PROJECT COMPLETION REPORT

Principal Investigator

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PROJECT TITLE: Pollution Studies of the Regional Ogallala Aquifer at Portales, New Mexico.

PROJECT NUMBER: 3109-45 A-034-New Mexico

NAMES: Principal Investigator-Robert G. Taylor
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PROJECT OBJECTIVES: To examine the regional Ogallala Aquifer at Portales, New Mexico for pollution during a one year period. The study examined both bacterial and chemical parameters. The analyses over a year period permitted elucidation of seasonal variations.

DEGREE OF ACHIEVEMENT OF PROJECT OBJECTIVES: Chemical analyses included nitrate, pH, and phosphate. Bacterial analyses were performed using membrane filter techniques. Bacterial analyses included both total coliform and fecal coliform analyses. Sampling area consisted of a series of two mile radii, extending a distance of ten miles from the town of Portales, Twenty-two rural wells were sampled.

Both bacterial and nitrate contamination was found in varying amounts in most wells sampled and a correlation between the two was established. Seasonal fluctuations of nitrate concentrations were observed. Nitrate concentrations were at their highest observed values during the peak irrigation season in those wells surrounded by typical agricultural crops for which nitrogenous fertilizers were locally applied. A relationship was found to exist between nitrate concentration and rainfall during sampling interval. No phosphate contamination was found. Periods of high recharge potential appeared to parallel pH variation. An in vitro study was performed to determine the extent of possible nitrate conversion to other nitrogenous compounds by the coliform contamination observed. It was found that 47% available nitrate was converted to other nitrogenous compounds (including the insidious nitrite) by coliforms in soil columns.

Throughout the year except for the summer months, little variation in nitrate concentration, coliform density, or pH was observed.

RESEARCH PROCEDURES USED: Bacterial and chemical analyses were done using techniques in accordance with the U. S. Public Health Service standards as published in Standard Methods for the examination of Water and Wastewater by the American Public Health Association.

Samples of water were taken from twenty-two well sources at weekly intervals. The test area consisted of a system of two-mile radii extending outward to a distance of ten miles from Portales, with the entire circle of the testing area having a diameter of twenty miles (figure 3).

Bacterial pollution of water is indicative of the degree of contamination of the water with wastes from human or animal sources. The coliform group of bacteria is used to indicate the pollution of water with wastes and thus the potability of water for domestic and dietetic uses. The group of coliforms belong to the family of bacteria known as Enterobacteriaciae.

The most common system of coliform detection now used and accepted by the A.P.H.A. is the membrane filter technique, or Millipore filter system, a commercial brand of the membrane system. The membrane filter technique provides a direct plating method for the detection and estimation of coliform densities in a given volume of water, usually a 100 ml sample. It is an effective and rapid method for the detection of bacteria from the coliform group, and thus for the presence of pollution. The U.S.P.H.S. standard for coliform organisms states that no more than four organism may be present in a 100 ml sample of water for it to be considered potable.

A 100 ml water sample was passed through a 0.45 micron pore size filter and bacteria that were larger than 0.45 micron were "trapped" on the filter surface. The filter was then placed on media, incubated, and examined for visible colonies. Coliform organisms have been shown to be approximately 0.5 micron wide and 2-3 microns long. The colonies which grew from one organism developed a characteristic color, and provided a direct count of the coliforms within twenty-four hours.

Two media were used for identification. M-Endo broth-MF (Difco co.), red in color, allowed coliform growth of bright red colonies with a green metallic sheen. This media was for the detection of "total coliforms", which means that they may or may not be specifically from a fecal source. These organisms were incubated at 35° C for twenty-four hours.

The other media used was M-FC broth (BBL Co.), which is blue in color. After the organisms were collected on the filter, and the filter placed on the M-FC media, the organisms were incubated at 44.5° C + 0.5° C for twenty-four hours in a water bath. The M-FC media depended on the use of a high incubation temperature for its selectivity because it relied on heat shock to prevent overgrowth of the membrane by non-fecal strains. Coliform organisms that are from a non-fecal source cannot survive at the higher temperature of 44.5° C whereas fecal strains can survive and reproduce at the higher temperature. The indicator system in the medium was such that fecal coliform colonies appeared blue in color and other non-coliforms which grew were gray to cream colored.

