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Potential Sources of Nitrate in South Fork
of Beaver Creek Watershed,
Sherman County, Kansas

by

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Abstract

Differences in nitrate concentrations in ground water in Kansas can be explained by variation in agricultural practices and vadose zone characteristics. In northwest Kansas a region of high nitrate water occurs in the Ogallala aquifer (depth to water of 100 to 150 ft). Nitrate-N concentrations of the contaminated ground water range from 12 to 20 mg/L. This 130 mi^2 area was impacted by high fertilizer use from sugar beet farming during the 1960s to 1980s. Infiltration from a local stream used in the past as a flood-irrigation tailwater channel may have been the principal intermittent avenue for nitrate to reach the ground water. Ground-water levels are about 100 ft below the stream bottom allowing recharge during periods of stream flow. Current nitrate-N concentrations of soil-water from 15 to 72 ft depth in the floodplain of the stream range from less than 10 to over 60 mg/L. These nitrate contents indicate that residual nitrogen is present and moving in the vadose zone. Nitrogen isotope values for soil-water range from +4 to +7 ‰ which is in the range for fertilizers (Herbel and Spalding, 1993; Gormly and Spalding, 1979). Nitrogen isotope values for the irrigation wells sampled in the area range from +7 to +10 ‰. Two domestic wells sampled had nitrogen isotope values of +6.8 and +7.5 ‰, indicating that enrichment of fertilizer was the probable source of nitrate in the wells.

Introduction

The occurrence of nitrate in the Ogallala aquifer in the vicinity of the South Fork of Beaver Creek in Sherman County, Kansas, has been studied since 1987. This report summarizes the findings from the previous work and discusses the results of the nitrogen-15 isotope method to determine the source of the nitrate in the ground water. Discussion of some management options for correction of the problem and suggestions for future research in the area are included.

Evaluation of Water Quality

Previous work (Townsend, 1989) in the area of the South Fork of Beaver Creek in Sherman County, Kansas, showed that irrigation wells oriented in a northeast-southwest direction parallel to Beaver Creek yield water with high nitrate-N concentrations (fig. 1). These wells were all installed between 1950 and 1981 and probably used for flood irrigation for sugar beets for at least part of the farming history of the fields.

Table 1 shows the complete chemistry for irrigation well-waters sampled in 1978 and in 1994. These data were plotted on a Piper trilinear diagram in order to evaluate the differences between the two sampling periods (fig. 2; Piper, 1944). A majority of the points for well-waters sampled in 1994 plot in the area of calcium, magnesium, and mixed anion type water. The effect of possible evaporation concentration processes on these waters causes an increase in total dissolved solids concentration, and shifts the waters out of the trilinear diagram area for the more common calcium, magnesium bicarbonate water typical of the Ogallala aquifer (Hathaway et al., 1979).

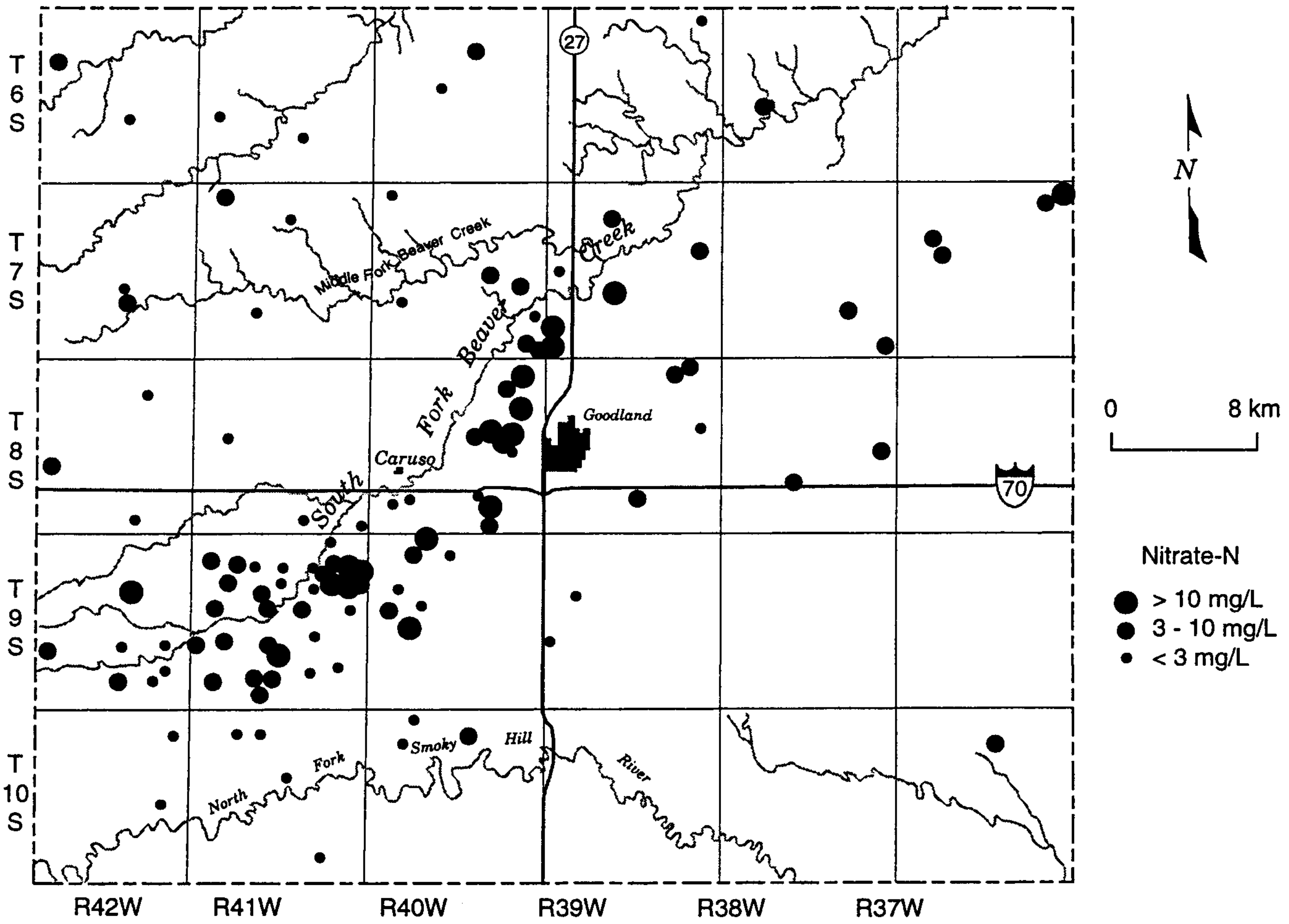

Figure 1. Location of study area in Sherman County , Kansas. Gradational dots represent range of nitrate-N measured in Ogallala water from irrigation and domestic wells. Note the northeast to southwest trend of high nitrate-N values parallel to South Fork of Beaver Creek.

Table 1. Complete water chemistry analyses for irrigation wells, GMD4, 1978 and 1994.

