A Survey of the Quality of Water Drawn from Domestic Wells in Nine Midwest States

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Acknowledgements

TABLE OF CONTENTS

Executive Summary

Introduction and Purpose

Methods
--Collection of water samples
--Data collection form
--Laboratory analysis
--Total coliform and E. coli
--Nitrate-nitrite
--Atrazine
--Quality assurance
--Data analysis
--Data entry
--Contamination levels
--Statistical analysis

Results
--Participation
--Analytes
--Bacteria
--Nitrate
--Atrazine
--Samples with multiple contaminants
--Well construction and contaminated water samples
--Sanitary survey
--Diarrhea and contaminated water samples
--Geographic distribution of contamination

Discussion
--Limitations of the Survey
--Conclusions
--Recommendations

References

Appendix I -
Data Collection Form Pg. 1-2
Data Collection From Pg. 3

Appendix II - Definitions

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A Survey of the Quality of Water Drawn from Domestic Wells in Nine Midwest States

Table of Contents | Introduction and Methods | Results | Discussion
| References | Appendix I | Appendix II

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- Minnesota
- Missouri
- Nebraska
- North Dakota
- South Dakota
- Wisconsin

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The use of a company or product name is for identification purposes and does not imply endorsement.

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A Survey of the Quality of Water Drawn from Domestic Wells in Nine Midwest States

Table of Contents | Introduction and Methods | Results | Discussion | References | Appendix I | Appendix II

Executive Summary

Domestic wells, cisterns, or springs supply drinking water to eighteen percent of the households in the nine upper midwestern states. Many of these wells were in areas of the Missouri and Mississippi River basins that were flooded during the 1993 midwest flood. After the flood waters receded, many state and county sanitarians reported that water samples collected from domestic wells in the flooded river basins contained coliform bacteria. Since the nature and magnitude of this contamination was unknown, a survey was initiated to assess the presence of bacteria and chemicals in water drawn from domestic wells in the states that were severely affected by the flood.

The survey was conducted in May to November of 1994 by state health and environmental departments of nine midwestern states with assistance from the Centers for Disease Control and Prevention (CDC). Because samples were collected one year after flooding and few of the sampled wells had preflood water quality results, the effect of this disturbance on the water quality of domestic wells could not be evaluated. Water samples were collected from 5520 households with domestic wells. These houses were near the intersections of a 10 mile grid overlaid on a map of Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, and Wisconsin. Samples were usually collected from the household faucet that was used to supply drinking water. Coliform bacteria, *Escherichia coli*, nitrate, and atrazine were measured. The coliform bacteria and *E. coli* serve as indicators of contamination and their presence in water supply systems indicate an increased risk for diarrheal illnesses. Fertilizers and herbicides are intensely applied in rural areas of the Midwest, the location of most domestic wells. Nitrate, a breakdown product of fertilizers, may produce methemoglobinemia (Coomley, 1945). Atrazine, a herbicide, has been classified as a possible human carcinogen (IARC, 1991).

Field personnel collected the water samples and interviewed survey participants on the construction, condition, and maintenance of their well; the potential sources of contamination near the well; the number of people drinking well water; and the occurrence of diarrhea in their household. A sanitary survey was performed to record the condition of the well, the local geography, and to determine the type, distance, and location of potential pollution sources.

A water sample was considered to be contaminated when coliform bacteria or E. coli were present or when nitrate or atrazine concentrations exceeded their maximum contamination level (MCL) established by the Environmental Protection Agency (EPA) for public water systems. Coliform bacteria were present in 41.3% and *E. coli* in 11.1% of the samples. Nitrate was detected in 65.4% of the samples, with 13.4% exceeding their MCL of 10 mg/L NO_3-N. The mean nitrate level was 8.4 mg/L NO_3-N and ranged from not detected to 266 mg/L. Atrazine and structurally related triazines were detected in 13.6% of the samples (mean, 0.4

ppb; range, not detected to 29 ppb), with 0.2 % exceeding the MCL of 3 ppb. Atrazine was not measured in the water samples collected in North Dakota because of its limited use in the state.

