Winona County
Nitrate-Nitrogen Probability Map

Prepared by the Minnesota Department of Health
September 2003

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Introduction

The Minnesota Department of Health (MDH) has developed a nitrate-nitrogen (nitrate) probability map for Winona County, Minnesota, to assist with state and local water quality planning efforts (see Figure 1). The probability map identifies areas of the county with relatively very high, high, moderate, and low probability of having elevated nitrate concentrations in groundwater drinking water supplies. Funding for this project was provided by the United States Environmental Protection Agency (US EPA) under section 106 of the Federal Clean Water Act for Federal Fiscal Year 2003.

The "Winona County Nitrate-Nitrogen Probability Map" was developed from available information in the data bases that can be illustrated in spatial, Geographical Information System (GIS) formats. The probability rating on the map represents nitrogen input and aquifer sensitivity. MDH's Source Water Assessment Program defines sensitivity as the likelihood that an aquifer will be isolated from contaminants by the intrinsic physical attributes of the geologic setting or geomorphology. Using this criteria, most of Winona County is susceptible to nitrate contamination.

This probability map is an illustration of level 2 mapping as described in the "Guidance for Mapping Nitrate in Minnesota Groundwater," dated December 11, 1998. According to the "Guidance for Mapping Nitrate in Minnesota Groundwater," concentrations less than 1 part per million (ppm) nitrate-nitrogen probably represent natural background levels. Concentrations of 1-3 ppm are transitional concentrations that may or may not represent anthropogenic influences. Concentrations of 3-10 ppm may indicate elevated concentrations representing human activities. Concentrations greater than 10 ppm are above state and federal groundwater standards.

These nitrate concentration classifications were used to define "elevated" nitrate concentrations on the probability map. Wells with concentrations less than 3 ppm are likely to be located in areas on the probability map labeled low probability. Areas where groundwater probably has been impacted by human activities (3-10 ppm) are likely to occur in areas labeled medium probability. Wells with nitrate concentrations near 10 ppm are likely to occur in areas labeled high or very high probability. However, it is important to remember that drinking water without nitrates also can be found in areas labeled medium high and very high probability. Good water quality generally can be found by using a deeper well installed by a licensed well driller. The absence of nitrate in groundwater may indicate that: (1) the nitrogen loading was small, (2) the nitrogen is in another form (such as ammonia), or (3) the nitrate has been denitrified (reduced to nitrogen gas).

Although nitrate can be a valuable indicator of environments that are susceptible to contamination, elevated nitrate concentrations may result either from contamination of the aquifer or more localized well problems, such as surface water drainage into the well, poor well construction, or location of the well near a pollution source, such as an old septic system or former out-house. Localized well problems may occur anywhere throughout the county and cannot be predicted by using the probability map.

Level 2 mapping efforts can be used by counties to provide source water protection; target education and funding programs; aid with planning, zoning, and land management decisions on a regional basis; and indicate where community behaviors or growth patterns need redirection. The probability map can be used to target areas to investigate the cause of the contamination in order to design appropriate remedial and preventative activities.

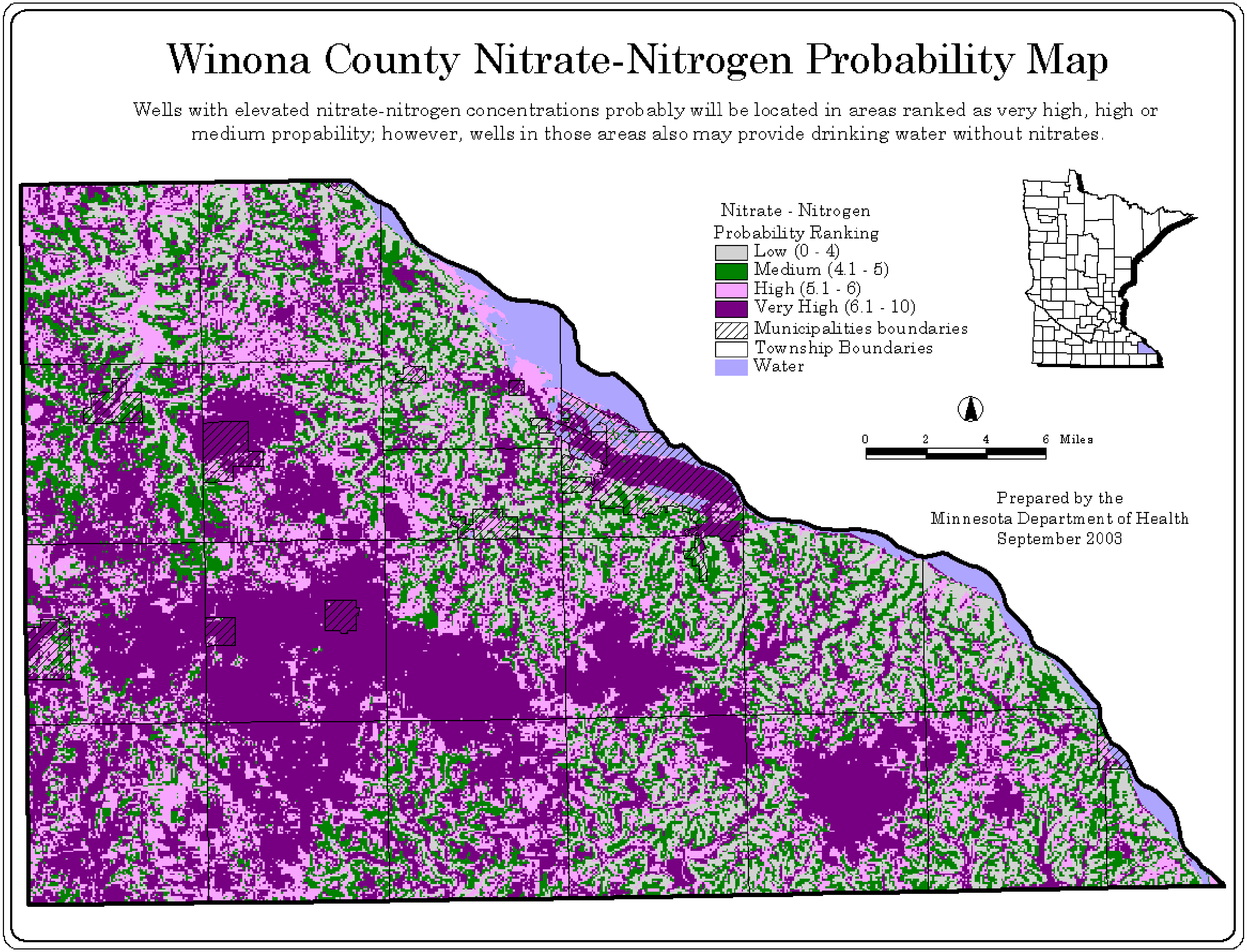
Winona County Nitrate-Nitrogen Probability Map
Wells with elevated nitrate-nitrogen concentrations probably will be located in areas ranked as very high, high or medium propability; however, wells in those areas also may provide drinking water without nitrates.
Nitrate - Nitrogen
Probability Ranking
Low (0 - 4)
Medium (4.1 - 5)
High (5.1 - 6)
Very High (6.1 - 10)
Municipalities boundaries
Township Boundaries
Water
0
2
4
6
Miles
Prepared by the
Minnesota Department of Health
September 2003

