1996

Regional Analysis of Rural Domestic Well-water Quality – Southeastern Glacial Drift Area

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Rural Domestic Well-water Quality in the *Southeastern Glacial Drift Area*

Groundwater Region 11 from *Domestic Water-well Quality in Rural Nebraska*
(A data-analysis report for the Nebraska Department of Health compiled by D. C. Gosselin and others, 1996)

Geology and Hydrogeology

Groundwater Region 11 occupies the glacial drift area of southeastern Nebraska. The base of the principal groundwater-bearing units in the northern and western parts of the region is the Dakota Group. The Dakota Group consists of variable amounts of interbedded sandstone and shale. In the extreme western part of the region, Cretaceous shales and limestone of the Greenhorn-Graneros and Carlile formations form the base of the principal groundwater-bearing units. In the southeastern part of the region, the base of the primary groundwater system is the relatively impermeable Pennsylvanian and Permian limestone and shale. Overlying these bedrock units are Pleistocene deposits consisting of the debris from glacial ice sheets, streams, and wind deposition. Erosion created numerous ancient valleys (paleovalleys) that were usually filled with relatively coarse Pleistocene sand and gravel. In areas where valleys did not exist, they were filled with fine-grained materials, primarily glacial tills over which wind- blown silts or loess was deposited. (Geologic cross sections are available at the Conservation and Survey Division; Figure 1.)

The primary units from which groundwater is obtained are sand and gravel deposits associated with paleovalleys and along some modern stream valleys; these are usually of limited extent (Table 1). Nearly all major water supplies in this region come from the paleovalleys. The Dakota Group serves as a secondary source of groundwater where the primary Pleistocene sources are insufficient to meet water-supply needs. Because of its geologic variability, the Dakota Group's capacity to yield groundwater can differ over short distances; consequently, well yields can be difficult to predict. The thickness of the saturated groundwater-bearing units is generally less than 300 feet. Depth to the regional water table varies as a function of topographic location. In upland areas, depth to water may be greater than 200 feet, while it may be less than 50 feet in the bottomlands of the principal valleys. Depending on the groundwater-bearing unit and its location, total dissolved solids may differ from 200 to more than 1,000 milligrams per liter (mg/l). In some areas, the Dakota Group may have total dissolved solids exceeding 5,000 mg/l.

In many locations where these units are not available, perched groundwater is used. Perched water conditions occur in areas underlain by glacial till. Water from precipitation or applied from irrigation moves readily through the loess and/or isolated lenses of sand and gravel, but not through glacial till. As a result, water saturates the sediments above the till and a perched water table forms. Many domestic farm and stock wells have been developed in these perched water bodies. Because of the variability in water quality and in the limited distribution of groundwater-bearing units, rural water districts are common.

Results*

Well Characteristics

Characteristics of the wells sampled during 1994-1995 are summarized in Table GW11.1. The average year of well installation was 1967; nearly 80 percent of the wells were installed after 1960. The oldest well was installed in 1900. Available information indicates that 95 percent of 165 wells were drilled. Steel or PVC casing was used to complete 90 percent of the wells, and 68 percent had sanitary seals. The depth of the wells averaged 122 feet and ranged from 18 to 470 feet. Fifty-three percent of the wells have depths greater than 200 feet. Of the 163 wells for which information was available, the well diameter averaged 6.3 inches, and 26 percent of the 163 wells have diameters greater than 6 inches. The minimum diameter was 1 inch, and the maximum was 72 inches. Each well is used by an average of 3.3 individuals. Nitrogen and pesticides were used at 92 percent of 161 sites.

**** Where associations, relationships, increases or decreases are discussed, our analyses have determined they are statistically significant. If the relationship between contaminant concentrations and various factors are not discussed, they have not been demonstrated to be statistically significant.***

