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Regional Analysis of Rural Domestic Well-water Quality – South Central Plains

D. C. Gosselin
University of Nebraska - Lincoln

J. Headrick

X- H. Chen

S. E. Summerside

Rural Domestic Well-water Quality in the *South Central Plains*

Groundwater Region 4 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 4 occupies the South Central Plains area of Nebraska and has an abundant groundwater supply (Figure 1). Pliocene and Pleistocene sand and gravel deposits, as well as the Ogallala Group, are the primary sources of groundwater and yield substantial amounts of water to wells. The Tertiary Ogallala Group, occurring in the western part of region, was deposited on the eroded, southeastern-sloping surface of the Cretaceous rocks. As much as 200 feet thick, the Ogallala Group consists of lime-cemented sand and gravel, loess-like silt, and unconsolidated sand and gravel. The overlying Quaternary system consists of more than 500 feet of clay, silt, sand, and gravel deposited by glacial and river-related processes. Deposits of wind-blown silt (loess) mantle the surface. (Geologic cross sections for Region 4 are available at the Conservation and Survey Division; Figure 1)

In the eastern part of the region, the base of the principal groundwater-bearing units is the Lower Cretaceous Dakota Group, which consists of interbedded layers of sandstone and shale (Table 1). The Dakota Group ranges in thickness from 350 to 400 feet and overlies less permeable Permian shale and limestone deposits. Although not widely used in region 4 as a water supply because of its highly mineralized water and relatively deep depths to water, the Dakota Group could be used as a secondary source of groundwater. In the rest of the region, the base of the principal groundwater-bearing units is the top of the low-permeability deposits of shale, shaly chalk and limestone that make up the following Upper Cretaceous formations that overlie the Dakota Group: Greenhorn-Graneros, Carlile, Niobrara, and Pierre.

Depth to the regional water table ranges from less than 50 feet to more than 200 feet. The saturated thicknesses of the several geologic units range from about 100 feet or less to about 300 feet or more. Generally, the water quality is good, and dissolved concentrations of mineral constituents typically range from 200 to 500 parts per million (ppm).

Results*

Well Characteristics

The characteristics of the wells sampled in this study are summarized in Table GW4.1. The average year of installation was 1972, and nearly 80 percent of the wells were installed between 1960 and 1979; the oldest well was installed in 1930. Where information was available, more than 99 percent of the wells were drilled and cased with PVC or steel casing. Ninety-six percent had sanitary seals. The average depth of the wells was 144 feet. Well depths ranged from 15 to 400 feet. Seventy-eight percent of the wells had depths between 100 and 199 feet. Of the 230 wells for which information was available, the average well diameter was 4.3 inches. Ninety percent of the samples have diameters between 4 and 5 inches. The minimum diameter was 3 inches; the maximum was 10 inches. Each well is used by an average of 3.5 individuals. Nitrogen was used at nearly 95 percent of the 276 sites. Pesticides were used at 97 percent of the sites.

Nitrates

The nitrate-concentration data for the 276 wells sampled during the 1994-1995 study are summarized in Table GW4.1. Their locations are shown in Figure GW4.1. The nitrate-nitrogen concentrations ranged from less than 0.1 ppm to a maximum of 50.2 ppm. Thirty-four percent of the wells had concentrations less than 3 ppm (Figure GW4.2); it is concluded that the other two-thirds have been affected by nitrate contamination. Nearly 23 percent of the wells exceeded the 10 ppm maximum contaminant level (mcl) for nitrate. The average value for all samples was 7.3 ppm, and the median value was 5.3 ppm.

