Nitrate-Nitrogen Probability Map - Water Table Aquifer

Steele County

Minnesota Department of Health
Environmental Health Division
Source Water Protection Unit

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MINNESOTA MDH DEPARTMENT OF HEALTH

SWP source water protection

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

October, 2011

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 Steele (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^{-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 may originate from human activities. Nitrate concentrations greater than 10 mg-L^{-1} 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 (soil parent material type and loess) and land slope. Nitrate loading to the subsurface was estimated through reclassification of land use data. Finally, 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 Steele County are listed in Table 1.

Table 1: Base Maps for Steele County Nitrate Probability Ranking

Figure No.	Map Name	Source	File Type	Comment
3	Land Use	2009 CDL, 2001 NLCD	Raster	
4	Land Slope	Steele County Soil Survey	Vector	Minimum/maximum land slopes
5	Soil Survey Base Map	Steele County Soil Survey	Vector	Includes loess coverage

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 Steele 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 Steele County Soil Survey (Cummins, et al., 1973) 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 moderate slopes of at least 6% and at most 12%. There are no areas of steep slopes (greater than 12%) in Steele County.

Figure 5: Soil Survey Base Map. No county geologic atlas or other source of surficial geologic base data is available for Steele County. Therefore, Figure 5 shows the parent material group as designated in the Steele County Soil Survey (Cummins, et al., 1973). Figure 5 also shows the extent of wind-blown silt (loess), as mapped in the Steele County Soil Survey (Cummins, 1973).

Derived Maps

The derived maps generated by MDH are potential nitrate loading estimated from land use (Figure 6), hydrogeologic sensitivity of the water table aquifer (Figure 7), and nitrate probability ranking for the water table aquifer (Figure 1); these maps are listed in Table 2.

Table 2: Derived Maps for Steele County Nitrate Probability Ranking

Figure No.	Map Name	File Type
1	Nitrate Probability Ranking, Water Table Aquifer	Raster
6	Nitrate Loading Estimated From Land Use	Raster
7	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 6) and hydrogeologic sensitivity (Figure 7). 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 6: 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 7: Hydrogeologic Sensitivity of the Water Table Aquifer. Land slope (Figure 4) and soil survey base map (Figure 5) were the datasets used to generate the hydrogeologic sensitivity of the water table aquifer (Figure 7). 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 covered by geologic materials primarily composed of clay or shale close to the surface.
- 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. Steele County soils generally contain a significant coarse fraction (Figure 5), and estimated nitrate loading is generally high (Figure 6). These conditions lead to generally high nitrate probability rankings throughout the county. Small areas of organic material and low to low-moderate estimated nitrate loading are assigned moderate nitrate probability rankings. Low nitrate probability rankings occur where nitrate loading is least: in wooded areas along rivers, and urban centers, particularly Owatonna.

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

Nitrate Probability Ranking	***Area (mi^2)***	***Percent of Total County Area***
High	278.4	65.2
Moderate	35.0	8.2
Low	111.4	26.1
Not evaluated	2.2	0.5
Totals	***427***	***100.0***

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 ranking maps include:

- 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 Steele 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

Cummins, Joseph F., Carlson, Carroll R., Harms, Grenfall F., and Woodworth, D. Kirk, 1973, *Soil Survey of Steele County, Minnesota*, Soil Survey, United States Department of Agriculture, Soil Conservation Service (in cooperation with the Minnesota Agricultural Experiment Station), Washington, D.C., 102 p., 32 sheets.

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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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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.