Wells in southern Illinois, western Iowa, northern Missouri, and eastern Kansas had a greater proportion of samples with coliform bacteria and E. coli. Elevated nitrate levels were more likely to be found in water samples from western Illinois, Iowa, northern Missouri, eastern Kansas, and southeast Nebraska. Only 9 samples in the survey contained atrazine levels exceeding 3 ppb, and were dispersed throughout the eight states. Samples with atrazine concentrations between the detection limit and 3 ppb were more likely to be from Illinois, Wisconsin, or Kansas.

Wells in this survey were built by drilling (77.0%), digging (10.6%), driving a sandpoint (5.4%), or boring with an auger (3.8%). The mean age of the wells was 27 years (range, less than 1 year to 200 years), the mean depth was 154 feet (range, 1 foot to 3500 feet) and the mean diameter was 10.6 inches (range, 1 inch to 144 inches). Steel or plastic casing was used in 80.3% of the wells. Water samples from households with wells older than 25 years, shallower than 100 feet, or greater than 6 inches in diameter were more likely to have contaminants than samples from households with a newer, deeper, and smaller-diameter drilled or driven well. Water samples from households with bored or dug wells were 10 to 15 times more likely to contain coliform bacteria or *E. coli* than were samples from households with drilled or driven wells.

Well owners reported using pesticides (14.3%), fertilizers (11.4%), and manure (7.8%) within the past 5 years and within 100 feet of the well. The application of these products was associated with the presence of coliform bacteria and *E. coli*, and with nitrate levels above 10 mg/L in the water samples.

The sanitary survey revealed that potential contamination sources were commonly found within 100 feet of the well head. Septic tanks (30.2%) and lateral fields (16.9%), structures that contain human fecal material, were the most common pollution sources. Less than 1% of the wells had a sewage lagoon, silage storage, agricultural drain, or sink hole within 100 feet. One-fourth of the wells not only had a contamination source within 100 feet but were also down gradient from that source.

Pitless adapters provide a seal between the well casing and the distribution system and backflow devices prevent back syphoning of water. Of the wells in the survey, 44.2% had pitless adapters and 20.7% had backflow devices. Wells with these devices had up to 20% fewer contaminated samples than wells lacking these devices. Samples from wells with a crack or hole in the well casing were up to 7 times more likely to be contaminated than were samples from wells with intact casings.

Of the 15,978 people who consumed water from these wells, 2.9% reported a diarrheal episode during the 2 weeks prior to the collection of water samples for this survey. There was no association between the occurrence of diarrheal episodes and the presence of coliform bacteria or E. coli in water samples. The diarrheal rate among participants in the survey (0.75/person/year) was similar to the endemic rate of gastrointestinal illness reported in other surveys in North America (0.66 to 1.6/person/year) (Hodges et al., 1956; Monto and Koopman, 1980; Payment et al., 1991).

In summary, coliform bacteria, *E. coli*, nitrate, and atrazine were found in many of the water samples collected from midwestern households with a domestic well. Most of the water samples with these pollutants were drawn from dug or bored wells that were old and shallow and had a large-diameter brick or concrete casing. People relying on these types of wells for their drinking water should be informed that they are at increased risk to these pollutants. Wells with a pitless adapter or backflow device had a lower contamination rate. A cracked casing or opening in the well greatly increased the risk for contamination. Samples from wells within 100 feet from septic tanks or cisterns; or had pesticides, manure, or fertilizer applied within 100 feet of the well; or down gradient from a pollutant source had a higher contamination rate.

