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Contamination of Farmstead Wells by Pesticides, Volatile Organics, and Inorganic Chemicals in Kansas

by James Steichen, James Koelliker, Doris Grosh, Alan Heiman, Robert Yearout, and Victor Robbins

Abstract

Concern about the public health consequences of possible contamination of farmstead wells led to a random statewide survey in Kansas. Results of the analyses showed that 8 percent of tested wells had detectable amounts of pesticides, 2 percent had detectable amounts of volatile organic chemicals, and 37 percent had some inorganic contaminant exceeding the maximum contaminant level (MCL). Nitrate was the most common source of inorganic contamination, exceeding the MCL in 28 percent of the wells. Selenium levels exceeded the MCL in 9 percent of the wells. A multiple regression model for nitrate-N was developed. The factors included the age of the well, land use around the well, and the distance to the closest possible source of organic contamination.

Introduction

"Sparkling spring water" is the public's perception of the ultimate in water quality. However, concern about the pollution of ground water has become increasingly apparent during the 1980s. Surveys of ground water contamination have usually focused on public water supplies and locations that were more likely to be contaminated (Westrick et al. 1984). A national study (Pye and Patrick 1983) found that the four pollutants most commonly reported — chloride, nitrate, heavy metals, and hydrocarbons — may be a reflection of the monitoring practices prevailing at the time the surveys were made. Estimates of the number of contaminated wells range from 1 or 2 percent (Pye and Patrick 1983) to 37 percent (Westrick et al. 1984). These estimates depend upon the parameters selected for analysis and the detection limits for the parameters. A non-random survey of the occurrence of inorganic contaminants in public water supplies in 37 states concluded, "Clearly, problems with meeting primary inorganic maximum contaminant levels (MCLs) are in small communities served by wells (98.4 percent), rather than in those served by surface water (1.6 percent) (AWWA 1985). High nitrate concentrations were the primary reason for inactivating wells or systems that have been shut down." The report also indicated that nitrate contamination was especially prevalent in the agricultural states.

There are no regulatory standards for private water supplies, and most supplies are not tested. In the grain-belt states, nearly all rural residents drink ground water, which is untreated and unmonitored (Hallberg 1986). The Kansas Department of Health and Environment (KDHE) is responsible for evaluating potential risks to public health in Kansas.

Objective

The objective of the research reported herein was to conduct a random survey to determine the degree and extent of contamination of drinking water from farmstead wells by pesticides, volatile organics, heavy metals, and other inorganic constituents.

Procedure

Sample Selection

The high cost (about $500 per water sample) of laboratory analyses limited the number of wells tested to about 100. We selected counties randomly based on the farmstead well density as reported in the 1980 census data for farm housing (Ott 1985). This census estimated that there were about 40,000 farmstead wells in Kansas. This provided a sampling ratio of about 1 in 400. Two subject farms were selected from each of 48 counties and four were picked from two counties because of the large numbers of wells in those counties. The counties that were selected are identified on a map (Figure 1) and tend to be clustered more in the central and northern parts of the state. This mirrors the distribution of all farmstead wells across the state.

Because information about the well and about the nature of activities around the well was also needed, four criteria were set forth to be met before a well was enrolled

in the program:

1. The well had to be at a farmstead performing farm operations;
2. Residents of the farmstead needed to be familiar with the activities near the well for the past 10 years;
3. Residents of the farmstead had to be willing to cooperate;
4. Residents of the farmstead had to use water from the well in their homes.

Because the authors lacked a list of farmstead well owners in each county, county extension agricultural and home economics agents in the selected counties were requested by letter to provide the names of five individuals whom they thought met the four preceding criteria. Nearly all county agents replied. One county was dropped from this list because rural water districts now supply nearly all rural areas of the county. Five names could not be supplied in this case. A neighboring county was then chosen as a substitute. In the two counties with a quota of four wells, 10 names were requested.

All individuals identified by the extension agents were sent a letter inviting them to participate in the study. The letter explained the other requirements: to fill out a questionnaire and allow KDHE to sample and analyze water from their wells in return for the results of the water analysis. The reply rate to this letter was 65 percent, and 90 percent of those responding agreed to participate. In most counties more than two individuals agreed to participate, so a random order was used to select two or four from the group of willing participants. One individual withdrew from the program after sampling began. The final sample included 103 wells.