**** 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.***

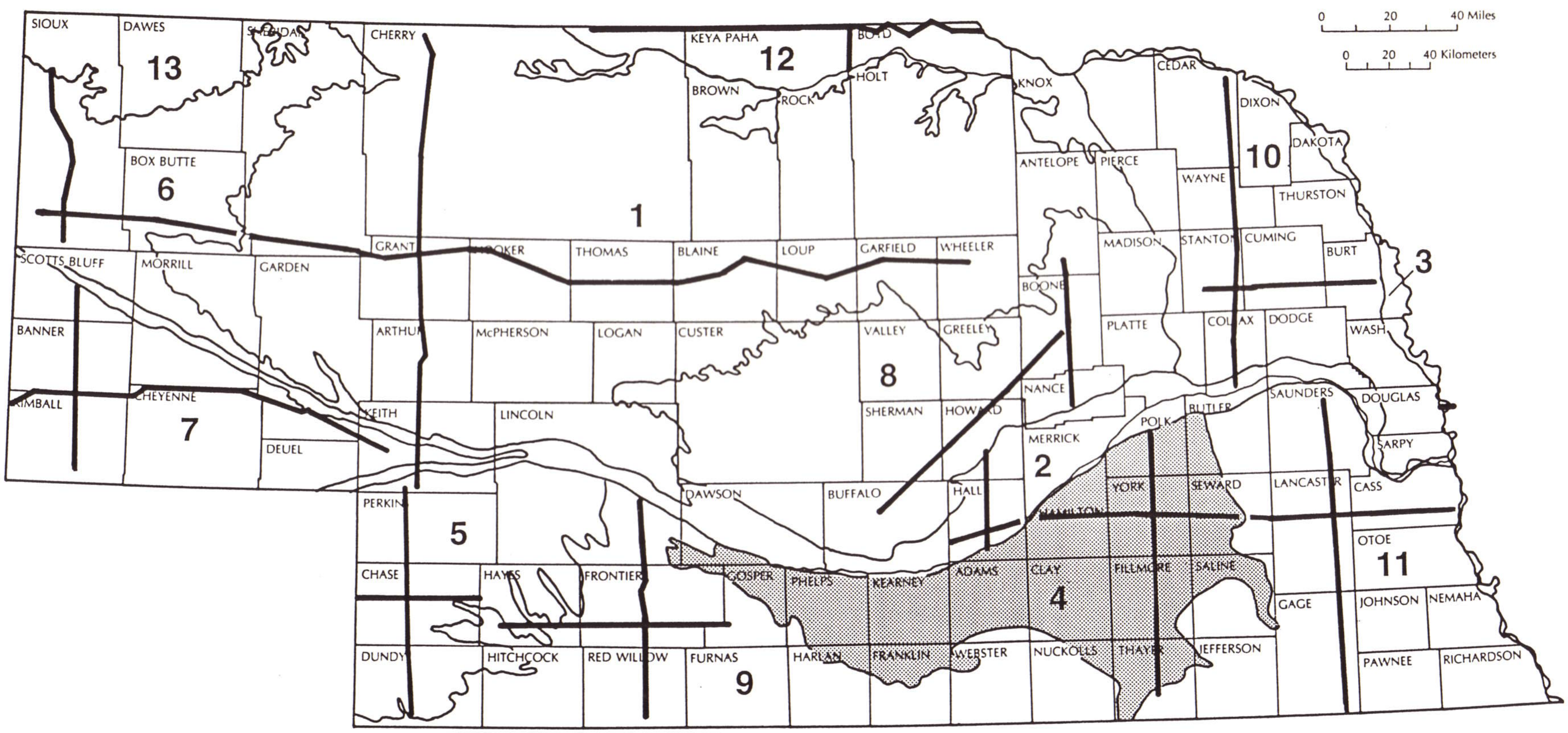

Fig. 1—*Locations of geologic cross sections* (Region 4 in gray)

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.