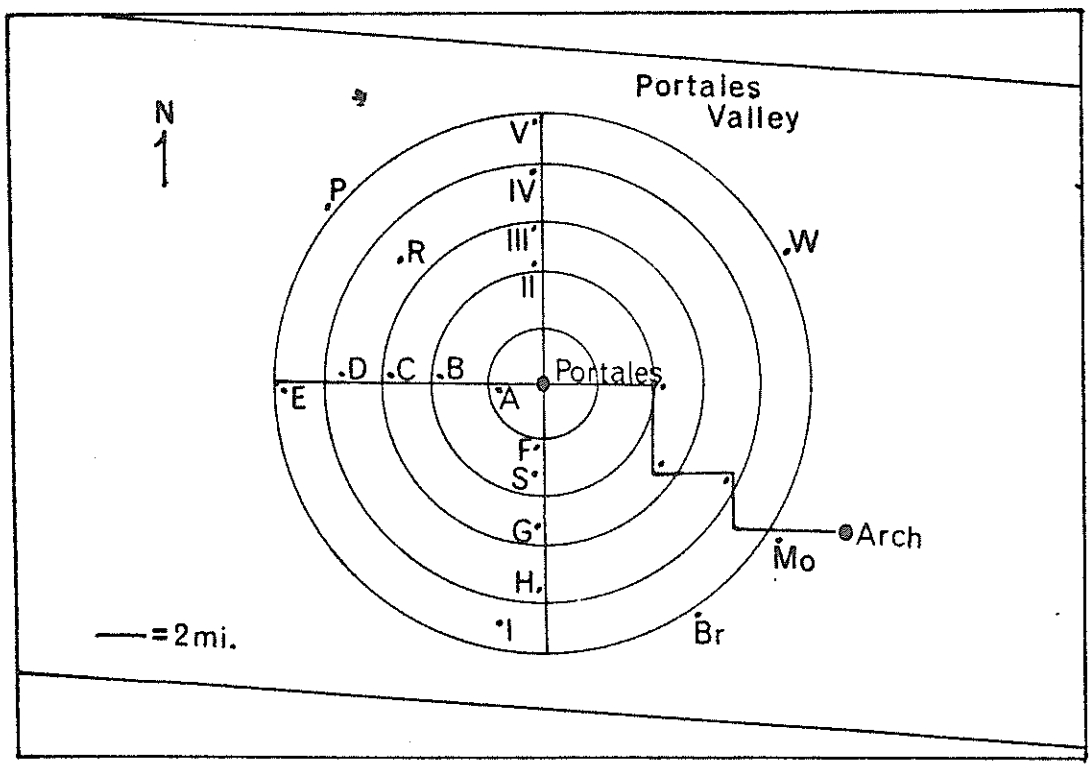

Figure 3. Well Sampling Locations Area

Laboratory items were sterilized before use to prevent extraneous contamination of the test samples. The filters from Millipore Corporation were obtained sterile, the supplied petri dished and the filter funnel apparatus were sterilized by use of ultraviolet light. All other glassware was sterilized by autoclaving. The ultraviolet light used was of a wavelenghth of 2537 Angstroms, which is the effective killing wavelength for bacteria. With the above precautions, and routine control tests, it was assured that no contamination entered the samples from the laboratory.

The coliforms are common inhabitants of the flora of the intestinal tract of man and animals. They belong to the Tribe Escherichia, Klebsiella, and Aerobacter. All the coliforms are lactose fermentors, meaning they are capable of fermenting the sugar lactose into lactic, succinic, formic, and/or acetic acids and, in some cases, 2, 3-butylene glycol. They also ferment lactose with the production of CO_2 and H_2 gases. Coliforms are gram negative rods, facultative anaerobes, and non-spore formers.

Occasionally a colony growing on a plate was suspected of being a coliform but did not exhibit the metallic sheen. To confirm the colony it was placed in a fermentation tube containing Brilliant Green Broth that has lactose as one ingredient. If the colony was a coliform, gas was produced within twenty-four hours from the fermentation of lactose in the media. If still in doubt, the cells were gram stained and examined under a microscope

When necessary differentiation between the specific members of the coliform group was accomplished by a series of tests known as the "IMViC" test were used. The "I" stands for the Indole test and analyzes for the ability of the organism to convert the amino acid tryptophan into the indole ring as a by product of bacterial metabolism. The "M" stands for the methyl red test. Methyl red, an acid indicator, when added to the media remained red if the organisms were producing acid but turned yellow if the organisms were not. The "V" is the Vogas Proskauer test, which checked the ability of the organism to produce acetyl-methyl-carbinol in the presence of 10% potassium hydroxide. The "C" stands for the citrate test used to determine if the organism could utilize citrate as its sole source of carbon. The "i" is simply a memnomic device.

Chemical analyses of the water included determinations of nitrate, phosphate and pH.

The method used for the determination of nitrates in the water was the "Brucine-Sulfate-Sulfanilic Acid" method. Briefly, two mls of the sample were mixed with one ml of brucine sulfate and sulfanilic acid was added. A yellow color was formed when the above reagents reacted with nitrates and placed in the dark for color development to occur. A set of standards was prepared using a range of 1 - 10 ppm nitrate nitrogen and a standard curve plotted using a Spectronic 20 color spectrophotometer at a wavelength of 410 nanometers. The curve was not straight when plotting transmittance versus concentration and did not obey Beer's law but a smooth curve was obtained and the unknown concentrations could be determined for

the standard curve. As many as 20 samples could be analyzed for nitrate at one time with this method. Residual chlorine, if present in the sample, was corrected for by the addition of sodium arsenite which precipitated the residual chlorine. Any strong oxidizing agent or reducing agent would also interfere with this test.

The method used for phosphate determination was the "Aminonaptholsulfonic Acid Method for Orthosphosphate". The phosphate concentration was determined from a standard curve, which obeys Beer's law, with the use of the Spectronic 20. Briefly, 50 mls of sample were mixed with two mls of Aminonaptholsulfonic acid and two mls of ammonium molybdate and allowed to stand for ten minutes for color development.

The pH of the water was measured with a Leeds and Northrup pH meter.

LISTING OF RESULTS AND CONCLUSIONS: Nitrates are the most highly oxidized phase in the nitrogen cycle of bacteria and normally reach important concentrations in the final stages of biological oxidation (A.P.H.A., 1971). The conversion of ammonia to nitrate (nitrification) is brought about by highly specialized soil bacteria of the Nitrobacteraceae Family. Nitrification takes place in two steps: the first step ammonia is oxidized to nitrite; in the second, nitrite is oxidized to nitrate (figure 4). Soil fertilized with manure, or manure on feedlot surfaces is converted from organic nitrogen to nitrate through ammonification and nitrification. A large number of the irrigated fields in the Portales area are fertilized with ammonia, which can be oxidized by the soil bacteria to form nitrates. Nitrates are water soluble and are not complexed by soil; therefore, they are easily leached from the soil and transported by water. These characteristics of nitrate often result in their attaining excessively high levels in ground waters. When present in excessive amounts, nitrates are a good indicator of pollution. In excessive amounts nitrates contribute to an illness known as infant methemoglobinemia. The condition of methemoglobinemia has been observed when the nitrate has been imposed on drinking waters by the U.S.P.H.S. as a means of averting this condition. The nitrate concentrations of most drinking waters usually falls below 10 ppm. However, a higher amount is undesirable and may indicate fecal and/or chemical pollution. At a range of 45 ppm or above, the water is reaching the danger level.