There are 14 million households in the United States that rely on a domestic well to supply their drinking water and over 90,000 new wells drilled each year. The risk of contracting waterborne diseases from domestic well water systems can be reduced by protecting the watershed and aquifer, building wells away from possible contamination sources, properly constructing and maintaining wells and their distribution systems, routinely testing for contaminants, and, if necessary, effectively disinfecting the water. Education should be available to well owners and users, water well drillers, and county and state personnel. With strong, effective programs that address these issues, a domestic well water system can provide potable water that is safe and economical.

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A Survey of the Quality of Water Drawn from Domestic Wells in Nine Midwest States

Table of Contents | Introduction and Methods | Results | Discussion | References| Appendix I | Appendix II

Introduction and Purpose

Domestic water wells supply water to 17.6% of the households in the upper midwestern states (**Table 1**). In the spring of 1993, flood waters covered some of the water wells in the Missouri and Mississippi river basins. River flooding can affect groundwater quality by raising the water table, altering hydraulic gradients, recharging from different areas, or flowing directly down the well casing. Many residents who tested water from their domestic well after the flood waters receded reported the presence of coliform bacteria or *E. coli* in these samples.

TABLE 1.
Sources of drinking water for households in nine Midwestern States

State	Drinking Water Source* (percent)			
	Number of Households	Public	Private	Other
Iowa	1,143,669	81.1	18.4	0.5
Illinois	4,506,275	89.8	09.8	0.4
Kansas	1,044,112	89.5	10.0	0.5
Minnesota	1,848,445	83.7	15.3	1.0
Missouri	2,199,129	73.0	26.2	0.8
Nebraska	660,621	82.9	16.9	0.2
North Dakota	276,340	79.0	19.2	1.8
South Dakota	292,436	81.4	16.7	1.9
Wisconsin	2,055,774	66.5	32.8	0.6
Total	**14,027,611**	**81.8**	**17.6**	**0.6**
US	***102,263,678***	***84.2***	***14.8***	***1.0***

***The US Census defines a public water source as one that provides water for five or more houses, apartments, or mobile homes and a private water source as one that provides water for four or fewer houses, apartments, or mobile homes
Source: 1990 US Census

The coliform group of bacteria is recognized as a microbial indicator of drinking water quality because these bacteria are commonly found in the environment, are present in large numbers in feces, and are easily detected by simple laboratory methods. *E. coli*, a member of the coliform group, is found only in fecal material. The presence of coliform bacteria in a water system indicates vulnerability to contamination and ineffective disinfection whereas the presence of *E. coli* indicates fecal pollution. People drinking water with these bacteria are at increased risk of contracting a waterborne disease.

In addition to measuring bacteria, samples were collected for nitrate and atrazine analysis. The major sources of nitrate in groundwater include fertilizers, animal manure, seepage from septic systems, and atmospheric fallout from combustion of fossil fuel. Background levels of nitrate in ground water may reach 3 mg/L because of natural decomposition and soil bacteria. Higher nitrate levels are associated with anthropogenic activity (Mueller et al., 1995). The Environmental Protection Agency (EPA) established an MCL of 10 mg/L for nitrate-nitrogen in public water systems (EPA, 1994) because infants are particularly susceptible to nitrate and may develop methemoglobinemia (Coomley, 1945).

Triazines are organic herbicides introduced in the 1950s. These synthetic chemicals are among the most widely used and effective herbicides in the world. In the Midwest, atrazine is used seasonally to control grassy and broadleaf weeds in corn and wheat fields. The chemical is applied to the surface of the land and degrades quickly when exposed to light. However, the half-life of atrazine in soil or water is several months (EPA, 1984a). Atrazine is the most commonly found herbicide in ground and surface water because of its high use, persistence in the environment, and ability to dissolve in water. The chemical is mutagenic in bacteria and is considered a possible human carcinogen (IARC, 1991).

