central, and southeastern Minnesota (Figure 1). Nitrate risk ranking has been carried out at the county scale and identifies areas of the water table aquifer with relatively high, moderate, and low sensitivity to contaminant sources originating at the ground surface, 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^{-1} are primarily due to natural processes. Nitrate concentrations in the range of 1-3 mg-L^{-1} 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^{-1} are elevated and probably originate from human activities. Nitrate concentrations greater than 10 mg-L^{-1} exceed the state and federal drinking water standards.

The nitrate risk ranking raster datasets for currently available counties are posted on the MDH web site http://www.health.state.mn.us/divs/eh/water/swp/maps/index.htm. Within a geographic information system (GIS) environment, the raster dataset can be masked to the borders of any polygon shapefile, such as county or watershed boundaries. Supporting raster datasets are posted also, and these include nitrate loading estimated from land use, and hydrogeologic sensitivity of the water table aquifer. These three datasets are intended to be used at scales no greater than 1:100,000 (approximately county-scale).

Nitrate Risk Database Assembly

MDH developed the nitrate risk database following Level 2 mapping methods outlined in the nitrate mapping guidance (MDH, 1998). The Level 2 assessment combines nitrate loading estimated from land use data with hydrogeologic sensitivity, to generate nitrate risk rankings in raster format. 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 procedure is illustrated for an example county in Figure 2. Nitrate loading to the subsurface was estimated by reclassification of land use data (Figure 2, Step 1). 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) land slope, and the relationship between depth to water and depth to bedrock (Figure 2, Step 2). Adding the nitrate loading raster to the hydrogeologic sensitivity raster simulated nitrate released to the water table aquifer, and produced the nitrate risk ranking raster for the water table aquifer (Figure 2, Step 3).

Base Data and Base Maps

Base data and base maps contain the background information required for initiating interpreted map datasets. Base data for this project include the County Well Index (CWI). Base maps consist of surficial and bedrock geologic maps from the County Geologic Atlas Part A series produced by Minnesota Geological Survey, and county soil survey maps typically produced by the counties in coordination with the local office of the Soil Conservation Service (SCS) or Natural Resources Conservation Service (NRCS). Base data and base maps used to generate the nitrate risk map for the water table aquifer are listed in Table 1 and discussed below.

County Well Index

The Minnesota Geological Survey's (MGS) County Well Index geodatabase (CWI) contains well and boring records for Minnesota. The data is derived from water-well contractors' logs of geologic materials encountered during drilling, well construction, locations, and geologic interpretation by MGS staff. CWI information is available using the Minnesota Well Index (MWI) web application which accesses the MGS CWI geodatabase, located here (http://www.health.state.mn.us/divs/eh/cwi/index.html).

Land Use Base Map

The source of land use base data is the Cropland Data Layer (CDL; National Agricultural Statistics Service, 2009), which contains information on over 40 crop types throughout the region. In urban areas, this dataset incorporates the 2001 National Land Cover Dataset (NLCD) 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.

Land Slope

The source for the land slope data is the most recent county soil survey. In these base maps, 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 percent and at most 12 percent; or 2) steep slopes greater than 12 percent.

Surficial Geology Base Map

The source for the surficial geology base map is typically Plate 3 (Surficial Geology) of the County Geologic Atlas Part A produced by the Minnesota Geological Survey (MGS).

Bedrock Geology Base Map

The source for the bedrock geology base map is typically Plate 2 (Bedrock Geology) of the County Geologic Atlas Part A produced by the MGS.

Table 1. Base Data and Base Maps for Nitrate Risk Ranking

Base Map or Base Data	Source	File Type
County Well Index	Minnesota Geological Survey, University of Minnesota	Vector
Land Use	2009 CDL, 2001 NLCD	Raster
Land Slope	County Soil Survey	Vector
Surficial Geology	MGS County Geologic Atlas Plate 3 Surficial Geology	Vector
Bedrock Geology	MGS County Geologic Atlas Plate 2 Bedrock Geology	Vector

Interpreted Maps

The interpreted map datasets that MDH generated include: nitrate loading estimated from land use (Figure 3); hydrogeologic sensitivity of the water table aquifer (Figure 4); and nitrate risk ranking for the water table aquifer (Figure 1). These map datasets are listed in Table 2.

Figure 1. Nitrate Risk Ranking, Water Table Aquifer

The map dataset was calculated by summing Nitrate Loading estimated From Land Use (Figure 3) and Hydrogeologic Sensitivity of the Water Table Aquifer (Figure 4). The resulting raster dataset was keyed as follows: low nitrate risk (2-4 points); moderate nitrate risk (5-6 points); high nitrate risk (7-9 points).

Figure 3. Nitrate Loading Estimated From Land Use

Cells of the land use base map were reclassified according to minimum estimates of relative nitrate input for different land uses (Puckett and Cowdery, 2002; staff from MDH and Minnesota Department of Agriculture, personal communication, 2011). The reclassified value of each cell was determined according to the base map land use category, as shown in the left-most column ("Relative nitrate loading, this report") of the table in Appendix 1.

Figure 4. Hydrogeologic Sensitivity of the Water Table Aquifer

Data sets used to generate the hydrogeologic sensitivity raster for the water table aquifer were land slope, surficial geology, bedrock geology, and estimated depth to water. Raster cells were ranked as low, moderate, high, or very high hydrogeologic sensitivity based on permeability of near-surface geologic materials, whether the water table occurred in bedrock or unconsolidated materials, and land slope.