Water Collection and Analysis

Water samples were collected and chemical analyses were performed by KDHE. Only raw, untreated water was collected and sampling was done as close to the well as possible to minimize any effects of plumbing. Water ran for about five minutes before collecting the samples. All samples were kept chilled during transport and storage until analytical tests were done. The 103 wells were sampled from December 1985 through February 1986. All wells that indicated the presence of volatile organic chemicals (VOCs) or pesticides were resampled in May or June of 1986 to confirm their presence.

All water samples were analyzed in the KDHE laboratory for the contaminants listed in Table 1. Volatile organics were collected and measured with a combination

LEGEND

• Well Sampled

☆ Pesticide Detected

☆ Volatile Organic Chemical Detected

✶ Nitrate Above MCL*

□ Selenium Above MCL*

• Fluoride Above MCL*

* Maximum Contaminant Level

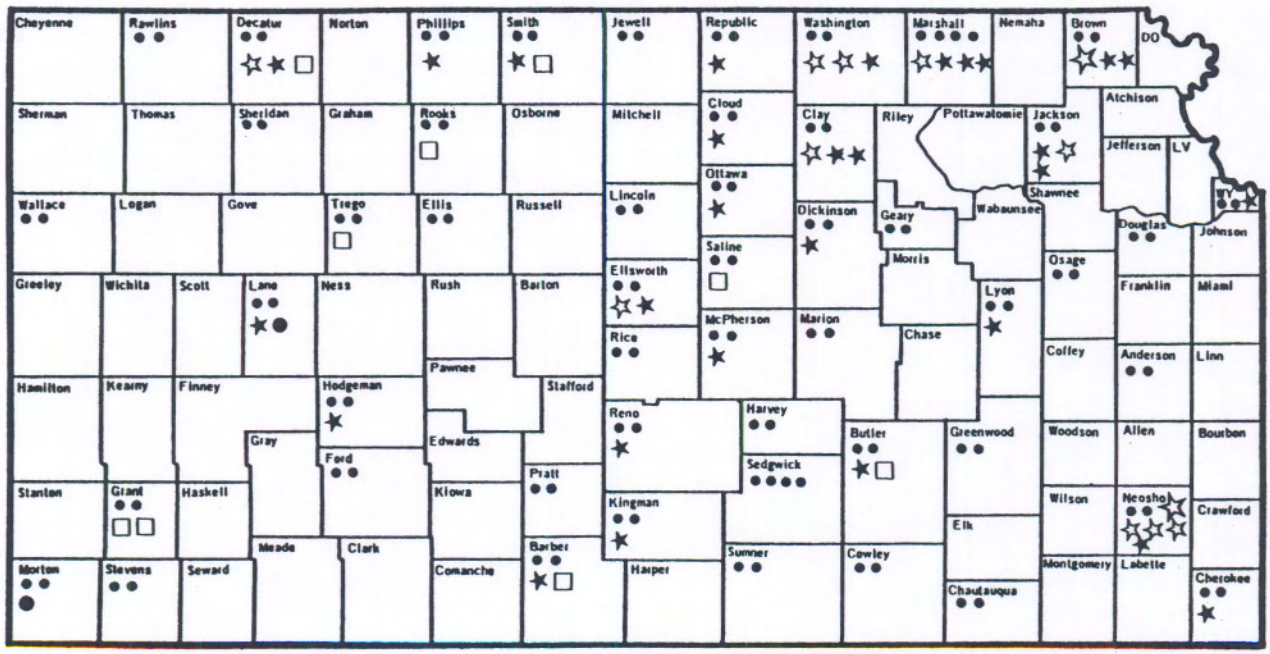

Figure 1. Map showing counties in Kansas in which wells were sampled, wells with detectable amounts of pesticides and VOCs were found, and wells with inorganic chemicals exceeding MCLs for public water supplies were found.