The purpose of the survey was to measure levels of coliform bacteria, *E. coli*, nitrate, and atrazine in water collected from households that are supplied water from a domestic well water system in nine midwestern states. This concern originated when many water samples from rural wells collected shortly after the 1993 midwest floods tested positive for coliform bacteria or *E. coli.* Public health officials from the affected states and from federal agencies met to discuss the contamination. They concluded that the available data was insufficient to characterize the nature and magnitude of the situation. They agreed to conduct a survey of the geographic distribution of chemical and bacteriological contamination of water from domestic well water systems in the affected states. The survey would collect information on the construction, maintenance, and condition of the well. To correlate health effects with contamination, participants in the survey would be asked whether they had a diarrheal episode in the 2 weeks before the water sample was collected from their house.

Methods

Any household in the nine upper midwestern states that used a domestic well to supply water for drinking, cooking, or bathing was eligible for the survey. The EPA defines a public water system as having at least 15 service connections or regularly serves an average of 25 people daily for 60 days out of the year (EPA, 1995). In this survey, a domestic well had fewer than 15 service connections and regularly served fewer than 25 people. Field personnel collected a water sample from the household closest to and within 3 miles of each intersection of a 10 mile grid overlaid on the 9 states. The grid was constructed by randomly choosing a starting point outside the 9-state region as the lower left corner (Gulf of Mexico). ArcInfo (Environmental Systems Research Inc., 1993) was the primary geographic information system (GIS) used to construct the sampling grid. This program also generated a list of the latitude and longitude of each grid intersection, a unique identification number for each intersection, and printed maps of each county showing the major rivers, roads, and railroads in the county, and the location and the unique identification number of each sampling unit (the area within a 3-mile radius of the intersect) in the county (Figure 1).

Figure 1. A county map used to locate households to be sampled in the 1994 Midwest Well Water Survey. Households nearest to the intersection and within the circle and county sampled.

When a sampling unit included more than one county, field personnel did not enter the adjacent county to collect that sample. Most field personnel were familiar with the area in which they were assigned to collect samples. Real-estate plats, U.S. Geological Survey quadrangles, and municipal maps were also used to locate the households to be sampled. Field personnel were employed by the state agency that was conducting the survey.

A systematic geographical sampling approach was used because a list of domestic wells was not available and variables that affect water supply and quality (e.g. geology, soil type, topography, land use, etc.) are not randomly distributed. In addition, conducting a census of wells in each sampling unit would have been difficult and time-consuming.

Collection of water samples

Water samples were collected from May to November 1994. Field personnel located the household closest to the grid intersection and asked an adult resident for permission to collect a water sample. An eligible household received water from a domestic well, had at least one member who drank the water, and was within 3 miles of the intersection. In addition, the well must not have been chlorinated in the previous 4 days because chlorine that was used to disinfect the well may still be present. If the resident declined to participate or the well did not meet enlistment criteria, the field personnel proceeded to the next closest household. If no well was sampled in the designated sampling unit, field personnel proceeded to the next sampling unit. When no households with wells could be found in several sampling units within a county, the sampling unit within that county was extended to a 5-mile radius from the grid intersection.

When a household member granted permission, field personnel marked the approximate location of the sampled well on the survey map or recorded the latitude and longitude of the sampled well if geographical positioning system instruments were available. Water samples were collected from the faucet most commonly used to provide drinking water. When possible, aerators, strainers, hoses, water treatment devices, or other attachments were removed before the sample was collected. Taps were sanitized by wiping the inside and outside of the tap with a paper towel or cotton-tipped swab saturated with 100 mg/L sodium hypochlorite. The tap was opened fully for 3 to 5 minutes prior to sampling, and then the water flow was reduced during sample collection. The sample bottle cap was removed, and without rinsing, sufficient water was collected to fill four-fifths of the container. Water was collected in polyethylene bottles for bacteriologic analysis. Two milliliters of dilute sulfuric acid were added to the sample bottle for nitrate and atrazine analysis. The caps were immediately replaced without touching the interior of the cap or container. After collection, samples were placed on ice until they were delivered to the state laboratory. Microbiology testing begun within 30 hours of collection.