ID	Date	Lab Sp. C.[a] µS/cm	TDS[b] mg/L	SiO_2 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Sr mg/L	HCO_3 mg/L	SO_4 mg/L	Cl mg/L	F mg/L	NO_3 mg/L	NO_3-N mg/L	Legal T R SEC[c]
15389	1994	488	340	58.8	38.3	15.9	36.5	4.6	0.72	202	26.9	13.6	1.83	43.2	9.8	7-39W-28AAD
7021	1994	795	549	55.2	67.7	33.4	44.9	6	1.51	197	129	27.7	1.53	85.2	19.2	7-39W-30CCB
9245	1994	559	381	56	48	19.9	31.9	4.8	0.91	192	46.5	24.3	1.38	52.9	11.9	7-39W-31CBC
24618	1994	400	287	58.8	39.7	10.9	25.9	4.6	0.53	180	29.4	9.9	1.21	17.7	3.9	7-40W-24
4405	1994	355	262	58.9	37.8	10.5	20.5	4.2	0.5	175	18.2	6.2	1.1	18.1	4.1	7-40W-24BCC
15894A	1994	442	309	56.8	30.3	15	38.2	4.1	0.69	196	38	12.1	1.78	15.7	3.5	8-40W-7CDB
9136B	1994	624	428	56.5	50.8	18.1	46.5	4.8	0.82	171	66.1	32.5	1.86	66.4	15	8-40W-11DAD
1037	1994	618	428	56.8	60	19.9	33.6	4.6	0.97	182	75.1	24.3	1.56	61.7	13.9	8-40W-14DCB
25735N	1994	694	485	57.8	67	23.1	41.6	5.1	1.14	191	94.1	26.2	1.53	74	16.7	8-40W-14DAB
25735S	1994	689	471	57.1	63.1	23.7	40.4	5.3	1.11	224	68.1	30.2	1.43	70.4	15.9	8-40W-14DAD
15894B	1994	409	290	54.1	30.9	13.1	37.9	4	0.6	206	23.9	6.9	1.85	15.7	3.5	8-40W-18BDB
25902	1994	490	331	52.7	37	15.7	40.9	4.2	0.73	229	37.2	15	1.93	12.8	2.9	8-40W-21ACA
6236	1994	700	465	40.7	69.9	22.4	34.9	4.9	1.16	181	72.1	38.1	0.84	91.4	20.6	8-40W-35CBB
4907	1994	563	376	41.7	57.4	18.6	25.4	4.2	0.91	188	54.1	21.6	0.93	58.3	13.1	9-41W-11DCB
14980A	1994	481	317	36.9	41.7	13.9	32.9	3.8	0.71	185	30	18.2	1.01	46.7	10.5	9-41W-12B
25071	1994	657	438	39.2	70.1	22.1	30.8	4.4	1.07	189	73.5	32.3	0.88	70.9	16	9-41W-12DBB
7976	1994	598	382	29.3	49.6	19.8	36.4	4	0.92	154	52.4	36.7	1.72	75.7	17.1	9-42W-11CCC
9367	1978	350	262	63	32	11	26	4.3	0.6	189	17	3.5	1	11	2.5	7-40W-6ADB
22759	1978	330	246	60	36	8.7	19	4.1	0.6	166	15	6	1.3	14	3.2	7-40W-23BDC
11182	1978	390	290	67	26	13	37	4.8	0.6	190	25	6.5	1.5	15	3.4	7-41W-5BBD
16373	1978	345	252	60	30	9.1	28	4.3	0.5	177	17	4.3	0.9	11	2.5	7-41W-10BAA
9079	1978	340	247	59	31	9.2	25	4.2	0.4	178	16	3.4	1.2	10	2.3	7-41W-28DBB
13068	1978	360	258	56	25	10	36	4.4	0.5	189	15	4.5	1.4	12	2.7	7-42W-7DDA
9070	1978	325	235	52	31	8.7	24	3.8	0.4	169	14	3	0.8	14	3.2	7-42W-27AAB
11854	1978	510	346	57	46	16	33	4.6	0.7	188	49	21	1.4	25	5.6	8-38W-24AAB
15456	1978	380	272	59	31	11	34	4	0.5	200	18	3.9	1.6	11	2.5	8-39-13AAB
5964/8127	1978	580	398	58	51	18	39	4.7	0.9	179	49	31	1.4	57	12.9	8-39W-17DCD
9023	1978	420	298	57	37	13	32	4.1	0.6	190	31	9.8	1.4	19	4.3	8-39W-27AAB
10327	1978	410	283	47	33	12	34	4	0.6	186	20	12	2.2	27	6.1	8-40W-14DCB

Table 1. Complete water chemistry analyses for irrigation wells, GMD4, 1978 and 1994 (cont.).

ID	Date	Lab Sp. C.[a] µS/cm	TDS[b] mg/L	SiO_2 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Sr mg/L	HCO_3 mg/L	SO_4 mg/L	Cl mg/L	F mg/L	NO_3 mg/L	NO_3-N mg/L	Legal T R SEC[c]
6236/9072	1978	395	254	27	38	11	29	3.7	0.6	186	27	7.5	1.1	18	4.1	8-40W-35CCB
10883	1978	305	216	48	36	8.5	13	3.4	0.5	160	11	4.3	1	12	2.7	8-41W-17CBA
13936	1978	320	230	48	33	7.6	23	3.7	0.5	178	13	2.6	1.1	10	2.3	8-42W-2DAB
9993	1978	390	250	31	29	15	31	4	0.6	200	19	8.3	2.1	12	2.7	8-42W-34DCB
22907	1978	390	241	23	39	10	25	3.5	0.5	178	27	9.3	1.2	15	3.4	9-39W-19CCC
20328	1978	360	227	24	31	8.9	31	3.3	0.5	186	17	5.1	1	14	3.2	9-40W-8CCB
8101	1978	420	266	26	33	13	33	3.7	0.6	172	19	13	2	38	8.6	9-41W-5DCC
7976/8843	1978	430	285	22	44	13	26	3.5	0.6	163	42	17	1.5	35	7.9	9-42W-11CCC
10683	1978	340	212	19	31	9.8	26	3	0.4	176	15	5.8	1.6	14	3.2	9-42W-35ABB
10573	1978	835	223	21	41	9.5	18	3.2	0.4	173	21	9.5	1.1	13	2.9	10-40W-8BAA
1779	1978	880	587	22	94	22	72	5.1	1	309	183	15	1	20	4.5	10-40W-10ADC
25611	1978	310	190	19	39	8.2	10	4.2	0.4	169	8.9	2.2	1	14	3.2	10-41W-15CAD
12118	1978	405	245	21	35	14	26	4.3	0.8	185	25	13	1	14	3.2	10-41W-35CAC
8695	1978	310	189	18	35	7.8	16	3.1	0.4	164	13	3.2	1.2	11	2.5	10-42W-24BBA

[a] Specific conductance at 25° C.

[b] Total dissolved solids.

[c] Township, range, section, quarter sections from largest to smallest.

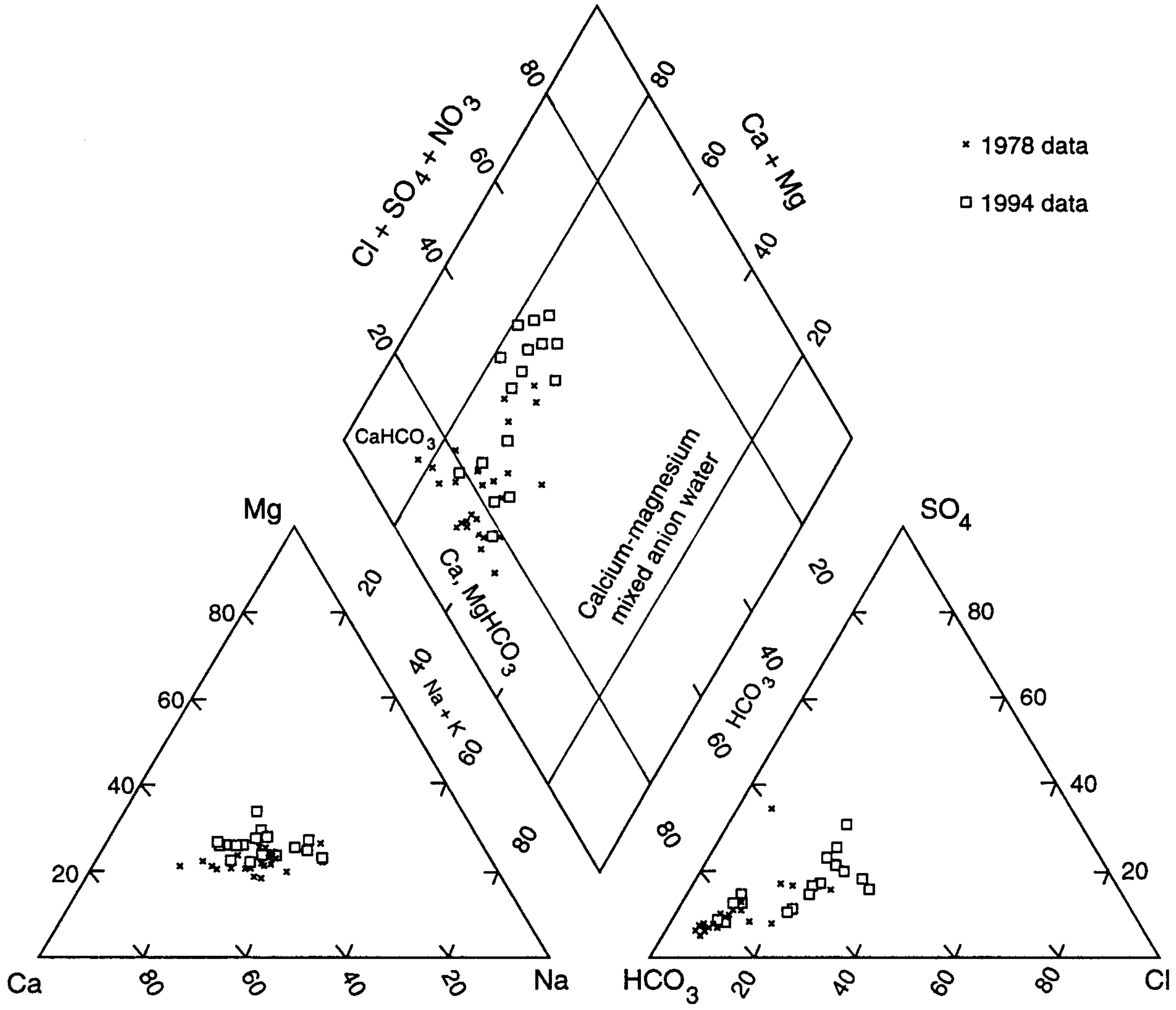

Figure 2. Trilinear diagram of water samples from study area collected in 1978 and 1994. Note that the 1994 samples have moved out of the trilinear diagram area for the calcium, magnesium bicarbonate water typical of the Ogallala because of increased total dissolved solids concentration from evapotranspiration processes.