TABLE 1
Contaminants for Which Analyses Were Made on Each Water Sample

Volatile Organic Compounds	Detection Limit µg/L	Pesticides	Detection Limit µg/L
Benzene	0.4	Alachlor	0.250
Bromodichloromethane	0.5	Aldrin	0.025
Bromoform	1.5	Atrazine	1.200
Bromomethane	1.2	Chlordane	0.250
Chlorobenzene	0.4	Dacthal	0.050
Chloroethane	3.7	Dieldrin	0.050
Cis 1,3-dichloropropene	0.9	Dual	0.250
Chloromethane	5.0	Endrin	0.100
Dibromochloromethane	0.7	Heptachlor epoxide	0.020
Dichloromethane	0.9	Lindane	0.025
Ethylbenzene	0.7	Methoxychlor	0.200
Meta-xylene	0.6	O,P' DDT	0.100
Ortho and/or para-xylene	1.0	P,P' DDT	0.100
Tetrachloroethylene	1.1	Ramrod	0.250
Tetrachloromethane	0.7	Sencor	0.100
Toluene	0.4	Silvex	0.200
Trans 1,2-dichloroethylene	0.5	Tordon	0.400
Trans 1,3-dichloropropene	0.8	Toxaphene	2.000
Trichloroethylene	0.6	2,4,5-T	0.200
Trichloromethane	0.5	2,4-D	0.400
Vinyl chloride	0.8		
1,1,1-trichloroethane	0.7	**Other**	
1,1,2,2-tetrachloroethane	0.6	PCBs	0.500
1,1,2-tetrachloroethane	0.6		
1,1-dichloroethane	0.5		
1,1-dichloroethylene	0.6		
1,2-dichloroethane	0.6		
1,2-dichloropropane	0.4		
1,2 and/or 1,4-dichlorobenzene	1.0		

Inorganic Chemicals (Minerals)

Alkalinity	Manganese
Ammonia	Mercury
Arsenic	Nitrate
Barium	Potassium
Cadmium	Selenium
Chloride	Silica
Chromium	Silver
Copper	Sodium
Fluoride	Sulfate
Iron	Total phosphorus
Lead	Zinc

Indicators

pH	Total hardness
Specific conductance	Turbidity
Total dissolved solids	

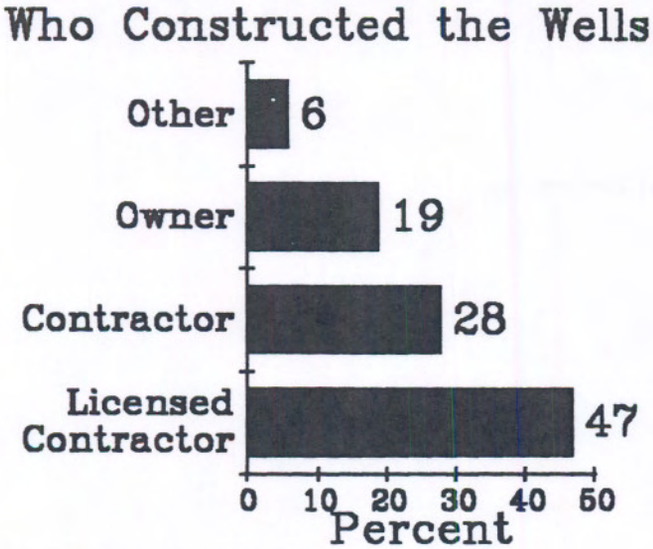

Figure 2. Who constructed the wells.

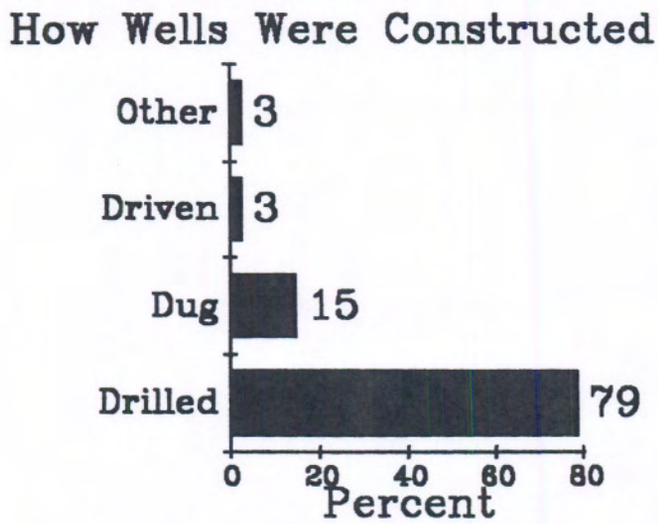

Figure 3. How wells were constructed.