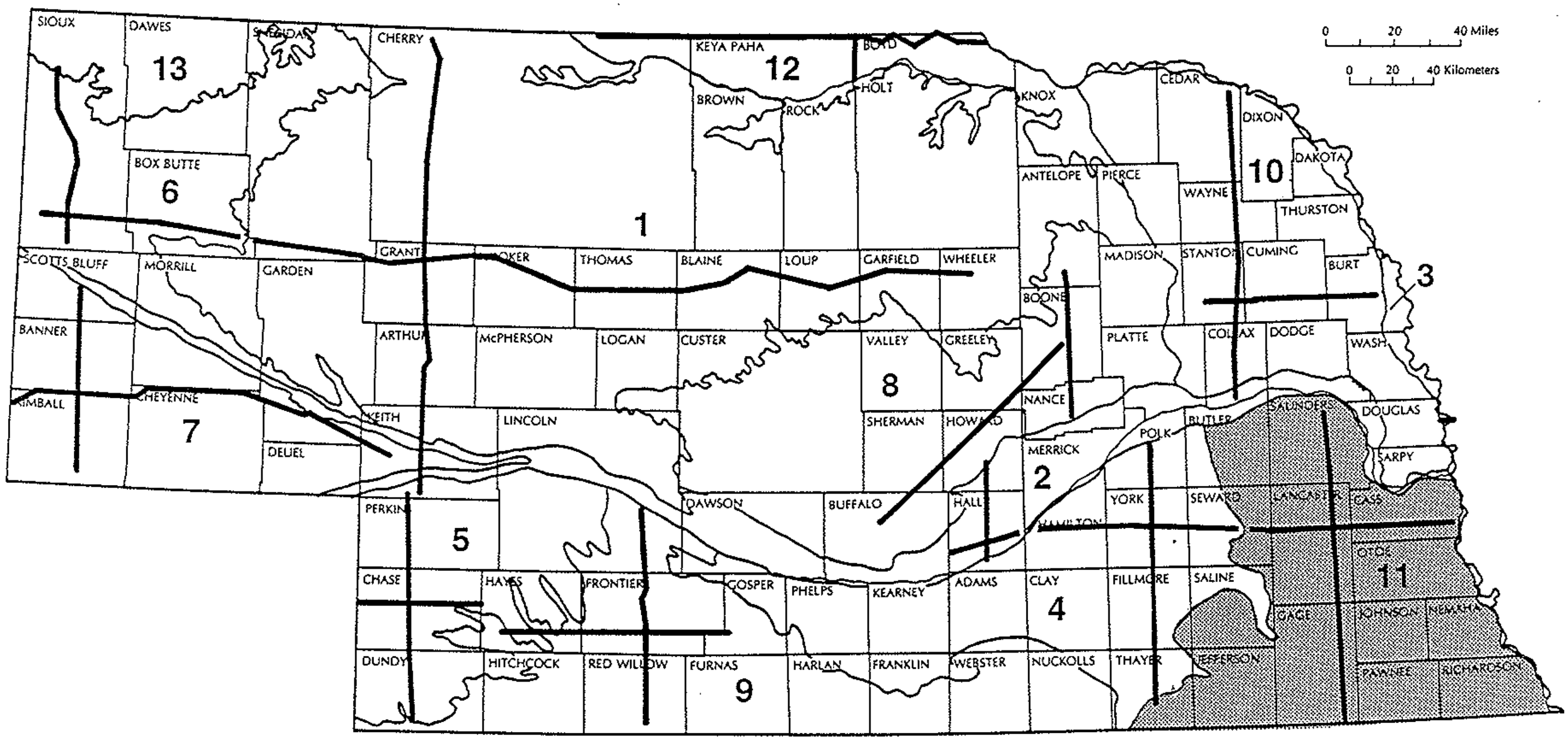

Fig. 1—*Locations of geologic cross sections* (Region 11 in gray)

Water-bearing Properties of Major Rock Units in Nebraska

From *The Groundwater Atlas of Nebraska* — Conservation and Survey Division, University of Nebraska-Lincoln

Era	Period	Epoch	Millions of years	Group or Formation	Lithology	Water-bearing Properties
Cenozoic	Quaternary	Holocene	0.01		Sand, silt, gravel and clay	Principal groundwater reservoir; Ogallala is absent in east and northwest. Arikaree is present primarily in west.
		Pleistocene	~2.0			
		Pliocene	5		Sand, gravel and silt	
		Miocene	24	Ogallala	Sand, sandstone, siltstone and some gravel	
		Oligocene		Arikaree	Sandstone and siltstone	
			37	White River	Siltstone, sandstone and clay in lower part	Secondary aquifer in west; water may be highly mineralized.
		Eocene	58	Rocks of this age are not identified in Nebraska.		
		Paleocene	67			
Mesozoic	Cretaceous	Late Cretaceous		Lance	Sandstone and siltstone	Generally not an aquifer; yields water to few wells in west.
				Fox Hills		
				Pierre	Shale and some sandstone in west	Generally not an aquifer; sandstones in west yield highly mineralized water to few industrial wells.
				Niobrara	Shaly chalk and limestone	Secondary aquifer where fractured and at shallow depths, primarily in east.
				Carlile	Shale; in some areas contains sandstones in upper part	Generally not an aquifer; sandstones yield water to few wells in northeast.
			98	Greenhorn-Graneros	Limestone and shale	Generally not an aquifer, yields water to few wells in east.
		Early Cretaceous	144	Dakota	Sandstone and shale	Secondary aquifer, primarily in east; water may be highly mineralized.
	Jurassic		208		Siltstone and some sandstone	Not an aquifer
	Triassic		245		Siltstone	Not an aquifer
Paleozoic	Permian		286		Limestone, dolomites, shales and sandstone.	Some sandstone, limestone and dolomites are secondary aquifers in east. Water may be highly mineralized.
	Pennsylvanian		320			
	Mississippian		360			
	Devonian		408			
	Silurian		438			
	Ordovician		505			
	Cambrian		570			
Precambrian						

Table 1—Hydrostratigraphic chart (showing water-bearing rock units) of Nebraska Time divisions are not to scale.