It has been found that during the summer months practically all wells sampled showed a gradual accumulative decrease in nitrate concentration, and with any appreciable amount of rainfall showed a dramatic decrease in nitrate concentration. One well, which had an unusually high concentration of nitrate, decreased from 226.82 ppm on June 1, 1971, to 166.60 on August 27 (all results are based on the data found in the appendix). Another well,

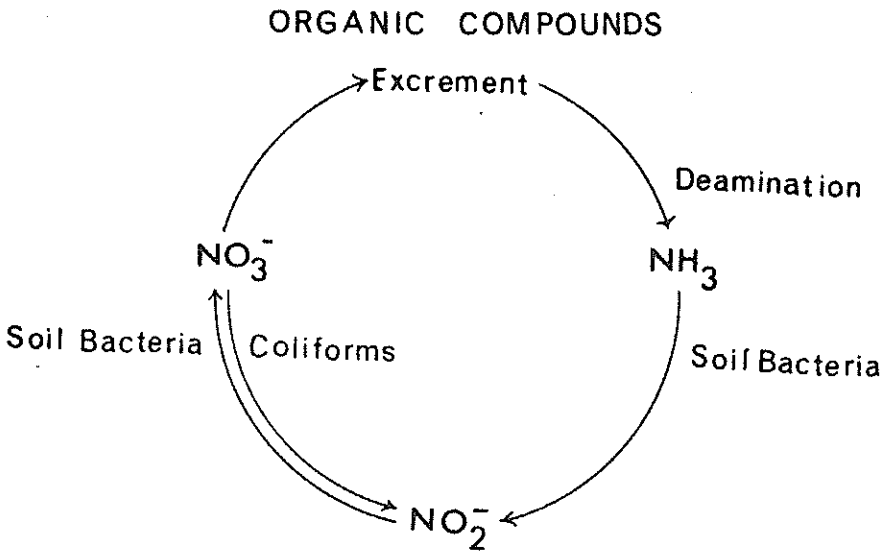

Figure 4. The Nitrogen Cycle

initially 36.77 ppm on June 1, 1971, decreased to 7.97 ppm on August 27. A third well, with a normally small amount of nitrate throughout the year, decreased from 7.54 ppm on June 1, 1971, to 4.40 ppm on August 27. The four graphs in figures 5,6,7, and 8, illustrate the decrease in nitrate concentration with respect to increasing rainfall. Where there is any appreciable amount of rainfall (bar graphs) the nitrate concentration decreases sharply (line graphs).

However, five wells of the twenty-two sampled increased in nitrate concentration throughout the three months. One sample increased from 3.99 ppm on June 1, 1971, to 38.54 ppm on August 27.

The summer months are the time of year in Portales when irrigation is at its maximum and a large amount of water is pumped onto the fields. The U.S. Weather Bureau Substation at Portales recorded almost 10 inches of rainfall from June to August of 1971. During the spring and early summer, Portales, as well as the whole southwest, was in a severe drought. The ten inches of rainfall from irrigation, might possibly dilute the concentration of nitrate in the ground water.

Most nitrogen fertilizer is applied to the fields in this area during the pre-planting season, and very little is applied during the summer months. The accumulative effect of rainfall during the summer may have diluted the nitrates that were carried into the water table during the spring. The absent of fertilization in the agricultural regions during the summer could account for this summer decrease in nitrate concentration.

It must also be considered that the nitrate concentration of the soil capable of being carried into the water table with accompanying rainfall is also decreased during the growing season because of utilization of nitrates by plants.

During these same three months the coliform count in practically all wells examined showed a marked increase. The increase in return flow to the aquifer could easily carry these organisms into the aquifer. Although some soil bacteria convert ammonia to nitrates, the coliform organisms convert nitrate to nitrite. The *in vitro* soil column study showed that 47.8% of all available nitrate that was loaded into the soil column was converted to nitrite or other nitrogenous compounds by *Escherichia coli.* Qualitatative tests for nitrite revealed large amounts of nitrites in the column B effluent and none in the control column A, indicating that a large amount of nitrate is converted to nitrite by the action of *E. coli* metabolism.

If nitrate concentration versus coliform density is plotted on a graph, it is evident that there is an inverse relationship between coliform density and nitrate concentration (figures 9 and 10). This relationship holds true for practically all wells examined irrespective of whether the initial nitrate concentration was abnormally high at all times, normal (less than 10 ppm), or contained only trace amounts of nitrate. During the summer months of this study, wells that previously never contained coliform contamination were found to be contaminated.