Appendix 1:

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

Relative Nitrate Loading (this report)	***Land Use Class (this report)***	***Original 2001 NLCD Land Use Class***	***Includes 2009 CDL Land Use Classes***
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	Grassland/herbaceous (71)	
	Developed	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, Steele County

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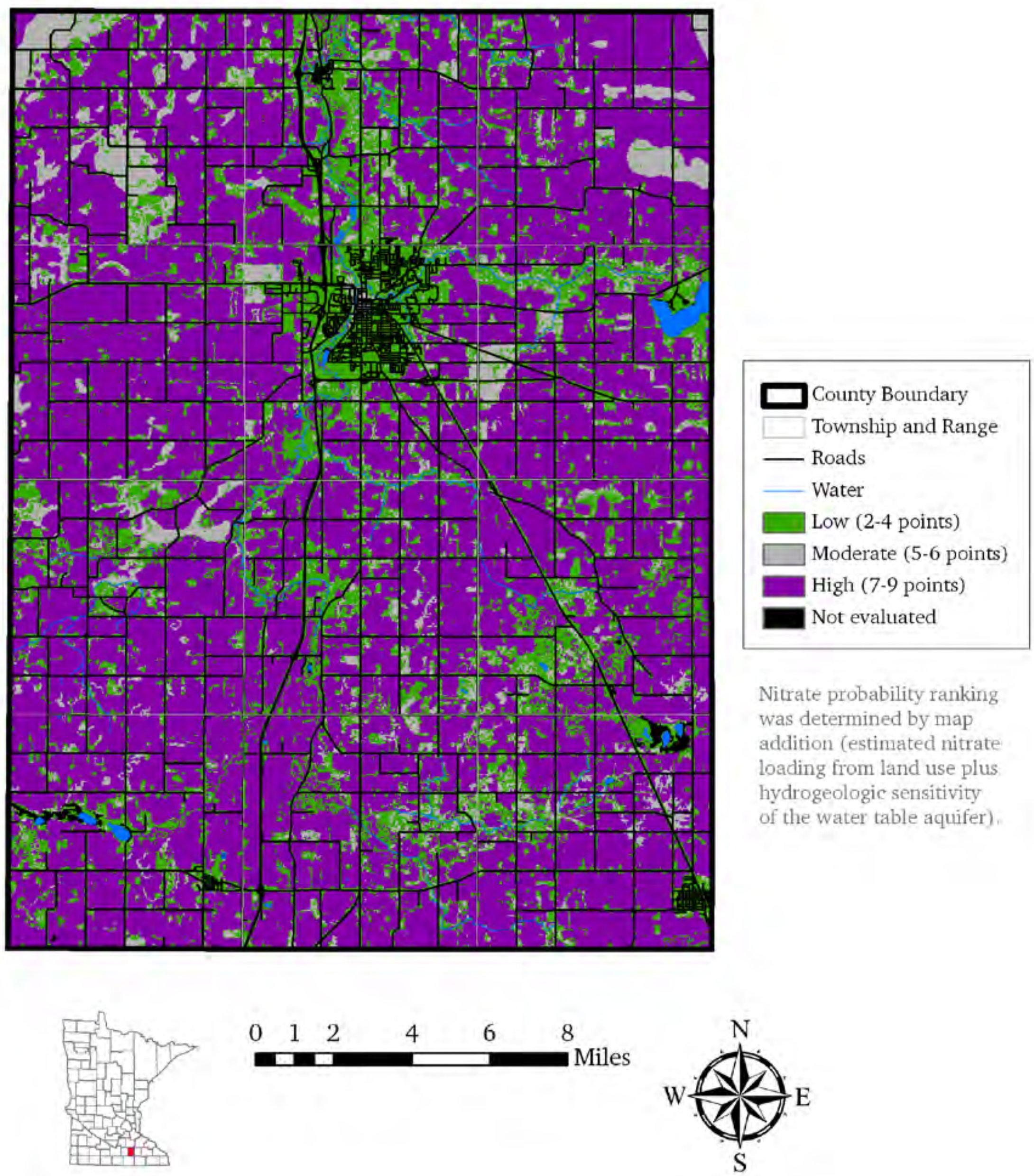

