Factors Affecting Nitrate Concentrations in Ground Water in Stafford County, Kansas

Margaret A. Townsend and David P. Young
Kansas Geological Survey, 1930 Constant Avenue, Lawrence, Kansas 66047

Abstract

Nitrate contamination of the Great Bend Prairie aquifer in south-central Kansas is more pronounced at shallower than at deeper portions of the aquifer. Factors influencing the occurrence of nitrate in the shallow ground water include irrigation-well density, subsurface clay lenses, and land-use practices. Ground-water samples were taken from 42 wells, including deep (irrigation) wells and shallow (domestic and stock) wells. Except for one well with an anomalously high concentration due to a point source, nitrate-N concentrations of sampled wells ranged from 1.3 to 13.3 mg/L with a mean of 5.4 mg/L and a median of 4.7 mg/L. Statistical analyses indicate that shallow ground water is more susceptible to contamination than deeper ground water and that lower nitrate-N concentrations are probable in wells with a greater thickness of clay above the well screen. Irrigation-well density showed a statistically significant positive correlation with nitrate-N concentrations of shallow wells. No significant difference in nitrate-N concentrations was found to result from the two irrigation methods (flood versus center-pivot) used in the area. Nor were there significant differences in nitrate-N concentrations between sandy and loamy soils. Land-use practices and subsurface stratigraphy may be better indicators of potential nitrate contamination than the surface soils.

Nitrate contamination of ground water can be a serious problem in rural areas where ground water is the major source of drinking water. Both regionally and nationally, concern about nitrate contamination has prompted a number of studies dealing with the relationships between agriculture and nitrate contamination of ground water (Madison and Brunett, 1984; Spalding and Exner, 1993; Thompson et al., 1986). A statistical study of farmstead wells in Kansas found that nitrate was the most common source of inorganic contamination, exceeding the maximum contaminant level (MCL) in 28% of the wells (Steichen et al., 1988).

Although geologic units can contribute nitrate to ground water (Boyce et al., 1976), sources of nitrogen generally occur at the land surface. A common nonpoint source in agricultural areas is the widespread use of nitrogen fertilizers, which over long periods of time may contaminate ground water (Hallberg, 1986). If nitrate in the soil system is not lost in runoff, used by the plants, or transformed to nitrogen gas or to organic nitrogen by bacteria, then nitrate is available for leaching (Keeney, 1986). Although point sources, such as spills or leaks during mixing and transfer of fertilizers, leaks from septic systems, and waste from feedlots, also may cause high nitrate concentrations in ground water, this study evaluated only the impact of nonpoint-source contamination.

Researchers have reported a background level of 3 mg/L or less for nitrate-N in uncontaminated ground water throughout the United States (Madison and Brunett, 1984). In the Great Bend Prairie aquifer (fig. 1), nitrate-N levels are frequently above background levels and often exceed the MCL of 10 mg/L. A 1978 survey of irrigation water quality in the area showed that 9% of 144 irrigation wells had nitrate-N concentrations above 10 mg/L (Hathaway et al., 1978).

Other work in the Great Bend Prairie has indicated that shallow ground water below areas with sandy soils is prone to nitrate contamination (Sophocleous et al., 1990; Townsend and Marks, 1990). In these studies the irrigation wells generally were deeper (21–38 m; 70–125 ft) and yielded water with lower nitrate-N concentrations than shallower (12–24 m; 40–80 ft) domestic wells (Townsend and Marks, 1990). Nitrate-N concentrations ranged from 2.7 to 6.8 mg/L in the irrigation wells and from 4.3 to 16.9 mg/L in the domestic wells. Samples collected near the base of the aquifer (30–46 m; 100–150 ft) had nitrate-N concentrations usually less than 3 mg/L (Whittemore, 1993). Recent work in Stafford County, Kansas (fig. 1) indicates a possible nonpoint source problem in areas without sandy soils (Young, 1992).

Work in Nebraska, Iowa, Minnesota, and Wisconsin indicates that higher nitrate-N levels in shallow ground water may occur because of nutrient loading to shallow water tables and low vertical gradients and that decreasing nitrate-N concentrations with depth may occur because of low vertical gradients and the possibility of denitrification (Anderson, 1989; Spalding and Exner, 1993; Thompson et al., 1986). Geologic controls on water movement are not