Figure 1

Section 2
Methods

Figure 2 is a schematic illustration of how the probability map was developed. Each GIS layer, or theme, used to prepare the probability map represents a data base illustrating nitrate input or aquifer sensitivity. A land use data base was used to represent nitrogen input. Different land use types in the land use data base were reclassified into three categories to represent potential nitrogen input. Aquifer sensitivity was represented by data bases illustrating landforms, geologic susceptibility, the percent of less permeable materials above the total depth of well, and the frequency of karst features. Landforms were divided into three categories to represent the potential for nitrate to migrate to the subsurface materials. The geologic susceptibility data base was divided into two categories, (1) carbonate bedrock and river valleys and (2) other. Geologic susceptibility illustrates (1) those areas where carbonate bedrock is within 50 feet of the ground surface and (2) river valleys. Carbonate bedrock and sand and gravel in the alluvium and terrace deposits in the river valleys both could allow rapid infiltration of surface water to the water table. Percent of less permeable materials was divided into three categories to represent the subsurface materials as defined by the information provided by well logs. The frequency of occurrence of stream sinks and sinkholes was divided into three categories to represent the ability of recharge to rapidly infiltrate the subsurface.

MDH staff evaluated and manipulated each layer to classify the layer as to its potential for impacting groundwater, and then overlaid and joined (unioned) the GIS layers to determine relative rankings for land areas within Winona County. Figure 2 illustrates the layers used for constructing the map and the relative scores for each data base used for probability mapping. Figure 3 shows a nitrate probability map illustrating the cumulative scores in more detail. For easier interpretation, the cumulative scores for the final nitrate probability map (Figure 1) were subdivided into four categories, representing relatively low, medium, high, and very high probability of having elevated nitrate concentrations.

Professional judgement of the MDH staff as to how to use each data base is inherent in this approach to mapping elevated nitrate concentrations. Specifics describing how each layer was formed, assumptions made, and limitations, are described in the following section, “Procedures,” along with a map of each layer to illustrate the steps in the mapping process. The ModelBuilder extension for ArcView was used to join the layers and add the ranking scores.

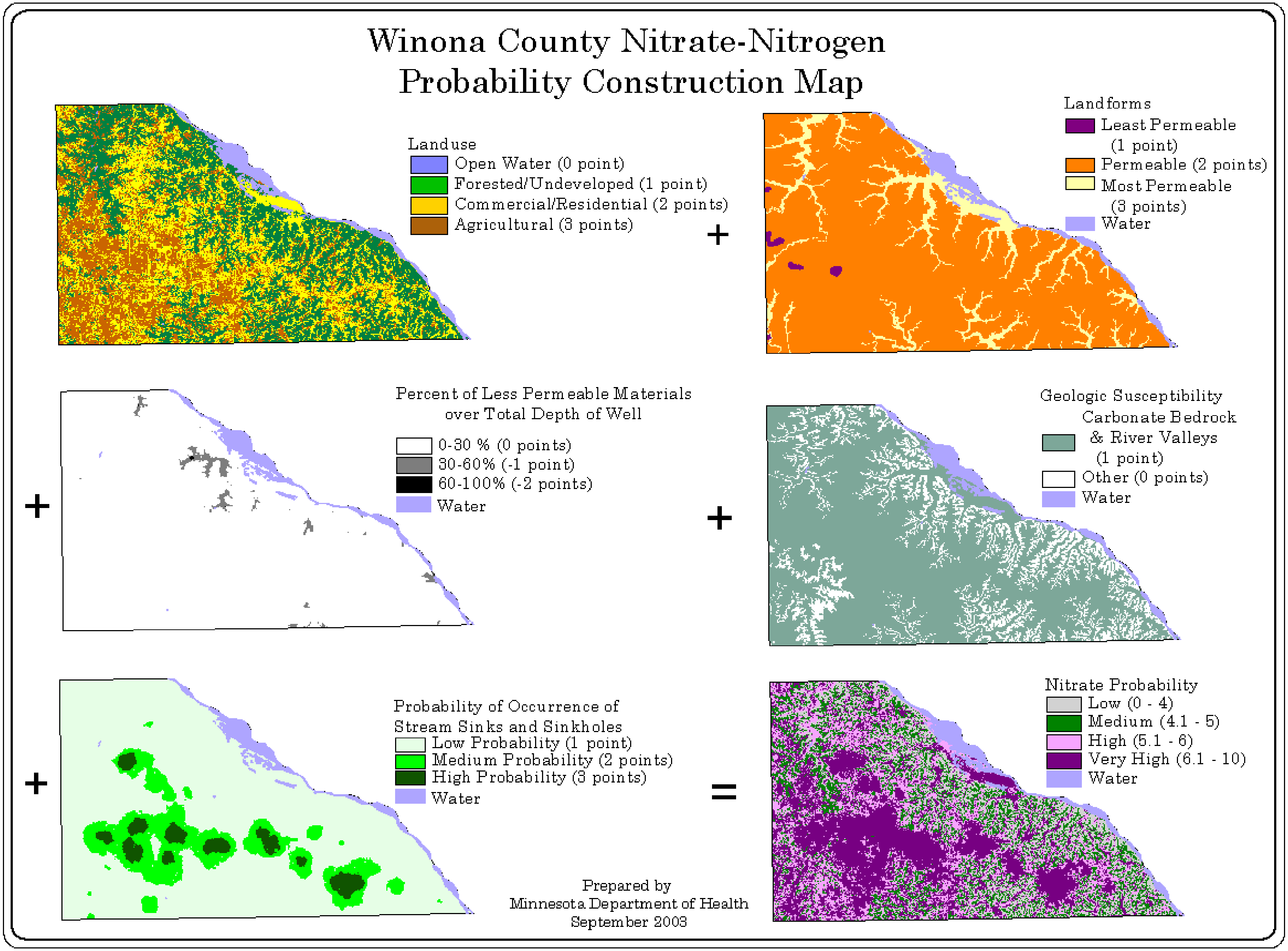
Winona County Nitrate-Nitrogen
Probability Construction Map
Landuse
Open Water (0 point)
Forested/Undeveloped (1 point)
Commercial/Residential (2 points)
Agricultural (3 points)
+
Landforms
Least Permeable (1 point)
Permeable (2 points)
Most Permeable (3 points)
Water
+
Percent of Less Permeable Materials over Total Depth of Well
0-30 % (0 points)
30-60% (-1 point)
60-100% (-2 points)
Water
+
Geologic Susceptibility
Carbonate Bedrock & River Valleys (1 point)
Other (0 points)
Water
+
Probability of Occurrence of Stream Sinks and Sinkholes
Low Probability (1 point)
Medium Probability (2 points)
High Probability (3 points)
Water
=
Nitrate Probability
Low (0 - 4)
Medium (4.1 - 5)
High (5.1 - 6)
Very High (6.1 - 10)
Water
Prepared by
Minnesota Department of Health
September 2003