gas chromatograph and mass spectrometer according to methodology prescribed by the Environmental Protection Agency (EPA) (U.S. EPA 1984b). Pesticides and polychlorinated biphenyls (PCBs) were measured by EPA-approved methods (U.S. EPA 1984a) and (U.S. EPA 1987a). The procedure for pesticides included extraction and preparation followed by gas chromatography and detection by electron capture. All inorganic chemicals (minerals) and indicators were measured by EPA-approved methods (U.S. EPA 1982) if available. If EPA did not prescribe methods, those described in *Standard Methods* (APHA-AWWA-WPCF 1985) were followed.

Results

Well Characteristics

Well construction is an important characteristic affecting ground water contamination. Figure 2 summarizes who constructed the wells. Figure 3 shows the type of construction for the wells. The type of construction agreed closely with census data compiled by Ott (1985). The census reported 19 percent were dug compared with 15 percent of the sampled wells reported as dug. Figure 4 shows the distribution of the age of wells sampled. The average well age was 31 years. Figure 5 shows the distribution of the depth to the water surface for the wells tested. In one-third of the wells, depth to the water surface was less than 20 feet.

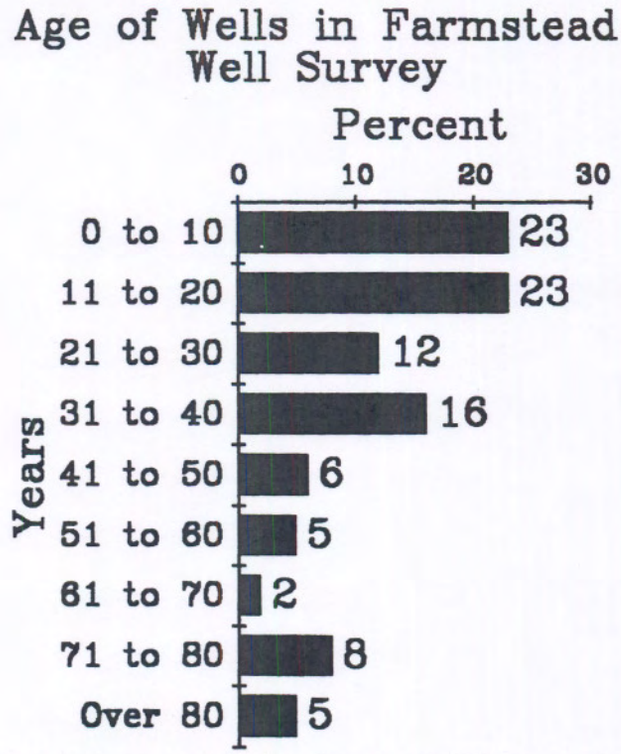

Figure 4. Frequency distribution of age of wells in farmstead well survey.