Table GW11.1. Summary of Domestic Well Characteristics and Water Quality Data (1994-95)

Well characteristics

	Number of wells	Mean	Minimum	Maximum	Standard deviation
Well Installation Date					
All	133	1967	1900	1989	21
<1940	17				
1940-1969	10				
1960-1979	80				
1980-present	26				
Well Depth (feet)					
All	144	122	18	470	83
<50	21				
50-99	47				
100-199	53				
>200	23				
Well Diameter (inches)					
All	163	6.3	1.0	72.0	7.9
<2	1				
2-3	9				
4-5	110				
6-7	20				
>8	23				
Number of Well Users	166	3.3	0.0	12.0	1.9
Distance to Contaminant Source (feet):					
cesspool	11	167	100	500	116
septic	126	168	25	1000	163
waste lagoon	17	741	150	1800	566
barnyard	126	304	6	2600	447
pasture land	134	590	5	3500	595
cropland	160	334	5	2600	425
Well Type:					
drilled	156				
driven	1				
dug	8				
other	0				
Casing Material:					
steel	46				
plastic	85				
concrete	2				
brick	4				
tile	9				
other	0				
Sanitary Seal:					
yes	106				
no	51				
Casing in Pit:					
yes	32				
no	133				
Nitrate Used:					
yes	148				
no	13				
Pesticide Used:					
yes	148				
no	13				

Water Quality Data

	Number of wells	Mean	Median	Minimum	Maximum	Standard deviation	Detections
Nitrate as Nitrogen (ppm NO3-N)							
1994-1995	168	7.7	3.4	0.1	98.2	12.3	
Bacteria (colonies per 100 ml)							
1994-1995	160			0	100		22
Pesticides (ppb)							
1994-1995							
Atrazine	168			0	1.4		7

Nitrates

A summary of the nitrate data for the 168 wells sampled during this study are given in Table GW11.1. Their locations are given in Figure GW11.1 The nitrate-nitrogen concentrations ranged from less than 0.1 parts per million (ppm) to a maximum of 98.2 ppm. Nearly 49 percent of the wells had concentrations less than 3 ppm (Figure. GW11.2), indicating that more than 51 percent of the wells have been affected by nitrate contamination. Slightly more than 24 percent of the wells exceeded the 10-ppm maximum contaminant level (mcl) for nitrate. The average value for all samples was 7.7 ppm, and the median value was 3.4 ppm.

Figure GW11.2 indicates only a small increase from 1985-1989 to 1994-1995 in the number of wells having concentrations exceeding 15 ppm. The remaining categories show relatively little change between the two sampling periods. The Wilcoxon Signed Rank Test indicated that for the 134 wells that had different concentrations from one period to the other, there is no statistically significant difference in their concentrations.

The factors that may influence the nitrate-nitrogen concentrations in these rural domestic wells are divided into three groups: 1) well-construction factors: casing type, age, diameter, well completion in or out of a pit, sanitary seal, and well type; 2) distance factors: distance to cesspool, septic systems, waste lagoons, barnyards, pasture, and cropland; and 3) hydrogeologic and site factors: well depth, depth to water, landscape and soil characteristics (Figure GW11.1), and agricultural chemical use.

Well-construction factors

We grouped the nitrate-nitrogen concentrations according to the well-construction factors, sanitary seal (yes or no), casing completion (in or out of pit), and well type (drilled or not). For these groupings, the Mann-Whitney Test demonstrated a statistically significant difference between the nitrate-nitrogen concentrations, as indicated by the median values, which were related to wells having casings completed in a pit (4.6 ppm) compared with wells completed outside a pit (2.5 ppm), and wells lacking sanitary seals (5.7 ppm) compared with wells having sanitary seals (2.2 ppm). Furthermore, the Fisher Exact Test indicated that those wells lacking a sanitary seal also were likely to have nitrate-nitrogen concentrations greater than 5 ppm. For the well-type grouping, the Mann-Whitney Test indicated different concentrations for drilled (median of 2.7 ppm) compared to driven or dug wells (median of 5.7 ppm); however, the p value of 0.07 did not fulfill our statistical objectives. Application of the Fisher Exact Test indicated that non-drilled wells (driven and dug wells) were more likely to have concentrations greater than 5 ppm.