Figure 2

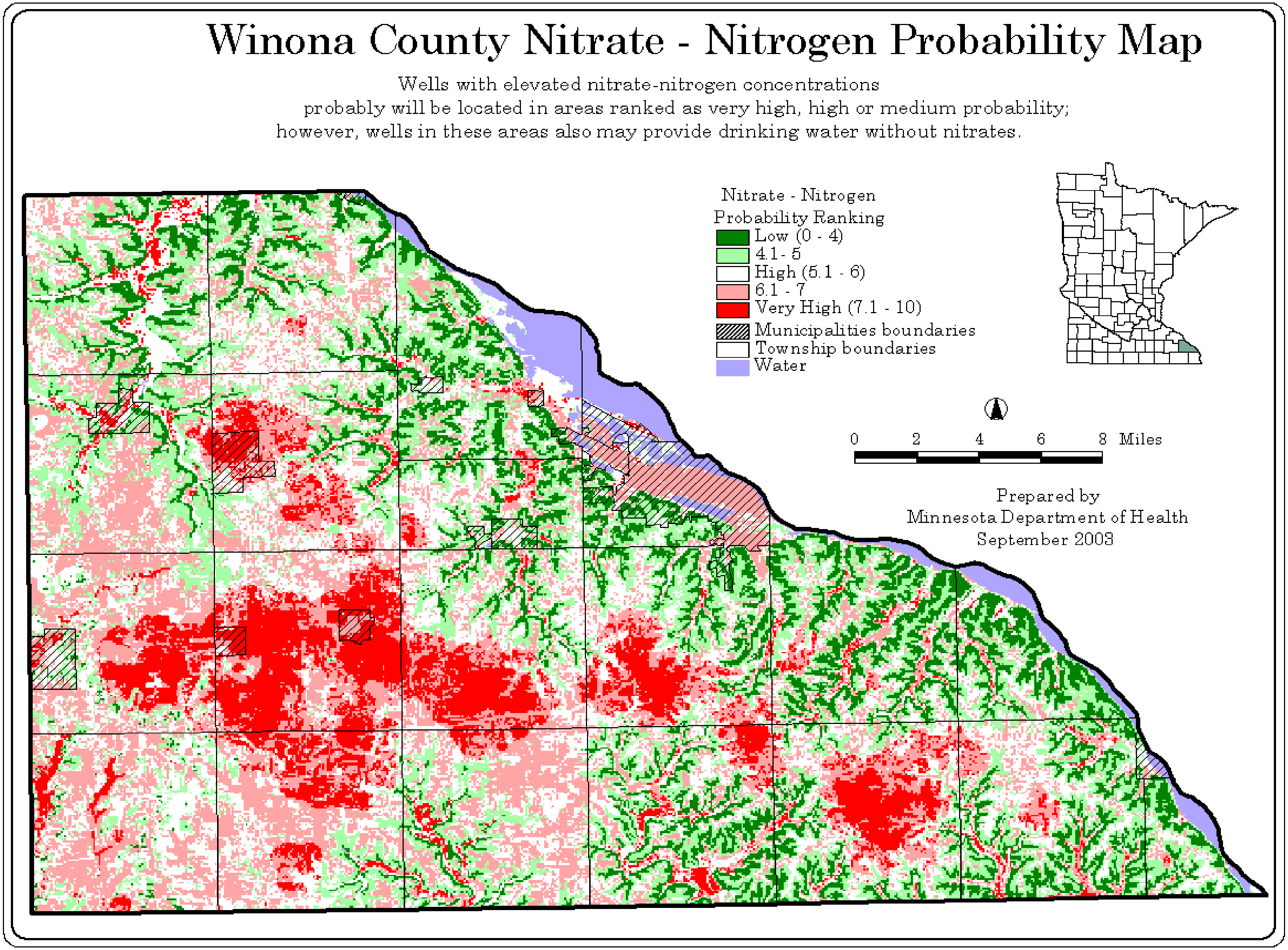
Winona County Nitrate - Nitrogen Probability Map
Wells with elevated nitrate-nitrogen concentrations
probably will be located in areas ranked as very high, high or medium probability;
however, wells in these areas also may provide drinking water without nitrates.
Nitrate - Nitrogen
Probability Ranking
Low (0 - 4)
4.1 - 5
High (5.1 - 6)
6.1 - 7
Very High (7.1 - 10)
Municipalities boundaries
Township boundaries
Water
0
2
4
6
8
Miles
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Figure 3

Section 3
Procedures

The following section describes the various steps in the mapping process. A map and expanded explanation are provided for each of the steps described in Section 2. Each map shows a GIS layer that was used to construct the nitrate probability map. All layers were converted to grids to use in ModelBuilder.

Land Use Reclassified
Figure 4

Theme name:	Landuse2 (from Extract from mn_nlcd_pre)
Source:	United States Geologic Survey, Earth Resources Observation Systems (EROS) Data Center

Background: MDH acquired the land use data base, the National Land Cover May 20, 2000, Dataset from the United States Geologic Survey (USGS) January 26, 2001. The USGS interpreted the National Land Cover Dataset from Landsat satellite TM imagery (circa 1992), supplemented by various ancillary data. Spatial resolution is 30 meters. Additional background information about the data base is available on the web site: landcover.usgs.gov.

MDH reclassified the land use classification in the National Land Cover Dataset into three categories: forested/undeveloped, commercial/residential, and agricultural, to indicate potential nitrate inputs, as indicated in the table below. The ranking of these classifications in accordance with “Guidance for Mapping Nitrate in Minnesota Groundwater.” The three land use reclassifications were assigned ranking scores of one to three, with a score of three indicating the highest potential for nitrate input. Open water bodies were assigned a zero.