- <u>LOW</u> (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 percent (regardless of underlying geologic materials).
- <u>MODERATE</u> (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 percent and at most 12 percent (regardless of the rank of underlying geologic materials, except that material already ranked LOW remained LOW).
- <u>HIGH</u> (3 points) was assigned to areas not already assigned LOW or MODERATE, and underlain by unconsolidated sands or sandy mixtures. HIGH was also assigned to areas where limestone, dolomite, or sandstone were close to the surface and covered by loess.
- <u>VERY HIGH</u> (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. VERY HIGH was also assigned to gravelly areas, or gravelly-sand mixtures.

Table 2. Interpreted Map Datasets for Nitrate Risk Ranking

Figure	Map Name	File Type	Map Scale
Figure 1	Nitrate Risk Ranking, Water Table Aquifer	Raster	1:100,000
Figure 3	Nitrate Loading Estimated From Land Use	Raster	1:100,000
Figure 4	Hydrogeologic Sensitivity of the Water Table Aquifer	Raster	1:100,000

Discussion and Conclusions

Descriptions of Nitrate Risk Rankings for All Counties

Table 3 shows the percentages of the land area of each county that was categorized as having high, moderate or low nitrate risk to the water table aquifer. Appendix 2 contains paragraph descriptions of the nitrate risk ranking results (Figure 1) for each of the counties mapped using the 2009 CDL.

Table 3. Area and Percentage of Counties in Nitrate Risk Rank

County	% High	% Moderate	% Low	% Not Evaluated	Total area of county (mi^2)[1]
Anoka	19.4	24.6	51.6	4.4	422
Benton	67.3	13.7	17.9	1.1	404
Blue Earth	71.0	11.7	15.4	1.9	753
Carver	39.0	31.7	24.0	5.3	341
Crow Wing	11.8	56.2	17.3	14.7	1157

[1] Tabulated county areas are those reported in the county soil surveys.

County	% High	% Moderate	% Low	% Not Evaluated	Total area of county (mi^2)[1]
Dakota	44.9	20.2	32.2	2.7	576
Dodge	16.8	61.6	21.6	0	435
Fillmore	36.3	29.0	34.7	0	859
Goodhue	21.7	40.5	35.8	2.0	758
Hennepin	8.3	33.7	50.1	7.9	554
Houston	19.6	23.3	54.4	2.7	570
McLeod	63.1	20.6	13.7	2.6	253
Meeker	56.7	23.3	14.7	5.3	714
Morrison	47.0	26.4	24.3	2.3	1127
Mower	33.6	47.4	19.0	0	703
Nicollet	68.1	10.7	19.2	1.9	467
Olmsted	29.1	35.9	35.0	0	656
Pope	60.2	24.3	8.6	6.9	681
Ramsey	2.0	33.9	56.2	7.9	152
Renville	75.4	11.4	12.8	0.4	988
Rice	36.0	31.9	29.3	2.8	495
Scott	31.0	34.3	31.3	3.4	352
Sherburne	42.7	35.5	18.6	3.2	451

County	% High	% Moderate	% Low	% Not Evaluated	Total area of county (mi^2)[1]
Sibley	72.9	9.5	16.0	1.6	600
Stearns	53.2	28.0	15.4	3.4	1394
Steele	65.2	8.2	26.1	0.5	427
Todd	45.4	28.1	23.1	3.4	980
Wabasha	21.8	30.8	44.2	3.2	521
Washington	31.6	21.6	39.8	7.0	423
Winona	27.4	18.0	50.6	4.0	628
Wright	37.2	33.3	22.1	7.4	467

Nitrate Risk Ranking Dataset Accuracy

The nitrate mapping guidance (MDH, 1998) directs the use of point data (e.g., nitrate concentration data from drinking water wells) to develop the nitrate risk ranking dataset. However, experience has shown that the distribution of data points (wells) is usually non-uniform and too sparse to support construction of consistent raster datasets of nitrate occurrence. Therefore, existing nitrate datasets were not used to determine nitrate risk, but were used to check accuracy.

Data sources with existing nitrate data in water table aquifer drinking water supply wells include: 1) MDH public water supply compliance monitoring data; 2) MDH investigative data; and 3) MDH new well construction water quality data.

Using these data, the distribution of nitrate concentrations can be compared to the nitrate risk rank mapping results to show overall accuracy of the map. Generally, wells with the highest nitrate concentrations occur in areas of the map ranked high or moderate. Of all wells in locations where nitrate risk was ranked as “low” (2-4 points), only 0.4% had nitrate concentrations of 10 mg/L or greater. Wells with lower nitrate concentrations tend to occur anywhere because acceptable water quality may still occur where the nitrate risk ranking is high, even though pumping from the water table aquifer system.

Map Limitations

There are several aspects associated with the mapping approach that may affect 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, polygon shapefile base data (surficial and bedrock geology, and land slope) for the hydrogeologic sensitivity map dataset was smoothed to combine or eliminate polygons of less than 10 acres. Consistent with base data limitations, the nitrate risk ranking map dataset is intended for use at an approximate scale of 1:100,000 (county-scale). However, the methodology could be effective at other scales with appropriately-scaled supporting data.

