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FLUCTUATIONS IN NITRATE CONCENTRATIONS UTILIZED AS AN ASSESSMENT OF AGRICULTURAL CONTAMINATION TO AN AQUIFER OF A SEMIARID CLIMATIC REGION

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Fluctuations in nitrate concentrations utilized as an assessment of agricultural contamination to an aquifer of a semiarid climatic region[1]

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Abstract. Aquifer water has become contaminated in regions that have been developed for agriculture. Nitrate contamination has been shown to be permeable to the aquifer and harmful to human health. An assessment of agricultural practices and their roles in contamination of aquifers has been undertaken with difficulty in the past. Nitrate concentrations have been utilized in this study to demonstrate their applicability to examining agriculture practices which contaminate aquifer water. Areas treated with nitrogenous fertilizers and subsequently irrigated were found to contain aquifer fluctuations in nitrate content directly in proportion to irrigation seasons. Agricultural industries with high animal densities per land area, and high water consumption for maintenance, were found to have high, but non-fluctuating, nitrate concentrations. Areas with high animal density per land area with low water usage for maintenance; areas with low animal density per land area; and agricultural practices for which little or no nitrogenous fertilizers were used demonstrated low aquifer nitrate concentrations regardless of water usage.

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Semiarid and arid lands are frequently a source of agricultural development where water for irrigation becomes available. When water for irrigation comes from aquifers, pollution often occurs as a result of the agricultural practices as shown by Hudson (1962) and Feth (1966). Nitrate contamination has been shown to be both hazardous to human health by McKee and Wolf (1963) and permeable, depending, of course, on the permeability of the soil and aquifer materials by Stewart, et al. (1967). This study has examined nitrate fluctuations in a semiarid region as a parameter for assessing agricultural involvement in contamination of aquifers. Semiarid and arid lands are unique in that their low levels of meteoric water permit determination of rainfall effects.

This study was conducted in the High Plains section of the Great Plains province of North America. The climate of the area has been classified as semi-arid continental, U.S.D.A. (1967). Typical of this climate, most of the annual precipitation occurs during the summer months in brief, heavy thundershowers. The area examined was located near the eastern border of New Mexico at the town of Portales. The area obtains its agricultural irrigation water from the southern Ogallala aquifer. This portion of the expansive Ogallala is isolated from any other aquifer or recharge source, Frye (1970). Return flow, or water from the surface returning to the aquifer, has been shown to be appreciable while recharge, or entrance of new water into the aquifer, has been shown by Cronin (1969) to be negligible. The soil associations of the region have been shown to be Amarillo-Clovis loams, Amarillo-Clovis fine sandy loams, Tivoli-Springer-Brownfield sands, and the Potter-Mansker association by the U.S.D.A. (1967). Permeability is typical of these soil associations and most are underlain by a porous or broken caliche ($CaCO_3$) layer at varying depths. The pH range in all types of soil in the five associations ranges from 7.5 to 9.4. Below the shallow soil zone was found the aquifer material which was composed of alluvially deposited coarse sand and gravel.

Methods and Materials

Sampling wells were located on 3.35 km radii extending to 16.25 km from the town of Portales in eastern New Mexico (Figure 1). Eleven wells were selected representative of the various soil associations and agricultural crops. All wells chosen for monitoring were properly cased and sealed. Sampling intervals were weekly during the study period.

Nitrate was quantitatively analyzed for using the Brucine Sulfate-Sulfanilic Acid method as described by A.P.H.A. (1971). Briefly, 2.0 ml of sample were mixed with 1.0 ml of brucine sulfate and sulfanilic acid mixture to which 10 ml. of concentrated sulfuric acid were added. Standard solutions and samples were placed in the dark for 10 minutes at 25°C, then mixed with 10 ml of distilled water and left to stand for an additional 20 minutes at 25°C to permit color development. The standard solutions and samples were then examined spectrophotometrically at a wavelength of 410 nm. Nitrate concentrations in the samples were determined from a standard curve obtained by use of standard solutions.