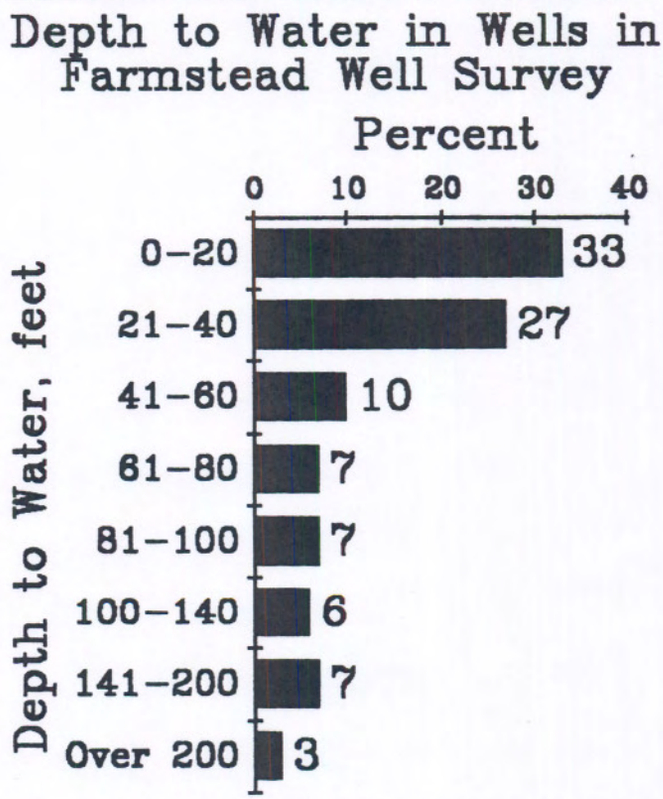

Figure 5. Frequency distribution of the depth to water in wells in farmstead well survey.

Water Quality Results

The results of the survey are summarized in Table 2. Of the 103 wells sampled, eight had detectable levels of pesticides present, two had detectable levels of VOCs, and 38 had inorganic chemicals exceeding the maximum contaminant level (MCL) as established by the National Primary Drinking Water Regulations for Public Drinking Water Supplies (U.S. EPA 1987b). Only one well was contaminated with a pesticide or VOC concentration above the Kansas Action Level (KAL) — the level at which KDHE considers the water unacceptable for long-term consumption. In cases where KDHE considered the well water quality to present a health concern or to be unacceptable as a drinking water supply, the users were so advised.

Detailed results are shown in Table 3. Nitrate was the most commonly found contaminant. Nitrate-N was present in 28 percent of the wells at a concentration exceeding the MCL of 10 mg/L. In half of these wells, the concentration exceeded 20 mg/L of nitrate-N. A frequency distribution of nitrate-N for the survey is presented in Figure 6. The highest concentration of nitrate-N observed was 129 mg/L, measured during resampling of a pesticide-contaminated well. Figure 6 does not include any results from resampling. Selenium was the next most common contaminant; samples from nine of the wells exceeded the MCL, with the largest five times greater than the MCL. Fluoride was the only other inorganic contaminant detected above the MCL.

Nitrate, selenium, and fluoride are naturally occurring constituents of ground water. There are many sources of nitrate, both natural and man-made, but nitrogen fertilizer is probably the most important. Contamination by septic tanks or barnyard runoff is also not unusual. In this study the source of nitrate contamination could not be determined.

The high selenium and fluoride concentrations in the ground water were very likely due to local soil and rock formations. An area of high selenium concentrations centered near Kansas is reported by the AWWA (1985).

The herbicide atrazine was the only pesticide detected more than once in the survey; it was present in four wells. If the first sample indicated the presence of a pesticide or VOC, the well was resampled to confirm its presence. One well contained both chlordane and heptachlor epoxide at concentrations exceeding the KAL values. Two wells were contaminated with VOCs, one with benzene and another with 1,2-dichloroethane. Resampling confirmed the presence of 1,2-dichloroethane only. Because fuel spills near both of these wells were recorded on the questionnaires, both occurrences were considered as confirmed. Trichloromethane at a concentration of 0.6 μg/L was detected in a different well. The questionnaire disclosed that the owner chlorinated this well regularly. Resampling showed no contamination. This well was not considered contaminated and it is not included in the totals in Tables 2 or 3.

The synthetic chemicals found in farmstead wells were almost certainly introduced by human activity. In the case of VOCs, questionnaire responses indicated that past fuel spills were responsible. It could not be determined conclusively if pesticide spills or normal agricultural application were responsible for pesticide contamination. However, in two cases the well owners knew of no spills nor other point sources, but the pesticides had been applied to nearby fields. In most cases, resampling during May and June 1986 showed equal or higher concentrations than the original samples taken during the winter. Higher pesticide and nitrate concentrations are expected during the spring, which is closer to the time of fertilizer and pesticide application and has a period of greater rainfall in the Midwest. Presence of pesticides in ground water during the winter indicates a background level of contamination, rather than temporary contamination near the time of application of fertilizers.