Table 1 shows that most of the cation and anion concentrations, and consequently total dissolved solids (TDS) and specific conductance, show increases from 1978 to 1994. Table 2 lists the mean and median values for each constituent for the two time periods. The values for each constituent are higher for the 1994 samples. Further comparison with historical data may substantiate this hypothesis of concentration processes.

Table 2. Mean and median values for concentrations of selected chemical constituents in ground waters, Ogallala Aquifer, 1978 and 1994. Values are in mg/L.

Constituent	Mean 1978	Mean 1994	Median 1978	Median 1994
Calcium	37.7	50.6	35	49.6
Magnesium	11.7	18.6	11	18.6
Sodium	28.4	35.3	26	36.4
Bicarbonate	185	191	179	189
Chloride	9	22.1	6.5	24.3
Sulfate	28	55	19	52
Nitrate-N	3.2	11.6	4.2	13.1
Total Dissolved Solids	269.3	333.6	253	334

Figures 3 and 4 show the relationship between nitrate concentration and TDS and specific conductance. There is a strong correlation of nitrate-N with TDS ($r = 0.92$) and with specific conductance ($r = 0.92$). The strong correlations suggest that th origin of the high nitrate-N may be related to the higher TDS and specific conductivity values. It is possible that specific conductance could be used as a screening tool to determine which wells have high nitrate-N concentrations. The equations listed on the graphs are for linear regressions based on the 1994 set of data. The equations could be refined by adding the data from 1989-1993 and also by considering analyses for other Ogallala wells in the district.

A strong relationship of chloride with specific conductance ($r=0.86$) and of sulfate with specific conductance (0.93) support the idea of evapotranspiration concentration of constituents in the irrigation water followed by infiltration of tailwater runoff to the ground-water system. At present the relationship between nitrate concentration and other constituents is not known. Work by Whittemore et al. (1993) on water chemistry from the Dakota aquifer resulted in a series of equations for the association of nitrate concentration with other chemical constituents. This sort of analysis could be done for the data from GMD4.

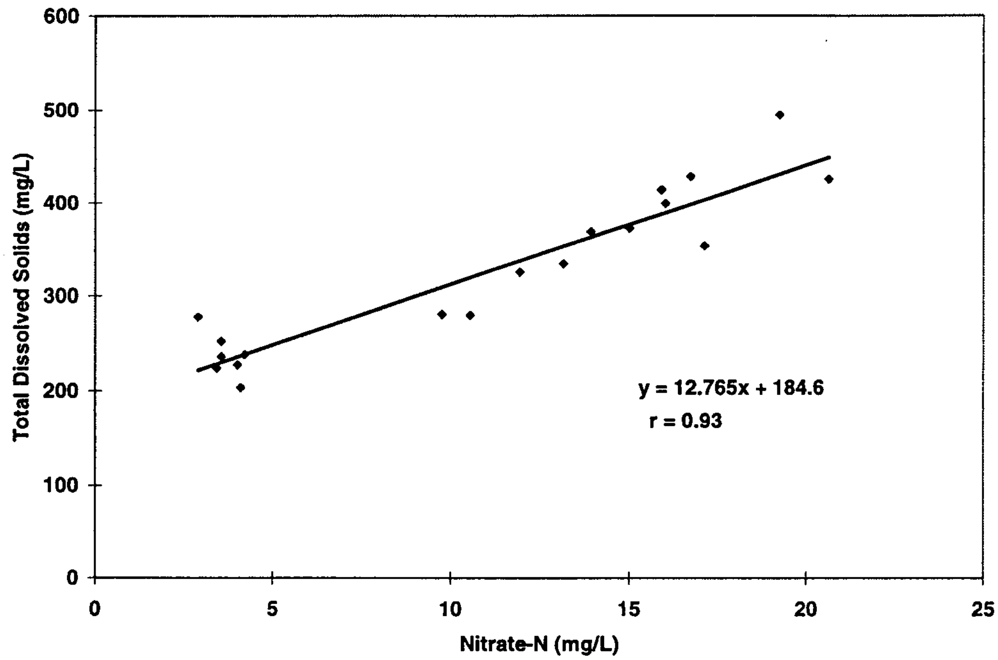

Figure 3. Relationship between total dissolved solids and nitrate-N concentrations for irrigation wells. Samples collected in 1994, Sherman County, Kansas. Graph shows that the occurence of high nitrate may be related to evapotranspiration processes as indicated by high total dissolved solids concentrations.

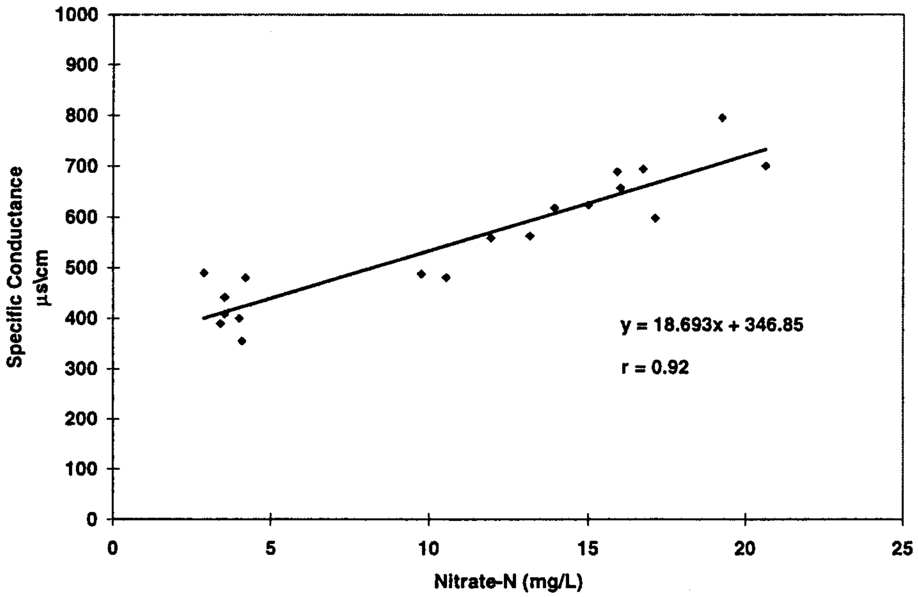

Figure 4. Relationship between nitrate-N concentration and specific conductance values from samples collected from irrigation wells, summer, 1994. Graph indicates that increasing specific conductance values might be used to screen water samples for high nitrate-N values.

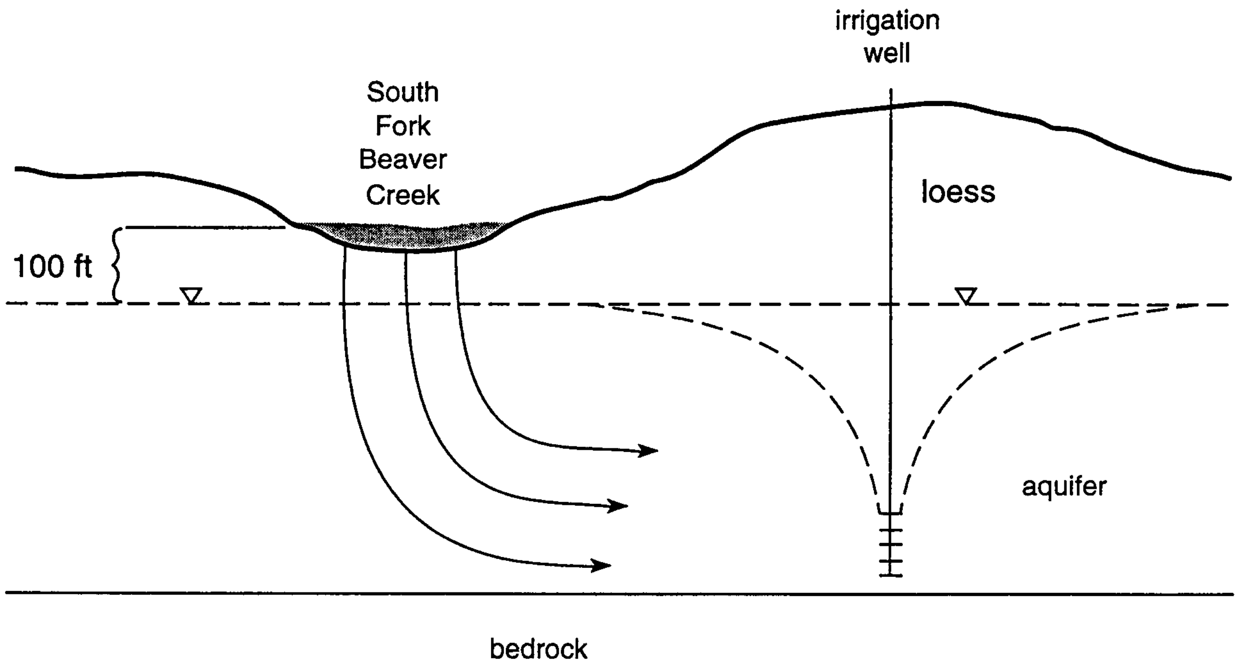

Figure 5. Proposed recharge mechanism for nitrate-rich tailwater runoff to South Fork of Beaver Creek to reach the deeper Ogallala aquifer.

