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Nitrate Contamination in the Seymour Aquifer, North-Central Texas, USA

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Agricultural practices often lead to nitrate contamination in groundwater. Tilling aerates soil and encourages nitrification (NRC 1978). Power and Schepers (1989) estimated that 60% of the nitrogen input by agricultural practices in the U.S. is not removed in harvested crops. Nitrate levels in groundwater beneath agricultural regions have been measured as high as 100 times those beneath areas with no fertilization and natural vegetation (Steinheimer et al. 1998). The purpose of this study was to compile and evaluate concentrations of nitrate and related solutes in an agricultural region of north-central Texas, USA.

The study area is a rural, agricultural setting in the Rolling Plains of north-central Texas (Figure 1). It has been intensively farmed since the early 1900s. The underlying Seymour Aquifer provides water for irrigation, municipal, domestic, and stock supplies. About 90% of the water pumped from the aquifer is used for irrigation. Median well depth in the aquifer is approximately 15 m, and well yields average about 1.0 m^3/min (Harden and Associates 1978). Most of the wells are completed in the lower part of the formation, where the deposits are coarser and more permeable.

The Seymour Formation is fluvial in origin, comprising unconsolidated, interbedded sand, gravel, silt, and clay of Pleistocene age. These deposits occur in discontinuous patches (Figure 1). Unconfined groundwater levels in the Seymour Aquifer average 7 m beneath the land surface, and saturated thickness averages 9 m. Permian shale underlies the aquifer.

Precipitation is the principal source of recharge to the aquifer. Sandy soils and flat topography facilitate recharge. The semiarid region has long, hot summers and short, mild winters. Precipitation maxima occur in late spring and early fall. Annual rainfall averages 61 cm, contributing 5-8 cm of recharge to the aquifer (Harden and Associates 1978). Groundwater discharges by evapotranspiration and to seeps, springs, underlying formations, and pumping wells.

Agriculture and oil/gas production dominate the region's economy. Cropland and grassland/shrubland account for more than 90% of the land cover. The main crops are wheat, cotton, and sorghum.

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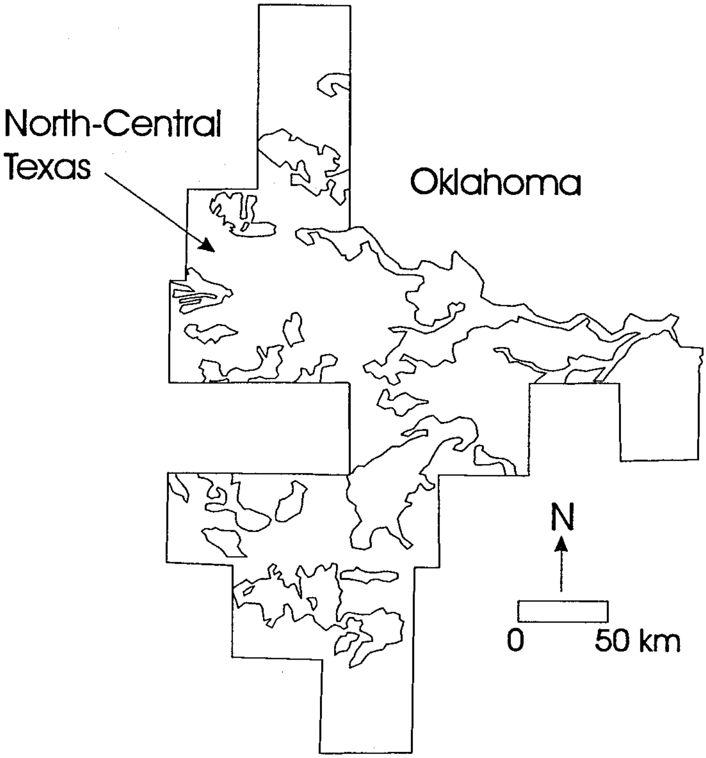

Figure 1. Map of study area showing spatial distribution (within irregular polygons) of Seymour Aquifer; orthogonal lines delineate county boundaries.