Nebraska Department of Health
Rural Domestic Well Water Quality Study: 1994-1995
Nitrate Sampling Locations - Region #4

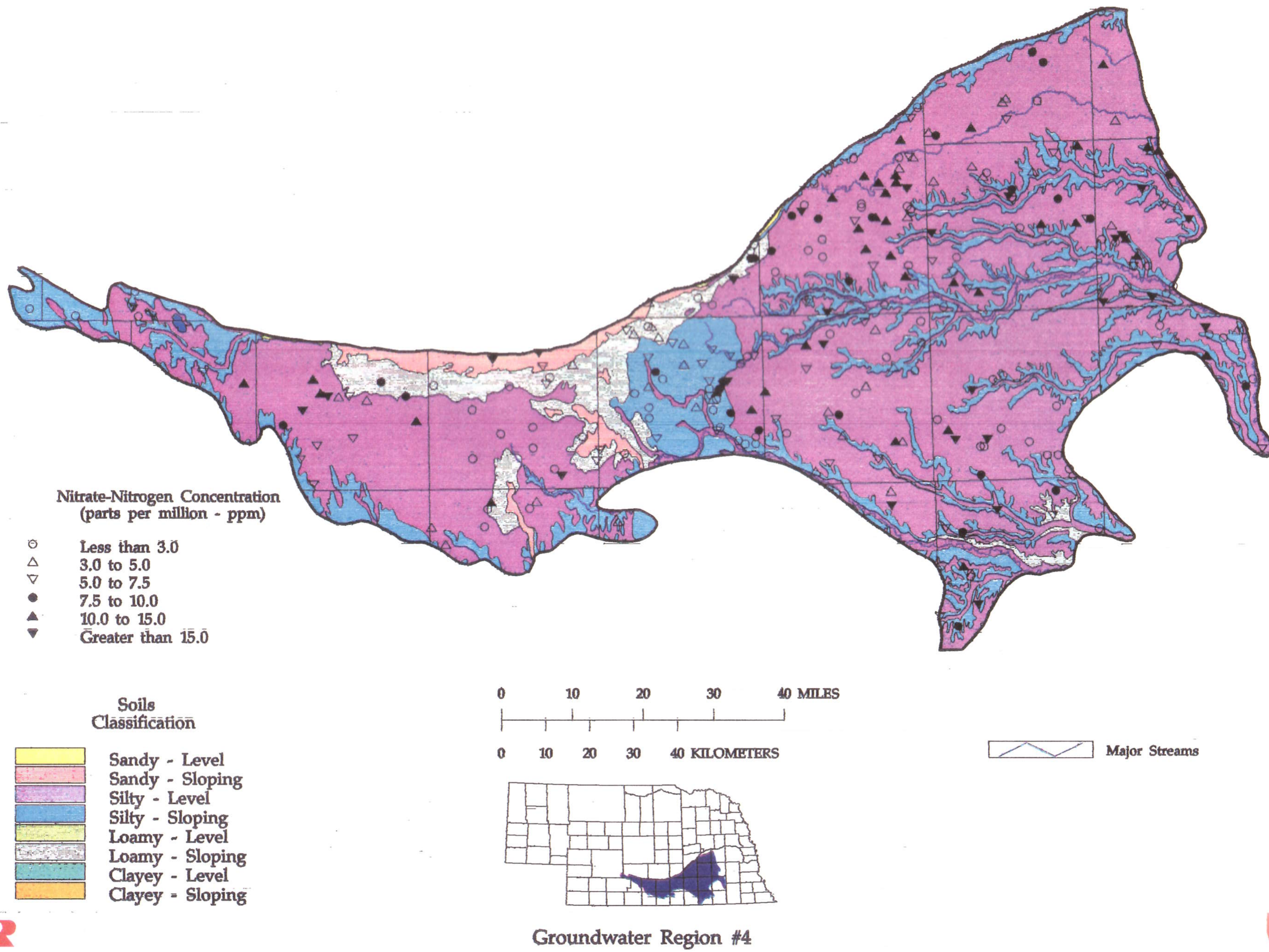

Figure GW4.1

Table GW4.1. 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	239	1972	1930	1987	8
	<1940	2				
	1940-1969	12				
	1960-1979	191				
	1980-present	34				
Well Depth (feet)						
	All	220	144	15	400	48
	<50	3				
	50-99	16				
	100-199	172				
	>200	29				
Well Diameter (inches)						
	All	230	4.3	3	10	0.9
	<2	0				
	2-3	3				
	4-5	208				
	6-7	14				
	>8	5				
Number of Well Users		231	3.4	1	10	1.7
Distance to Contaminant Source (feet):						
	cesspool	21	129	35	260	64
	septic	234	119	15	1240	100
	waste lagoon	20	678	50	2600	648
	barnyard	177	219	5	2600	411
	pasture land	137	723	10	2600	777
	cropland	232	204	15	1350	149
Well Type:						