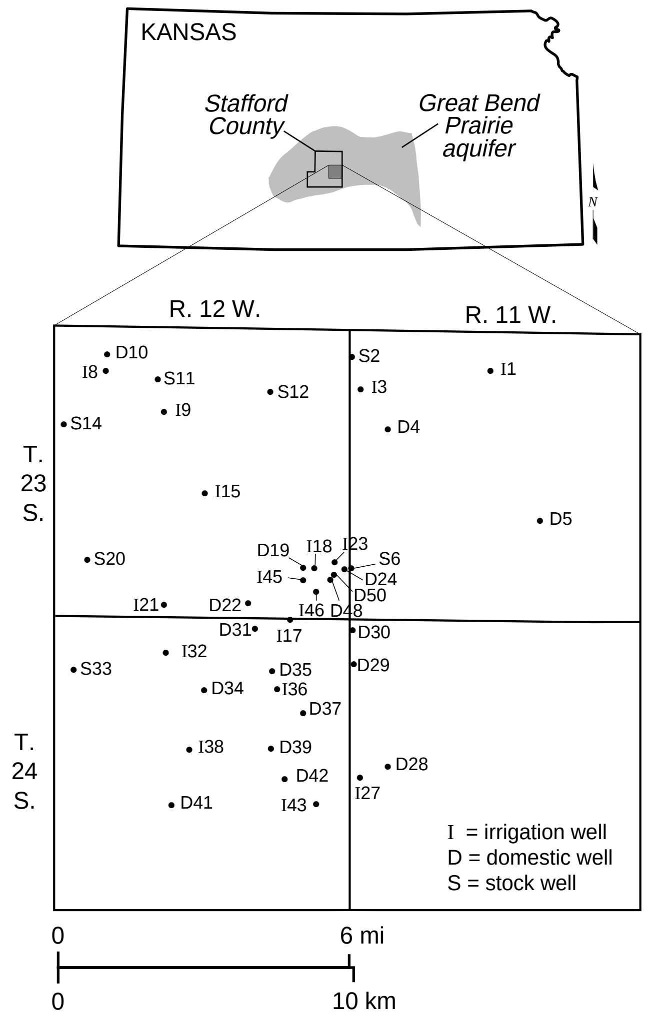

FIGURE 1. Location of sampled wells in the study area.

necessarily a factor. In these areas, composed principally of coarse-textured soils, clay zones have not been widely reported. In the Great Bend Prairie aquifer the occurrence of clay lenses, as indicated by various studies (Rosner, 1988; Sophocleous et al., 1990; Townsend and Marks, 1990), supports the idea that better quality water at depth is a result of vertical retardation of water and nitrate movement by perching of water above the clay zones.

Studies in Kansas and in other states suggest that dense irrigation in areas with shallow water tables contributes to nitrate contamination of ground water, particularly in areas with soils of relatively high permeability (Hallberg, 1986; Muir et al., 1973; Spalding, 1984; Spalding and Kitchen, 1988; Spalding et al., 1978; Thompson et al., 1986; Young, 1992). Irrigation can increase nitrate contamination in several ways: (1) an increase in the area of irrigated cropland generally results in a greater source of fertilizer-N with time than when the land was not cultivated or was dryland farmed; (2) the additional input of water can be the driving force for nitrate movement if the fertilizer or water is not utilized by the crop; (3) increased density of irrigation wells may result in more mixing of shallow and deep ground water; (4) fertigation backsiphoning from faulty or leaking equipment near the well can result in nitrate entering ground water directly; and (5) improper or deteriorated construction of irrigation wells (and others) can permit contaminated surface and subsurface flow to enter the aquifer.

Although some natural mixing of different zones of water in the aquifer occurs naturally, mixing can be enhanced by irrigation. If the shallow zone of the aquifer becomes contaminated, then the deeper zones of the aquifer may become contaminated with time as a result of vertical mixing of the water from the two zones. If there are several irrigation wells pumping at the same time, the area of pumping influence may be greater because of competition for the same water. Other studies in the Great Bend Prairie showed that irrigation-well density in areas with sandy soils correlated strongly with nitrate concentrations in shallow ground water (Young, 1992).

Purpose and scope

This study was designed in response to concern about the potential for deteriorating ground-water quality throughout Stafford County. Its purposes were to determine (1) the extent of nonpoint-source nitrate contamination of the ground water in four townships of Stafford County, Kansas, that have both sandy and loam soils and (2) the variables associated with the distribution of contamination. The variables examined in the study were soil characteristics, irrigation methods, well characteristics, and clay thickness in the subsurface. The results are intended to assist the local ground-water management district in making management decisions by identifying areas that may be vulnerable to nitrate contamination.

Study Area

Stafford County is located in the Great Bend Prairie in south-central Kansas (fig. 1). The Great Bend Prairie is an alluvial plain covered mostly with wind-blown sand and characterized by typical sand dune topography (Latta, 1950). Well- to poorly drained loamy and sandy soils are typical of the area (Dodge et al., 1978). Since at least 1885, farming has been a major occupation in the county (Kansas Board of Agriculture, 1887), and today the land is primarily used to produce row crops, though some pasture remains. Oil production is extensive and oil wells are numerous.

Ground water from the Great Bend Prairie aquifer is the sole source of usable water in the study area, supplying domestic, municipal, irrigation, oil-field supply, and stock wells. The alluvial aquifer consists of unconsolidated deposits of gravel, sand, silt, and clay of Quaternary age. Subsurface silt and clay lenses of varying thickness and lateral extent occur throughout the area (Rosner,