Land Use Reclassification

1990 Land Use Classification	Reclassification Name	Reclassification Score
Barren Transitional	Forested/Undeveloped	1
Deciduous Forest	Forested/Undeveloped	1
Evergreen Forest	Forested/Undeveloped	1
High Intensity Residential	Commercial/Residential	2
Low Intensity Residential	Commercial/Residential	2
Mixed Forest	Forested/Undeveloped	1
Open Water	Open Water	0
Pasture/Hay	Commercial/Residential	2
Quarries/Strip Mines/ Gravel Pits	Forested/Undeveloped	1
Commercial/Industrial/ Transportation	Commercial/Residential	2
Row Crops	Agricultural	3
Shrubland	Forested/Undeveloped	1
Small Grains	Agricultural	3
Urban/Recreational Grasses	Commercial/Residential	2
Woody Wetlands	Forested/Undeveloped	1

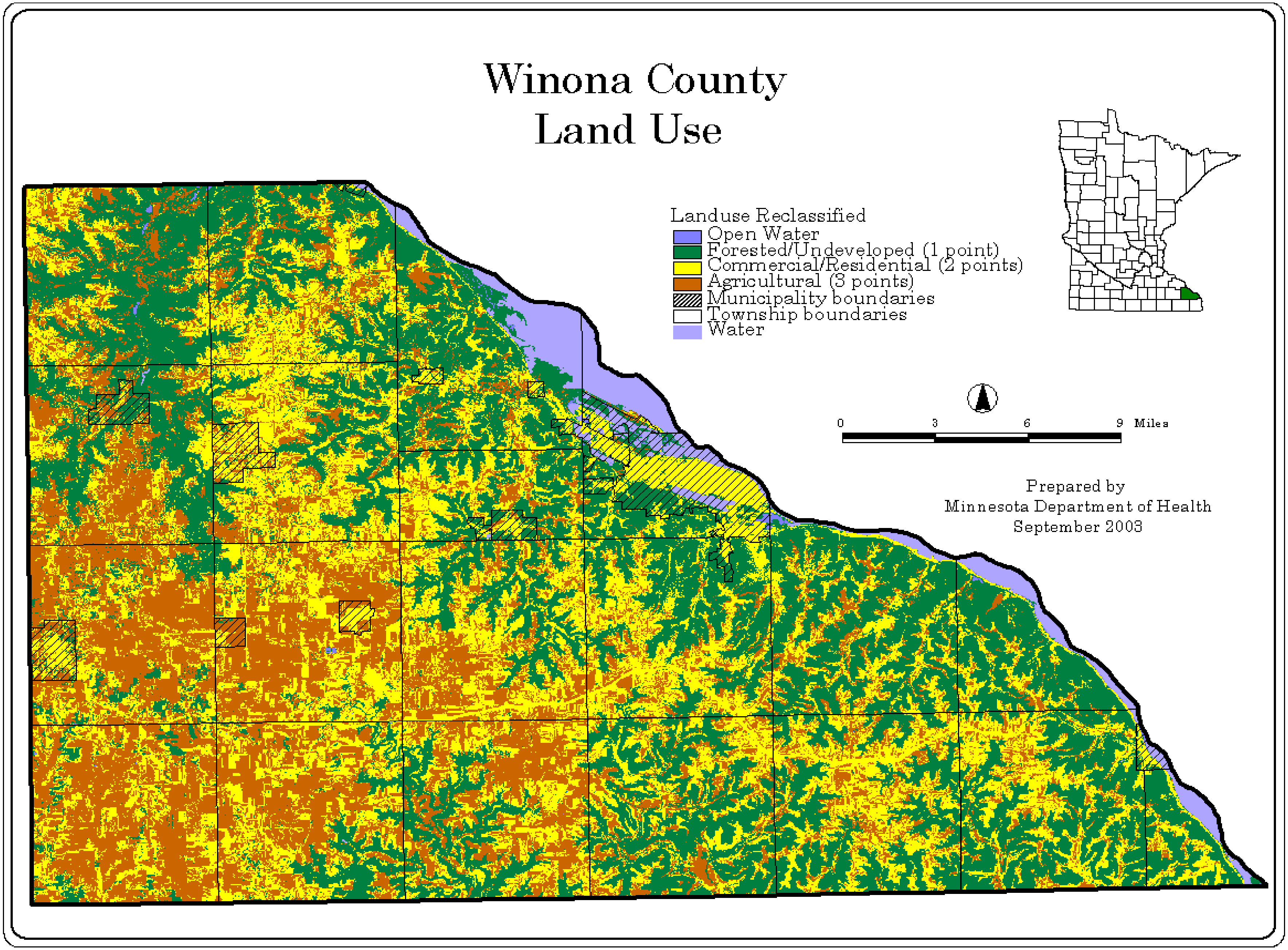

Winona County
Land Use
Landuse Reclassified
Open Water
Forested/Undeveloped (1 point)
Commercial/Residential (2 points)
Agricultural (3 points)
Municipality boundaries
Township boundaries
Water
0
3
6
9
Miles
Prepared by
Minnesota Department of Health
September 2003