	drilled	273				
	driven	2				
	dug	0				
	other	0				
Casing Material:						
	steel	35				
	plastic	217				
	concrete	1				
	brick	0				
	tile	1				
	other	0				
Sanitary Seal:						
	yes	255				
	no	12				
Casing in Pit:						
	yes	41				
	no	230				
Nitrate Used:						
	yes	259				
	no	3				
Pesticide Used:						
	yes	257				
	no	7				

Water Quality Data

		Number of wells	Mean	Median	Minimum	Maximum	Standard deviation	Detections
Nitrate as Nitrogen (ppm NO3-N)								
1994-1995		276	7.3	5.3	0.1	50.2	8.1	
Bacteria (colonies per 100 ml)								
1994-1995		237			0	100		33
Pesticides (ppb)								
1994-1995								
	Atrazine	276			0	13.6		25

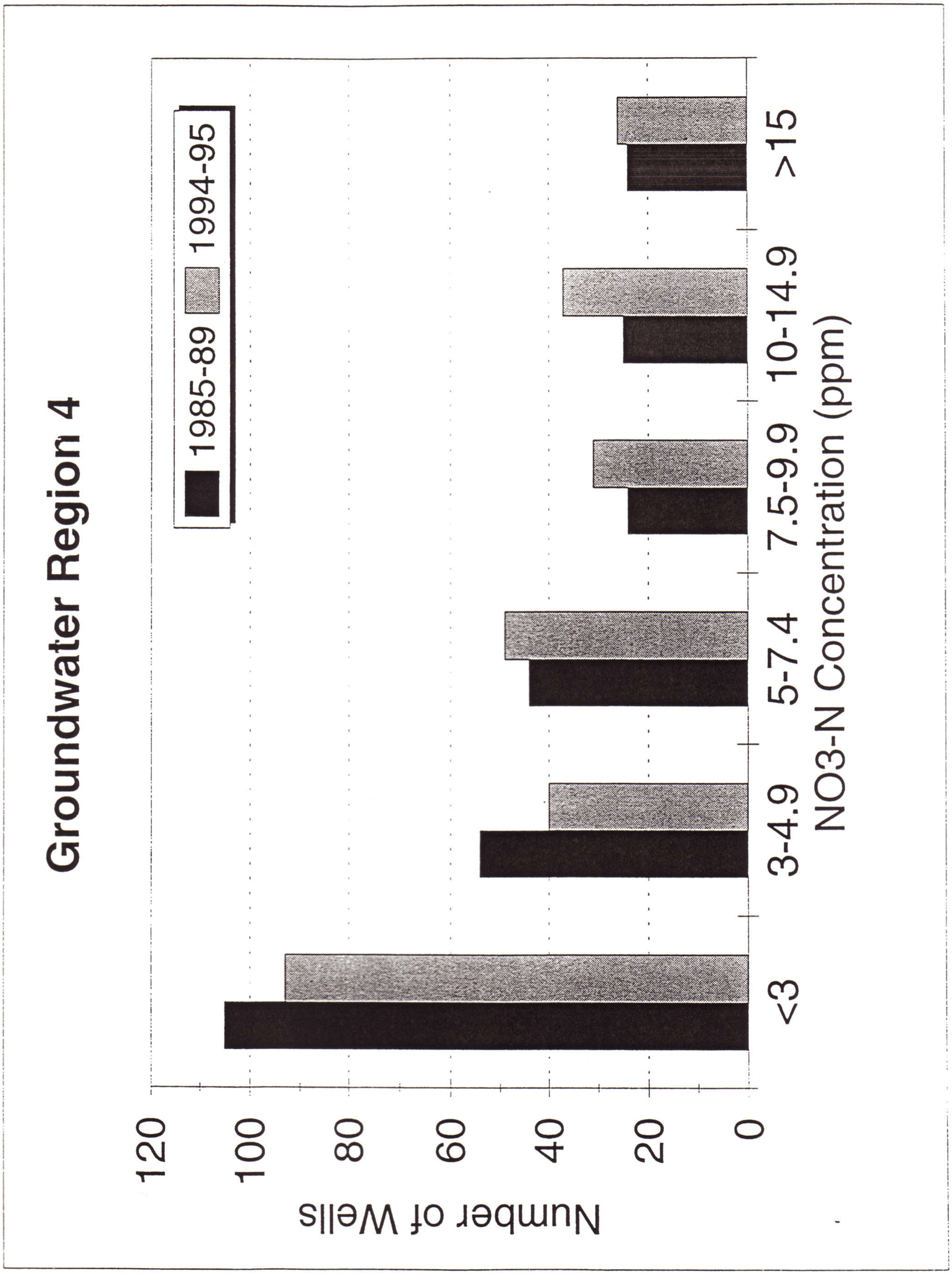
Groundwater Region 4
1985-89
1994-95
Number of Wells
0
20
40
60
80
100
120
<3
3-4.9
5-7.4
7.5-9.9
10-14.9
>15
NO3-N Concentration (ppm)