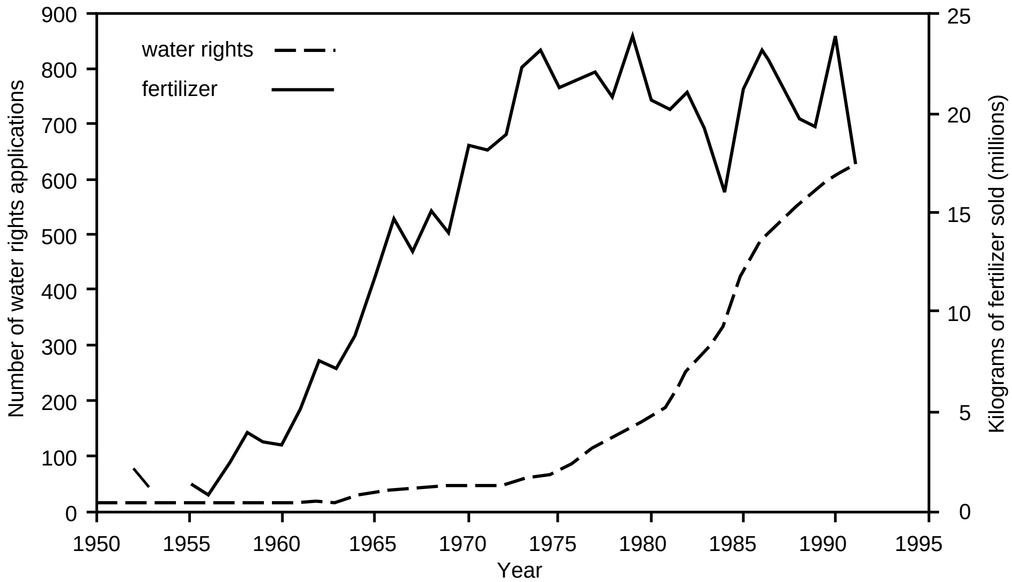

FIGURE 2. Increases in amount of fertilizer sold and number of water rights issued with time reflect the increase in irrigated farming in Stafford County, Kansas.

1988; Sophocleous et al., 1990). Saturated thickness of the aquifer varies from 0 to 60 m (0 to 200 ft). Depth to water is generally less than 9 m (30 ft), and ground-water flow is to the east at a rate of about 84 m/yr (275 ft/yr) (Stullken et al., 1987). Nitrate-N concentrations of the ground water in the study area in the 1940's were less than 2 mg/L (Latta, 1950).

Water rights applications and the total quantity of fertilizer sold in Stafford County show a general increase from the mid-1960's to the present, reflecting the increase in irrigated farming (fig. 2). Annually, farmers in Stafford County plant approximately 10,520 ha (26,000 acres) of irrigated corn using 220–280 kg N/ha (200–250 lb N/acre); 6,070 ha (15,000 acres) of irrigated wheat using 80–130 kg N/ha (70–120 lb N/acre); 4,050 ha (10,000 acres) of irrigated sorghum using 130–180 kg N/ha (120–160 lb N/acre); and 780 ha (2,000 acres) of irrigated alfalfa and 5,840 ha (15,000 acres) of irrigated soybeans which require little to no fertilizer input (Young, 1992). Irrigation accounts for approximately 85% of water use in the county (Young, 1992).

Methods

Site selection criteria

Soil characteristics and hydrogeologic variables such as depth of well, depth below the water table, aggregated thickness of clay above the well screen, and thickness of clay in the unsaturated and saturated zones were considered potential factors influencing nitrate contamination in the study area. Wells were selected from different soil textures and on the basis of the occurrence of irrigation (deep) and domestic and stock (shallow) wells within 1.6 km (1 mile) of each other (fig. 3). The classification of soil texture was based on the county soil survey (Dodge et al., 1978). Information on wells, water levels, and stratigraphy was obtained from water-well completion records filed at the Kansas Geological Survey.

Water samples

Water samples were collected during July 1991 in clean polyethylene bottles (100 ml with 10% HCL as preservative) and kept refrigerated until analyzed for nitrate-N. Domestic-well hydrants were purged until a constant temperature was reached to ensure that freshwater from the aquifer was collected. Samples were collected from irrigation and stock wells only if the wells had been pumping for a considerable amount of time.

Statistical methods

Statistical tests were conducted on a variety of variables that might affect or control nitrate-N concentrations in the ground water. Independent variables included well type, depth of well, depth to water, depth below water table, clay thickness above the screen, irrigation-well density, irrigation practice, and soil texture. When depth of well and clay thickness were evaluated, only wells with available drillers logs were used in the analyses (table 1). Therefore only 33 and 32 data sets respectively were used instead of the 41 for the other variables (see table 4).

Nonparametric statistics were used because of the small number of samples and the non-normal distribution of many of the parameters, as indicated by the Shapiro-Wilk test for normality (Conover, 1980). SAS/STAT software (version 6, 1991) was used for the statistical

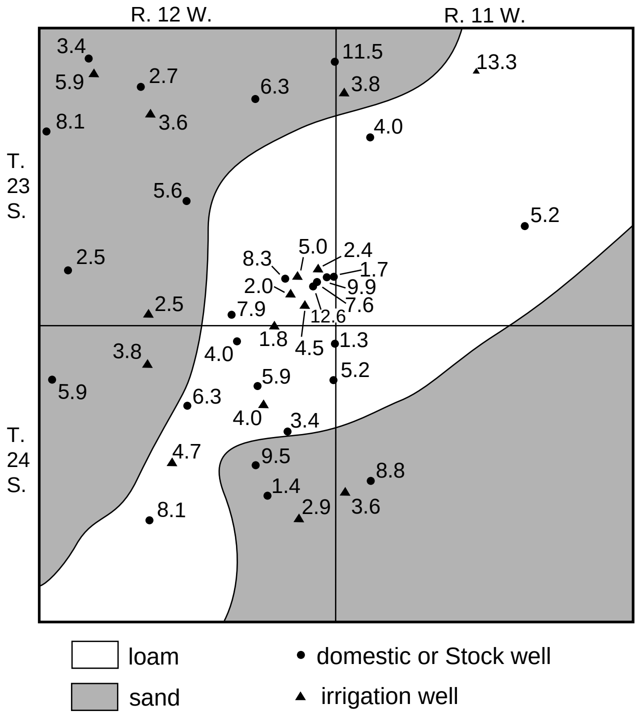

FIGURE 3. Nitrate-N concentrations (mg/L) of sampled irrigation (▲) and domestic and stock (●)wells in loam vs. sand soils.

analyses. The basis of the nonparametric tests is the hypothesis that there is no difference in the dependent variable (nitrate-N concentrations) in relation to the independent variables listed above.