Meteorlogical data on precipitation was obtained from the U.S. Weather Bureau substation located in the town of Portales. Agricultural crops surrounding the various wells monitored were recorded from visual observation. Well depths for the selected sampling wells were obtained from the New Mexico State Engineer, Roswell, New Mexico.

Results and Discussion

The observed nitrate concentrations for the eleven wells sampled are presented in Table I and Table II. Table I includes those wells in which seasonal fluctuations were observed while those wells in which no fluctuations were observed are

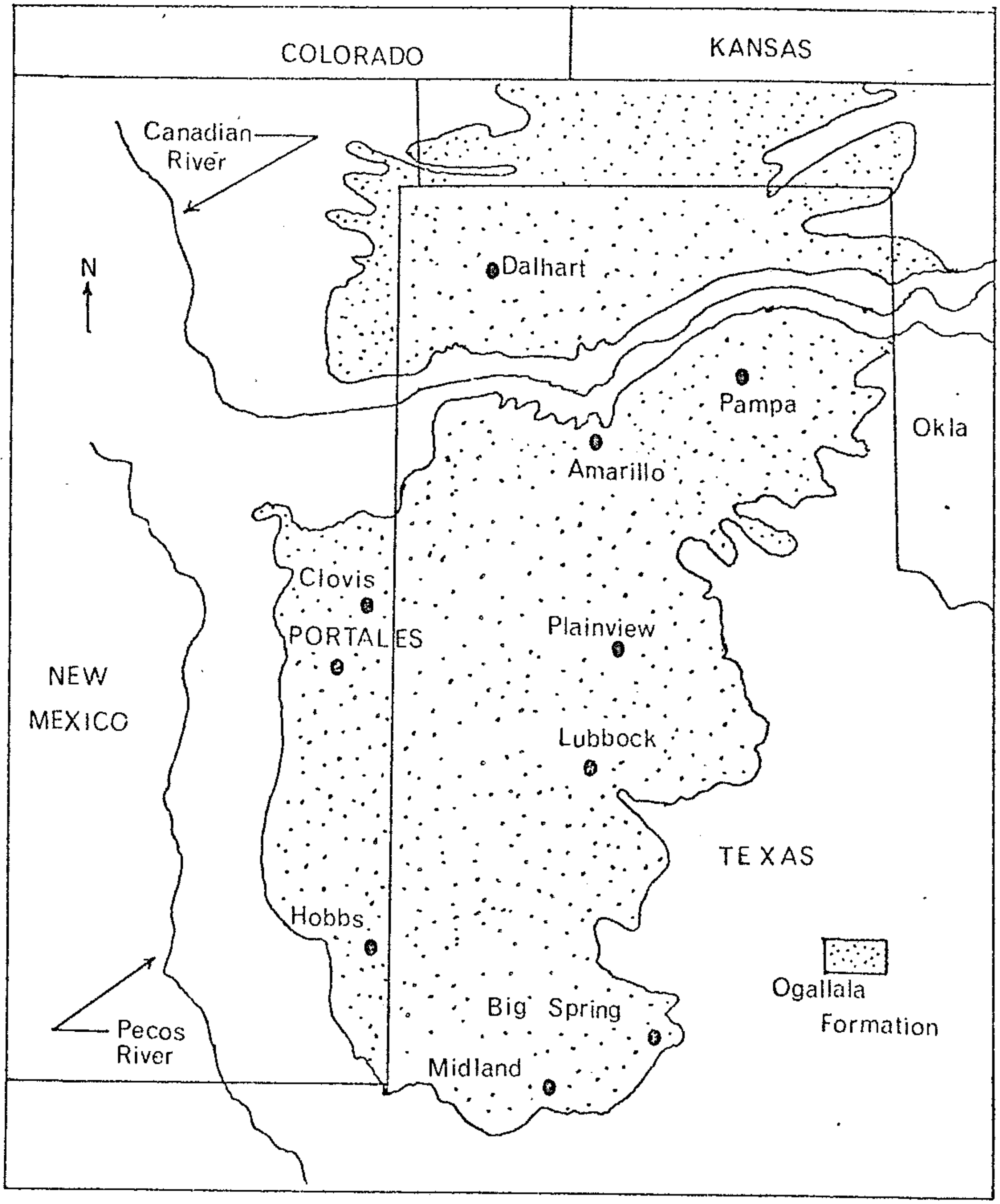

Figure 1. Location of the sampling area and the southern Ogallala aquifer.

presented in Table II. The crops under cultivation surrounding each well, in addition to the soil association that each well is located in, are presented in Table III.