Figure GW4.2

Figure GW4.2 shows a general shift to higher nitrate concentrations from the 1985-1989 sampling period to the 1994-1995 period; wells with concentrations greater than 5 ppm increased 10 percent, and wells with less than 5 ppm of nitrate-nitrogen decreased the same percentage. The Wilcoxon Signed Rank Test supports this observation. There is a statistically significant increase in the nitrate-nitrogen concentrations among the 256 wells that had different values between the two sampling periods.

The factors that may influence the nitrate-nitrogen concentrations in rural domestic wells are divided into three groups: 1) well-construction factors: casing type (for example, steel or PVC); installation date (age); diameter; well completion (in or out of a pit); sanitary seal
yes or no); and well type (drilled or not); 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 GW4.1), and agricultural chemical use.

Well-construction factors

The application of the Mann-Whitney Rank Sum Test and, where appropriate, the Fisher Exact Test did not indicate any significant relationships between the nitrate-nitrogen concentrations and any well-construction factors. Two exceptions were a well having concrete casing and another having tile casing. Usually, these two types of casings are not sealed. Moreover, the tile-cased well is only 30 feet deep. Their relatively high concentrations, 9.1 ppm and 13.4 ppm in 1994-1995, respectively, indicate that the lack of a sealed casing and the relatively shallow depth of the tile-cased well probably do not provide significant protection from local sources of contamination.

The Spearman Rank Order Correlation Test showed no statistical association between nitrate-nitrogen concentrations, installation date (age) and well diameter. The Kruskal-Wallis Test yielded no significant relationship between nitrate-nitrogen concentrations and age or well group.

Distance factors

These factors relate to the distance between a well and likely sources of contamination, which are typically a point source. The Spearman Test indicated no association of nitrate-nitrogen concentrations and local contamination sources.

Hydrogeologic and site factors

Nitrogen was used on the premises in more than 99 percent of the 262 wells where such data were provided. No relationships between nitrate contamination and well depth were indicated by the Spearman Test or Kruskal-Wallis Test. However, there was an association between depth to water and nitrate concentrations for the 50 wells where such information was available.