The Mann-Whitney *U* test was used to test the hypothesis that the nitrate-N concentrations of two subgroups of a variable [example: depth of well < 18 m (60 ft) and depth of well ≥ 18 m (60 ft)] were drawn from the same population. This hypothesis was rejected if the calculated probability value (*p*) was less than 0.10. In other words, the subgroups of the variable were determined to be significant in the distribution and occurrence of nitrate-N concentration. The level of significance was chosen at a = 0.10 because of the small data set and because the wells were chosen on the basis of well logs (where available) and soil type, and therefore cannot be considered a truly random sample.

The Spearman correlation analysis was used to determine whether definable statistical relationships exist between the observed nitrate-N concentrations and several variables: depth of well, depth to water, depth below water table, clay above screen, and irrigation-well density. The Spearman correlation coefficient r_s shows the strength of the relationship and whether the relationship is positive or negative; the *p* value shows the significance level for the test.

Several parametric multiple regression techniques were used to evaluate the relationships among the variables. Multiple regression methods are used to define a predictive equation or model based on all available information. This model would permit use of variables such as irrigation-well density, thickness of clay above the well screen, and depth of well to predict nitrate-N concentration in areas where no sample has been collected.

Methods such as backward elimination, stepwise elimination, and maximum r^2 were used. The r^2 value is a measure of the degree of relationship between the nitrate-N concentration and the independent variables. If the variables used in the model are good predictors for where nitrate will occur, then r^2 will be near 1.00. If the variables are not good predictors, then the r^2 value will be closer to zero.

Results and discussion

In the 42 wells sampled, nitrate-N concentrations ranged from 1.3 (well 30) to 59.5 mg/L (well 16). Because the high nitrate concentration in well 16 was obviously due to a nearby dairy farm, this site was not used in the statistical analysis. Nitrate-N concentrations in the remaining 41 wells ranged from 1.3 to 13.3 mg/L, with a mean of 5.4 and a median of 4.7 mg/L.

Of the variables examined, well type, well depth, depth below water table, irrigation-well density, and aggregated clay thickness above well screen had statistically significant relationships to nitrate-N, whereas soil textural class and irrigation method did not. Table 1 summarizes the data collected in the well survey. Figure 4 illustrates the following variables used in the study: depth to well screen, depth below water table, thickness of clay above the screen, depth to water, and depth of well.

Well type, well depth, and depth below water table

As shown in table 2, irrigation wells are significantly deeper [median depth of 26.1 m (85.5 ft)] than domestic and stock wells [median depth of 18.3 m (60 ft)]. For the purposes of analysis, a depth of 18.3 m was used to divide deep from shallow wells. The median depth of 18.3 m is not based on a stratigraphic division within the aquifer but is merely a convenient separation for statistical analysis.

Evaluation of Mann-Whitney results of nitrate-N values versus well type shows that irrigation wells have significantly lower nitrate-N concentrations compared with domestic and stock wells (table 3). Comparison of nitrate-N values in deep and shallow wells also shows significantly higher concentrations in the shallow wells (table 2). These two tests support the idea that the shallow portion of the aquifer is more contaminated than the deeper portion and suggest that classification by well type may substitute for well depth if well logs are not available.

Nitrate-N concentrations of all wells decreased with depth as is shown by a significant negative Spearman

TABLE 1. Summary of data from Stafford County well survey, 1991.