Figure 4

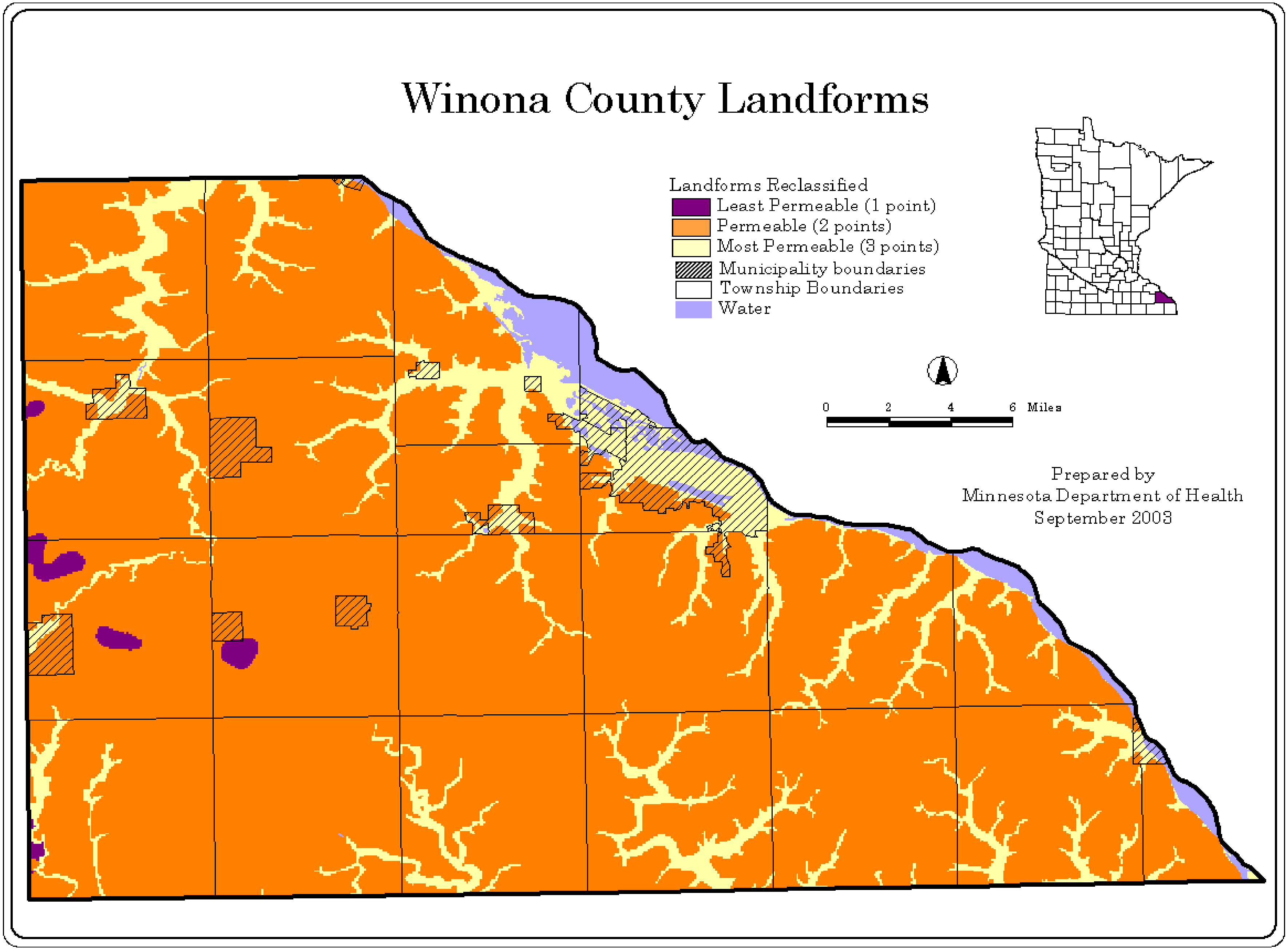
Landforms Reclassified
Figure 5

Theme name: Landforms 3
Source: Minnesota Geological Survey
Landform Associations of Minnesota

Background: The Minnesota Geological Survey Landform Associations of Minnesota data base provides Arc/Info polygon coverage that provides a statewide interpretation of the geomorphology. The University of Minnesota at Duluth interpreted the northern two-thirds of the state by using aerial photography. The Minnesota Geological Survey interpreted the southern one-third of the state from geologic maps. The Department of Natural Resources merged the two files. Interpretation differences along the boundary remain unresolved. The MDH acquire the data set during 1997.

Landform Classification	Reclassification Name	Ranking Score
Alluvium	Most Permeable	3
Terrace Deposits	Most Permeable	3
Bedrock	Permeable	2
Till Plain	Least Permeable	1

MDH reclassified the landforms, with assistance from Howard Hobbs at the Minnesota Geologic Survey, into three categories to indicate the geologic sensitivity: most permeable, permeable, and least permeable. As shown in the table above, the three landform classifications were assigned ranking scores of one to three, with the score of three indicating the most potential for contaminants to infiltrate the surficial materials. Landform classifications only apply to the surface geology and it is important to realize that surficial layers extend to different depths in different areas. The geology of underlying layers may significantly affect aquifer sensitivity. Although areas where the bedrock outcrops at the surface also are very permeable, shallow drift deposits above the bedrock may provide minimal protection in the large areas identified as bedrock in the landform data base. Therefore, the alluvium and terrace deposits of the river valleys were assigned a score of 3 and the bedrock areas a score of 2.



Winona County Landforms
Landforms Reclassified
Least Permeable (1 point)
Permeable (2 points)
Most Permeable (3 points)
Municipality boundaries
Township Boundaries
Water
0 2 4 6 Miles
Prepared by
Minnesota Department of Health
September 2003

Figure 5

Percent Less Permeable Materials above Total Depth of Well
Figure 6

Theme Name: EffDepth4
Source: Minnesota Department of Health

Background: This data base layer illustrating the relative percent of less permeable materials above the total depth of well is based on the likelihood that the aquifer would be isolated from contaminants by the intrinsic physical attributes of the geologic setting. Rankings for this layer, therefore, were divided into three values, as shown in the table below.

Percent	Ranking Score
0 - 30 percent less permeable materials	3
30 - 60 percent less permeable materials	2
60 - 100 percent less permeable materials	1

This layer was developed by using a program that calculated the percent of less permeable materials above the total depth of well from 2,351 well logs from Winona County and the surrounding area. Well drillers have been required since 1974 to submit well logs for all permitted wells to the MDH for inclusion in the County Well Index (CWI). Currently, there are more than 350,000 well logs in the electronic data base known as the CWI for the entire state. The program was developed by MDH and is available to interested parties.

To develop this layer, MDH staff reclassified the driller's description of the lithology on the well logs with respect to the permeability of the geologic materials (i.e., the ability for a contaminant, if present, to migrate to the water table). The density of wells in these areas did not define the valley walls where deposition would not have occurred. Because the density of well logs does not adequately define the areas where clay was deposited in the river valleys, the areas shown as having a high percentage of less permeable materials were defined or "clipped" using the river valleys (most permeable ranking) as mapped in the landform data base, discussed previously.

Only lithologies that typically retard the migration of groundwater were reclassified as less permeable materials (e.g., clay). All other lithologies were assumed to be permeable and were reclassified as sand. 1400 well logs had sufficient information to be used for calculating the layer. The reclassification scheme is presented in the table below.

Reclassification Scheme

Lithology	Sand	Clay
Boulder	X	
Clay		X
Cobble	X	
Drift	X	
Fill	X	
Gravel	X	
Hardpan		X
Loam	X	
Organic Material		X
Peat		X
Sand	X	
Silt		X
Soil	X	
Till		X