More than 90 percent of the area in which the sampled wells are located is dominated by soils of class 3 (63 percent; silty-level) and class 4 (27 percent; silty-sloping) (Figure. GW4.1). Using the Chi-Square Test to analyze the relationships between soil characteristics and nitrate-nitrogen concentration groups (<3, ≥ 3 to <5, ≥ 5 to < 10, ≥ 10 ppm) indicated no statistical differences. However, use of the Fisher Test indicated a difference between the soil classes; wells in level-silty soils were more likely than those in sloping-silty soils to have concentrations greater than 10 ppm.

Pesticides

Out of the 276 wells analyzed for pesticides, only 25 (about 9 percent) had detections (Figure. GW4.3). Atrazine was the only pesticide detected, and the highest concentration was 13.6 parts per billion (ppb). Three wells exceeded the 3 ppb mcl. The Wilcoxon Test indicated no differences in the pesticide concentrations for 42 wells that had different concentrations between the two sampling periods.

Atrazine is associated with higher nitrate concentrations (Spearman Test). The average nitrate-nitrogen concentration for wells having atrazine was 14.3 ppm, and more than 50 percent exceeded the 10 ppm mcl for nitrate-nitrogen.

Bacteria

Coliform bacteria data for the 237 wells analyzed during this study are summarized in Table GW4.3. Their locations are shown in Figure GW4.4. The bacteria data range from 0 to greater than 100 colonies per 100 ml of

Nebraska Department of Health
Rural Domestic Well Water Quality Study: 1994-1995
Pesticide Sampling Locations - Region #4