ID	Well type	NO_3-N (mg/L)	Soil textural class	Well depth (m)	Depth to static water table (m)	Clay above screen (m)	Irrigation well density	Depth to well screen (m)	Depth below water table (m)	Comments
1[a]	I	13.3	Loam	12.8[b]	2.7	nd	2	nd	nd	Milo, flood
2	S	11.5	Sand	10.9	3.9	0.3	1	7.6	3.6	Pasture
3	I	3.8	Sand	31.7	3.6	4.8	1	19.5	15.9	Milo, wheat, pivot
4	D	4.0	Loam	23.7	6.4	14.0	1	14.6	8.2	Pens, house
5	D	5.2	Loam	17.3	5.5	3.9	1	14.3	8.8	Wheat, house
6	S	1.7	Loam	27.4	3.0	13.1	4	21.3	18.3	Stock well
8	I	5.9	Loam	14.0	2.4	2.1	2	7.9	5.5	Corn, alfalfa, soybeans, flood
9	I	3.6	Sand	28.0	3.9	14.6	1	18.5	14.6	Flood
10	D	3.4	Sand	8.9	1.8	4.3	1	5ß.8	4.0	Some livestock
11[a]	S	2.7	Sand	nd	3.0	nd	1	nd	nd	Pasture
12	S	6.3	Sand	12.2	2.1	2.7	1	6.1	4.0	Pasture, pond
14	S	8.1	Sand	16.7	3.9	3.6	3	13.7	9.8	Pasture
15[a]	I	5.6	Loam	nd	4.5	nd	3	nd	nd	Milo, flood
17	I	1.8	Loam	21.0	4.5	0	3	17	12.5	Milo, alfalfa, flood
18[a]	I	5.0	Loam	nd	6.1	nd	5	nd	nd	Milo, beans, flood
19	D	8.3	Loam	19.8	6.1	9.1	5	13.7	7.6	Lawn, house
20	S	2.5	Sand	18.6	5.7	10.9	1	15.5	9.8	Pens to east
21	I	2.5	Sand	36.6	8.2	17.6	2	24.3	16.1	Corn, pivot
22	D	7.9	Loam	15.8	6.7	9.1	2	12.8	6.1	Garden, yard
23	I	2.5	Loam	18.3	4.2	7.3	4	7.9	3.7	Pivot
24	D	9.9	Loam	13.7	4.3	6.1	4	10.6	6.3	
27	I	3.6	Sand	25.6	6.4	9.1	1	14.6	8.2	Corn, pivot
28	D	8.8	Sand	18.3	4.5	5.5	2	12.2	7.7	
29	D	5.2	Loam	18.3	7.9	11.2	0	15.2	7.3	Barns, pens
30	D	1.3	Loam	18.3	5.8	9.4	0	13.4	7.6	Pig pens nearby
31	D	4.0	Loam	21.0	5.5	12.5	1	17.9	12.4	Wheat, garden
32	I	3.8	Sand	41.2	7.0	10.3	3	21.3	14.3	Corn, pivot
33	S	5.9	Sand	28.6	7.6	20.1	1	22.5	14.9	Pasture
34	D	6.3	Loam	16.7	6.7	9.1	1	14.3	7.6	Strip farm to west
35	D	5.9	Loam	18.3	7.3	9.1	2	12.2	4.9	Corn, lawn
36[a]	I	4.0	Loam	nd	8.2	nd	3	nd	nd	Corn, flood
37	D	3.4	Loam	18.3	8.2	5.2	2	12.2	4.0	
38	I	4.7	Loam	31.4	9.1	9.4	3	19.2	10.1	Corn, pivot
39	D	9.5	Sand	21.3	6.4	10.3	5	18.2	11.8	
41[a]	D	8.1	Loam	nd	7.9	nd	4	nd	nd	Corn, beans to west
42	D	1.4	Sand	25.9	5.2	20.7	3	23.2	18.0	Barns to west
43	I	2.9	Sand	26.5	7.3	10.6	2	20.4	13.1	Milo, beans, pivot
45[a]	I	2.0	Loam	nd	5.5	nd	5	nd	nd	Corn, flood
46[a]	I	4.5	Loam	nd	5.5	nd	5	nd	nd	Corn, flood
48[a]	D	12.6	Loam	nd	3.6	nd	5	nd	nd	Feedlot, barn
50	D	7.6	Loam	11.5	3.6	4.8	5	10.3	6.7	Observation well
16	D	59.5	Loam	27	7.0	21	0	20.7	13.7	Dairy barns to west of house

a. Pre-1976 wells. No well log available.
b. Depth reported (USGS, 1974).
nd = no data, I = irrigation well, D = domestic well, S = stock well.

correlation coefficient (r_s) of –0.48 (table 4). This corresponds with the results from the Mann-Whitney tests in which the nitrate-N concentrations of the deeper wells were lower than those of shallower wells (table 2).

Depth below the water table is defined as depth to screen minus depth to water (fig. 4). This is the vertical distance a contaminant will travel to enter a well once it reaches the water table. Where the depth below water

TABLE 2. Comparison of well depth with well type.

Well type[a]	Number of wells	Mean depth (m)	Median depth (m)	Range (m)	Significance level of test (p)
Irrigation	11	25.6	26.1	12.8 – 41.2	0.012
Domestic/Stock	22	18.2	18.3	8.8 – 28.6	

a. Only wells with well logs or documented reported depth were used for depth analyses (see table 1).

table is less than the median value of 8.2 m (27 ft), the concentrations of nitrate-N were significantly higher (table 2). These results also compare favorably with those found in the analysis of well type and depth.

Soils

Soils were evaluated using a variety of classifications or groupings including soil association, soil series, least permeable horizon of the most clayey soil versus all others, and sand versus loam soils. Nitrate-N concentrations were not significantly different under any classification or grouping of the soils. Soil textural information, sand versus clay loam, is listed in table 1. Nitrate-N concentrations of sampled points are mapped by soil texture in fig. 3. Table 2 shows the lack of correlation even at this most basic textural grouping.

Irrigation-well density

A large part of the study area is irrigated cropland. More water and, in general, more fertilizer are applied to irrigated than to nonirrigated land, thus increasing the potential for nitrate leaching. Irrigation-well density was defined as the number of irrigation wells within a 1.6 km (1 mile) radius of a sampled well (fig. 1).

Nitrate-N concentrations of domestic and stock (shallow) wells were compared on the basis of irrigation-well density (IWD, table 2). The Spearman correlation analysis shows a significant correlation ($r_s = 0.50$) between irrigation-well density and nitrate-N concentration (table 4), indicating that in shallow ground water there is a greater probability of higher concentrations of nitrate-N occurring in more heavily irrigated areas. The significant Mann-Whitney test results (table 2) indicate that increasing the number of irrigation wells in an area may result in higher nitrate-N concentrations with time.