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 risk ranking maps do not address such localized well problems. The special conditions not addressed by the nitrate risk 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 fundamental difference between the MDH geologic sensitivity mapping scheme and the approach discussed by Department of Natural Resource (DNR) (1991) centers on the use of geologic mapping units versus using specific well log descriptions associated with the term “clay.” The DNR scheme assigns vulnerability rankings to single boreholes, and only assigns a “low” ranking if sediments are logged as “clay” or “shale” with no modifiers such as “sandy” or “silty.” In contrast, MDH nitrate risk method is based on geologic mapping, which evaluates the overall composition of a sediment or bedrock type. Map polygons classified as “clay-rich” by the MGS are designated as protective. Furthermore, groundwater in aquifers beneath such low-permeability sediments is likely to be oxygen-depleted, and denitrification processes in such settings are well documented.

Map Applications

The nitrate risk map can help:

- Identify drinking water supply wells that may be at greatest risk to nitrate contamination.
- Prioritize community and non-transient non-community public water supply systems for phasing into the wellhead protection program under state rule provisions.

- Inform communities about general 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.

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Minnesota Department of Natural Resources (MDNR), 1991, *Criteria and guidelines for assessing geologic sensitivity of ground water resources in Minnesota,* Chapter VI: Level 2 Assessment—Vadose Zone Materials, pp. 45-61.

MRLC Regional Team, 2001, *Minnesota national land cover dataset (NLCD)*, United States Geological Survey, EROS Data Center.

National Agriculture Statistics Service, 2009, *Cropland data layer*.

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.