Oil and gas wells have been drilled in every county of the study area. A major oil field, tapped by thousands of production wells, underlies the southeastern two-thirds of the study area. Oilfield brine discharged to unlined earthen pits, leaking from injection wells, or migrating through abandoned wells is a potential source of groundwater contamination in the Seymour Aquifer.

MATERIALS AND METHODS

Well depth and location coordinates, and nitrate, chloride, and bromide concentrations were compiled from the Ground Water Database of the Texas Water Development Board. The dataset used in this study included a total of 819 wells, including 184 domestic use, 12 public supply, 267 irrigation, 106 stock, 13 industrial, 233 unused, and 4 unknown wells. Samples were taken directly from each well. Analyses were completed using automated colorimetry or ion chromatography. Solute concentrations were compiled for each of 12 sampling years, including 1936, 1944, 1953, 1957, 1963, 1967, 1972, 1978, 1982, 1987, 1991, and 1997.

Land cover data were obtained from the U.S. Geological Survey's Geographic Approach to Planning (GAP) database. Cover types were consolidated into five categories, including cropland, grassland/shrubland, woodland, urban, and other. A geographic information system, ArcView (ESRI 1998), was used to map solute concentrations and land use, and to identify the land cover at each well sampled in 1982, 1987, 1991, and 1997. Solute concentrations beneath land cover classifications having at least five observations were compared using Kruskal-Wallis tests. Spearman rank correlations were used to explore associations between variables. Nonparametric statistics were used because the solute concentration data were not normally distributed.

RESULTS AND DISCUSSION

In each of the 12 sampling years, at least 37% of the water samples registered nitrate values greater than or equal to the maximum contaminant level (MCL) (Table 1). In eight years, more than 50% of the nitrate observations exceeded the MCL. High chloride levels were also observed. In each year, at least 27% of the chloride observations exceeded 250 mg/L. More than 50% of the chloride observations exceeded 250 mg/L in each of four years.

High chloride/bromide ratios (> 300) generally suggest possible impacts from domestic wastewater or feedlots (Vengosh and Pankratov 1998), or a water source low in bromide. However, more than 80% of the chloride/bromide ratios were less than 300, more consistent with agricultural return flow or oilfield brine. Marine organisms that form petroleum are generally enriched in bromine relative to chlorine (Whittemore 1995). Many chloride observations exceeded 1,000 mg/L — these could also result from groundwater mixing with oilfield brine. Texas oilfield brine contains 20,000-250,000 mg/L chloride (TWC 1989).

Table 2 shows median nitrate concentrations for each land use. Nitrate concentrations were generally higher beneath cropland compared to other land uses. In 10 of 12 years, median nitrate concentrations beneath cropland were equal to or higher than those beneath all land uses. These results suggest that agricultural activities, including cultivation (and subsequent mineralization of soil organic nitrogen in plant detritus, bacterial biomass, and soil constituents) and fertilizer applications are probable sources of nitrate in the Seymour Aquifer.

Excluding 1953 (when nitrate and chloride concentrations were inversely correlated), there were no statistically significant associations between any pair of solutes, or between any solute paired with well depth (α=0.05). A significant positive association between nitrate and chloride could potentially indicate septic system or feedlot contamination (Canter and Knox 1985), but was not observed. There are few feedlots in the study area. Moreover, compacted feedlot floors retard infiltration and provide an anaerobic environment for denitrification (Sweeten 1992). In general, feedlots contribute substantially less nitrate to groundwater than cropland (Ator and Denis 1997).

Table 1. Summary of water quality data (mg/L).