Figure 2: Map Assembly

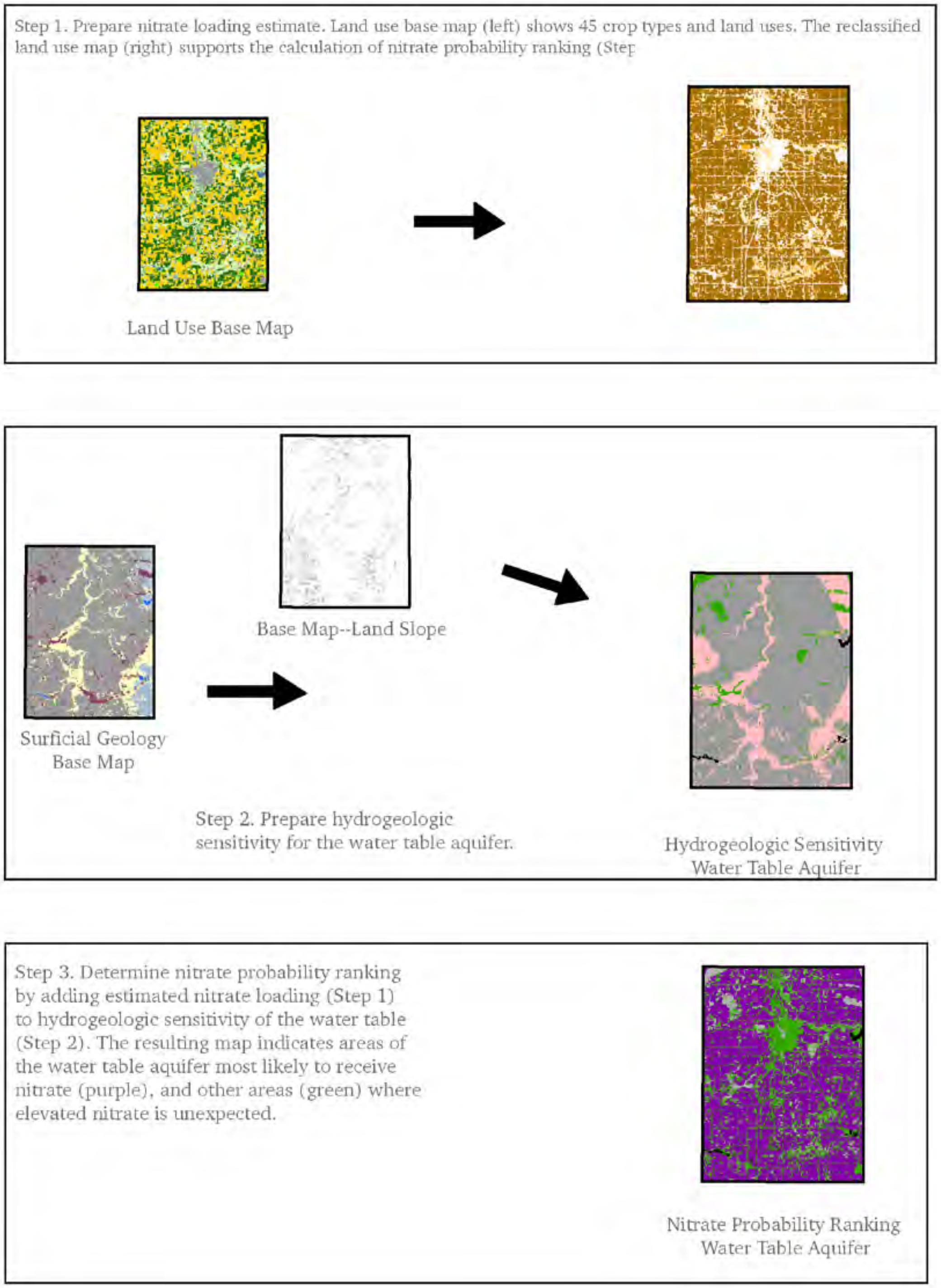

Figure 3: Land Use Base Map, Steele County

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