Statistical Analysis

A number of statistical analyses were conducted using Statistical Analysis System (SAS). The most useful analysis was a multiple regression model for nitrate-N. To ensure that every possible predictor variable was considered, the "all-models" approach to regression analysis was used. The assumption was made that a new well should have only low concentrations of nitrate; thus, only zero-intercept models were examined. Several models were significant at the alpha = 0.01 significance level. The best model included the age of the well (AGE in years), land use around the well (USE values are: pasture or grass, 30; farmyard, 25; paved lot, 20; crop-

TABLE 2
Summary of Water Quality Analyses

	Number	Percentage	Confidence Band[a]
Wells sampled	103	100	—
Wells with pesticide	8	8	±6%
Wells with VOC	2	2	±3%
Wells with inorganic chemicals exceeding MCL[b]	38	37	±9%

[a] Probability is 0.95 that the true percentage for all wells differs from stated percentage by no more than this amount (Devore 1982).

[b] Maximum contaminant level as established by the National Primary Drinking Water Regulations (U.S. EPA 1987b).

TABLE 3
Contaminants Found in Farmstead Wells[a]

Chemical	No. of Wells	Concentration Initial	Concentration Resample	MCL or KAL[b]	
Nitrate-N (mg/L)	29	high = 91	high = 129	10	(MCL)
Selenium (μg/L)	9	high = 56	—	10	(MCL)
Atrazine (μg/L)	4	high = 7.4	high = 40	150	(KAL)
Fluoride (mg/L)	2	high = 2.3	—	1.8	(MCL)
2,4-D[c] (μg/L)	1	1.3	d	100	(MCL)
2,4,5-T[c] (μg/L)	1	1.1	d	700	(KAL)
Tordon (μg/L)	1	5.6	3.3	175	(KAL)
Chlordane[e] (μg/L)	1	0.47	0.58	0.22	(KAL)
Heptachlor epoxide[e] (μg/L)	1	0.026	0.023	0.006	(KAL)
Alachlor[f] (μg/L)	1	0.88	1.8	15	(KAL)
1,2-dichloroethane[f] (μg/L)	1	0.90	1.6	5	(KAL)
Benzene (μg/L)	1	2.3	0.0	5	(KAL)

[a] Contaminants were any synthetic chemical at any detectable concentration and naturally occurring chemicals above the MCL.

[b] MCL is the maximum contaminant level established by the National Primary Drinking Water Regulations (U.S. EPA 1987b). Kansas Action Level (KAL) is the level at which KDHE considers the water unacceptable for long-term consumption. The KAL is a guideline for those chemicals without MCLs and is not a regulatory standard.

[c] 2,4-D and 2,4,5-T were found in the same well.

[d] This well could not be resampled because the pump had failed and was no longer in use.

[e] Chlordane and heptachlor epoxide were found in the same well.

[f] Alachlor and 1,2-dichloroethane were found in the same well.

land, 15; drylot, 10; and feedlot, 5) and the distance from the well to any possible source of organic contamination (PSOC from 1 to 1000 feet). This model can be depicted as:

$$\text{NITRATE-N} = 19.2 + 0.0941(\text{AGE}) - 0.509(\text{USE}) - 0.0108(\text{PSOC}), \text{ mg/L}.$$

From this model an estimate of the nitrate-N concentration would be 3.9 mg/L for a well that is 30 years old, land use around the well is primarily farmyard (a value of 25), and where the well is 500 feet from a septic tank or feedlot. This model was selected in preference to its competitors based on its having one of the higher coefficients of determination ($R^2 = 0.18$), lower mean square error and intuitive appeal. Predictions using a regression model should not be made outside the range of the data points used in its development, which in this case is from 0 to 91 mg/L.