Year	Solutes	Number of Observations	Min	Median	Max	Percent Greater than MCL
1936	N	35	ND	57	242	74
	C	61	25	215	19500	33
1944	N	28	2	56	244	75
	C	38	17	159	2131	32
1953	N	34	ND	32	105	38
	C	34	5	291.5	3020	3
1957	N	27	ND	113	177	81
	C	37	58	355	3018	68
1963	N	26	10	51	149	58
	C	51	35	183	10333	41
1967	N	400	ND	28	1484	37
	C	448	7	272.5	77780	52
1972	N	42	ND	60.5	306	74
	C	54	14	173	5900	37
1978	N	35	ND	46	1840	51
	C	37	10	280	10364	51
1982	N	38	ND	55.5	380	53
	C	41	9	131	1260	27
1987	N	30	12	57	276	67
	C	44	16	56	14400	36
1991	N	40	ND	37.5	273	40
	C	43	13	128	2520	37
	B	26	ND	1	11	NA
	R	26	5	90.5	U	19
1997	N	45	ND	37	178	38
	C	58	4	89	2800	29
	B	56	ND	1	6	NA
	R	56	5	57.5	U	18

Notes: MCL 44.3 mg/L nitrate, 250 mg/L chloride, 300 chloride/bromide; N = nitrate; C = chloride; B = bromide; R = chloride/bromide ratio; ND = not detected; NA = not applicable; U = undefined (infinite ratio).

Vertical mixing within the aquifer, along with a narrow range of well depths (most are screened near the bottom of the aquifer) contribute to insignificant associations between solute concentrations and well depth. The aquifer's thin and permeable character, long-term contaminant sources, and conservative solutes facilitate mixing throughout saturated intervals.

Table 2. Median nitrate concentrations (mg/L) by land use.

Year	Cropland	Grassland/ Shrubland	Woodland	Urban	Other	All Land Uses
1936	57.0	48.0				57.0
1944	56.5	56.0		47.0*		56.0
1953	56.0	23.0	32.0*			32.0
1957	115.0	39.5*	41.0*			113.0
1963	54.5	44.5				51.5
1967	42.0	25.0	18.5	16.5*	36.0*	28.0
1972	59.5	62.0				60.5
1978	30.0	68.0	68.0*	7.0*	47.0*	46.0
1982	62.0	39.0	20.0*	26.5*		55.5
1987	58.0	62.0	37.01*		20.0*	57.0
1991	52.0	22.0				37.5
1997	38.0	31.0	40.0*		36.0*	37.0

Notes: * = fewer than five observations; blank cell = no data; Kruskal Wallis test significant ($\alpha = 0.05$) for cropland versus grassland/shrubland for 1991.

The nitrate problem in the Seymour Aquifer has been long term and widespread, impacting the entire thickness of the aquifer. Measures that could be taken to address or ameliorate the problem include: (1) source control, (2) consuming bottled water (using contaminated water for other purposes), (3) household filters, (4) diluting contaminated water with other sources, (5) drilling new wells (away from adverse land uses), (6) avoiding adverse land uses near existing production wells, and (7) continued monitoring to identify problem areas.

Alternatives (1), (2), (6), and (7) seem most plausible. The others are too costly or impractical to be used throughout the study area. Recently, water from lakes has become available, but only for small municipalities at the eastern margin of the study area. Water pipelines do not service a vast majority of the study area. Drilling new wells does not guarantee low nitrate concentrations. The permeable nature of the aquifer allows contaminated groundwater to impact nearby properties.

Crop-related source control measures include applying fertilizer based on nutrient concentrations in soil (to avoid over application), when plants are actively growing (to minimize losses from the root zone), and not during extremely wet periods (to avoid losses to percolation). Infrequent tilling and keeping the ground covered with actively growing vegetation would further reduce nitrate losses, and also slow soil erosion.

Future monitoring is needed to define appropriate levels of mitigation throughout the study area. Such monitoring should be structured to include a set of wells covering the entire aquifer. The entire set of wells should be sampled regularly to identify problem areas and decipher trends over time.

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