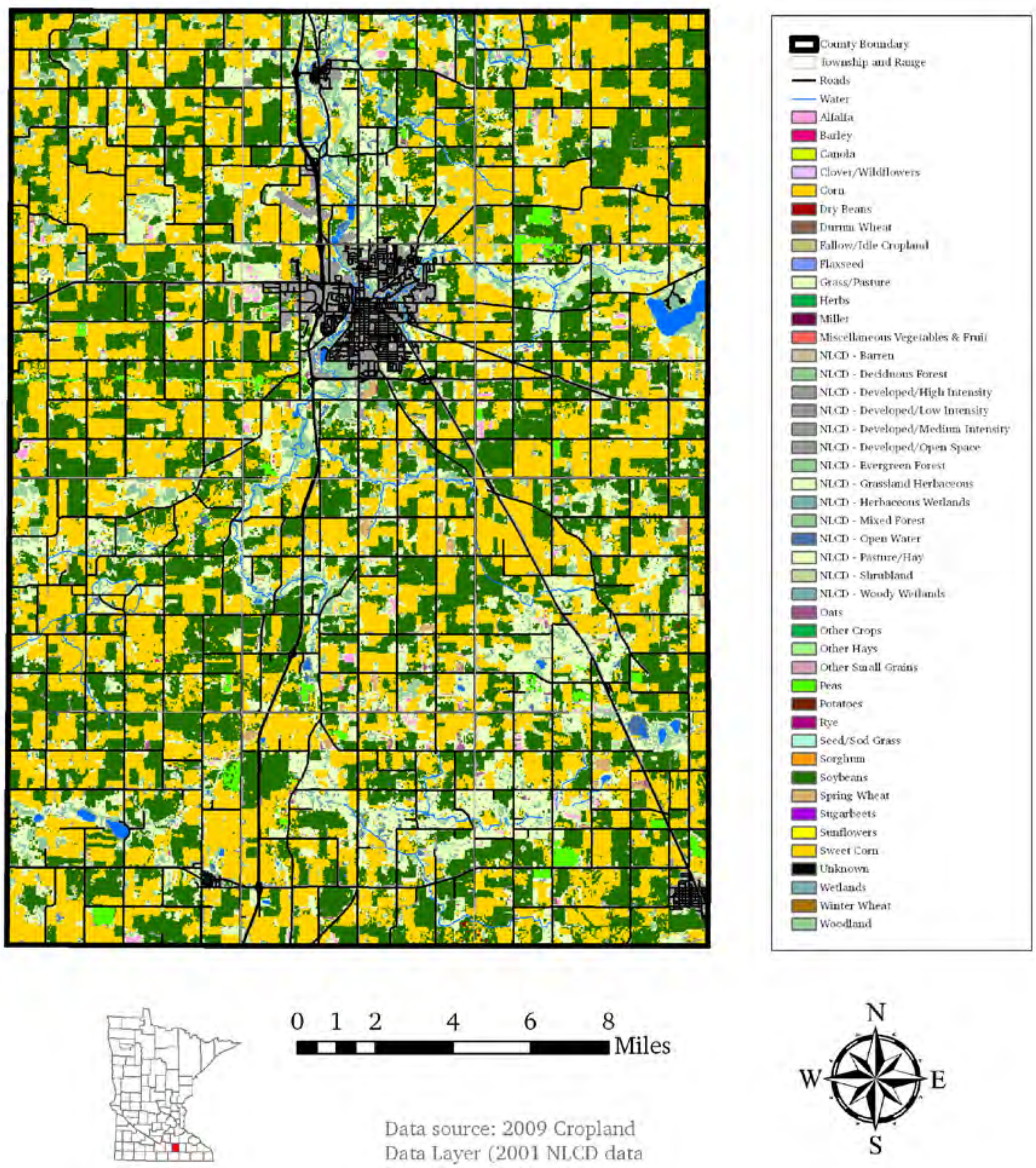

Data source: 2009 Cropland Data Layer (2001 NLCD data for urban areas).