Use of the Kruskal-Wallis Test indicated a statistically significant difference among the nitrate concentrations associated with the well-casing groups: steel, PVC, brick, and tile. Examination of individual relationships between the groups using the Mann-Whitney Test showed that there were statistically significant differences between the nitrate-nitrogen concentrations of the steel-cased wells (median of 5 ppm) and wells cased with PVC (median of 2.3 ppm). An expected result was the distinct differences between PVC-cased wells (median of 2.3 ppm) and tile-cased wells (median of 22.4 ppm). The Fisher Exact Test also indicated tile-cased wells were more likely to have nitrate-nitrogen concentrations greater than 5 ppm.

The Spearman Test indicated that for wells having greater than 5 ppm nitrate-nitrogen, there was an association of higher concentrations with larger diameter wells. In addition, there was a significant association between higher nitrate-nitrogen concentrations and older wells. The Mann-Whitney Test compared nitrate concentrations for wells installed prior to and after 1960 and indicated that wells older than 1960 had statistically higher values (median of 5.2 ppm) than their younger counterparts (median of 2.5 ppm). For the diameter groups, all of them had similar degrees of nitrate contamination, with the exception of wells having diameters greater than 8 inches. These wells had significantly higher concentrations (median of 6.6 ppm), compared with those wells having diameters between 4 and 5 inches (median of 2.5 ppm).

Distance factors

The Spearman Test did not indicate any significant relationships between nitrate-nitrogen and the distance factors.

Nebraska Department of Health
Rural Domestic Well Water Quality Study: 1994-1995
Nitrate Sampling Locations - Region #11