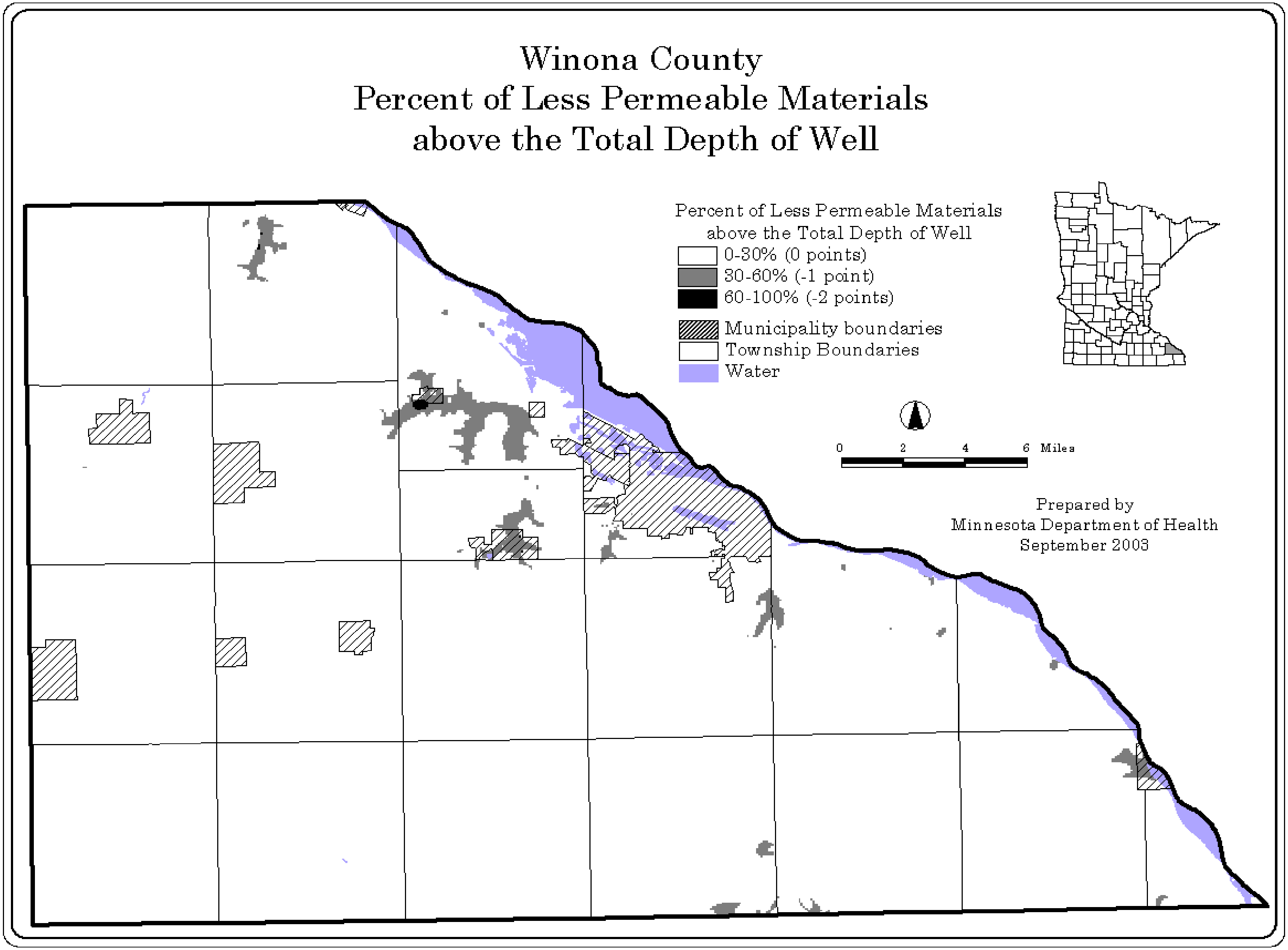

Winona County
Percent of Less Permeable Materials
above the Total Depth of Well
Percent of Less Permeable Materials
above the Total Depth of Well
0-30% (0 points)
30-60% (-1 point)
60-100% (-2 points)
Municipality boundaries
Township Boundaries
Water
0 2 4 6 Miles
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Figure 6

Geologic Sensitivity
Figures 7&8

Theme: Carbterrace2.shp
Source: Minnesota Department of Health

Background: The Minnesota Department of Health prepared this layer from three data bases to illustrate areas of the county most susceptible to nitrate contamination due to geology. This layer shows where carbonate formations are the closest bedrock unit to the ground surface and the river valleys. Both of these geologic conditions can allow recharge to move rapidly to the water table. Carbonate bedrock can provide rapid pathways for groundwater movement if the surficial glacial deposits do not protect the bedrock from dissolution. Dissolution of the carbonate bedrock is most likely to occur where the bedrock is close to the ground surface. "Most surficial karst features such as sinkholes are found only in those areas with less than fifty feet of sedimentary cover over bedrock surface (Gao, and others, 2002)". Most of the glacial deposits above the bedrock in Winona County are less than 50 feet thick (i.e., the top of the bedrock has less than 50 feet of cover). Carbonate bedrock units illustrated on this map include the Galena, the Decorah/Platteville/Glenwood/ and the Prairie du Chien. The next section of this report describing karst features further discusses the relationship between water quality and carbonate bedrock. All of the areas underlain by carbonate bedrock or in river valleys depicted on this map were given an extra point for susceptibility to nitrate contamination. The data bases used to prepare this layer are described below.

1. One data base includes the alluvium and terrace deposits in river valleys from the Landform data base that was described earlier in this report.
2. Another data base shows the extent of the Prairie du Chien in Winona County. This data base was prepared by the Minnesota Geologic Survey (MGS) by digitizing the Winona County Geologic Atlas (Balaban and Olsen, 1984).
3. The extent of Galena and the Decorah/Platteville/Glenwood units are from an unpublished map prepared by John Mossler at MGS as part of an Environmental Protection Agency (EPA) 319 demonstration grant that includes bedrock in the western portion of Winona and the entire counties of Olmsted, Dodge, and Steele. The filename for this map is K319_bdrk.shp and is available from the MGS.

The thickness of the surficial glacial deposits is documented by another map prepared as part of the same project, which shows the depth to bedrock for the same area. The name of this map is K319_d2br.shp. Both maps, generated by MGS as part of the EPA 319 demonstration grant, are available in digital form from the MGS. MGS did not map the depth of the bedrock in the eastern portion of Winona County because the depth generally is less than 50 feet to the Prairie du Chien, which is a carbonate bedrock unit. (Robert Tipping, MGS, personal communication, 2003).

Geologic Susceptibility

Bedrock Aquifer	Sensitivity	Ranking Score
Prairie du Chien	Sensitive	1
Galena	Sensitive	1
Decorah/Platteville/ Glenwood	Sensitive	1
Terrace Deposit	Sensitive	1
Alluvium	Sensitive	1