Soil preparation, fertilization and planting were completed by May, 1971, for all cultivated areas in which sampling wells were located. Irrigation had commenced in May and continued until the first killing frost in late September. From Table I, it can be seen that fluctuations in nitrate concentrations did occur. Nitrate concentrations increased in the aquifer to their highest observed values during the summer growing season. The wells represented in Table I are surrounded by typical agricultural crops for which nitrogen fertilizers are locally utilized. The different times during the growing season in which nitrate concentrations peaked appear to be explained on the basis of the soil association in which the sampling well was located. The soil association and the soil types within the association represent variations in permeability and the subsequent return flow to the aquifer from applied irrigation water. The decline in nitrate concentrations during the late and post-growing seasons can be explained on the basis of crop utilization and the fact that most nitrogen fertilization takes place in the pre-planting season.

Some wells monitored exhibited an absence of fluctuations in nitrate concentrations (Table II). Sample wells "G" and "H" were both continually high in nitrate concentrations from the pre-growing season through the post-growing season. The agricultural industry associated in both sampling sites was a dairy. The practice of pit storage of ensilage in the area, in addition to the large quantities of water required for cleanliness in dairy operations, most likely accounts for the relatively high, non-fluctuating, nitrate levels found.

Sample "I" (Table II) was representative of rangeland pasture. Rangeland was quite prevalent in the region examined. Most of the land utilized as rangeland pasture was due to its unsuitability to farming. Land in this type of utilization can support approximately one cow per 6.5 to 8 hectacres. No tilling or fertilization has been practiced in these lands. It can be expected that lands utilized in this manner would yield relatively low and consistent concentrations of nitrate in the aquifer. The low nitrate levels observed most probably result from natural sources and represent a base level for aquifer nitrate concentrations in the area.

Wells "J" and "K" are similar to "I" in that consistently low concentrations of nitrate were detected. Well "J" was circumscribed by cattle feedlots. The high concentrations of animals in this industry, unlike dairy cattle, utilize little water for maintenance. The nitrate levels in soils below these areas of high animal density have been shown by Stewart et.al. (1967) to be extremely high. The depth to the water table in the area examined in conjunction with the small amount of annual precipitation and the newness of the industry most probably accounts for the low concentrations of nitrates observed. Given sufficient time, or adequate moisture, it might be expected that nitrate from this industry would percolate to the water table.

Well "K" was surrounded by alfalfa. The depth of alfalfa roots, in addition to the practice of non-nitrogen fertilization of this crop, appears to account for the absence of high nitrate concentrations in the aquifer, even though the crop requires large amounts of irrigation water (cf. Stewart et. al., 1967).

The depth to the water table for the wells examined (Table III) was quite consistent. The homogenous nature of the southern Ogallala in conjunction with the flat relief of the local topography would account for this. The entire High Plains section of the Great Plains province is gradually slanted from northwest to southeast. Cronin (1969) has demonstrated that the water flow within the aquifer is also in this direction with an annual movement of 46 meters. The location of wells sampled were such that cross contamination, even from large draw-down cones, would not be encountered. Meteoric precipitation, due to the flat relief, did not undergo surface runoff. Precipitation data for the study period are presented in Table IV. It has been observed that, after appreciable rainfall, nitrate concentrations decreased slightly in several wells sampled. An explanation for this observation, other than the possibility of physical dilution, is currently under investigation.