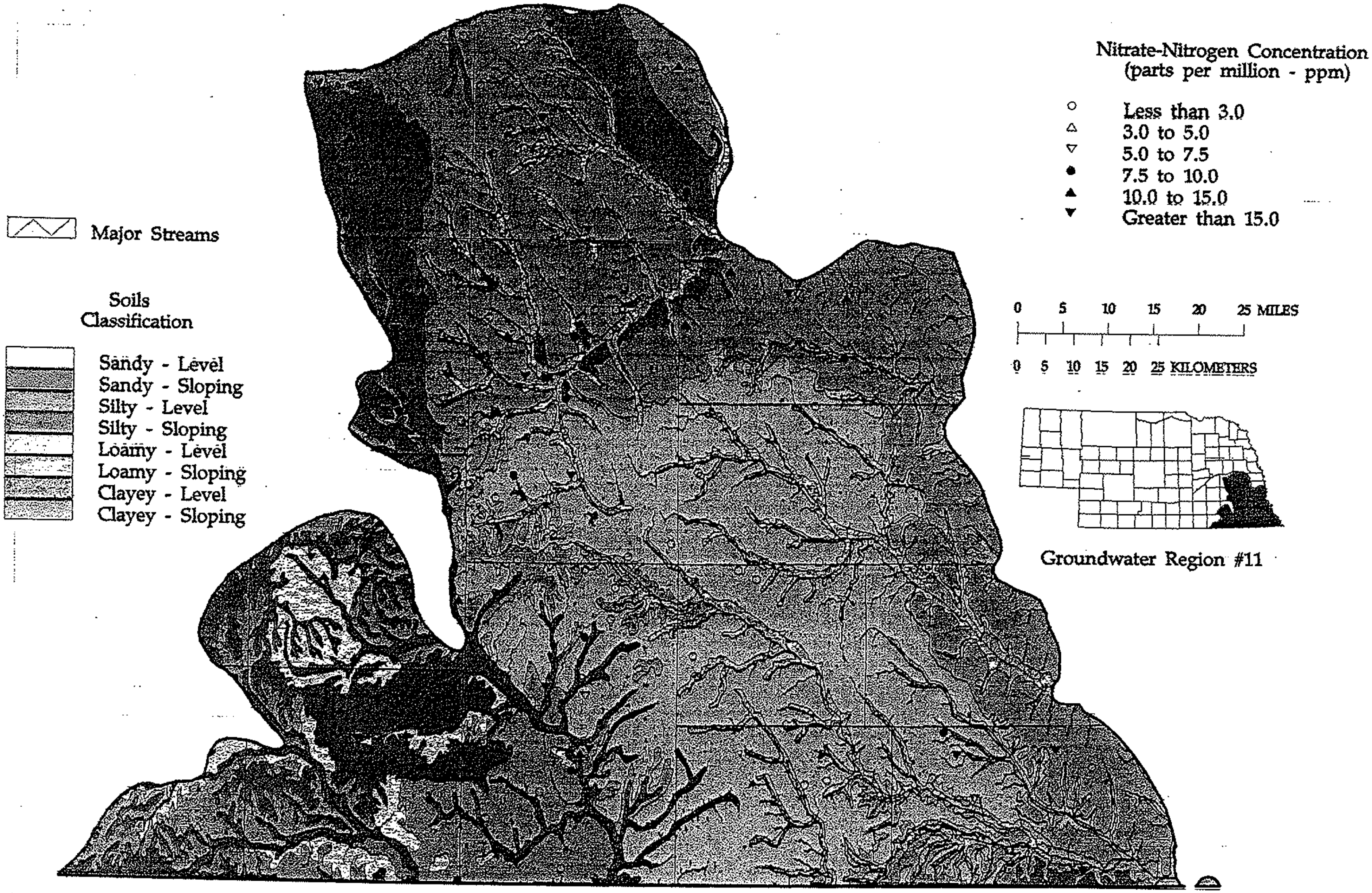

Figure GW11.1

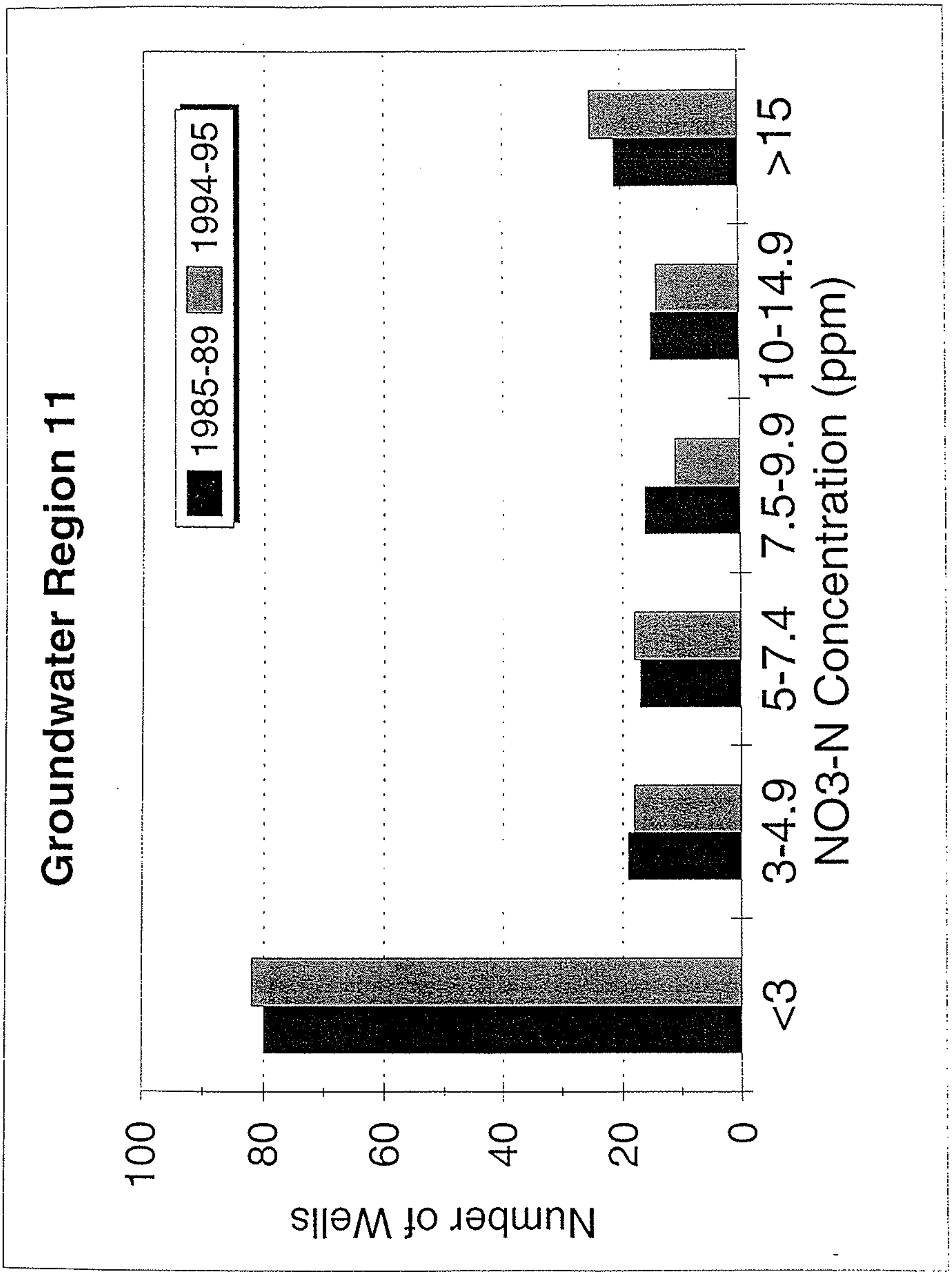

Figure GW11.2

Hydrogeologic and site factors

Nitrogen was used on the premises in 92 percent of the 173 wells where this data was provided. Although the median for wells where nitrogen was used was 3.7 ppm higher than the median of 1.6 ppm where it is not used, the Mann-Whitney Test did not support any differences between the wells.