Figure 5 shows the proposed mechanism whereby the tailwater runoff could reach the ground-water table more quickly than by recharge from the uplands. The farmers in the area report that South Fork of Beaver Creek ran bank full during the irrigation season. The shorter distance to the ground-water table (100 ft vs 200+ ft), the more permeable alluvial sediments in the area of the stream, and the presumed increased hydraulic head in the stream could result in increased recharge of tailwater runoff during the irrigation season. Assuming that evaporation concentration occurred during the same time period, then increased TDS water would infiltrate faster than normal recharge to the area resulting in a plume of higher concentration water in the irrigation wells downgradient. The high nitrate-N concentrations could be a result of the high fertilizer use (250-300 lb N/acre) at that time period.

Figure 6 shows the distribution of nitrate-N concentrations based on the number of wells sampled from 1989 to 1994. Of the 72 samples collected since 1987, 17 have nitrate-N greater than 10 mg/L, seven are between 7 to 10 mg/L, 10 are between 5 to 7 mg/L, 25 are between 3 to 5 mg/L, and 13 are less than 3 mg/L. The majority of the wells have less than 7 mg/L of nitrate-N. However, 83% of the wells have nitrate-N greater than 3 mg/L, which is considered the indicator level for anthropogenic sources of nitrate (fertilizer or animal waste; Madison and Brunett, 1985).

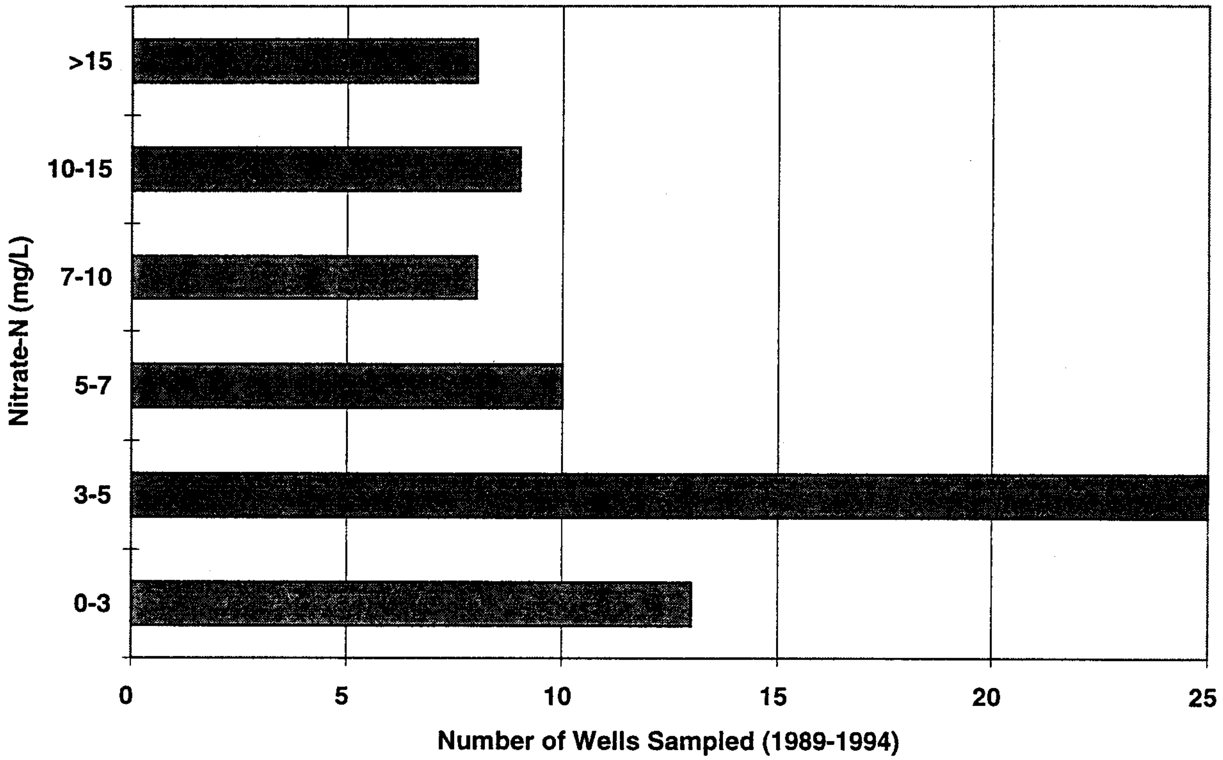

Figure 6. Nitrate-N concentrations for irrigaiton wells sampled during study period (1989-1994). Graph shows that the majority of wells have nitrate-N concentrations above the 3 mg/L level indicative of probable anthropogenic sources of contamination (Madison and Brunett, 1985).

Nitrogen Isotopes

Background

Nitrogen-15 isotopes have been used throughout the United States as a tool for delineating potential sources for nitrate contamination in ground water. Work by Kreitler (1975), Kreitler and Jones (1975), Kreitler (1979), Heaton (1986), Herbel and Spalding (1993), Bobier et al. (1993), Gormly and Spalding (1979), Spalding and Kitchen (1988), and Spalding and Exner (1993) indicate that nitrogen-15 values from nitrogen species in the vadose zone and ground water can be used for identification of sources of contamination. Figure 7 shows the ranges of $\delta^{15}N$ (nitrogen-15) for a variety of source materials (after Heaton, 1986). Units for isotope values are in parts per thousand (ppt) which is represented by the symbol ‰. The typical isotope range for fertilizer nitrogen is -5 to +8 ‰. The range for animal waste is +10 ‰ and above.

The $\delta^{15}N$ for ammonium-N based fertilizer in Nebraska is approximately -1 ‰ while the $\delta\ ^{15}N$ for nitrate-N based fertilizers is approximately +4 ‰ (Gormly and Spalding, 1979). While the actual signature for the fertilizer used in Sherman County is not available, it is likely that a combination of both ammonium- and nitrate-based fertilizers were used and that the $\delta^{15}N$ of the fertilizer was around +1.5 ‰ as observed by Herbel and Spalding (1993). This means that any increase in the nitrogen isotope concentration is due to fractionation enrichment of the isotope. Fractionation is the process by which the lighter isotope ^{14}N is preferentially released and the heavier isotope ^{15}N is concentrated in the remaining nitrogen compound whether it is ammonium, nitrate, or organic nitrogen.

Enrichment Processes

There are several processes by which fractionation enrichment can occur: volatilization of ammonia and then nitrification of the remaining dissolved ammonium ion to nitrate; or denitrification of the nitrate and/or ammonium ion by microbes in which case the nitrate is converted to nitrous oxide or nitrogen gas and removed from the system. Work by Herbel and Spalding (1993) indicated that nitrate that started from fertilizer with an isotopic value of around +1.5‰ could obtain a nitrogen isotope value of +8‰ because of volatilization and/or denitrification processes. In their study the abundance of carbonate increased in the core with depth indicating that the pH of the system became more alkaline with depth (pH=8.5). This pH is within the range where volatilization of ammonia may occur, thereby enriching the remaining nitrogen compounds with ^{15}N.

Work by Heaton (1986) and Mariotti et al. (1988) showed that denitrification processes can result in enriched ^{15}N isotope values in the same range as animal waste. However, these studies indicated that generally there is a large decrease in nitrate concentration with an increase in ^{15}N value. Denitrification enrichment up to +20 ‰ with nitrate concentrations of 0.2 mg/L have been observed in ground water in south-central Kansas (Townsend et al., 1995).