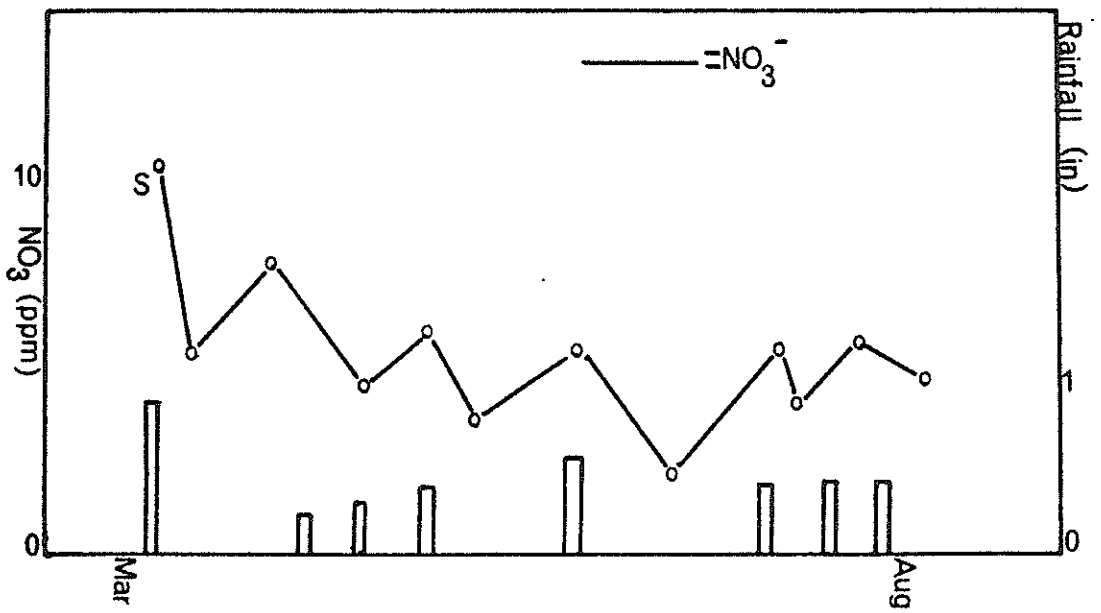

Figure 5. Rainfall vs. NO_3 concentration in Sample S

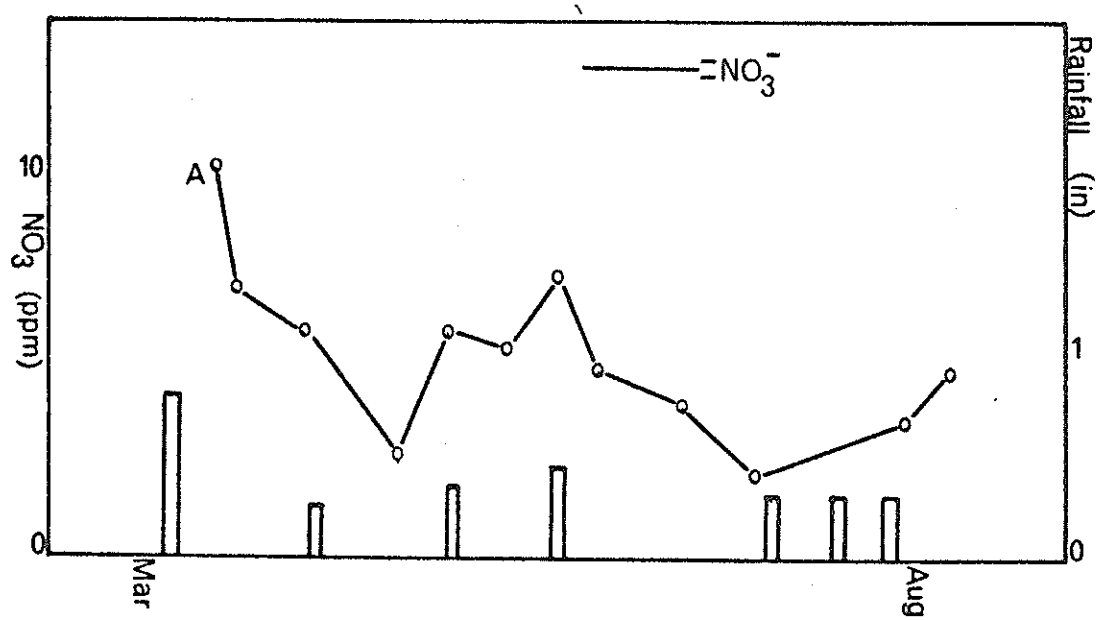

Figure 6. Rainfall vs. NO_3 concentration in Sample A

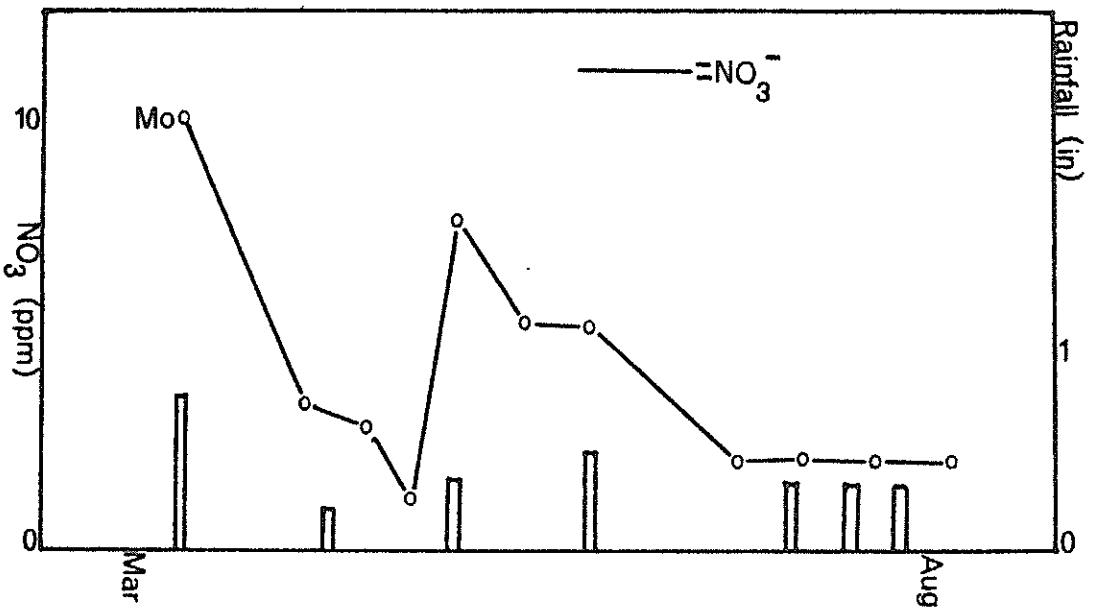

Figure 7. Rainfall vs. NO_3 concentration in Sample M_o

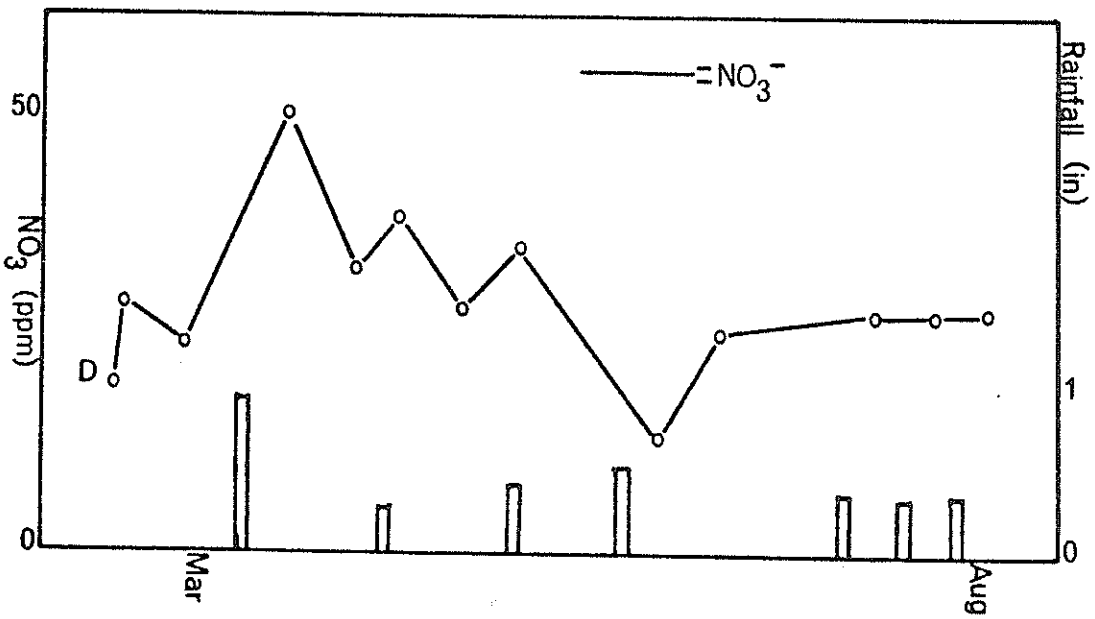

Figure 8. Rainfall vs. NO_3 concentration in Sample D

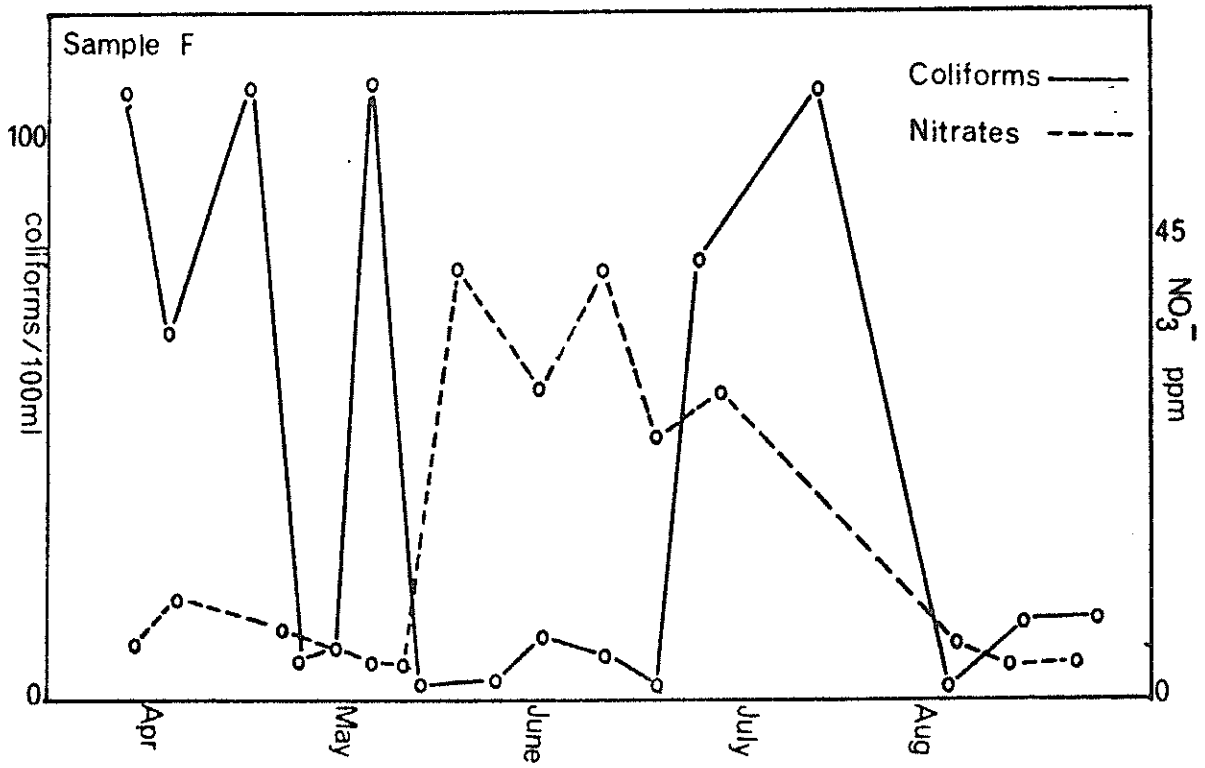

Figure 9. Coliforms vs. NO_3 concentration in Sample F

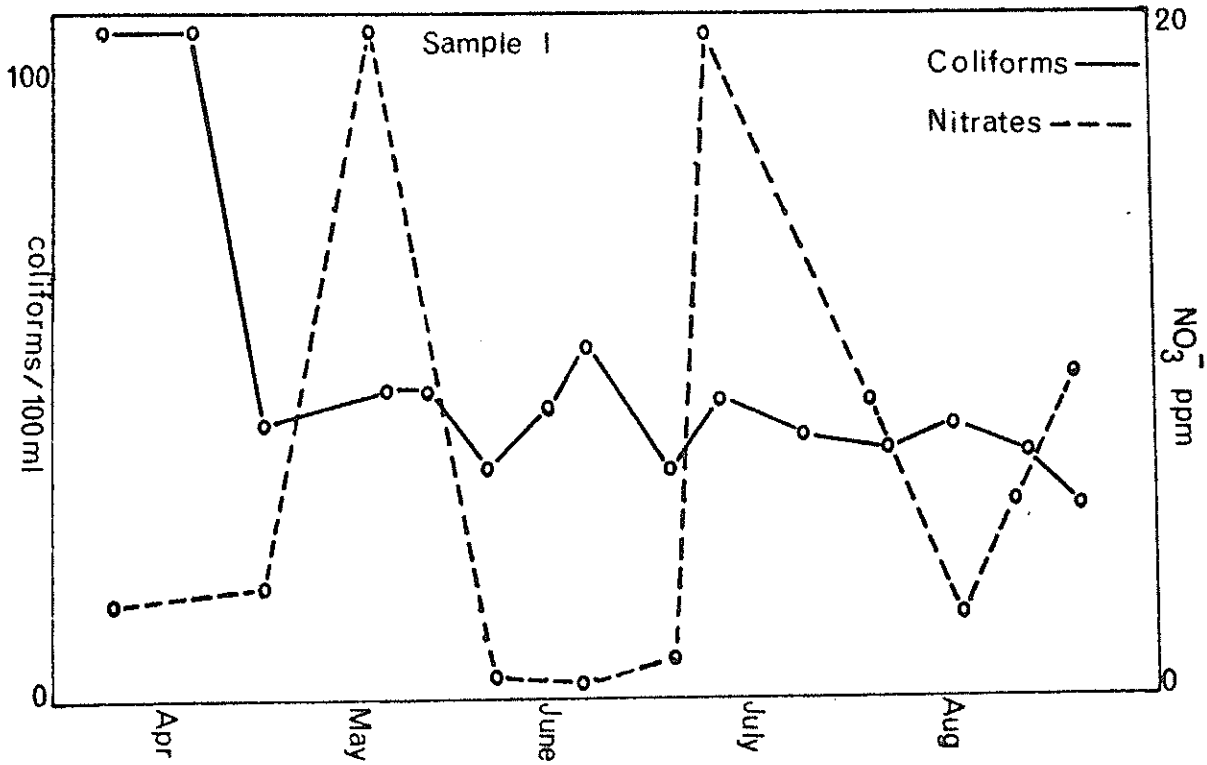

Figure 10. Coliforms vs. NO_3 concentration in Sample I

With the coliform increase, it is interesting to note that a feedlot sampled regularly increased from no coliforms on June 1, 1971, to 140 colonies per 100 ml on August 27. The amount of excrement on the feedlot surface obviously contains a correspondingly high amount of coliforms. With increased rainfall the organisms could have been carried into the water table at the feedlot. It is interesting to note at the same time the coliforms increased, the nitrate concentration in the water sampled at the feedlot decreased. Certainly