A significant association was indicated between higher nitrate concentrations and wells having shallower depth.

We evaluated the nitrate-nitrogen concentrations related to the well-depth groups in Table GW11.1 using the Kruskal-Wallis Test. This test supported statistically significant differences between the groups. The Mann-Whitney Test indicated no differences between wells less than 50 feet deep and wells 50 to 99 feet deep. However, there were significant differences between the median values of wells less than 50 feet deep (median of 8.9 ppm), wells 50 to 99 feet deep (median of 7.6 ppm), wells 100 to 200 feet deep (median of 2.4 ppm) and wells greater than 200 feet deep (median of 0.1 ppm).

Wells in this region occur in areas dominated by soils in class 4 (47 percent; silty-sloping), in class 3 (26 percent; silty-level) and in class 8 (15 percent; clayey-sloping) (Figure GW11.1). Using the Chi-Square and Fisher Exact tests indicated that wells associated with class 3 soils were more likely to have concentrations greater than 5 ppm when compared to wells associated with classes 3 and 8.

Pesticides

Of the 168 wells analyzed for pesticides in this study, only 7 wells had detectable atrazine (Figure GW11.3; Table GW11.1). Concentrations ranged from 0.2 to 1.4 ppb.

The limited data indicated a possible association between pesticide occurrence and nitrate concentrations greater than 5 ppm. Four of the 7 wells that had pesticide detections had nitrate-nitrogen concentrations greater than 23 ppm. Five out of those seven wells had depths less than 100 feet, and four were less than 65 feet deep. In addition, one well was 15 feet from cropland.

Bacteria

A summary of the coliform-bacteria data for the 160 wells sampled during the 1994-1995 study are summarized in Table GW11.1. Their locations are shown in Figure GW11.4. Bacteria data expressed in colonies per 100 ml of water ranged from 0 to greater than 100, but more than 86 percent of the wells had no detectable coliform bacteria. This indicates that 14 percent of the wells have been affected by bacterial contamination and exceeded the mcl for bacteria. This number of wells affected by bacterial contamination represents a drop of nearly 5 percent from the previous sampling. Although an apparent decrease is indicated, the Wilcoxon Signed Rank Test did not support any significant difference for the 52 wells that had different counts between the two periods.

The Spearman Test indicated a statistical association between the occurrence of coliform bacteria and nitrate-nitrogen concentrations but did not indicate any associations with the distance factors.

Examination of the 22 wells that have been affected by bacterial contamination indicated that 55 percent have diameters greater than 10 inches. These wells are cased with either tile, brick or concrete. An additional 27 percent of these contaminated wells are less than 100 feet deep.

Discussion

Results of our analyses indicated statistically significant associations between higher nitrate-nitrogen concentrations and: 1) well-construction factors that include lack of sanitary seals; diameters greater than 8 inches; steel instead of PVC casing; tile casing instead of PVC casing; completed in a well pit; driven or dug wells; and wells installed prior to 1960; 2) lesser depths to water; and 3) silty-level soils instead of silty-sloping and clayey-sloping soils. In addition, no apparent increase in nitrate concentrations is indicated in the wells sampled during the 1985-1989 and the 1994-1995 sampling periods. No statistical change in degree of bacterial contamination was indicated.

The impact of agricultural chemical contamination on domestic wells in the southeasternmost part of region 11 has been evaluated by Exner and Spalding (1985). Their basic conclusion was that point sources--commonly barnyards--and poor well construction are the primary contributors to the degradation of water quality in rural domestic wells in this region. The relationships between nitrate-nitrogen concentration and basically all the well

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Pesticide Sampling Locations - Region #11