Appendices

Figures Depicting Map Assembly

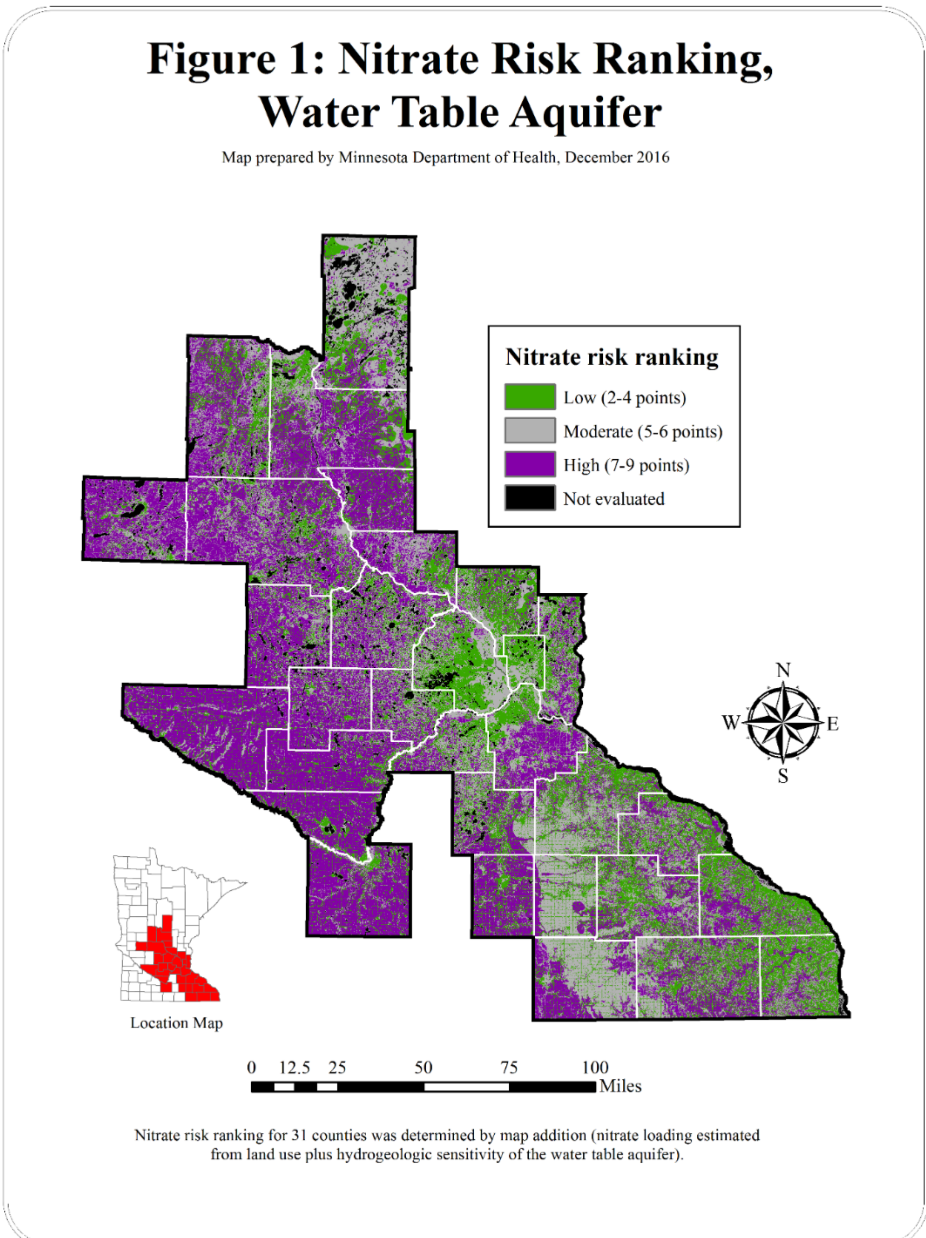


Figure 2: Map Assembly

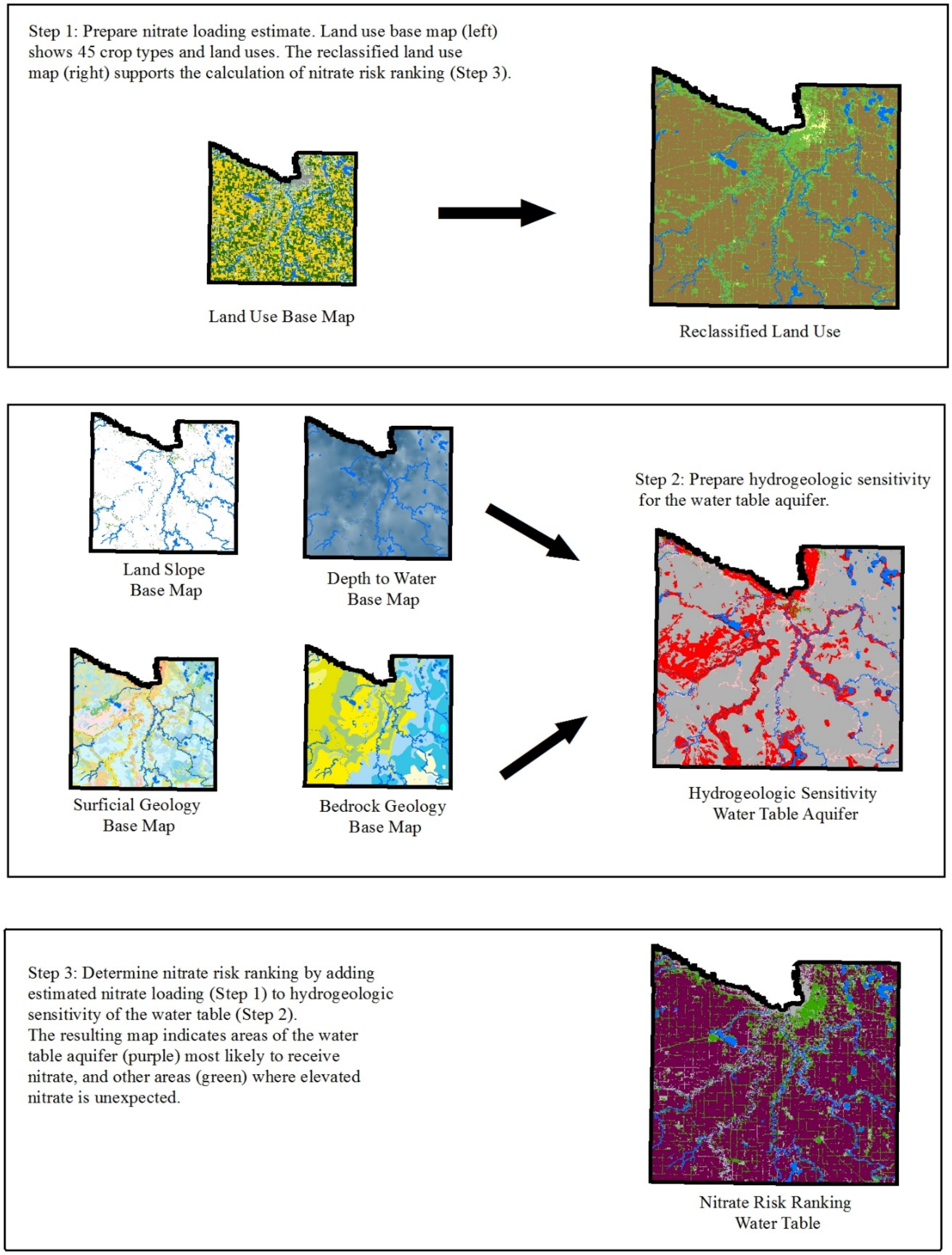
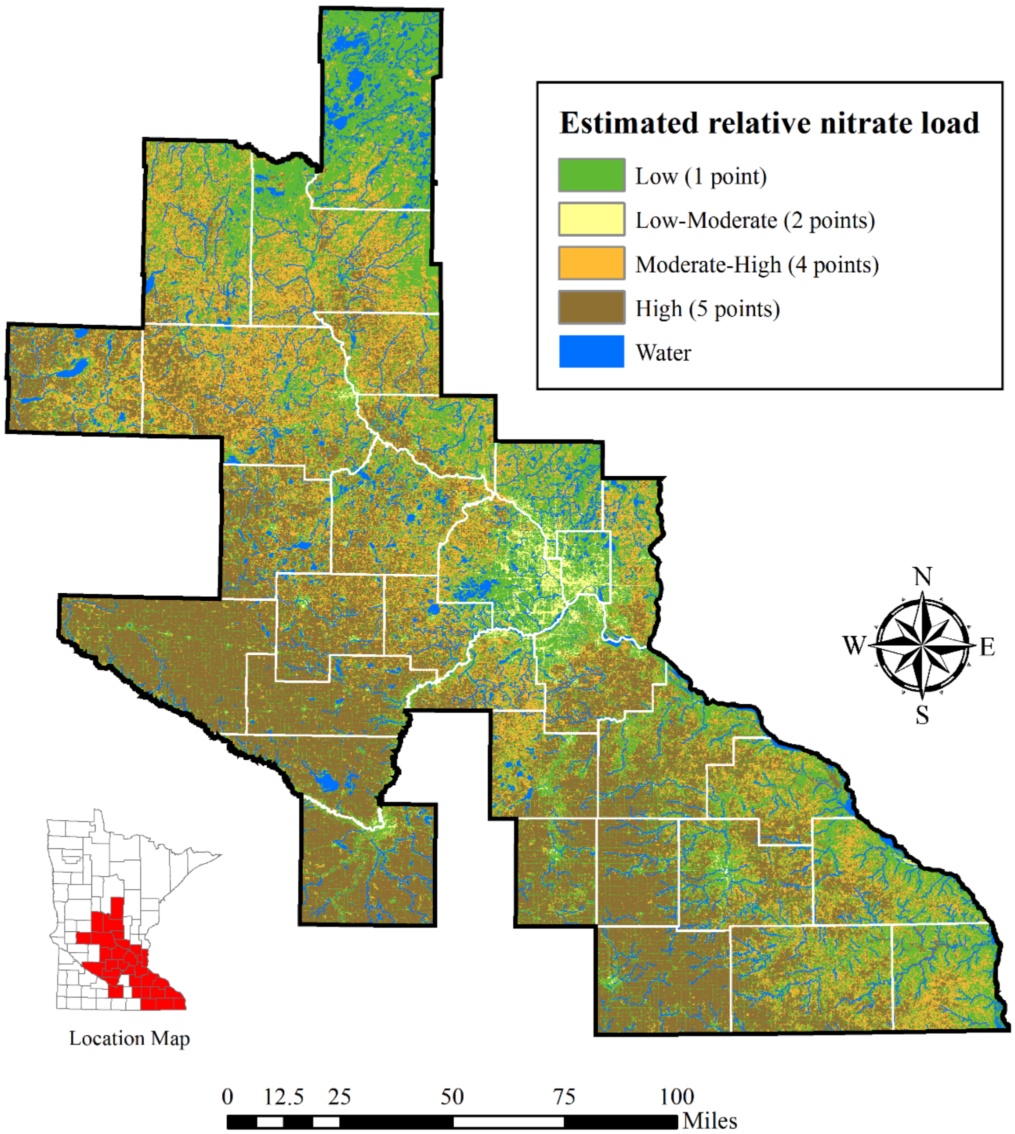