Irrigation methods

Evaluation of irrigation method (flood versus center pivot) showed a trend of higher nitrate-N values under flood-irrigated land than under center-pivot-irrigated land, although the result was not statistically significant (table 2). All of the flood-irrigation wells in the study were pre-

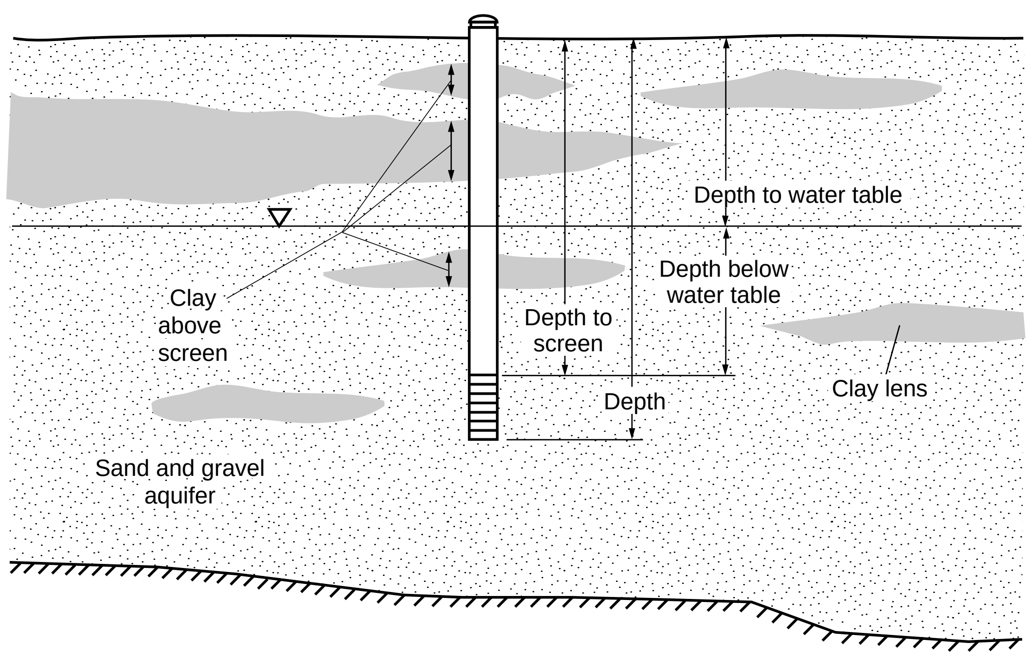

FIGURE 4. Generalized cross section showing variables used in statistical analyses.

TABLE 3. Mann-Whitney results for nitrate-N concentration compared with each of the independent variables.

	Number of samples	Mean NO_3-N (mg/L)	Median NO_3-N (mg/L)	Range (mg/L)	Significance level of test (p)
Well type[a]					
Dom. + Stock	25	6.1	5.9	1.3 – 12.6	0.058
Irrigation	16	4.3	3.8	1.8 – 13.3	
Well depth[b, c]					
Shallow (≤18.3 m)	17	6.6	6.3	1.3 – 11.5	0.017
Deep (>18.3 m)	16	3.9	3.7	1.4 – 9.5	
Depth below water table[b]					
Shallow (≤8.2 m)	17	5.9	5.9	1.3 – 11.5	0.05
Deep (>8.2 m)	15	4.0	3.8	1.4 – 9.5	
Soil Textural Class[a]					
Clay loam	25	5.6	5.2	1.3 – 13.3	0.422
Sand	16	5.0	3.7	1.4 – 11.5	
Irrigation-well density (domestic and stock wells only)					
IWD ≤ 1	12	4.8	5.0	1.3 – 11.5	0.047
IWD ≥ 2	13	7.2	8.1	1.4 – 12.6	
Irrigation practice					
Flood	9	5.1	4.5	1.8 – 13.3	0.203
Pivot	7	3.4	3.6	2.5 – 4.7	
Clay above screen[b]					
Thickness ≤ 8.8 m	19	6.0	5.9	1.8 – 11.5	0.016
Thickness > 8.8 m	13	3.7	3.6	1.3 – 9.5	

a. Includes wells without well logs.
b. Only wells with well logs were used for depth related analyses (see table 1).
c. Well-depth analysis includes well with documented reported depth (well 1, table 1).

1976 (table 1) and did not have well-depth information available. We were thus unable to examine the possible relationship between well depth and irrigation method used.

Variables such as the irrigation method as well as the number of years it has been practiced, the quantity of fertilizer applied with a particular irrigation method, the age of the well, and the quantity of water applied probably affect the observed nitrate-N value. These variables and their relationships warrant more research.

Flood-irrigation wells 1 and 15 were sampled during 1978 with resulting nitrate-N concentrations of 14.2 and 5.19 mg/L respectively (Hathaway et al., 1978). These values are similar to the results measured during this study (13.3 and 5.6 mg/L, table 1). This may imply that the rate of change of nitrate-N concentration in the ground water is slow and that similar land-use practices in the study area over time may result in a near-constant recharge of nitrate to the ground water. This relationship also warrants more study.