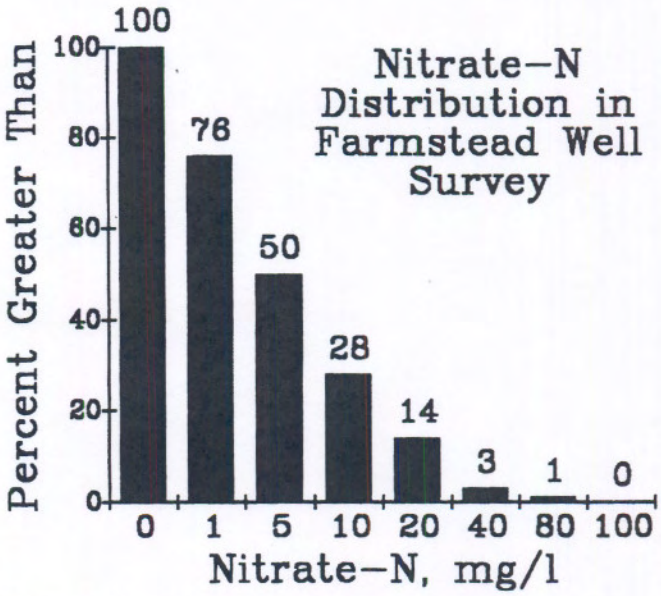

Figure 6. Nitrate-N distribution in farmstead well survey.

Discussion

Eight wells had detectable levels of pesticides and two had detectable amounts of VOCs. The low concentrations found indicate that most farmstead wells are not grossly contaminated with these chemicals. However, results point out that contamination is already occurring. The number of wells contaminated and the concentration of contaminants may increase in the future as greater amounts of chemicals are used and there is more time for these chemicals to move into ground water and into wells. Concern for the future must not be dismissed.

Nitrate is a naturally occurring contaminant in ground water in some areas. Also, there are many sources of nitrate, both natural and man-made. Nitrate contamination by septic tanks has been indicated by accompanying high chloride levels (Driscoll 1986). For the data collected in this study, 25 percent of wells that were high in nitrate were also high in chloride. Statistical analysis of the relationship between nitrate and chloride levels yielded a low correlation coefficient, $r = 0.102$ (this corresponds to $R^2 = 0.0106$), and a non-significant F value at the alpha = 0.10 confidence level.

Nitrogen fertilizer is another major source of nitrate. The authors could not get an estimate of the effect, if any, of fertilizers on ground water quality.

The large number of wells with nitrate levels exceeding the MCL of 10 mg/L is worrisome, particularly because more than half of these wells contained more than twice the nitrate MCL. Infants and fetuses are affected by high nitrate levels, resulting in methemoglobinemia, which can be fatal. Because so many wells are likely contaminated with excess nitrate, every private well where infants or pregnant women might drink the water should be tested for nitrate. Long-term chronic effects on adults who drink water with high levels of nitrate have not been demonstrated.

High selenium and fluoride concentrations in some samples were likely due to naturally occurring soil and rock formations. Selenium levels are generally higher in exposed Cretaceous shales. If these shales are buried, this may lead to the elevated selenium levels in ground water. There have been no reports of human health problems related to selenium in the United States (Oldfield 1986).

The pesticides and VOCs found in farmstead wells were certainly introduced by human activity. At the present time, the actual sources of all of these contaminants have not been determined. In the case of VOCs, the two occurrences were attributed to fuel spills near the well. For pesticides it is not known whether spills or normal agricultural application practices were responsible. Resampling of wells with pesticides or VOCs during May and June 1986 usually revealed concentrations greater than in the original samples taken during the winter months. This reveals the persistence of pesticides in ground water. Higher nitrate (Libra et al. 1986) and pesticide (Hallberg 1986) levels have been reported in the spring of the year. The increase in the spring is thought to result from higher moisture levels in soils, which allows percolation, and coincides with the application season of most fertilizer and pesticides.

Several characteristics of the aquifer and well construction are important. Major factors examined in detail were soil type; depth to water table, well screen, and well bottom; horizontal distance to PSOC; well history; and method of well construction. Factors found to correlate with nitrate contamination were the age of the well, the land use around the well, and the distance to a PSOC. Old wells are more likely to be contaminated than new ones. The age of the well is a likely indicator of the age of the farmstead and the length of time that potentially polluting activities have been located near the well. For land use around a well, pasture is less likely to be a cause of contamination than feedlots or cropland. Distance to a PSOC is also related to land use around the well. All of these factors are interrelated.

Statistical analyses were performed on as many aspects of the well construction and location as possible, using the data available. Information was adequate for model building only for nitrate. Even in the nitrate study the authors were unable to determine strong relationships between nitrate levels and various characteristics of the wells, as indicated by the low value $R^2 = 0.18$. An argument may be made for depth to water table as a predictor variable, but several outliers had the effect of casting doubt on its role. Again, the wells studied for this project were chosen to be representative of farmstead wells in Kansas and to obtain an unbiased estimate of the percentage of wells contaminated with pesticides, VOCs, and inorganic chemicals. Because the amount of contamination seen in the study was relatively low, the effective sample size for predicting contaminants is small and only weak conclusions can be reached. The problem of prediction is exacerbated by the "noisiness" (high intrinsic variability) of the variables.