Figure 3: Nitrate Loading Estimated From Land Use

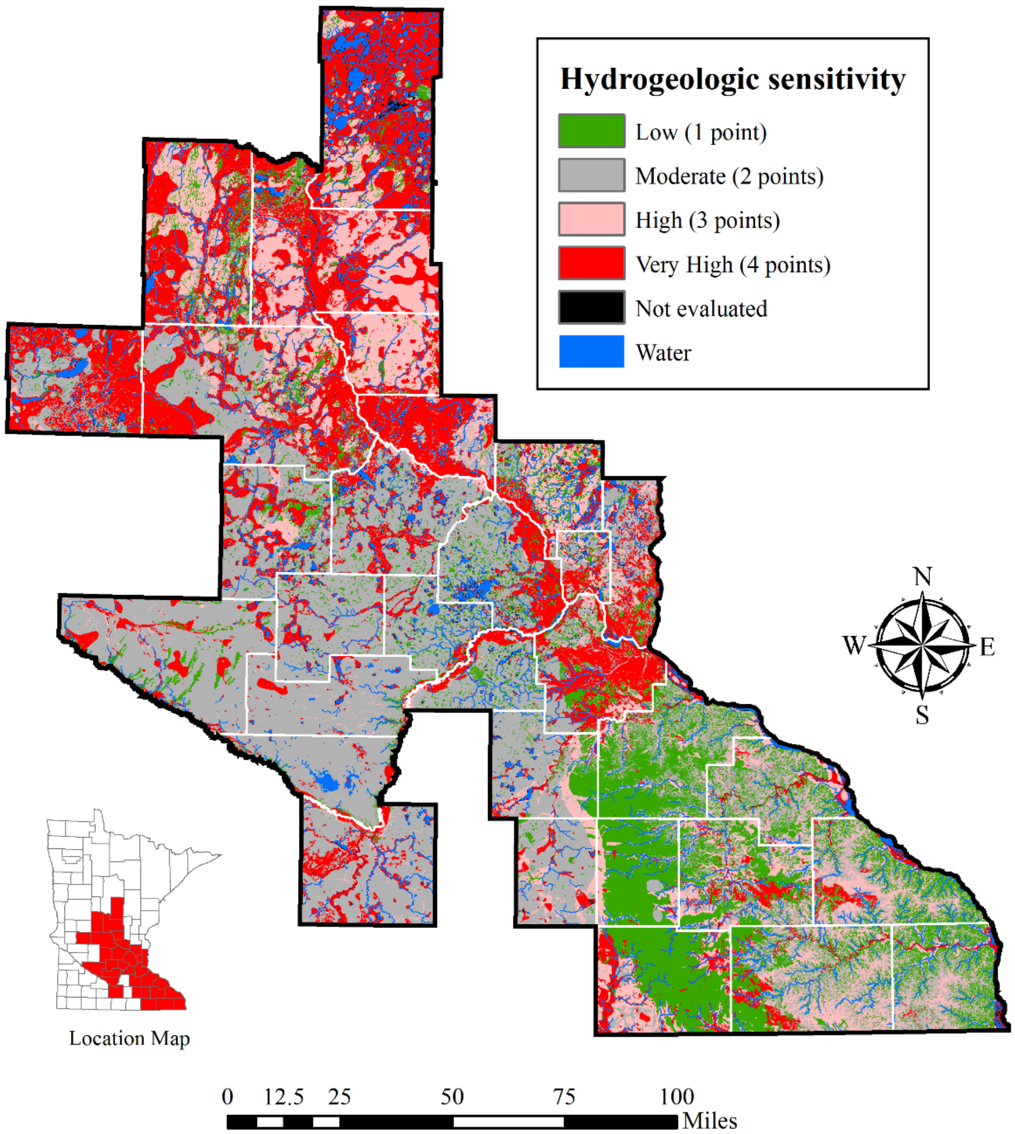
Map prepared by Minnesota Department of Health, December 2016