Figure 4: Land Slope Base Map, Steele County

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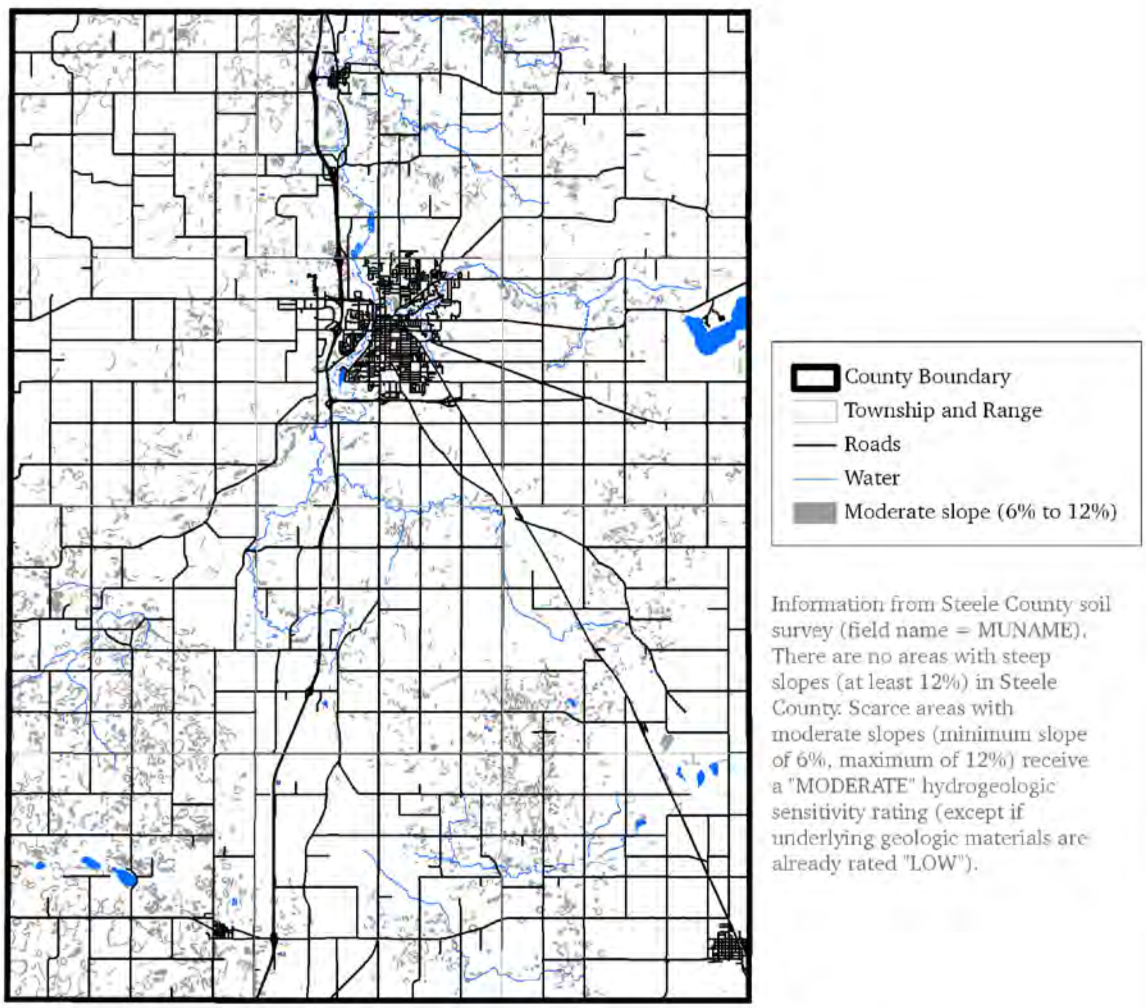

Information from Steele County soil survey (field name = MUNAME). There are no areas with steep slopes (at least 12%) in Steele County. Scarce areas with moderate slopes (minimum slope of 6%, maximum of 12%) receive a "MODERATE" hydrogeologic sensitivity rating (except if underlying geologic materials are already rated "LOW").