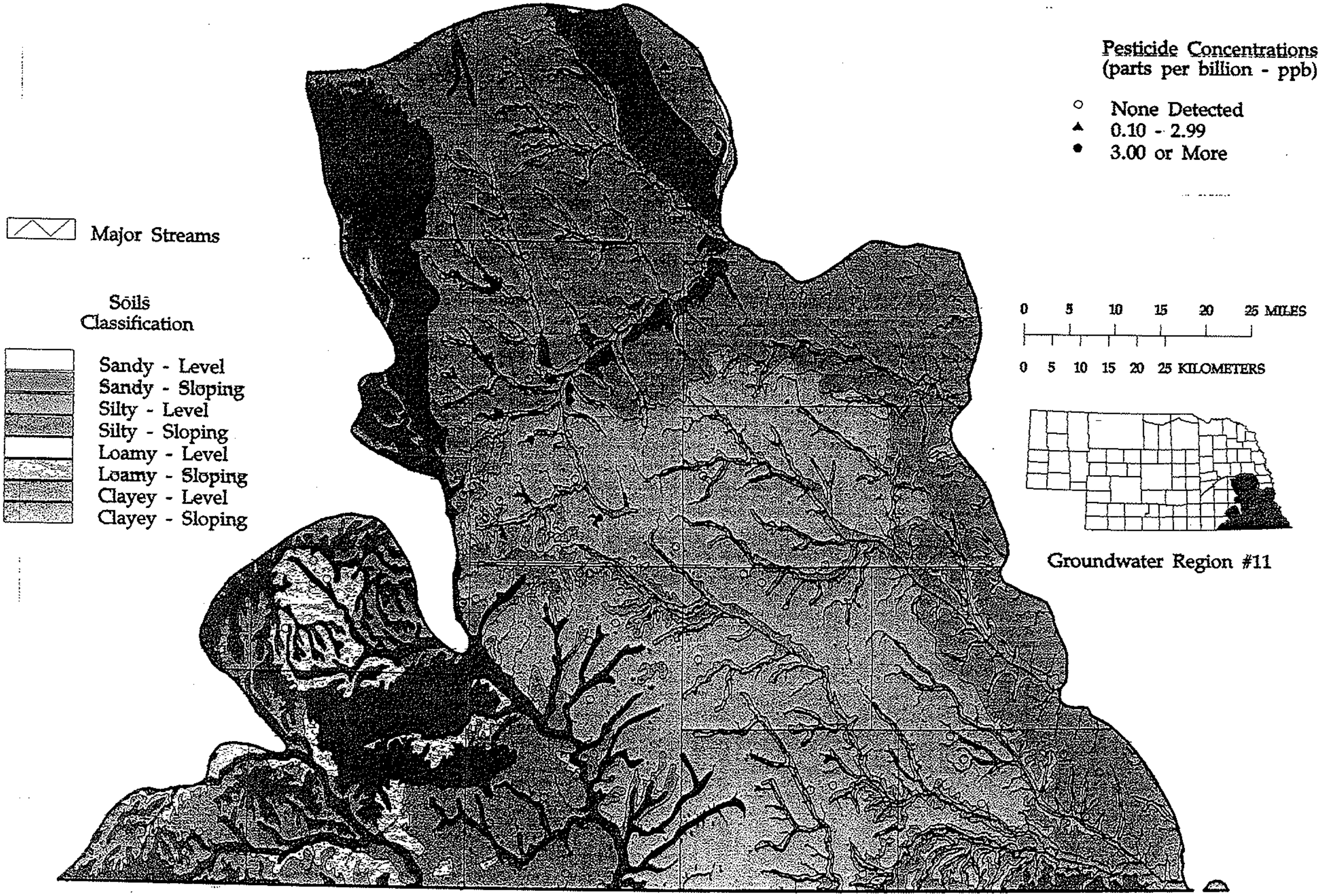

Figure GW11.3

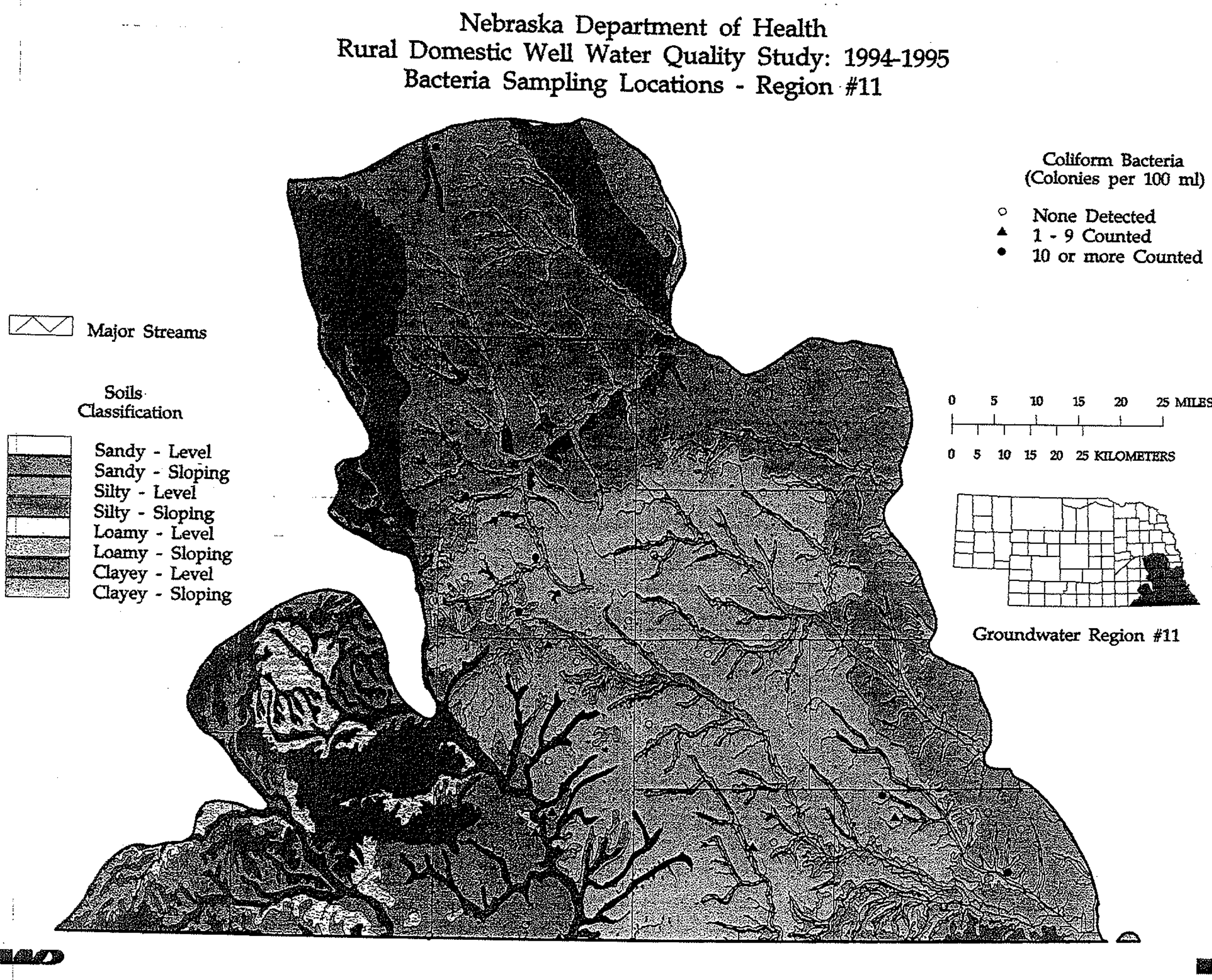

Figure GW11.4

construction characteristics support this conclusion. Associations of higher nitrate concentrations with shallow wells is also consistent with well-construction parameters: most shallow wells were either dug or driven, had tile, concrete or brick casing, and had diameters exceeding 8 inches. Furthermore, seven out of nine tile-cased wells had nitrate-nitrogen concentrations exceeding 6 ppm and five exceeded 22 ppm. Bacteria data is consistent with these observations. The last installation date for concrete, tile, or brick casings was 1970, 1960, and 1920, respectively, indicating that using water-tight casings has helped minimize contamination problems. It should be noted, however, that although nitrate-nitrogen concentrations are predominantly controlled by point sources of contamination and well-construction problems, the atrazine data and the related high nitrate-nitrogen concentrations clearly reflect nonpoint-source contamination.

The analysis of the depth to water groups indicates that wells should be installed to depths greater than 100 feet whenever possible. This is supported also by the available, but limited, pesticide data. Unfortunately, in many areas, this may not be possible because there is not an adequate groundwater-bearing unit or the natural water quality is poor. Although the statistical analysis did not indicate significant differences in those groups of wells less than 100 feet deep (that is, wells less than 50 feet and 50 to 100 feet), the decrease in the median values with increasing well depth indicates that shallow wells are the most likely to become contaminated. If there is no other choice than to install a shallow well, well-construction guidelines should be adhered to as strictly as possible. It is important to use every effort to minimize the impact of point sources by use of proper well construction. Because of the quantity and quality problems, rural water districts have become common in this region.