Nitrate loading was estimated for each land use within 31 counties, 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 for the detailed reclassification scheme.

Figure 4: Hydrogeologic Sensitivity of the Water Table Aquifer

Map prepared by Minnesota Department of Health, December 2016



Hydrogeologic sensitivity for 31 counties was estimated based on available data from Minnesota Geological Survey and county soil survey information

Nitrate Loading by Land Use Classification

Table 4. Relative Nitrate Loading for 2009 CDL and 2001 NLCD Land Use Classifications

Relative Nitrate Loading	Land Use Class	Data source
1	Barren	NLCD
1	Deciduous forest	NLCD
1	Developed/low intensity	NLCD
1	Developed/open space	NLCD
1	Evergreen forest	NLCD
1	Grassland herbaceous	NLCD
1	Herbaceous wetlands	NLCD
1	Mixed forest	NLCD
1	Open water	NLCD
1	Shrubland	NLCD
1	Woody wetlands	NLCD
1	Wetlands	CDL
1	Woodland	CDL
2	Developed/high intensity	NLCD
2	Developed/medium intensity	NLCD
4	Pasture/hay	NLCD
4	Alfalfa	CDL
4	Clover/wildflowers	CDL
4	Fallow/idle ground	CDL
4	Grass/pasture	CDL
4	Herbs	CDL
4	Other crops	CDL
4	Other hays	CDL
4	Rye	CDL
4	Seed/sod grass	CDL
5	Barley	CDL

Relative Nitrate Loading	Land Use Class	Data source
5	Canola	CDL
5	Corn	CDL
5	Dry beans	CDL
5	Durum wheat	CDL
5	Flaxseed	CDL
5	Millet	CDL
5	Miscellaneous vegetables/fruit	CDL
5	Oats	CDL
5	Other small grains	CDL
5	Peas	CDL
5	Potatoes	CDL
5	Sorghum	CDL
5	Soybeans	CDL
5	Spring wheat	CDL
5	Sugar beets	CDL
5	Sunflowers	CDL
5	Sweet corn	CDL
5	Winter wheat	CDL

General Descriptions of Nitrate Risk Rankings for Counties Mapped

Anoka County

Generally shallow water depths generate high to very high hydrogeologic sensitivity throughout much of Anoka County, however nitrate risk rankings are generally low. This fact is attributed to generally low estimated nitrate loading throughout the county. The low estimated nitrate loading results from large areas of developed land, and other undeveloped land that is not under cultivation for row crops.

Benton County

Approximately two-thirds of the county is ranked high for nitrate risk. The high rankings that occur throughout Benton County are attributed to: in the northwest, very high hydrogeologic sensitivity combined with high estimated nitrate loads; in central Benton County, moderate to high hydrogeologic sensitivity combined with moderate to high estimated nitrate loads; and in the south, high to very high hydrogeologic sensitivity combined with moderate to high estimated nitrate loads.

Moderate and low nitrate risk rankings occur sporadically throughout the county. A significant area of low nitrate risk also occurs in the northeastern corner of Benton County in spite of highly sensitive hydrogeologic conditions, and this is attributed to low estimated nitrate loading. Low to moderately-low estimated nitrate loading rates beneath urban areas (for instance, Sauk Rapids in the southwestern corner of Benton County) create low to moderate nitrate risk even though hydrogeologic sensitivity is moderate to very high.

Blue Earth County

Approximately 71 percent of Blue Earth County is ranked high for estimated nitrate risk. High estimated nitrate loading offsets moderate hydrogeologic sensitivity in these areas to calculate a high estimated nitrate risk. Low nitrate risk occurs across approximately 15 percent of Blue Earth County, along the Minnesota River and in urban areas. Although hydrogeologic sensitivity rankings in these areas are high or very high, estimated nitrate loads are generally low.

Carver County

Hydrogeologic sensitivity throughout much of Carver County is assessed to be moderate, yet in over 70% of the county nitrate risk rankings are moderate to high. This fact is attributed to moderate-high to high estimated nitrate loading across most of the county.

Crow Wing County

Moderate estimated nitrate risk predominates (56.2 percent) in a fairly even distribution across most of Crow Wing County. This distribution results from the combination of generally low estimated nitrate loading and widespread very high hydrogeological sensitivity. Low estimated risk occurs across 17.3 percent of the county, and high estimated risk occurs in small patches over 12 percent of the county, but primarily in the south due to moderate-high estimated nitrate inputs.