Acknowledgment

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Biographical Sketches

Dr. James M. Steichen is professor of agricultural engineering at Kansas State University (Agricultural Engineering Department, Seaton Hall, Manhattan, KS 66506). He joined the faculty at KSU in 1978. His responsibilities are teaching and research in soil and water conservation and water quality. He holds B.S. and Ph.D. degrees in agricultural engineering from Oklahoma State University. He has authored numerous articles, papers and extensive publications on hydrology, water quality and soil conservation planning.

Dr. Doris L. Grosh is a professor of industrial engineering and statistics at Kansas State University (Industrial Engineering & Statistics Departments, Manhattan, KS 66506). Her responsibilities include administration, teaching, and research. Her major fields of interest are applied statistics, reliability, and operations research. She is the author of a book, A Primer of Reliability Theory. *She majored in mathematics and physics, earning a B.S. from the University of Chicago and an M.S. and Ph.D in statistics from Kansas State University.*

Alan Heiman has been a soil conservationist with the U.S. Soil Conservation Service (122 W. Main, Beloit, KS 67420) since 1987. He has earned B.S. and M.S. degrees in agricultural mechanization at Kansas State University.

Robert D. Yearout received a Ph.D. in industrial engineering at Kansas State University in 1987. He has just finished his first year teaching industrial and engineering management at the University of North Carolina-Asheville, (One University Heights, Asheville, NC 28804).

Dr. James K. Koelliker is professor of civil engineering at Kansas State University (Manhattan, KS 66506). His teaching and research are in the areas of water resources systems with emphasis on agricultural water management and the effects of agriculture on water quality. He graduated from Kansas State University in 1967 with a B.S. in agricultural engineering. He received an M.S. in water resources and a Ph.D. in engineering from Iowa State University. He has been on the faculty of Oregon State University in addition to his 15 years at Kansas State.

Vic Robbins, P.E., is an environmental engineer in the Bureau of Water Protection of the Kansas Department of Health and Environment (Building 740, Forbes Field, Topeka, KS 66620). His duties involve the monitoring and assessment of both surface water and ground water quality, with special emphasis on the evaluation of impairments due to non-point pollution sources. Robbins obtained a B.S. in agricultural engineering at Kansas State University, where he served on eight years as a research engineer with primary emphasis on mathematical modeling of environmental systems.

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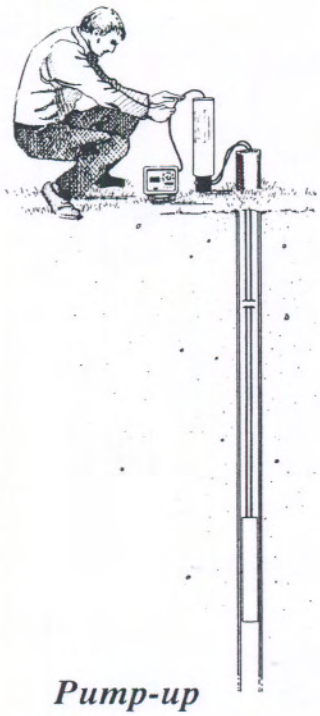

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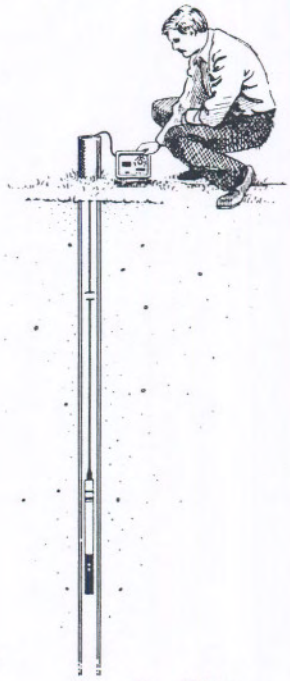

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