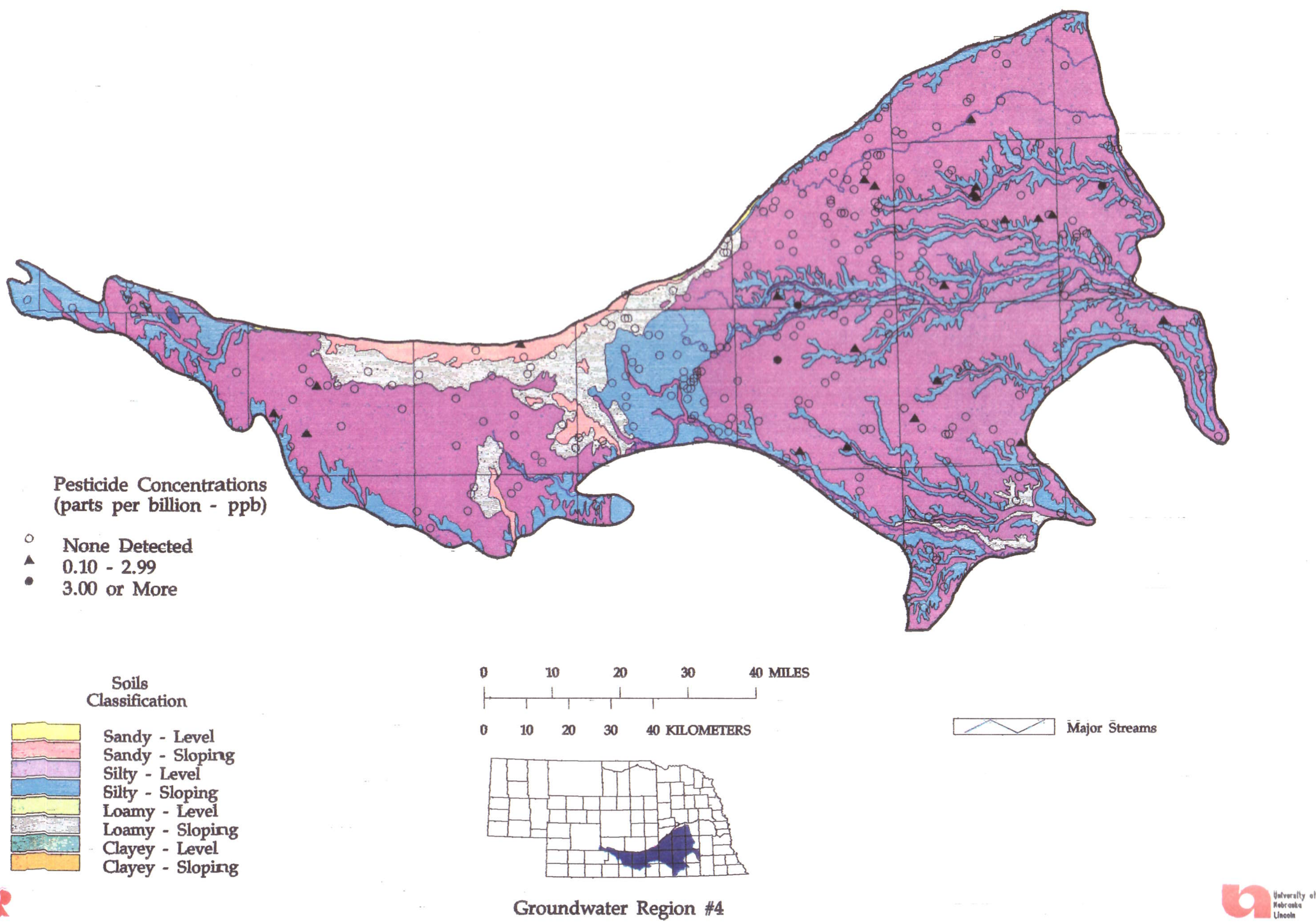

Figure GW4.3

Nebraska Department of Health
Rural Domestic Well Water Quality Study: 1994-1995
Bacteria Sampling Locations - Region #4