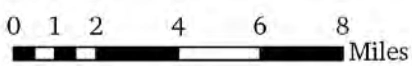

Figure 5: Soil Survey Base Map, Steele County

Prepared by Minnesota Department of Health, October 2011

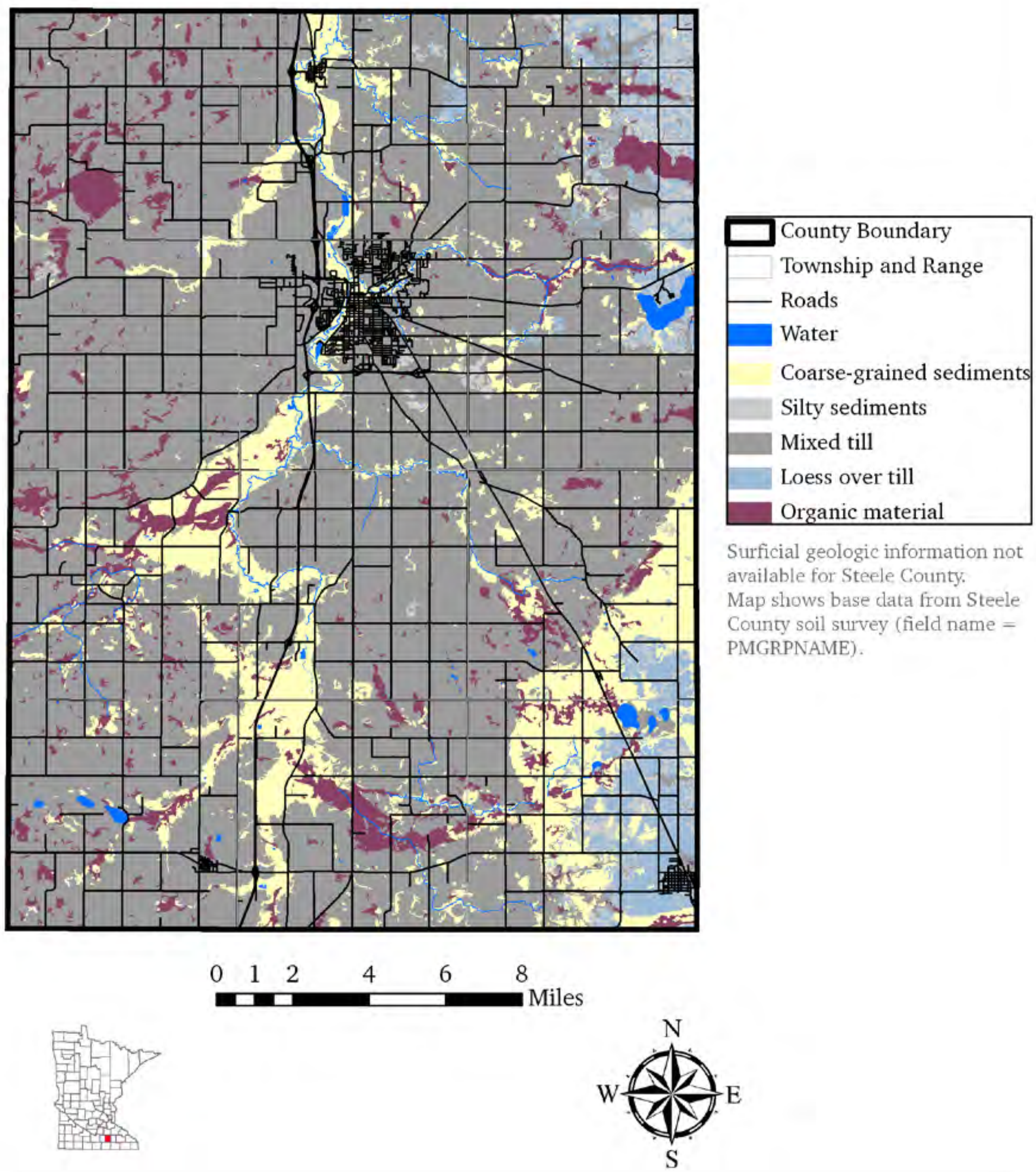

Figure 6: Nitrate Loading Estimated From Land Use, Steele County

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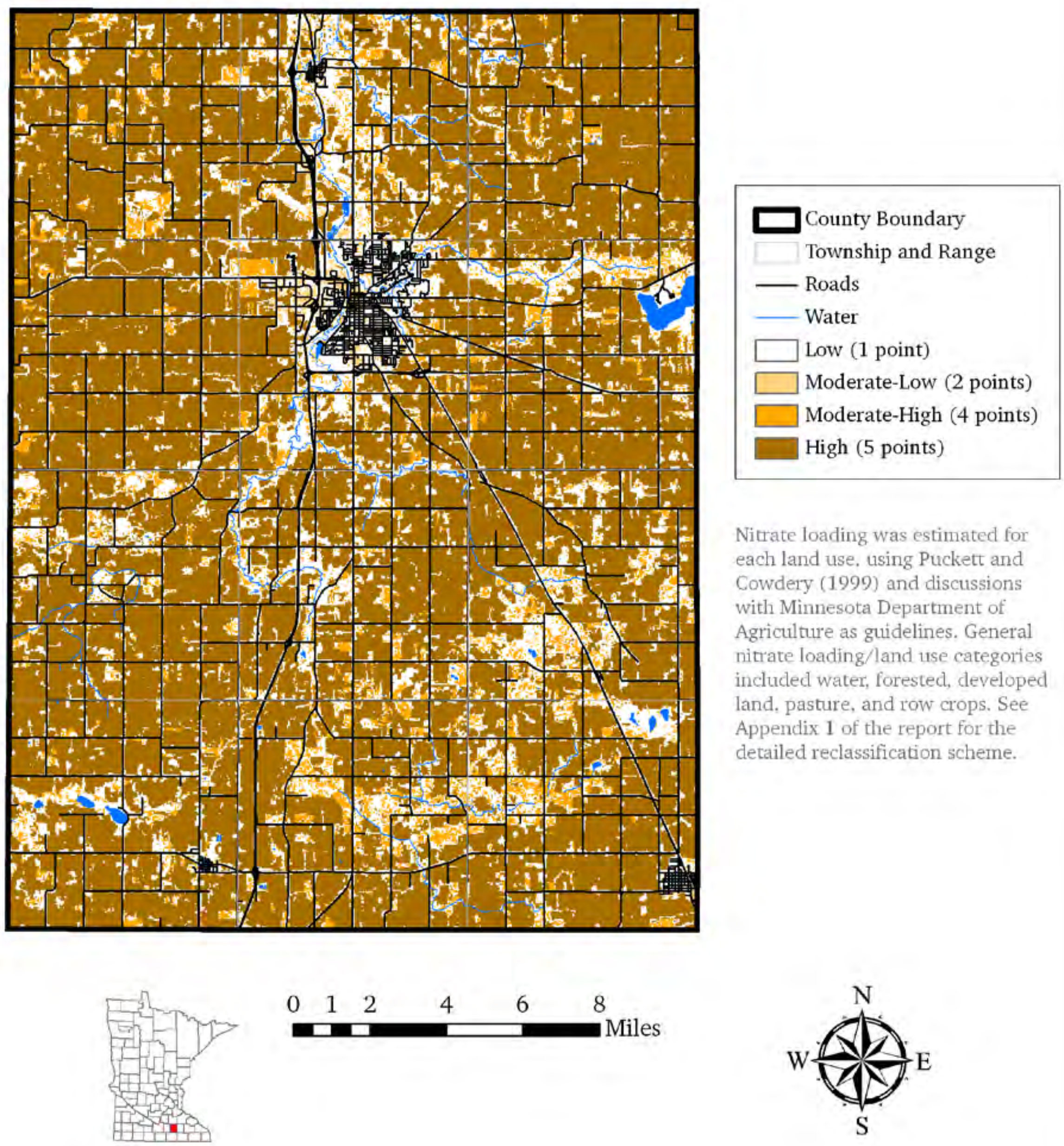