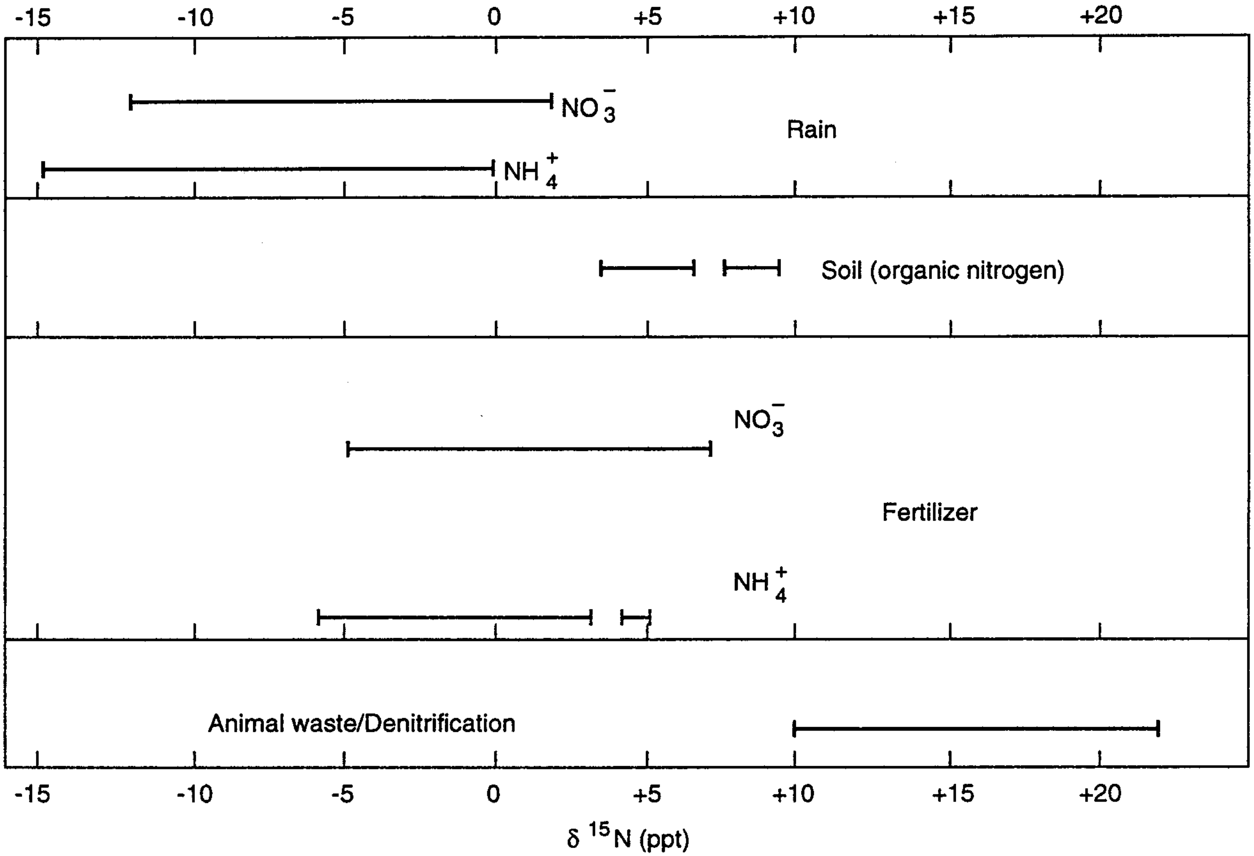

Figure 7. Range of $\delta^{15}N$ values for different source materials. Fertilizer values range from -5 to +8 ‰ for both ammonium- and nitrate-based fertilizers. Animal waste is generally greater than +10 ‰ usually with a nitrate-N concentration greater than 10 mg/L. Denitrification processes can also result in $\delta^{15}N$ greater than +10 ‰ but nitrate-N values are generally less than 3 mg/L. Nitrogen isotope values obtained from literature review of Heaton (1986).

Factors Influencing Evaluation of N-15 Data

The variability of cause of isotope enrichment means that the use of ^{15}N isotopes for source detection is not a straightforward process. The careful observation of surface geomorphology, stratigraphy, geochemistry of the ground water, and land use need to be included in the evaluation of the data (Townsend et al., 1994).

Geomorphologic processes can affect the thickness of the unsaturated zone, stream-channel morphologies, surface-soil types, and general land forms in an area. Topographic position in a landform was found to be an important factor in determining whether denitrification processes occurred in the Palouse loess in Washington (Geyer et al, 1992). Factors associated with slope position, such as a shallow water table and impeding stratigraphic layers helped to explain higher denitrification potential at a bottom slope position. Presence of impeding stratigraphic layers such as silt/clay over/under sand zones can permit areas for denitrification if water is perched above a clay or for nitrification of ammonium to nitrate if pH and temperature conditions are correct.

Geochemistry of the ground water (reducing or oxidizing conditions) helps to determine if nitrate concentration will be high or low and whether denitrification might occur. Denitrification occurs optimally with a pH around 7, low oxygen concentration, microbial population, and carbon concentration. Presence of very low nitrate concentration, measurable ammonium, iron, and manganese, and a hydrogen sulfur odor were found to be indicators of chemically reducing conditions in ground water in Harvey County, Kansas (Townsend et al., 1995). These indicators plus the enriched $\delta^{15}N$ suggested that denitrification was responsible for the low nitrate concentration in these ground waters. In another portion of the county, these indicators were not present and the nitrate concentrations were high with enriched nitrogen isotopes above +10‰ because of animal-waste point sources.

Land-use observations and farm-chemical-use records are important for categorizing the possible source materials responsible for the observed nitrate in the ground water. Use of fertilizer alone or in combination with manure will result in different isotopic signatures in the soil and ground water. Presence of septic system lateral fields, abandoned septic systems, feedlots, abandoned feedlots, or manure storage facilities would provide sources for an animal waste isotope signature (≥+10 ‰) and an observable high nitrate-N concentration in the ground water.

Most of the studies cited above deal with areas with shallow water tables of 20- to 50-ft depths. The nitrogen isotope method has been used fairly successfully in Great Bend Prairie and Equus Beds regions of south-central Kansas. Not much work has been done on using nitrogen isotopes to identify sources in deep ground water. Past work in Sherman County evaluating the nitrogen isotope concentration from cores and soil waters suggested that some fractionation enrichment of the isotope may occur in the vadose zone above the Ogallala aquifer (Townsend, unpublished data). One of the aims of this study was to determine the effectiveness of the method in a deep aquifer situation.

Isotope Sampling, 1994

In the summer of 1994, five irrigation wells with high nitrate-N concentrations (above 10 mg/L) were sampled and tested for nitrogen isotopes. In addition, two domestic wells with high nitrate-N concentrations, the monitoring wells in the area, and those soil-water samplers with sufficient water available were also tested (fig. 8). At present, the results look promising for use of the method to evaluate possible sources for the nitrate plume in the area. Table 3 lists the nitrate-N concentrations and $\delta^{15}N$ values for soil-water, irrigation, domestic, and monitoring wells.