It has been shown by Legrand (1965) that the movement of contaminants tended to be chiefly vertical in the zone of aeration. Lateral dispersions in areas above the water table were not shown to be commonly great, but once the water table or zone of saturation was reached, lateral dispersion was predominant. On the basis of the results reported in Tables I, II, and III, it appears that fluctuations in nitrate concentrations in an aquifer can be utilized in assessing the contamination resulting from agricultural practices in semiarid climates. Requisite conditions include permeable soil types, the absence of an aquaclude between the land surface and the zone of saturation, and adequate surface moisture for downward percolation.

Table I.

Nitrate concentrations of individual wells observed during the sampling period
(Nitrate expressed as mg/l)

Sampling Date	Well A	B	C	D	E	F
29/III/71	8.40	9.34	20.85	36.80	10.07	54.49
2/IV/71	8.25	29.24	29.24	50.50	10.65	60.20
9/IV/71	8.40	7.32	25.20	10.70	6.65	66.45
29/IV/71	2.66	28.35	49.17	70.88	4.43	80.88
6/V/71	6.30	31.90	31.89	80.62	6.65	75.31
14/V/71	6.65	43.41	36.77	62.02	3.99	150.00
21/V/71	4.43	35.44	26.58	64.24	4.43	124.00
1/VI/71	10.20	36.77	31.90	48.73	3.72	90.20
12/VI/71	4.87	36.77	25.20	39.87	5.65	90.37
23/VI/71	5.53	38.54	12.85	40.31	33.23	101.00
3/VII/71	10.19	16.83	23.02	41.65	10.02	85.04
14/VII/71	10.19	12.85	23.04	41.65	30.12	80.62
26/VII/71	5.76	11.07	23.04	43.42	3.98	62.02
11/VIII/71	15.50	11.96	30.12	46.96	5.54	86.83
16/VIII/71	13.73	10.20	23.04	41.65	4.83	60.24
27/VIII/71	11.08	7.97	21.26	38.54	3.99	62.02
2/IX/71	12.85	7.53	30.12	35.44	3.54	66.90
8/IX/71	13.73	7.53	36.77	31.90	3.54	52.72
16/IX/71	15.50	19.94	21.26	30.12	3.99	53.16
23/IX/71	10.20	8.86	23.04	28.35	2.66	53.16
30/IX/71	12.85	7.53	19.94	21.26	T*	39.88
7/X/71	15.50	7.12	17.43	33.45	T	23.04
14/X/71	12.85	5.53	14.62	28.35	T	20.40
28/X/71	10.63	3.99	11.08	26.58	T	26.85
4/XI/71	9.30	7.12	13.73	27.54	T	28.35
11/XI/71	8.86	10.20	15.50	31.90	T	27.54

*T = trace (less than 1.00 mg nitrate/liter)

Table II.

Nitrate concentrations of individual wells observed during the sampling period
(Nitrate expressed as mg/l)

	Well				
Sampling Date	1	2	3	IV	V
	G	H	I	J	K
29/III/71	46.51	51.72	9.34	N	N
2/IV/71	52.72	43.50	5.31	N	N
9/IV/71	35.30	50.50	7.10	N	N
29/IV/71	62.02	51.60	4.43	3.99	7.97
6/V/71	43.41	57.69	5.54	4.43	5.31
14/V/71	N*	50.50	3.54	4.43	4.87
21/V/71	64.24	57.15	5.31	6.20	3.99
1/VI/71	50.50	50.50	4.43	4.43	7.08
12/VI/71	56.70	41.64	2.21	N	5.80
23/VI/71	11.96	38.54	T**	N	5.76
3/VII/71	43.41	38.54	4.87	N	3.54
14/VII/71	23.04	41.65	4.40	3.98	4.40
26/VII/71	48.73	43.41	3.98	3.98	4.40
11/VIII/71	43.41	50.50	T	3.99	4.40
16/VIII/71	45.19	48.73	T	3.98	4.43
27/VIII/71	46.96	45.19	3.20	3.99	4.40
2/IX/71	35.44	45.19	3.20	3.99	4.40
8/IX/71	26.58	45.19	3.99	3.98	3.99
16/IX/71	33.45	31.65	3.10	3.54	3.54
23/IX/71	43.41	41.65	3.10	T	4.40
30/IX/71	36.77	33.45	2.66	2.90	2.66
7/X/71	N	41.65	4.43	7.53	3.10
14/X/71	28.35	41.65	3.32	5.54	3.32
28/X/71	23.04	41.65	T	T	2.90
4/XI/71	30.12	43.41	T	T	T
11/XI/71	35.44	45.19	T	2.66	3.10