it could be expected that if urea, which is converted to nitrate by soil microbes, is being carried back into the water table from the feedlot, the concentration of nitrates would be high. However, if the in vitro study holds true, these results may be explained on the basis of the in vitro study which suggest that bacteria contained in the water table are capable of converting the nitrates to nitrites, then the observed results can be understood.

One well, where nitrate concentration has reached a high of 248.00 ppm on April 9, 1971, and a low of 166.60 on September 8, 1971, is an exception to the normal nitrate concentration in the remainder of the wells examined. The owner of the well had owned a dairy herd until recently and kept them confined near the well entrance. The well is situated out of the Portales Valley and is drilled into the Triassic formation. It has been observed that in the Triassic, chemicals tend to accumulate in "pools". Although the well has shown that previously noted inverse relationship between nitrates and coliform density which existed in the other wells observed during the summer months, the extraordinarily high nitrate concentration can be attributed to the nitrate accumulation in pools at this location through the years when the dairy herd was maintained. Another well, on the same farm, one mile away from the high nitrate well showed a nitrate concentration of 6.202 ppm on the same day. This well was distant from any cattle herds. It must also be considered that domestic wells distant to any type of livestock show individual fluctuation in nitrate concentration and coliform densities. This could be due to nitrate and coliforms being "washed" from cesspools and septic tanks back into the well water supply. This possibility must not be overlooked since cesspools and septic tanks in some areas are the only apparent sources of pollution by fecal organisms. It is unlikely that fluctuations were due to the flow of water table, because all wells sampled vary highly in data obtained. It is also improbable, since the water table at Portales flows at such a slow rate (50 feet per year), and is slowed even more during the summer by heavy irrigation practices.