Dakota County

Much of Dakota County is covered by coarse clastic material, sometimes underlain by shallow bedrock, and the areas mapped with high nitrate risk rankings therefore correspond closely with areas of high estimated nitrate loading. Urbanized areas near the Minnesota and Mississippi Rivers have generally higher slopes and lower estimated nitrate loading, resulting in low nitrate risk rankings.

Dodge County

Estimated nitrate loading is moderately-high to high across Dodge County, leading to generally moderate nitrate risk rankings even where clay till is present. Along the western boundary, the southeastern corner, and the northwestern corner of the county, unconsolidated materials are permeable outwash or alluvium, commonly with bedrock close to the surface, leading to high nitrate risk rankings. The lowest nitrate risk rankings occur in wooded areas along rivers where nitrate loading is least.

Fillmore County

Nitrate risk rankings were greatest in the uplands of the eastern two-thirds of Fillmore County. Lower in the landscape, steep valley slopes maximize runoff at the expense of infiltration; this, along with a lack of nitrate sources, causes low nitrate risk rankings. Even with elevated estimated nitrate loads in the western part of the county, the presence of clay till suppresses nitrate risk rankings.

Goodhue County

About 22% of Goodhue County is ranked high for nitrate risk, and these areas co-occur with areas of outwash or shallow bedrock combined with moderate to high nitrate loading. Areas with low nitrate risk generally have low nitrate loading or moderate to steep slopes. About 40% of Goodhue County is ranked moderate for nitrate risk. These areas of moderate-high or high nitrate loading are generally underlain by clay till, which provides some protection against the recharge of nitrate-contaminated water.

Hennepin County

Low to moderate nitrate risk rankings occur across more than 80% of Hennepin County. This is primarily due to the heavily urbanized setting which contributes only low to moderate estimated nitrate loads. The highest nitrate risk rankings occur in northwestern Hennepin County where agriculture dominates and estimated nitrate loading ranges from moderate-high to high.

Houston County

Wind-blown eolian deposits (loess) cover much of Houston County, but provide little geologic protection. Therefore, the estimated nitrate load controls the geographic patterns of nitrate risk. The estimated nitrate load is greatest in the uplands of central and southeastern Houston County, where slopes are low. The estimated nitrate load is also high in the uppermost reach of the Root River Valley. These two areas carry the highest nitrate risk rankings. The estimated nitrate load is moderate to low in other areas, where slopes are too steep to farm. Consequently, these areas carry low nitrate risk rankings.

McLeod County

High estimated nitrate risk dominates McLeod County (63.1 percent). Throughout most of the county, high estimated nitrate loads offset moderate hydrogeologic sensitivity to calculate high estimated nitrate risk. Evenly distributed small patches of moderate nitrate risk occur in the northern half of the county and correlate with moderate nitrate estimated loads. Low nitrate risk is calculated for approximately 14 percent of the county, focused predominantly around urban areas and lakes, and likely due to a combination of moderate hydrogeologic sensitivity and low estimated nitrate loading.

Meeker County

High estimated nitrate risk dominates Meeker County (57%). Over much of the county the high nitrate risk ranking is attributed to dominant moderate to high estimated nitrate loading combined with moderate to high or very high hydrogeologic sensitivity. Areas ranked low for nitrate risk are uncommon (14% of the county), and are mostly linked to low estimated nitrate loading in urban or forested areas, combined with low to moderate hydrogeologic sensitivity.

Morrison County

Figure 1 indicates that high nitrate risk dominates central Morrison County, and low to moderate nitrate risk dominates the northwest and east. Since high and very hydrogeologic sensitivity dominate the entire county, the distribution of nitrate risk is primarily due to variations in estimated nitrate loading. The zone of high nitrate risk in the central portion of the county coincides with areas of high estimated nitrate loading.

Mower County

Nitrate risk rankings are greatest in the southwestern third of the county, along portions the eastern county boundary, and wherever the Browerville Till is absent. Low relief caused the lowest nitrate risk rankings to occur where nitrate loading was least, in wooded areas near streams and in urban areas.

Nicollet County

High estimated nitrate risk dominates Nicollet County. Across much of the county, high estimated nitrate load offsets moderate hydrogeologic sensitivity to calculate a high estimated risk level. Along the Minnesota River, high to very high hydrogeologic sensitivity combines with low estimated nitrate loading to calculate low to moderate nitrate risk.

Olmsted County

Estimated nitrate loading is moderately-high to high across Olmsted County, and limestone or sandstone bedrock is commonly shallow, leading to moderate to high nitrate risk rankings in rural areas. Low nitrate risk rankings interrupt this pattern in urban Rochester and surrounding areas, and in steeply sloping portions of river valleys, where nitrate loading is low.

Pope County

High or moderate nitrate risk rankings occur over approximately 85 percent of the county. High nitrate risk occurs across much of the county even where hydrogeologic sensitivity is low, due to generally high estimated nitrate loading. Areas with low nitrate risk rankings occur near Lake Minnewaska and in the southeastern portion of the county where low to moderate hydrogeologic sensitivity and low to low-moderate estimated nitrate loading occurs.