As expected, tile-cased and the other open-jointed cased wells had a higher incidence of nitrate-nitrogen contamination than PVC-cased wells. More interestingly, however, steel-cased wells had statistically higher concentrations than PVC-cased wells. Although this relationship at first was not expected, there is a high risk of uncoated steel corroding in glacial till, which dominates the landscape (SCS, 1985). This potential for corrosion indicates that wells should not be cased with steel. Of the sampled wells, the last to be installed with steel casing was in 1978. This probably reflects the lower cost of PVC pipe.

Lack of association of nitrate with distance and well-construction factors, which are often related to point sources, indicates that these sources have not contributed significantly to variations in the concentration of nitrate-nitrogen in individual wells. However, distance between a well and a point source is only one of the factors that determines whether a well will become contaminated. Other factors are the spatial relationship of the well to the point source--that is, whether the well is near or far, upgradient, downgradient, or located laterally from the point source. Furthermore, another important factor is whether the groundwater-bearing units have similar properties. The groundwater-bearing units include stratigraphic layers that affect the direction and rate of local groundwater movement.

Regarding hydrogeologic conditions, wells associated with silty-level soils had a greater likelihood of having nitrate contamination than the silty-sloping and clayey-sloping soils. This is consistent with water falling on level areas, usually in the higher part of the landscape, having greater opportunity to infiltrate. In addition, the association to soil type supports a contribution from nonpoint sources.

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