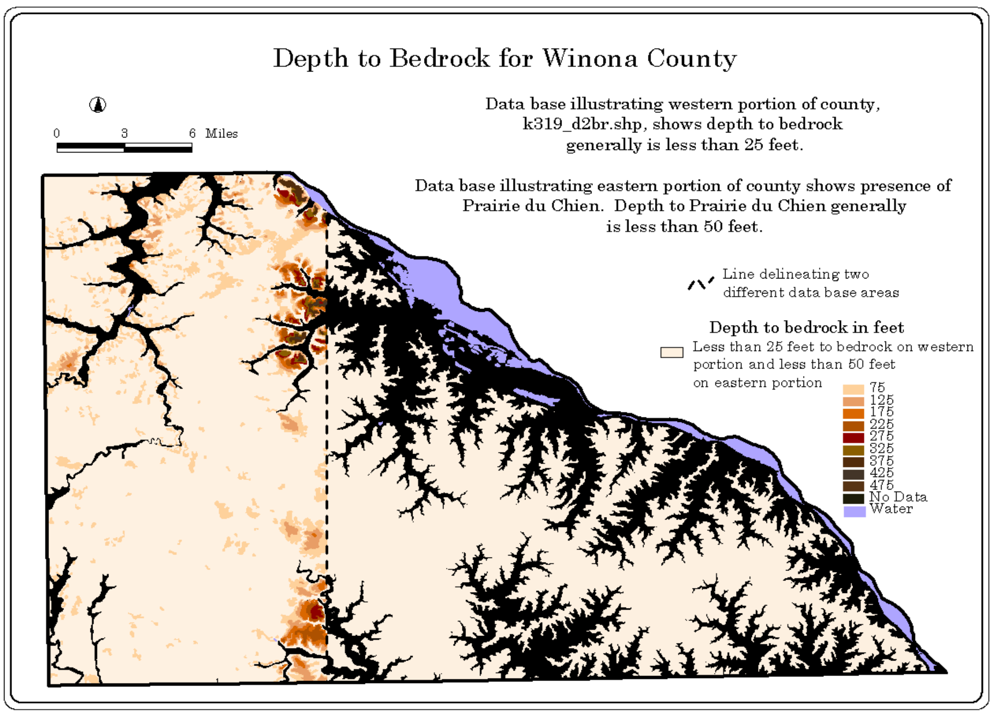

Figure 7

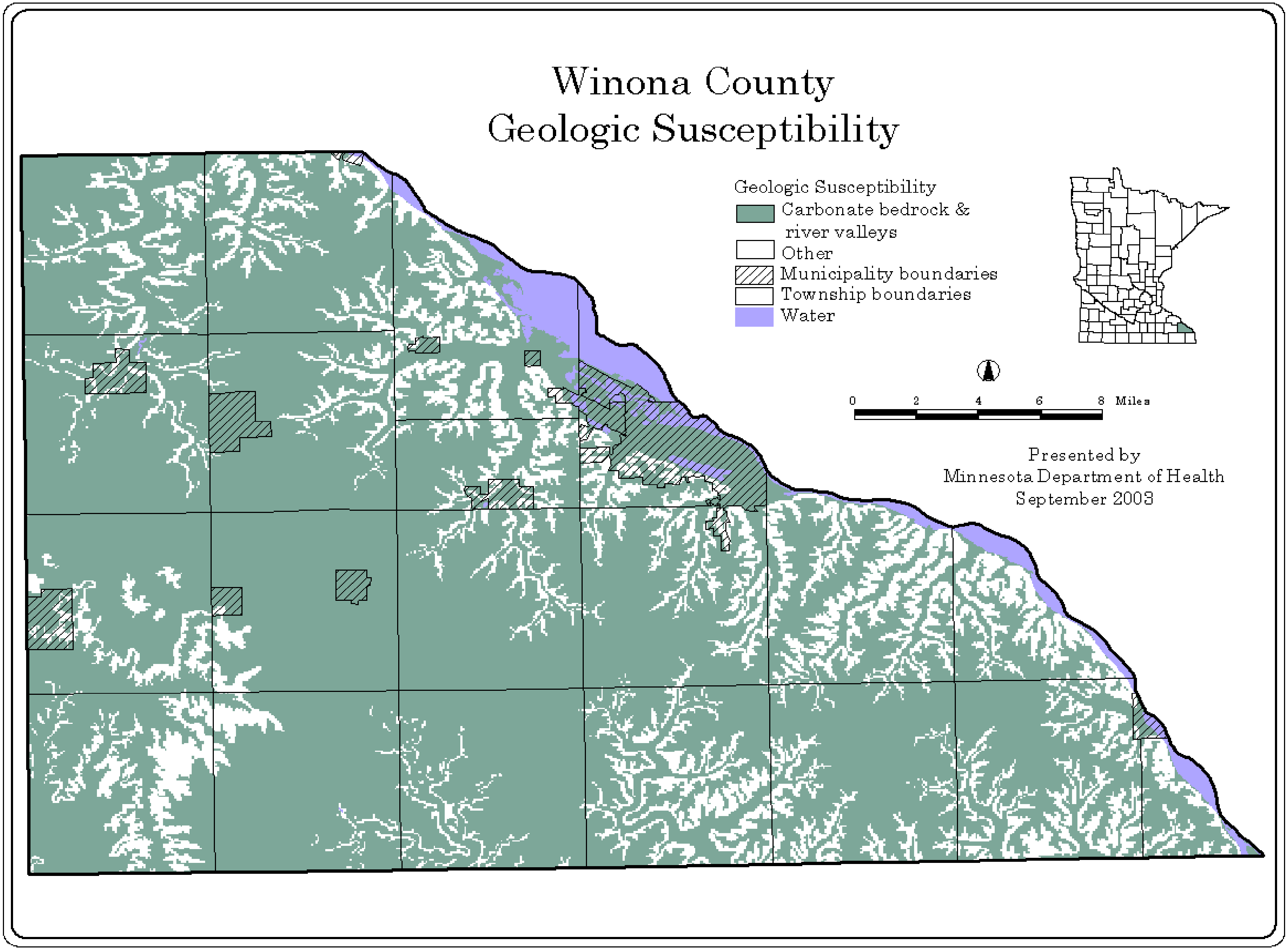
Winona County
Geologic Susceptibility
Geologic Susceptibility
Carbonate bedrock &
river valleys
Other
Municipality boundaries
Township boundaries
Water
0
2
4
6
8
Miles
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Figure 8

Probability of Occurrence of Stream Sinks and Sinkholes
Figure 8

Theme:	Surface from Zero_New_Karst.shp
Source:	Karst Features in Winona County from the Karst Feature Inventory Points, file name: krstindx University of Minnesota, Department of Geology and Geophysics; Minnesota DNR - Division of Waters
Contact:	Dr. E. Calvin Alexander, Jr., Department of Geology and Geophysics, University of Minnesota

The description from the metadata for the Karst Features in Winona County says that the karst inventory points are features such as sinkholes, springs, and stream sinks extracted from the karst feature database of Southeastern Minnesota. The Minnesota Geological Survey and the department of Geology and Geophysics at the University of Minnesota mapped karst features as part of a program to produce county geologic atlases since the early 1980's. The Geologic Atlas for Winona County (Balaban and Olsen, 1984) contains a plate, "sinkholes and sinkhole probability", illustrating karst features for Winona County. The Minnesota Department of Natural Resources assumed responsibility for karst mapping as part of the hydrogeologic portion of the county atlases during the mid 1990s. Both the inventory points and the karst feature data base are updated on a regular basis. The Legislative Commission on Minnesota Resources, the Minnesota Department of Natural Resources, and several counties provided initial funding for these projects. Updates to their research have been funded by the Minnesota Department of Health.

Karst features develop on the landscape as groundwater moving along joints, fractures, and bedding planes dissolve the underlying bedrock. As the passages become larger, erosion by abrasion contributes to the enlargement of the passages. There may be little filtration of contaminants as surface water quickly becomes groundwater. Karst topography can be characterized by sinking streams and resurgent springs. Groundwater can form surface streams at contacts with less permeable layers. As mentioned earlier, karst topography generally develops in areas where the bedrock is less than 50 feet beneath the ground surface.

MDH staff used the karst features point data to form a layer illustrating the frequency of karst features that may contribute to elevated nitrates if a source of nitrate is available. Only the sinkholes and stream sinks were used to form this layer since sinkholes and sinking streams can provide direct connections between the surface and subsurface. Resurgent springs would not be as directly linked to elevated nitrates in groundwater.

MDH staff developed this layer by joining the point coverage of karst features to a coverage of geographic sections in Winona County, forming a grid and assigning the number of karst features per county. These sections were then contoured to illustrate the density of karst features. The county section grids were divided into three categories based on how many known sinkholes and stream sinks were in that section: Sections with (1) 0 to 2.9 karst features were given a low probability ranking, (2) 3 to 7.9 karst features were given a medium probability rating, and (3) more than 8 karst features per section were given a high rating. A deficiency of this map is that karst features are not naturally evenly distributed. Therefore, if three karst features are closely located, but happen to be in different sections, this method may not show that cluster.