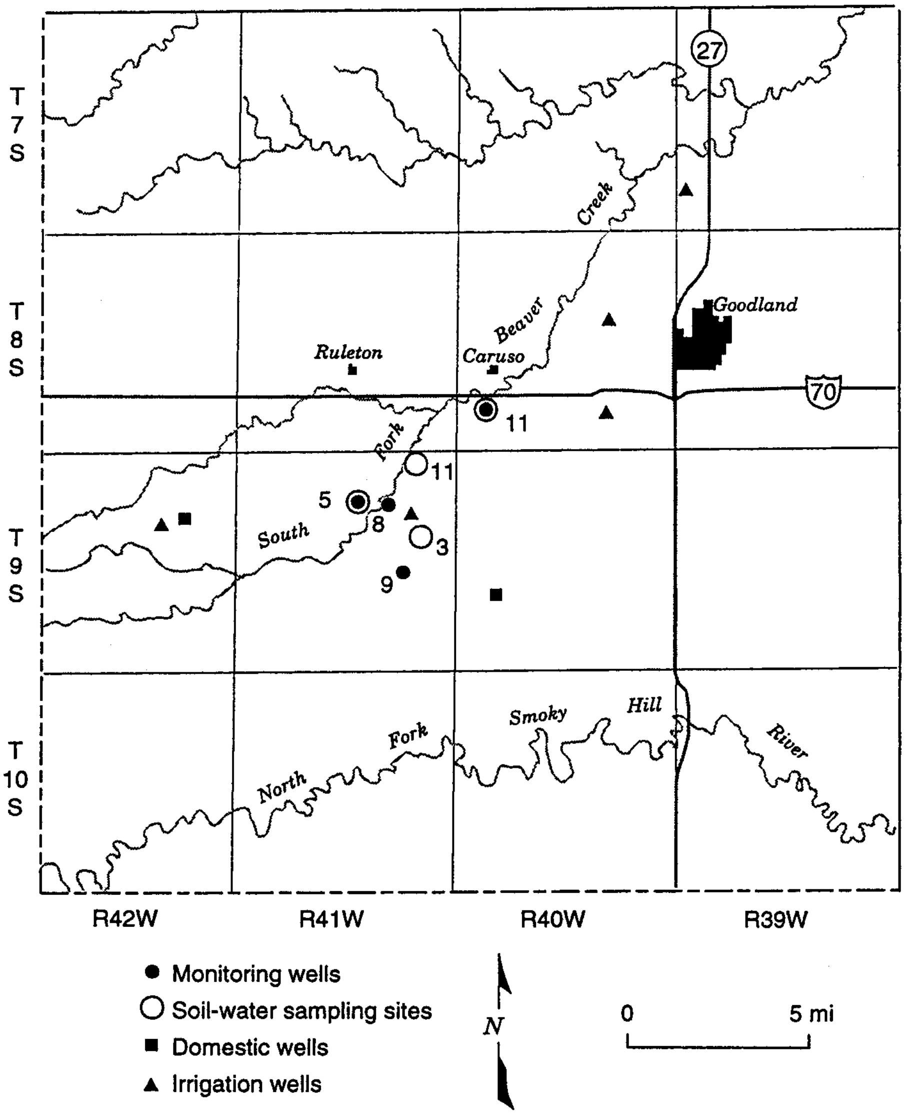

Figure 8. Location of sampling points for complete chemical and nitrogen-15 isotope analyses. Results are listed in tables 1 and 3.

Table 3. Nitrogen-15 values from GMD4 soil-water samplers, monitoring wells, and irrigation wells.

Date	**Site ID**	**Nitrate-N mg/L**	**$\delta^{15}N$ ‰**	**Date**	**Site ID**	**Nitrate-N mg/L**	**$\delta^{15}N$ ‰**
	Soil-water samplers				**Irrigation Wells**		
08/27/90	5-25	53	6.0	7/94	7021	9.2	7.8
	5-40	115	3.5		4907	20.1	7.9
	5-50	142	3.3		6236	20.6	10.2
					7976	17.1	8.5
10/16/90	5-25	52	5.1		9136B	15	9.7
	5-40	103	4.0				
	5-50	135	3.9				
	10-46	6.9	3.5		**Monitoring Wells**		
06/04/91	5-25	47	5.2	7/94	5-110 ft	10.5	9.9
	5-50	124	3.3		5-200 ft	2.2	6.8
	10-27	16	4.7		8-	2.3	7.1
	10-72	9	6.6		9-	4.6	11.7
					11-104 ft	1.8	10.1
7/94	3-20	27.5	5.0		11-139 ft	0.7	8.2
	3-40	20.1	7.4				
	5-25	28.4	8.6				
	5-40	84	4.4		**Domestic Wells**		
	5-50	18.2	6.5				
	10-17	66.1	5.7	7/94	Dom 11	27.7	6.8
	10-27	0.2	10.2		Dom W	69.7	7.4
	11-33	6.2	12.4				
	11-72	3.8	8.1				

Domestic-well Waters

The nitrogen-15 results are shown in figure 9 for the irrigation, domestic, and monitoring wells sampled in 1994. The figure shows that the domestic-well waters fall into the fertilizer range for the nitrogen isotopes (+2 to +8‰). These domestic wells have very high nitrate-N concentrations and it was originally supposed that animal waste from septic systems or animal pens at the farms were the source of the nitrate. The values recorded for these wells are not in the animal waste range (> +10 ‰) but are within the fertilizer range (+6.8, +7.2 ‰; fig. 7).

The isotope values are near the upper range for fertilizer but based on the findings of Herbel and Spalding (1993) the domestic well-water values may be explained by possible volatilization enrichment in the vadose zone and the long travel time through the vadose zone to the ground water. The presence of numerous caliche zones in the loess profile above the Ogallala aquifer suggests that the pH of the loess profile has varied above pH = 8. With a pH above 8, volatilization of ammonia from any ammonium-based fertilizer could occur, even at depth, resulting in enrichment of the nitrogen isotopic signature. Possible nitrification of the remaining ammonium to nitrate could follow. This would result in continued high nitrate concentration in the ground water but an enriched isotopic signature such as was seen by Herbel and Spalding (1993).

In addition, at both sites extensive irrigation surrounds the farms where the domestic wells are located. Also, both farms have a closed depression within 1 mile of the homestead that may have been (or is currently) used for tailwater runoff. It is possible that these depressions acted as concentrated recharge points for tailwater runoff when sugar beets were planted in the area. Work on recharge processes in the southern Texas High Plains based on $\delta^{18}O$ and δD isotopes showed that focused percolation of playa-lake water fed by precipitation is a major source of recharge to the Ogallala aquifer (Nativ, 1988). If the recharge water were irrigation tailwater instead of precipitation, it might result in the observed $\delta^{15}N$ values. This is an area that needs more investigation.

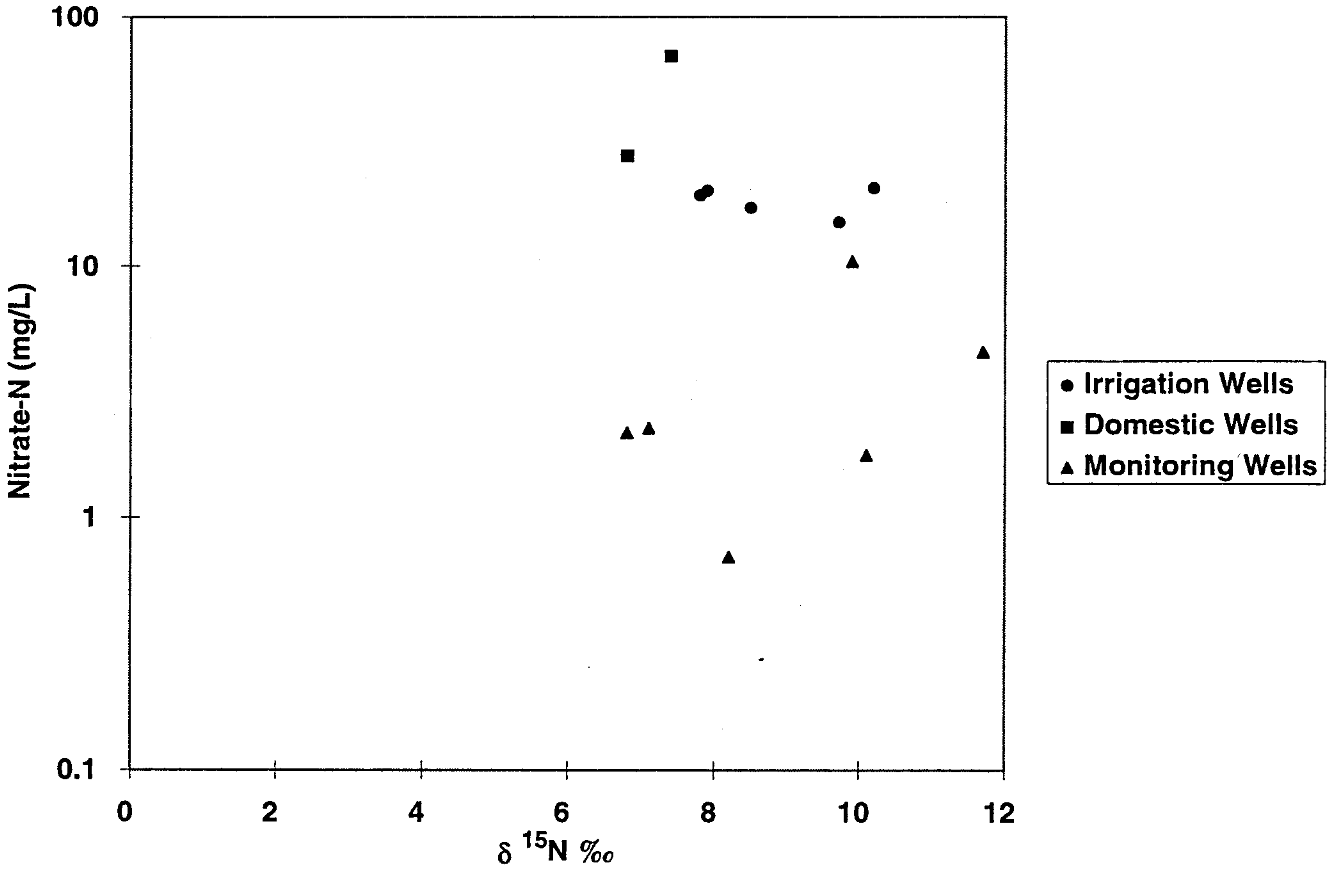

Figure 9. Graph shows relationship between nitrate-N concentraiton and δ ^{15}N values. Monitoring wells are below 10 mg/L as nitrate-N and have enriched δ ^{15}N values because of volatilization enrichement or denitrification processes. Domestic and irrigation wells have high nitrate-N concentrations but δ ^{15}N values are in the range of fertilizer or enriched fertilizer sources.