Clay thickness

The relationship between nitrate-N concentration in shallow wells and the cumulative thickness of clay lenses, from below the root zone to above the screened interval of the well, was examined. We assumed that contaminants moving downward would be slowed by the clay, diverted downgradient from the well, or denitrified. Table 1 shows that the thickness of clay above the screen varies throughout the study area, indicating lack of continuity of the clay zones between wells. The median thickness of 8.8 m (29 ft) was used as a convenient separation for statistical analysis.

In wells with a cumulative clay thickness of 8.8 m (29 ft) or less above the well screen, the nitrate-N concentration is significantly higher than in wells with more than 8.8

TABLE 4. Spearman correlation results for nitrate-N concentration versus independent variables.

Variable	Number of samples	r_s	Significance level of test (p)
Depth	33	–0.48	0.005
Irrigation Well Density	25	0.50	0.010
Thickness of Clay above Well Screen	32	–0.44	0.011

m (29 ft) of clay above the well screen (tables 1 and 2). Results were similar when nitrate-N concentrations were compared with (1) thickness of clay in the unsaturated zone and (2) thickness of clay in the saturated zone above the well screen.

The nitrate-N concentrations of all wells also show a statistically significant negative Spearman correlation with thickness of clay above the well screen ($r_s = -0.44$), indicating that nitrate-N concentrations decrease with increasing thickness of clay above the well screen (table 4). This suggests that, even though the clay lenses are not continuous, the thickness of clay in the subsurface above the screen plays a significant role in protecting the deeper zones of the aquifer by retarding nitrate movement, redirecting nitrate movement, or facilitating denitrification processes.

Regression analysis

Work by Muir et al. (1973) showed that regression analysis is a useful tool for evaluating the interactions of variables affecting nitrate concentration in ground water. Because there are several statistically significant variables that appear to affect the movement of nitrate through the unsaturated zone and in ground water in our study, multiple regression analysis was utilized to develop a predictive model to determine areas where nitrate contamination is more likely to occur.

Several regression methods were tried, including backward elimination, stepwise elimination, forward elimination, and maximum r^2. None of these methods resulted in an r^2 of more than 0.30, meaning that only 30% of the variation of the model could be explained by the variables included in the model. The multiple regression method was not successful with our data set partly because of the small sample size and the non-normal distribution of many of the variables.

All of the variables we looked at in the study (depth of well, depth to water, depth below water table, thickness of clay, irrigation-well density, and soil type) were used in the initial runs of the regression models. The variables that contributed most to the different models were irrigation-well density, thickness of clay above well screen, depth of well, and depth below water table. Irrigation-well density contributed the most to each model run, but all of the variables did not contribute to a model together, primarily because of cross-correlation between many of the other variables.

These results lead us to believe that additional factors influence the movement of nitrate to the ground water. Generally, shallow wells in more heavily irrigated areas with relatively little subsurface clay are most likely to have elevated nitrate-N concentrations. However, other factors such as age and condition of well, point sources, and denitrification processes probably affect nitrate concentrations at a particular site. This study has illuminated some but not all of the factors that need to be evaluated in order to predict areas most vulnerable to nitrate contamination.

Summary

The shallow portion of the Great Bend Prairie aquifer in east-central Stafford County is contaminated by nitrate-N to a greater degree than deeper portions of the aquifer. Particularly in shallow wells, nitrate-N concentrations are directly related to the extent of irrigation near the well and inversely related to the depth of the well and amount of clay above the well screen.

Nitrate-N concentrations exceeded the MCL of 10 mg/L in 4 of the 42 wells sampled in the study. One of the wells is contaminated by an obvious point source. Sixteen additional wells have nitrate-N concentrations between 5 and 10 mg/L, indicating that nitrate concentrations in many wells are elevated relative to a background level of 3 mg/L. The potential exists for further increases if present land-use practices continue and there is more time for nitrate to move through the unsaturated zone and into ground water.

Irrigation-well density shows a positive correlation with nitrate-N concentrations in shallow wells. Concentrations are significantly higher where there are more irrigation wells. Irrigation-well density may be a useful indicator of potential areas of contamination in the shallow portion of the aquifer.

Nitrate-N concentrations in flood-irrigation wells tend to be higher than those in center-pivot-irrigation wells. This difference suggests that other variables, such as differences in fertilizer application, differences in quantity of water applied, number of years that a particular irrigation practice has been used, and the age of the well, should be evaluated in future studies.

Nitrate-N concentrations are lower where more subsurface clay is present above the well screen. Also, nitrate concentrations decrease as depth of well and depth below water table increase. These relationships indicate that the shallow ground water is more susceptible to contamination than deeper water because of the shorter pathway for nitrate transport and less subsurface clay to retard the downward transport.

Soil type did not have an independent influence on nitrate-N concentration at these study sites. This suggests that the land-use practices and the subsurface stratigraphy are more important influences than the surface soil class on the occurrence and concentration of nitrate in ground water. Regression analysis showed that irrigation-well density, aggregated thickness of clay above the well screen, depth below water table, and depth of well are important predictors of the occurrence of nitrate in ground water but that other factors contribute a significant influence. Future work in the area will use a larger data set and evaluate such other variables as irrigation type (center-pivot or flood), age and condition of well, estimated water use, and quantity of fertilizer used to try to develop a better model for predicting possible nitrate contamination in the subsurface.