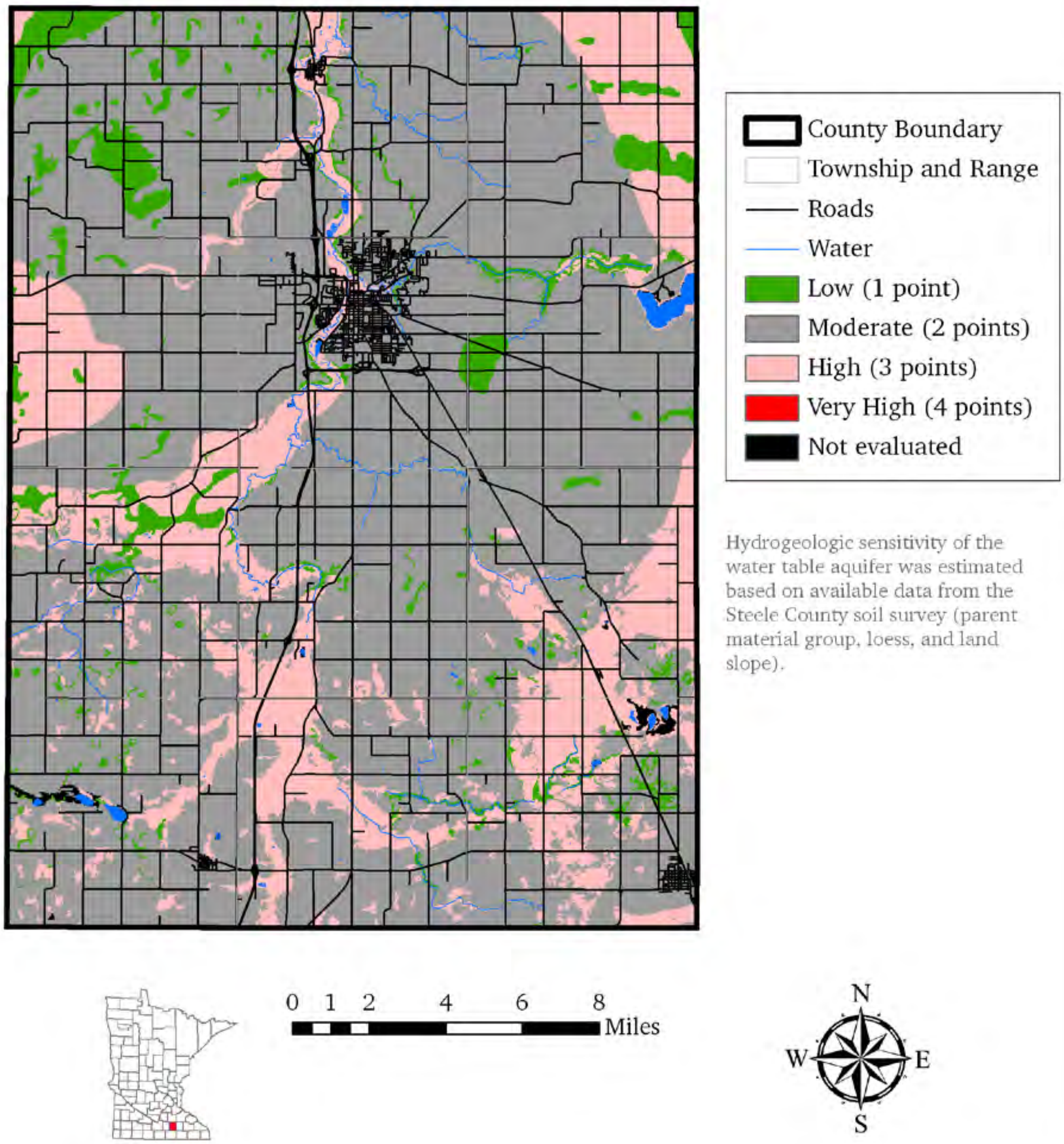


Nitrate loading was estimated for each land use, using Puckett and Cowdery (1999) and discussions with Minnesota Department of Agriculture as guidelines. General nitrate loading/land use categories included water, forested, developed land, pasture, and row crops. See Appendix 1 of the report for the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

Figure 7: Hydrogeologic Sensitivity of the Water Table Aquifer, Steele County

Prepared by Minnesota Department of Health, June 2011



Hydrogeologic sensitivity of the water table aquifer was estimated based on available data from the Steele County soil survey (parent material group, loess, and land slope).