It has been demonstrated that in wells never containing bacterial contamination, nitrate concentrations do fluctuate in the summer months. This suggests that although there is a definite correlation between nitrate concentration and bacterial contamination, these two factors may vary independently of each other. The three wells in figure 11, having contained no or few coliforms, show a

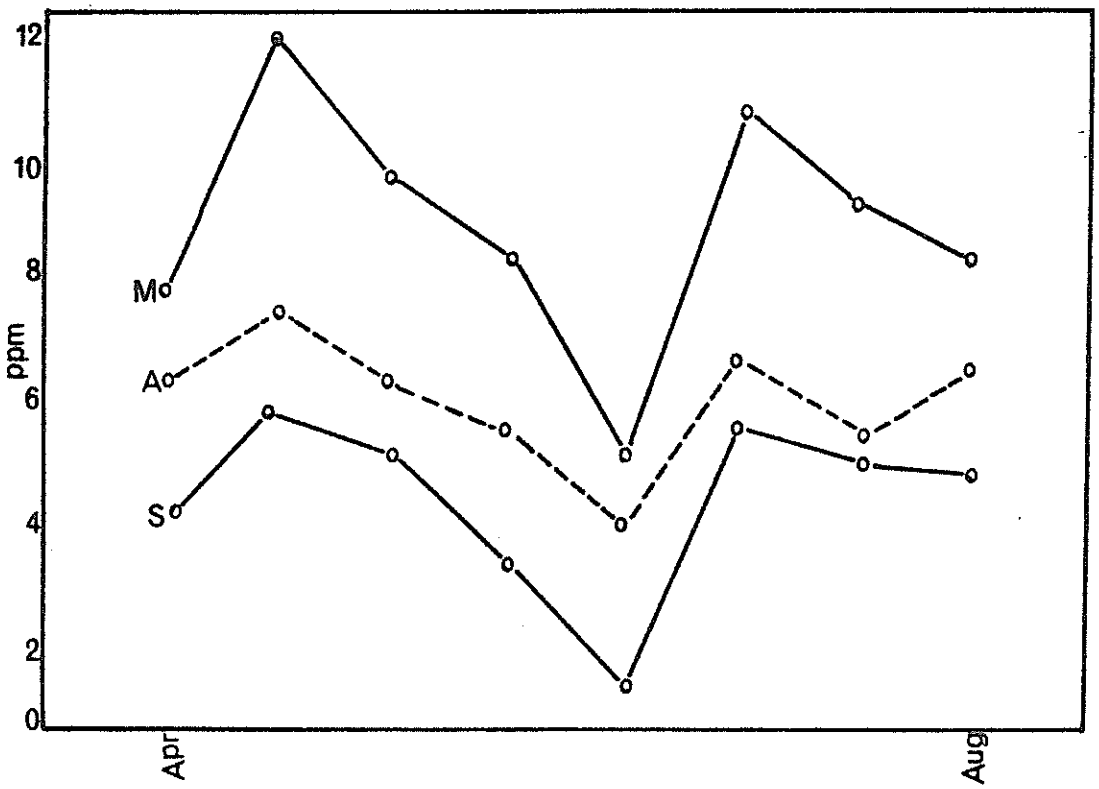

Figure 11. Graph showing NO_3 concentration in Samples M, A, and S with no coliform organisms

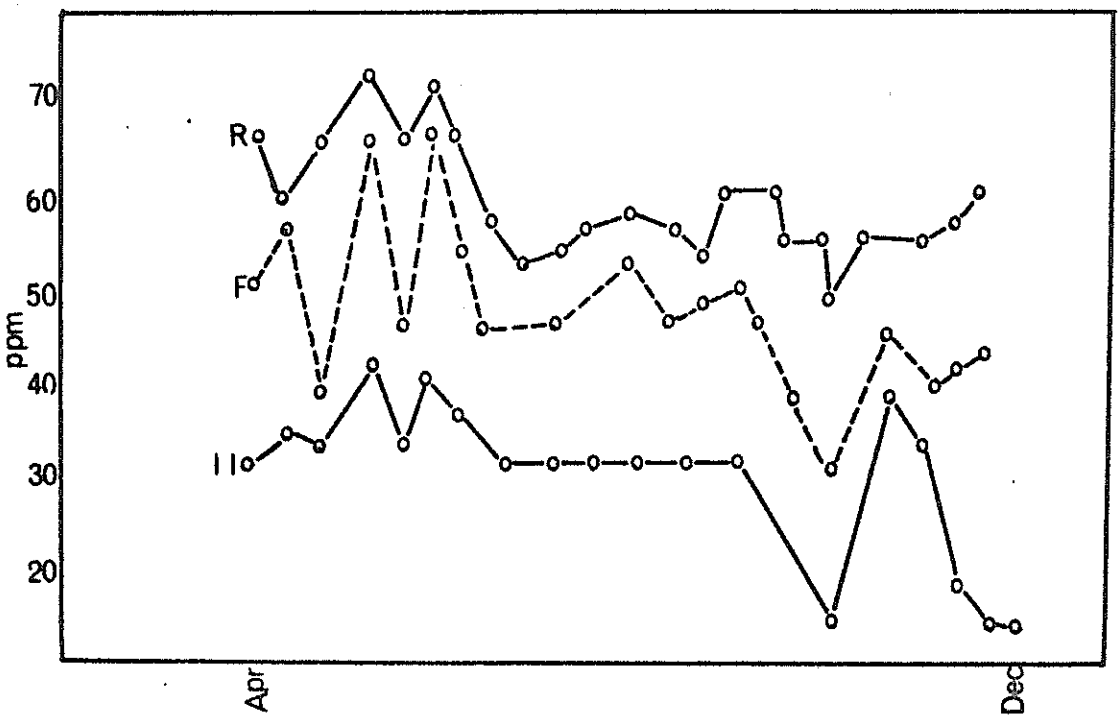

Figure 12. Graph showing NO_3 concentration in samples with dairy herds or feedlots

striking similarity in nitrate fluctuation when considered in the absence of coliforms. The three wells are approximately ten miles from each other.