Ramsey County

The hydrogeologic sensitivity throughout most of Ramsey County is high to very high, however estimated nitrate loads (Figure 7) are low-moderate or low. The resulting nitrate risk rankings are low across more than 50% of the county. Combined low and moderate nitrate risk rankings cover over 90% of the county.

Renville County

High estimated nitrate loads offset moderate hydrogeologic sensitivity to calculate a high estimated nitrate risk level across most of Renville County. Areas of lake clay or basal clay fill are protective enough to calculate moderate nitrate risk across approximately 13% of Renville County, despite high estimated nitrate loading. Low nitrate risk is predicted in the Minnesota River valley, where hydrogeologic sensitivity spans from low to very high, and nitrate loads are low.

Rice County

Low, moderate and high nitrate risk rankings are evenly distributed across Rice County. Moderate risk rankings dominate in the east, where clay-rich till dominates. High risk rankings dominate central Rice County where mixed tills are present, except in forested river valleys. High rankings also occur in other areas where permeable sediments (outwash and alluvium) dominate or bedrock is close to the surface. In western Rice County there is an approximately even mixture of low, moderate, and high nitrate risk rankings due to variations in both the nitrate loading and permeability of the surficial geologic material.

Scott County

Across the uplands of Scott County, the hydrogeologic sensitivity is moderate, and nitrate risk ranking largely reflects estimated nitrate loading: high in rural areas and low to moderate in urbanized areas to the north and east.

Sherburne County

Lands where hydrogeologic sensitivity is high or very high cover nearly 80 percent of Sherburne County, and lands with low hydrogeologic sensitivity occur over only about 1 percent. Nitrate risk is largely a factor of the intensity of estimated nitrate loading to the subsurface, and consequently nearly 80 percent of Sherburne County is ranked moderate or high for nitrate risk. High nitrate risk occurs along the agricultural corridor along the Mississippi River, and also as scattered patches throughout the interior, interspersed with areas of moderate nitrate risk. Low nitrate risk is concentrated in the east, where hydrogeologic sensitivity is moderate to high but nitrate loading rates are generally low.

Sibley County

High nitrate risk dominates Sibley County, accounting for approximately 73 percent of the area. Low nitrate risk is estimated over 16 percent of the county, primarily in the east, along the

Minnesota River. Moderate nitrate risk is estimated across 9.5 percent of Sibley County, scattered throughout the county but concentrated around lakes and along the Minnesota River where the hydrogeologic sensitivity is high to very high but estimated nitrate loads are low.

Stearns County

Over 80% of Stearns County is ranked moderate or high for nitrate risk. Rankings are high in the western and northeast portions of the county due to high nitrate loading rates combined with moderate to very high hydrogeologic sensitivity. Low nitrate risk rankings dominate the east-central portion of Stearns County, with generally low nitrate loading and low hydrogeologic sensitivity. Nitrate risk in the remainder of Stearns County is generally moderate to high.

Steele County

Steele County soils generally contain a significant coarse fraction, and estimated nitrate loading is generally high. These conditions lead to generally high nitrate risk rankings throughout the county. Small areas of organic material and low to low-moderate estimated nitrate loading are assigned moderate nitrate risk rankings. Low nitrate risk occurs where nitrate loading is least: in wooded areas along rivers, and urban centers, particularly Owatonna.

Todd County

Nearly three-fourths (74%) of Todd County is classified as having high or very high hydrogeologic sensitivity. In these areas, even a moderately-high nitrate load can calculate high nitrate risk. These conditions occur across nearly half (45%) of the county, and dominate the southwestern corner where estimated nitrate loading is high. Because of the generally highly sensitive hydrogeologic conditions, areas of high expected nitrate loading correspond closely with high nitrate risk.

Wabasha County

Nitrate risk rankings were greatest in the uplands of northwestern and southern Wabasha County, where terrain is flat, bedrock dominates, and estimated nitrate loading rates are high. High nitrate risk also occurs lower in the landscape, where floodplain alluvium is present and estimated nitrate loading rates are high. Upland areas with moderate nitrate risk rankings had generally high estimated nitrate loading rates, but the presence of clay till added geologic protection. Low nitrate risk occurred where steep slopes limit the estimated nitrate load, and also in non-agricultural areas within the Mississippi River floodplain.

Washington County

The hydrogeologic sensitivity of the water table aquifer is generally high, and much of the county is characterized by a roughly equal mixture of low, moderate and high nitrate risk. The pattern is broken near the St. Croix River and in urban areas in the west-central portion of the county where land use is non-agricultural or urban, and in the south where estimated nitrate loading is high.

Winona County

Eolian deposits (mainly loess) cover most of Winona County, and provide little geologic protection. Therefore, the estimated nitrate load controls the patterns shown on the nitrate risk ranking map. The estimated nitrate load is greatest in the uplands of southern and western Winona County, where slopes are low. The estimated nitrate load is moderate to low in other areas, where slopes are too steep to farm. Consequently, these areas carry low nitrate risk rankings.

Wright County

Areas of high and moderate nitrate risk dominate Wright County (70.5 percent). Generally high estimated nitrate loading across much of the county offsets moderate hydrogeologic sensitivity in some areas to calculate a high estimated risk level. Areas of low nitrate risk comprise just 22.1 percent of Wright County, and these areas generally occur close to the northern and eastern county borders where estimated nitrate loads are somewhat lower than elsewhere.