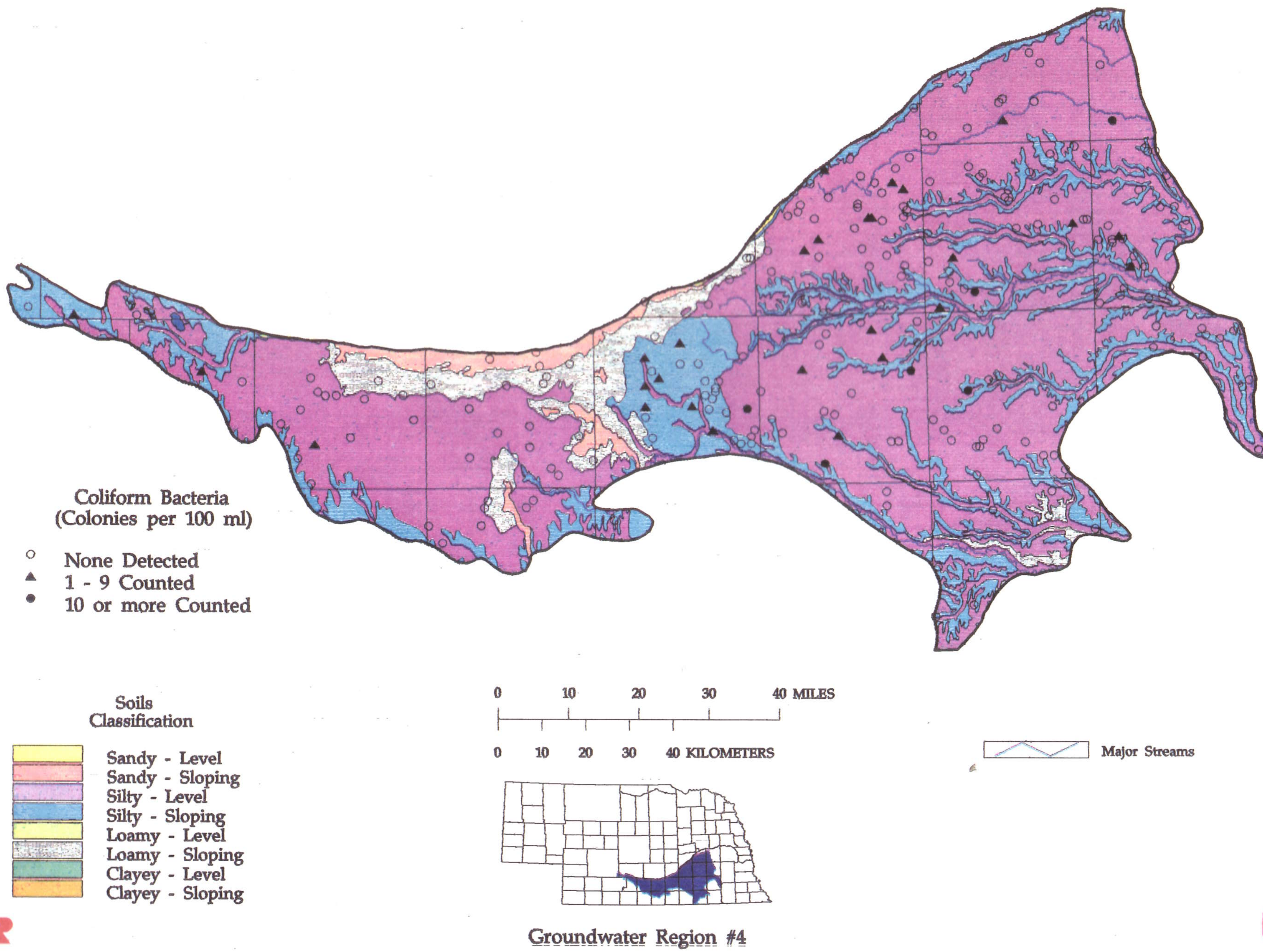

Figure GW4.4

water. Water sampled from nearly 86 percent of the wells had no detectable coliform bacteria, indicating that water from less than 14 percent of the wells has been affected by bacterial contamination. Of the wells affected by bacteria, 45 percent had only one detectable colony. Twenty-four percent had nitrate-nitrogen concentrations greater than 10 ppm.

Comparing the 1994-1995 and 1985-1989 data using the Wilcoxon Test indicated that in the 64 wells that had different counts of bacteria between the two periods, an overall decrease in coliform bacteria occurred.

There were nearly no statistical relationships between coliform bacteria and distances to any possible point sources such as barnyards or septic systems. One exception was that nearly 55 percent of the wells were less than 100 feet from a barnyard. The Spearman Test did indicate that wells having higher coliform counts had generally higher pesticide concentrations. However, this was controlled by only four wells that had pesticides associated with bacteria.

Discussion

Results of our analyses indicate significant associations between higher nitrate-nitrogen concentrations and: 1) greater depth to water; 2) silty-level soils compared to silty-sloping soils; and 3) greater pesticide concentrations. In addition, there has also been a general increase in nitrate concentrations in the wells sampled during the 1985-1989 period and again during the 1994-1995 period.

The impact of agrichemical contamination of groundwater in the eastern part of region 4 has been documented by a series of Special Protection Area studies by the Nebraska Department of Environmental Quality (Gottula, 1990, 1991; Gottula and Link, 1992). They concluded that nonpoint-source agricultural contamination is responsible for groundwater degradation. Further support for this conclusion comes from our examination of the relationship between nitrate-nitrogen concentrations and the landscape and soils characteristics, depth to water, and increasing pesticide concentrations. At first glance, the association of nitrate contamination with greater depth would seem contrary to what might be expected, especially if one considers contamination in the Platte River valley, where the opposite is true. However, in the context of a groundwater flow system, areas that are dominated by net addition of water to the groundwater system (net recharge areas) are typically associated with higher parts of the landscape where depths to water would be greater (Gosselin, 1991). In this region, the higher landscape positions are occupied by silty-level soils. These soils are more likely to be under agricultural production and are mostly level, minimizing overland runoff and enhancing infiltration. An alternative explanation is that in many parts of this region, several groundwater-bearing units are separated from one another by lower permeability materials. Many wells intersect these units and are gravel-packed from bottom to top. As a result, contamination can move from the upper groundwater-bearing units down the gravel pack to deeper units. The cascading wells in this region are evidence for vertical movement of water.

Lack of association of nitrate with distance and well-construction factors, 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 sitting 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.

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