Number of known Sinkholes or Stream Sinks	Reclassification Name	Ranking Score
0-2.9	Low Probability	1
3-7.9	Some Probability	2
>8	High Probability	3

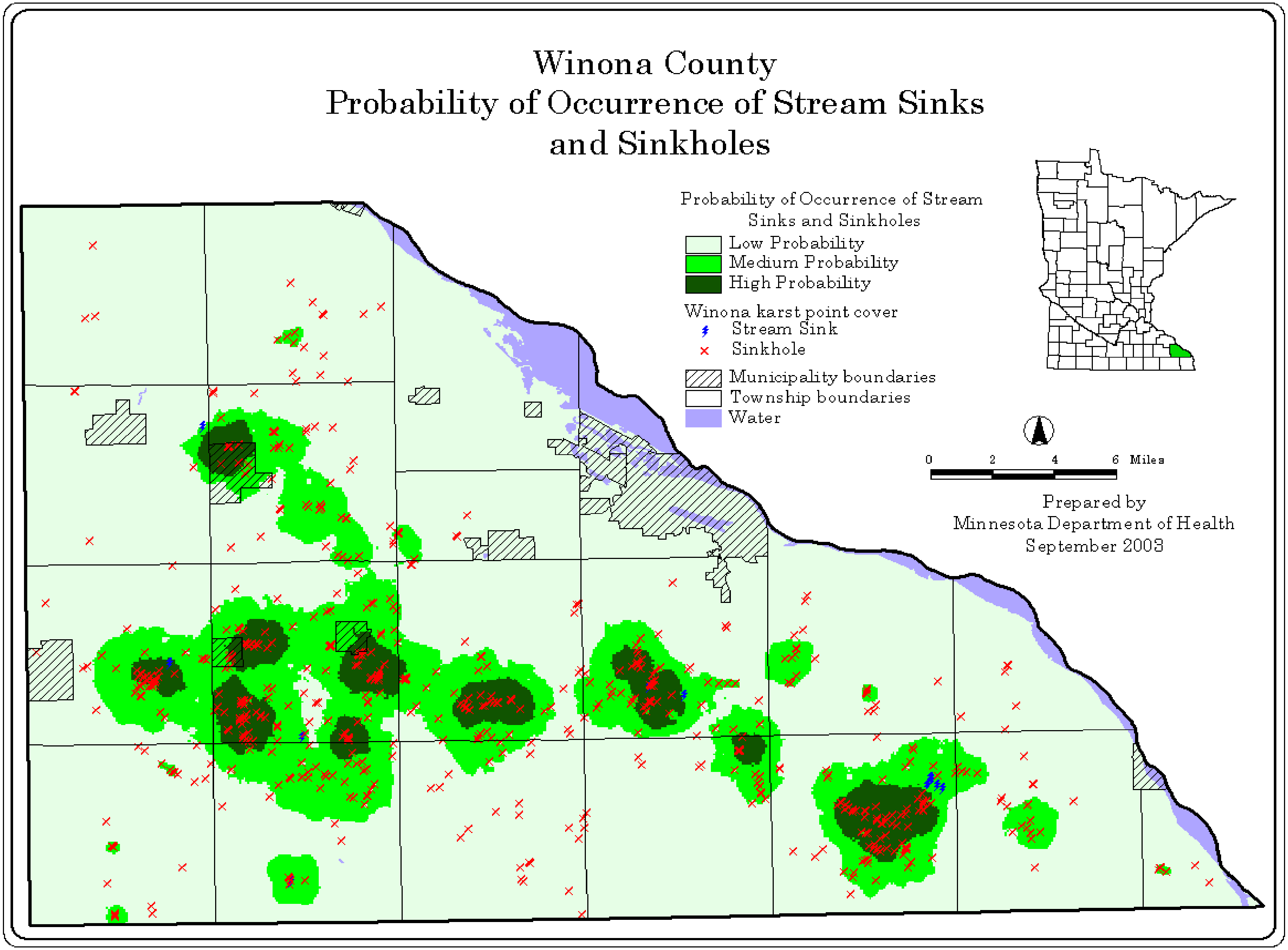
Winona County
Probability of Occurrence of Stream Sinks
and Sinkholes
Probability of Occurrence of Stream
Sinks and Sinkholes
Low Probability
Medium Probability
High Probability
Winona karst point cover
Stream Sink
Sinkhole
Municipality boundaries
Township boundaries
Water
0
2
4
6
Miles
Prepared by
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Figure 9

Section 4
Map Applications

The nitrate probability map has a wide variety of applications. The nitrate probability map and associated data bases help provide a better understanding of the geology and land use in each county. The nitrate probability map is one more source of information that can be used when developing zoning and land use practices to prevent water quality degradation. Uses for these maps will depend on activities within the various counties. Mapping can help:

4. Identify public water supply wells that are at greatest risk to sources of nitrate-nitrogen;

5. Identify the community and nontransient noncommunity systems that should receive priority fro being phased into the wellhead protection program under state rule provisions;

6. Inform water operators about areas to avoid when siting new water supply wells;

7. Municipalities determine where resources should be focused to manage potential sources of nitrate-nitrogen;

8. Identify areas that may be susceptible to other contaminants, such as volatile organic chemicals, pesticides, or pathogens;

9. Municipal, county, and regional officials determine areas where development should not occur if private water supply wells and individual on-site wastewater disposal systems are proposed;

10. Identify areas where monitoring for nitrate levels in groundwater needs to be incorporated into local wellhead protection plans or local efforts to evaluate water quality in private water supply wells;

11. Target educational programs to address water quality problems;

12. Select water supply wells that will be used for evaluating trend analysis of nitrate levels; and

13. Develop effective approaches to remediation.

Currently, MDH is using the map to prioritize the preparation of source water assessments for noncommunity public water supply systems. Washington County used the Washington County probability map in their application for a successful Clean Water Partnership application for nitrate study. Brown, Nicollet, and Cottonwood Counties are using their nitrate maps for an education program to address well construction issues identified by the nitrate mapping process. Nicollet County is using the nitrate probability map to assist with wellhead protection in the St. Peter area. Wright County plans to use a probability map to identify areas of the county to begin a nitrate water quality data base. Often, the probability map is only one step in developing other strategies to protect the quality of drinking water.

Section 5
Recommendations

The Minnesota Department of Health is assisting Winona County to develop a county water quality data base that is compatible with the County Well Index. Funding for this new data base is being provided by the U.S. EPA, MDH, and Winona County. Data that has been collected as part of previous investigations and for regulatory programs will be entered into the new county data base, as well as new data that is generated. When this data base has sufficient information, the water quality results could be used as another layer in the nitrate probability map. This layer would help confirm the accuracy of the nitrate probability map.

Section 6
Bibliography

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