*N = No sample available

**T = trace (less than 1.00 mg nitrate/liter)

Table III.

Crops surrounding the individual wells sampled and the soil association the well was located in.

	Well	Well Depth	Soil Association	Crop
B	A	36.0 m	Amarillo-Clovis fine sandy loams	Milo (*Sorghum vulgare*)
C	B	36.6 m	Amarillo-Clovis loamy fine sands	Milo (*Sorghum vulgare*)
D	C	41.4 m	Amarillo-Clovis fine sandy loams	Peanuts (*Arachis hypogaea*) Cotton (*Sorghum vulgare*)
9	D	34.2 m	Amarillo-Clovis fine sandy loams	Peanuts (*Arachis hypogaea*)
[illegible]	E	36.3 m	Amarillo-Clovis fine sandy loams	Cotton (*Gossypium* sp.)
[illegible]	F	37.8 m	Potter-Mansker	Milo (*Sorghum vulgare*)
F	G	34.2 m	Potter-Mansker	Dairy Herd
K	H	31.4 m	Amarillo-Clovis fine sandy loams	Dairy Herd
S	I	39.0	Potter	Rangeland Pasture
N	J	48.1 m	Tivoli-Springer-Brownfield sands	Cattle Feedlot
Mi	K	35.0 m	Amarillo-Clovis loamy fine sands	Alfalfa (*Medicago sativa* L.)

Table IV
Precipitation reported by the U.S. Weather Bureau substation at Portales, N. M.
(reported in inches)

RAINFALL DATA[+]

Date	Amount (in)
2 Mar 71	0.13
15 Apr 71	0.01
16 Apr 71	0.83
19 Apr 71	T[++]
2 May 71	T
8 May 71	0.12
11 May 71	T
26 May 71	0.05
27 May 71	0.08
29 May 71	0.41
30 May 71	0.16
8 June 71	T
11 June 71	0.60
12 June 71	0.13
15 June 71	0.32
17 June 71	T
19 June 71	T
20 June 71	0.04
2 July 71	0.04
3 July 71	T
20 July 71	0.47
21 July 71	0.25
22 July 71	0.02
23 July 71	0.16
28 July 71	0.18
29 July 71	0.38
30 July 71	0.43
1 Aug 71	0.49
6 Aug 71	0.15
8 Aug 71	2.45
10 Aug 71	0.14
11 Aug 71	T
14 Aug 71	T
15 Aug 71	T
16 Aug 71	0.24
17 Aug 71	0.57
23 Aug 71	0.20
25 Aug 71	T
2 Sept 71	1.80
9 Sept 71	T
17 Sept 71	0.16
18 Sept 71	T
22 Sept 71	0.02
24 Sept 71	0.44
25 Sept 71	T
17 Oct 71	0.10
18 Oct 71	0.08
19 Oct 71	0.74
25 Oct 71	0.04
26 Oct 71	0.26
14 Nov 71	T
16 Nov 71	0.05
17 Nov 71	1.03
18 Nov 71	T
21 Nov 71	T
22 Nov 71	T
28 Nov 71	T
30 Nov 71	T
1 Dec 71	0.31
2 Dec 71	0.45
4 Dec 71	T
5 Dec 71	0.16
9 Dec 71	T
14 Dec 71	0.12
28 Dec 71	0.01
4 Jan 72	2.50

[+] Data obtained from the U.S. Weather Bureau Sub-Station at Portales, New Mexico.

[++] T = Trace amount.

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