References

Anderson, H. W. Jr., 1989, Effects of agriculture on quality of water in surficial sand-plain aquifers in Douglas, Kandiyohi, Pope, and Stearns counties, Minnesota: U.S. Geological Survey, Water Resources Investigation Report 84-4040, 52 p.

Boyce, J. S., Muir, J., Edwards, A. P., Seim, E. C., and Olson, R. A., 1976, Geologic nitrogen in Pleistocene loess of Nebraska: Journal of Environmental Quality, v. 5, no. 1, p. 93–96

Conover, W. J., 1980, Practical nonparametric statistics: New York, John Wiley and Sons, p. 363–367

Dodge, D. A., Hoffman, B. R., and Horsch, M. L., 1978, Soil survey of Stafford County, Kansas: U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C., 59 p.

Hallberg, G. R., 1986, From hoes to herbicides—agriculture and groundwater quality: Journal Soil and Water Conservation, v. 41, p. 357–364

Hathaway, L. R., Galle, O. K., Waugh, T. C., and Dickey, H. P., 1978, Chemical quality of irrigation waters in Ford County and the Great Bend Prairie of Kansas: Kansas Geological Survey, Chemical Quality Series 7, 41 p.

Kansas Board of Agriculture, 1887, Fifth biennial report of the Kansas State Board of Agriculture to the Legislature of the State, for the years 1885–86: Kansas Publishing House, Topeka, p. 540–545

Keeney, D., 1986, Sources of nitrate to ground water: CRC Critical Review Environmental Control, v. 16, p. 257–304

Latta, B. F., 1950, Geology and ground-water resources of Barton and Stafford counties, Kansas: Kansas Geological Survey, Bulletin 88, 228 p.

Madison, R. J., and Brunett, J. O., 1984, Overview of the occurrence of nitrate in ground water of the United States; *in*, USGS National Water Summary 1984: U.S. Geological Survey, Water-Supply Paper 2275, p. 93–105

Muir, J., Seim, E. C., and Olson, R. A., 1973, A study of factors influencing the nitrogen and phosphorous contents of Nebraska waters: Journal of Environmental Quality, v. 2, no. 4, p. 466–470

Rosner, M. L., 1988, The stratigraphy of the Quaternary alluvium in the Great Bend Prairie, Kansas: MS thesis, University of Kansas, Lawrence, 183 p. (available as Kansas Geological Survey, Open-file Report 88-32)

Sophocleous, M., Townsend, M. A., Orountiotis, C., Evenson, R. A., Whittemore, D. O., Watts, C. E., and Marks, E. T., 1990, Movement and aquifer contamination potential of atrazine and inorganic chemicals in central Kansas cropland: Kansas Geological Survey, Ground Water Series 12, 64 p.

Spalding, M. E., 1984, Implication of temporal variations and vertical stratification of groundwater nitrate-nitrogen in the Hall County special use area: Nebraska Water Resources Research Institute, Report no. 372906, University of Nebraska, Lincoln, 44 p.

Spalding, R. F., and Exner, M. E., 1993, Occurrence of nitrate in groundwater—a review: Journal of Environmental Quality, v. 22, p. 392–402

Spalding, R. F., and Kitchen, L. A., 1988, Nitrate in the intermediate vadose zone beneath irrigated cropland: Ground Water Monitoring Review, v. 8, p. 89–95

Spalding, R. F., Gormly, J. R., Curtiss, B. H., and Exner, M. E., 1978, Nonpoint nitrate contamination of ground water in Merrick County, Nebraska: Ground Water, v. 16, p. 86–95

Steichen, J., Koelliker, J., Grosh, D., Heiman, A., Yearout, R., and Robbins, V., 1988, Contamination of farmstead wells by pesticides, volatile organics, and inorganic chemicals in Kansas: Ground Water Monitoring Review, v. 8, no. 3, p. 153–160

Stullken, L. E., Stamer, J. K., and Carr, J. E., 1987, Reconnaissance of water quality in the High Plains aquifer beneath agricultural lands, south-central Kansas: U.S. Geological Survey, Water Resources Investigation Report 87-4003, 25 p.

Thompson, C. A., Libra, R. D., and Hallberg, G. R., 1986, Water quality related to agchemicals in alluvial aquifers in Iowa; *in*, Proceedings of the Agricultural Impacts on Ground Water—a Conference, August 11–13, 1986, Omaha, Nebraska: National Water Well Association, Dublin, Ohio, p. 224–242

Townsend, M. A., and Marks, E. T., 1990, Occurrence of nitrate in soil and ground water in south-central Kansas; *in*, Proceedings Ground Water Management, 1990 Cluster of Conferences, Kansas City, Missouri, 20–21 February: National Water Well Association, Dublin, Ohio, p. 145–158

U.S. Geological Survey, 1974, Water resources data for Kansas, Part 2, Water Quality Records: U.S. Department of the Interior, p. 184

Whittemore, D. O., 1993, Ground-water geochemistry in the mineral intrusion area of Groundwater Management District No. 5, south-central Kansas: Kansas Geological Survey, Open-file Report 93-2, 107 p.

Young, D. P., 1992, Nitrate contamination of ground water in northern Stafford County, Kansas: M.S. thesis, University of Kansas, Lawrence, 94 p. (available as Kansas Geological Survey, Open-file Report 92-11)