Within the sampling area there are three locations where either a dairy herd or a cattle feedlot is maintained. The graph in figure 12 illustrates the high similarity of nitrate concentrations throughout the year in these wells.

Orthosphophates applied to agricultural or residential land as fertilizers are carried into surface waters with storm runoff. Organic phosphates are formed primarily in biological processes; hence, they contribute to sewage in body wastes and food residues, or they may be formed from orthophosphates in biological treatment processes or by life in the receiving waters.

Only a slight trace of phosphate contamination of two wells in the entire area has been found. This seems unusual, because of the relative ease of both nitrate and bacteria being percolated into the water table. The reason for this is probably due to the large amount of divalent calcium in the caliche layers of soil in this area. This would explain why phosphate from agricultural fertilizers or other sources is unable to percolate into the water table as easily as other ions.

On August 11, 1971, three samples showed an acidic pH of 6.8. These data were triple checked because the Portales Valley water is famous for being alkaline. Until these data of August 11, all samples had been alkaline and no acidity had been observed. During the summer in the Portales area, vast amounts of pesticides, especially some relatively water soluble "systemics", are commonly applied to the fields. Pesticides such as "Disyston" and "Sevin", which are commonly used, hydrolyze to acids in water. It is possible that with an increasing amount of rainfall, some of these pesticides may have been carried back into the water table in high enough concentrations to give the water an acidic character.

Except for the summer months the nitrate level in most wells leveled off at a relatively low concentration during the remainder of the year. The nitrate concentration throughout the fall, winter, and spring remained relatively constant. The bacterial contamination during these same months was practically void. The temperature of the ground water may be the factor that will not allow bacterial growth in the water, since the organisms cannot survive below $8^{o}C$.

Table I includes those wells in which seasonal fluctuations were observed while those wells in which no fluctuations were observed are presented in Table II. The crops under cultivation surrounding each well, inaddition 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 of late September. From Table I, it can be

Table I

Nitrate concentrations of individual wells Observed during the sampling period. (Nitrates expressed as mg/L).

Sampling Date	Well B A	C B	D C	J D	L E	N 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. (Nitrates expressed as mg/Liter)

Sampling Date	Well F G	K H	S I	IV J	Mo 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	51.02	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	41.65	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
A	36.0m	Amarillo-Clovis fine sandy loams	Milo (Sorghum vulgare)
B	36.6m	Amarillo-Clovis loamy fine sands	Milo (Sorghum vulgare)
C	41.4m	Amarillo-Clovis fine sandy loams	Peanuts and Cotton (Arachis hypogaea) (Sorghum vulgare)
D	34.2m	Amarillo-Clovis fine sandy loams	Peanuts (Arachis hypogaea)
E	36.3m	Amarillo-Clovis fine sandy loams	Cotton (Gossypium sp.)
F	37.8m	Potter-Mansker	Milo (Sorghum vulgare)
G	34.2m	Potter-Mansker	Dairy Herd
H	31.4m	Amarillo-Clovis fine sandy loams	Dairy Herd
I	39.0m	Potter	Rangeland Pasture
J	48.1m	Tivoli-Springer (Brownfield sands)	Cattle Feedlot
K	35.0m	Amarillo-Clovis loamy find sands	Alfalfa (Medicago sativa L.)

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 permeablity 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 insuitability to farming. Land in this type of utilization can support approximately one cow per 6.5 to 8 hectares. 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 consistant 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 consistantly low concentrations of nitrate were detected. Well "J" was circumscribed by cattle feedlots. The high concentrations of annuals in this industry, unlike dairy cattle, utilizes little water for maintenance. The nitrate levels in soils below these areas of high animal density have been shown 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.

The depth to the water table for the wells examined (Table III) was quite consistant. 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. 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 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 predominate. 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 semi-arid 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 downward percolation.

LIST OF PUBLICATIONS

1. Fluctuations in Nitrate Concentrations Utilized as an Assessment of Agricultural Contamination to an Aquifer of a Semiarid Climatic Region

   by: R.G. Taylor and P.D. Bigbee
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   Submitted to: Journal of Water Research

2. Pollution Studies of the Regional Ogallala Aquifer at Portales, New Mexico

   by: P.D. Bigbee and R.G. Taylor
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   Presented at: Underground Water Institute Symposium on Groundwater Research: St. Louis, Mo. 1971.

3. Contamination of the Regional Ogallala Aquifer of Eastern New Mexico

   by: Robert G. Taylor

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4. An In Vitro Study to Determine the Concentration of Nitrate Converted to Nitrite by E. coli in Soil Columns.

   by: Paul D. Bigbee

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5. Groundwater Analyses of the Portales Valley Establishing Seasonal Variations of Contaminants.

   by: P. David Bigbee and Robert G. Taylor
   Eastern New Mexico University
   Portales, New Mexico

   Submitted to: The Southwestern Naturalist

NAMES OF PERSONS WHO CONTRIBUTED

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