Irrigation Wells

The irrigation wells have nitrogen isotope values from +7.8 to +10.2 ‰ (fig. 9). Although the higher values are near and above the limit for animal wastes, there are no obvious point sources of animal-waste near these wells to explain the higher isotope values. Conversations with the farmers indicated that manure was not commonly used as a fertilizer on these fields. It is most likely that the $\delta^{15}N$ values represent volatilization enrichment of the nitrate because of the long travel time through the vadose zone. Depth to water in the region of these wells is 150 to 200 ft deep.

Monitoring Well and Soil Waters

The shallow well at site 5 (104 ft) is near the water table and yields water with an $\delta^{15}N$ value of +9.9 ‰ (fig. 9). The deep well-water (200 ft) has a value of +6.8 ‰. The difference in values may reflect the flow path taken through the vadose zone. The value that is in the fertilizer range may reflect movement through a macropore or fracture or may be a result of mixing of a smaller volume of water from the vadose zone with more abundant regional flow in the Ogallala aquifer.

The presence of the two different nitrogen isotope values at the two wells may also represent stratification of nitrate near the top of the water table and a lack of vertical mixing at the site. This is supported by the higher nitrate-N concentration for water from the shallow well and the lower nitrate-N concentration for samples from the deeper well. This type of stratification is typical of wells sampled in the Platte River region of Nebraska (Spalding, 1984; Gormly and Spalding, 1979).

Figure 10 shows the inverse relationship of nitrogen isotope values with nitrate-N concentrations for waters from the soil-water samplers and monitoring wells installed in the study area. The correlation coefficient is $r = -0.66$. The presence of decreased nitrate-N concentration with increased nitrogen-15 values suggests that denitrification processes are occurring over time as the nitrate moves through the soil to the ground water.

The shallow well-water at site 5 (104 ft) has a $\delta^{15}N$ signature greater than that of the soil water at 50 ft depth (table 3). Figure 11 shows the increase of nitrate-N concentration in well 5 water over the period of study. The figure shows the decrease in nitrate-N concentration in the soil waters with time corresponding to the increase of nitrate in the ground water, suggesting that the nitrate in the soil profile finally reached the water table.

Nitrate-N concentrations from the monitoring wells in the area show that, except for the shallow well at site 5, the nitrate-N concentration is below 7 mg/L (fig. 9). The well-water at site 9 has the next highest concentration to the shallow well-water at site 5. The well is located in a dryland field that is surrounded by irrigated fields. The nitrogen-15 value for this well is +11.2 ‰, which is in the animal waste range (fig. 7, table 3). However, no immediate source of animal waste exists near this field. Because this is a dryland site, it is possible that we are observing overall enrichment because of fractionation and volatilization or denitrification processes in the vadose zone.

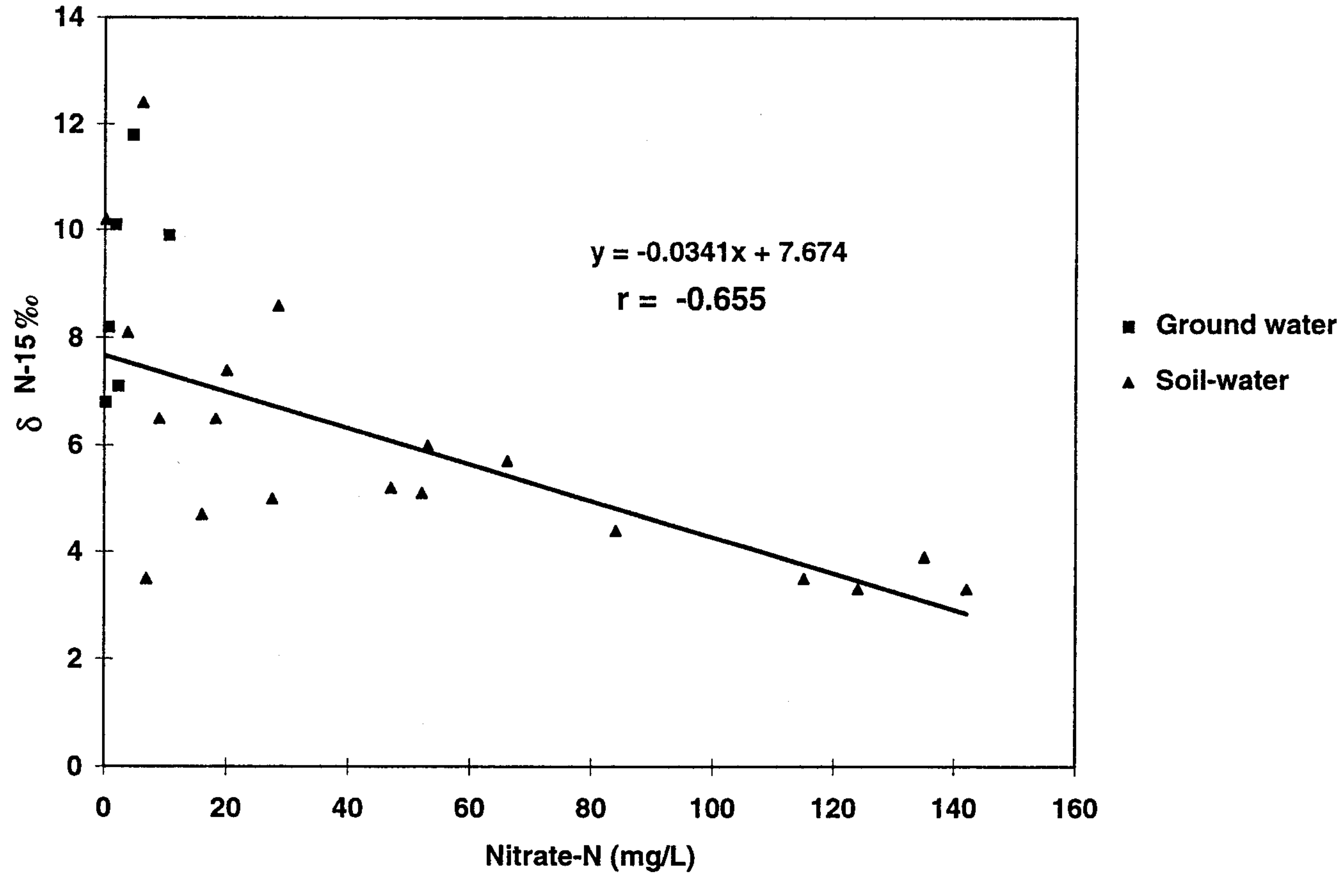

Figure 10. Graph shows decreasing $\delta\ ^{15}N$ values with increasing nitrate-N concentration which is typical for fertilizer sources. The presence of increased $\delta\ ^{15}N$ values with decreasing nitrogen-N concentration is typical of denitrification enrichment processes typical of water moving through the vadose zone to ground water.

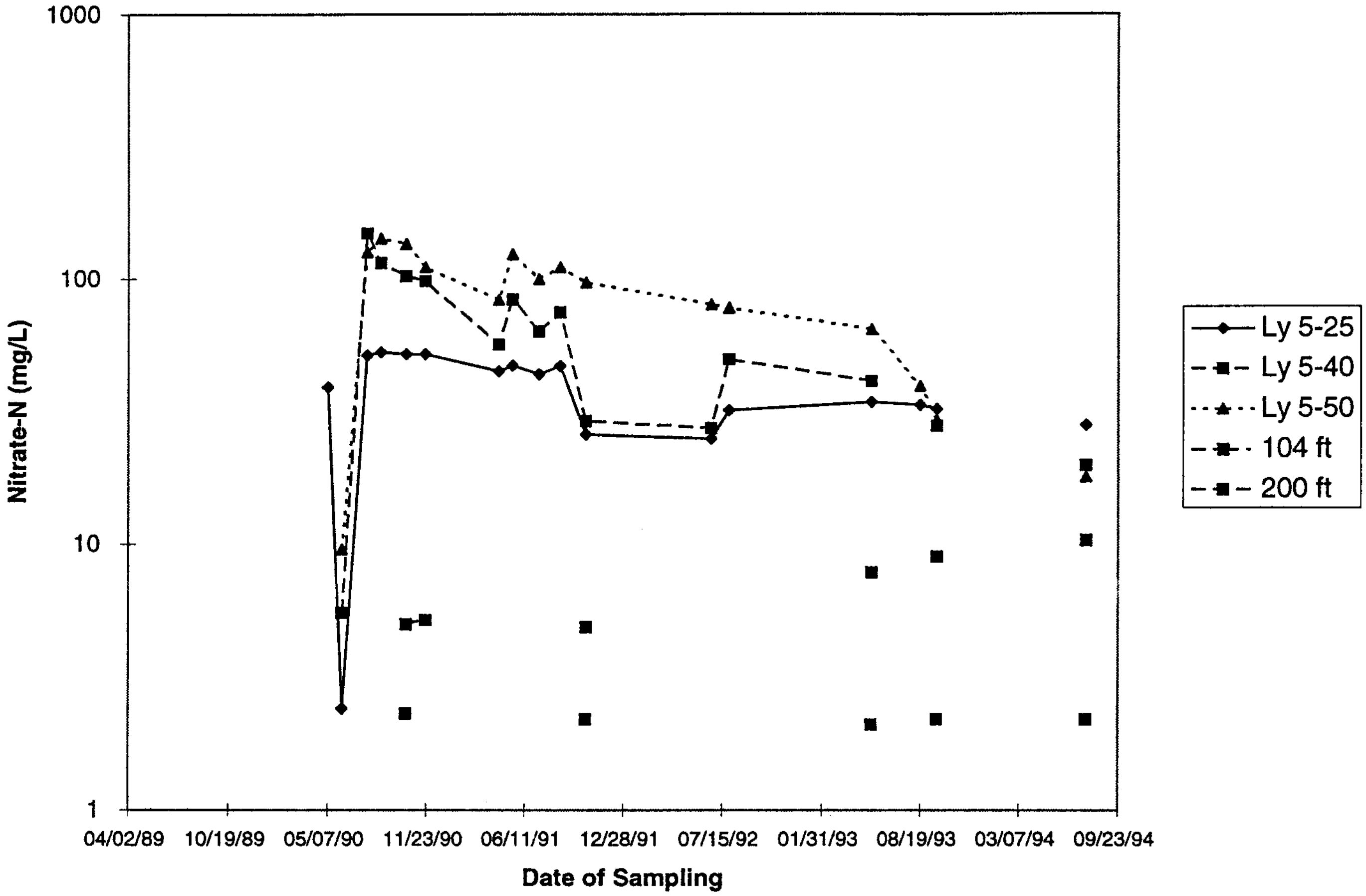

Figure 11. Decrease in nitrate-N concentrations for soil-water samples over time correspond to increase in concentrations in shallow ground water (104 ft) suggesting that nitrate in the vadose zone finally reached the water table.

The well at site 8 is in a pasture on a feeder stream to the South Fork of Beaver Creek. This well is also located downgradient from several irrigated fields. The nitrogen-15 value for water from this well is +7.1 ‰ which is in the fertilizer range. This well is closer to the stream than that of site 9, and is similar to the deeper well at site 5 suggesting that the deeper ground water may have a $\delta^{15}N$ signature in the soil nitrogen/enriched fertilizer range (fig. 7).

The wells at site 11 are the furthest monitoring site downgradient on the South Fork of Beaver Creek and are sited in a pasture (fig 8). Waters from these wells have varied but enriched nitrogen-15 signatures. The shallow well-water shows a much-enriched signature of +10.1 ‰ with low nitrate-N (1.8 mg/L; fig. 9). This well has very low yield with a minimum recovery period of 8 to 12 hours after being pumped dry. The slow recovery may indicate that this well is sited in a perched water table. Similar enriched $\delta^{15}N$ signatures were found in a perched water table in south-central Kansas suggesting that slow recharge may enhance denitrification processes (Townsend et al., 1994). The deeper well is also somewhat enriched (+8.2 ‰ with a very low nitrate-N concentration [0.2 mg/L; table 3]).

The soil-water samplers at site 11 yielded samples that also have enriched $\delta^{15}N$ with low nitrate-N concentrations (table 3). The presence of the very low nitrate concentration along with the enriched isotope values suggests that denitrification processes are occurring at this site rather than an animal-waste source for the enriched nitrogen isotopes. The low nitrate-N concentrations from the soil water and ground water also help to support the idea of denitrification processes occurring at this site.

Discussion of Sources for Nitrate

The primary reasons for concluding that sugar beet farming practices are a major source of the nitrate problem in the area are

(1) Monitoring site 5 is located in a pasture adjacent to Beaver Creek. The site has not been irrigated but has high nitrate-N concentrations throughout the soil profile that are not consistent with a soil nitrogen source. The nitrate-N concentrations (>10 mg/L) are consistent with an anthropogenic source.

(2) An isotopic and nitrate-N concentration difference exists between different depths in the aquifer indicating the possibility of macropore and/or diffuse flow in the vadose zone or mixing within the aquifer. The shallow ground water (104 ft) has a nitrate-N concentration >10 mg/L and $\delta^{15}N$ of +9.9‰ whereas the deeper ground water (200 ft) has a nitrate-N concentration of 2.2 mg/L with a $\delta^{15}N$ of +6.8. The difference between the two values may be due to volatilization enrichment of fertilizer in the vadose zone and the possibility of mixing or dilution of the original fertilizer-enriched water upon reaching the deeper portion of the aquifer.

In addition, the domestic well-waters with high nitrate-N concentrations are downgradient of irrigated land that has been in production since the 1950s to 1960s. The isotope values for these well-waters are in the fertilizer and/or soil nitrogen range (+2 to +8 ‰), not in the animal waste range (> +10 ‰). The high concentration of nitrate in these wells and the fact that other well-waters, both domestic and irrigation, within the area do not uniformly have high nitrate concentrations, suggests that fertilizer is probably the main source. The isotope values are not in the range of animal waste but are similar to those found by Herbel and Spalding (1993) in the loess-type deposits of Nebraska. The presence of long-term depressions in irrigated fields upgradient and adjacent to the farmsteads suggests a possible route for increased recharge to the water table as suggested by Nativ (1988).

The irrigation well-waters have a range of isotope values within the fertilizer range that are consistent with data from other areas when fractionation and volatilization enrichment processes are taken into consideration. Also, if the source of the nitrate were from a natural source, such as the breakdown of organic nitrogen during the initial farming of the area, one would expect a wider area of contamination and not such a narrow band as has occurred in this area.

Management and Research Recommendations

1. Specific conductance may be a useful tool for selecting wells for possible testing for nitrate and complete analyses (for total dissolved solids computations) in ground waters. Values greater than 500 µS/cm appear to influenced by high nitrate. This method has to used with some caution because there are probably areas in the district that are influenced by other sources of high salinity or other contamination problems that would also affect the specific conductance.

2. The well-waters that have high nitrate-N values appear to retain these values over many years suggesting a long term source. A number of wells in the area have been sampled periodically since 1987 and have retained their high nitrate values.

Values of nitrate-N consistently at 10 mg/L are equivalent to 27 lb N/acre-ft of water applied. A possible means of preventing the further migration of the plume would be to recommend using the irrigation water as part of the nitrogen application rate as has been done in Nebraska. Use of specific conductance as a screening tool and a simple nitrate test such as by a Hach or other chemical kit would permit an easy estimate of nitrate-N concentration.

3. Based on a reconnaissance study of five irrigation wells, two domestic wells, and six monitoring wells, nitrogen isotopes appear to define possible sources of nitrate in the area. The combination of nitrate-N concentrations and isotope data seems to be a useful tool for determining source. As long as the land use of the area is evaluated for potential point sources

such as abandoned septic tanks, feedlots, or fertilizer spills and mixing points it appears that the method may work in this area.

It would be helpful to expand the area of testing in terms of evaluating wells at feedlots and irrigation wells downgradient of feedlots to determine the animal-waste end member of the method as well as sampling at fertilizer cooperatives to determine if fertilizer is getting into the ground water by way of leaks or spills. It would also be very useful to obtain representative samples of fertilizers used in the area in order to have these values on record.

In addition, it would be useful to obtain background nitrate-N and isotope values for irrigation and domestic well-waters from the Ogallala aquifer in areas that are not affected by the present nitrate contamination problem. These samples would provide a comparison for the contaminated water samples.

4. It is possible to determine the correction for the influence of high nitrate-n values on the total dissolved solids concentrations and specific conductance values for the waters in the area. This might assist the district in determining areas of potential contamination or degradation because of nitrate.

5. Use of Geographic Information Systems (GIS) methodology would be useful in plotting the geographic relationship between high nitrate well-water and water-rights application to determine if mainly the older wells are contaminated or if it is solely a geographic location that determines whether a well is contaminated.

6. A further area of investigation would be to construct a generalized input/output model for the area of study to try to determine the volume of nitrogen that may have moved (or is moving) through the system to the ground water and possibly determine estimates of travel time for the plume to the Ogallala aquifer.

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