Duplicate samples were chosen in advance. In each state, the survey coordinator decided the rate at which duplicate samples were collected -- usually every eighth, ninth or tenth household -- and maintained this frequency throughout the state. Field surveyors collected the duplicate samples at the preselected rate. If no sample could be collected at the designated site, the sample was collected at the next available sample site.

Data Collection Form

In addition to collecting water samples, field personnel interviewed survey participants to obtain information on the construction, condition, and maintenance of the well; the potential sources of contamination; the number of people drinking water from the well; and the occurrence of diarrhea in the household (Appendix I). For most wells, a sanitary survey was performed to determine the condition of the well; the character of local geography; and the nature, distance, and location of potential pollution sources in the area.

Laboratory Analysis

Coliform Bacteria and *E. coli.* A 10-tube assay (Colilert, IDEXX Laboratories Inc., 1994) measured the concentration of coliform bacteria and E. coli in the water samples. In this procedure, an aliquot of the sample is placed in each of ten tubes containing nutrient broth and indicator chemicals. The broth turns yellow when coliform bacteria metabolize O-Nitrophenol-b-d-galactopyranoside and fluoresces under ultraviolet light when E. coli breaks down 4-methylumbellifery-b-d-glucuronide. The medium contains chemicals tha suppress the growth of noncoliform bacteria. The result, number of coliform bacteria or E. coli per 100 mL, is a statistical estimate of the mean density of bacteria in a water sample and is based on the number of samples testing positive. The assay had a quantitative range from 1.1 (95% confidence interval 0.0., 5.9) to 23 (95% confidence interval 8.1, 59.5) bacteria per 100 mL.

Nitrate. The colorimetric, automated, cadmium reduction method (APHA, 1992) measured nitrate concentrations as milligrams nitrate-nitrogen per liter (mg/L NO_3-N). The preserved water sample was filtered and passed through a column containing granulated copper-cadmium. This step converts nitrate (NO_3) tonitrite (NO_2), which forms an azo dye when sulfanilamide couples with N-(1-naphthyl)-ethylenediamine dihydrochloride. The azo dye is measured colorimetrically and is proportional to the amount of nitrate in the sample. This assay had a limit of detection of 0.01 mg/L.

Atrazine. An enzyme-linked immunosorbent assay measured atrazine in the water samples (Ohmicron, 1995). This method used atrazine-selective antibodies linked to a peroxidase enzyme detector system. In the presence of atrazine, a colored product is formed that is inversely proportional to the concentration of triazines in solution. As with most immunoassays, structurally related chemicals may cross-react with the antibody. These include other triazines such as cyanazine, simazine, and terbutryn and the atrazine metabolites 6-hydroxy atrazine and, desisopropyl atrazine. This assay had a limit of detection of 0.05 ppb.

Quality Assurance

In an effort to produce data that is precise and comparable, standard protocols for sample collection and analysis were established by the laboratories conducting the water analysis. One quality control procedure involved collecting duplicate samples for every eighth to tenth well. The difference between the original and the duplicate samples for coliform bacteria, E. coli, or nitrate was not statistically significant ($p = 0.14$, student=s t-test). Other quality control measures used by the laboratories included standardized sample collection and transport procedures; standard solutions, reagents, and preservatives; and use of analytical reagents with the same lot number for the Colilert and the atrazine assays. Laboratories also performed routine internal quality control procedures.

Data Analysis

Data entry. State survey coordinators mailed completed data collection forms, county maps, lists of well identification numbers, and the latitude and longitude of each well, when available, to CDC. Forms were examined for completeness and logged into a program that monitored the progress of each form in the data-entry process. The latitude and longitude of each well were entered into an ArcInfo data base. The data were double-entered. Each state's well survey manager reviewed a data base of the information of the wells sampled in their state.

Contamination levels. The EPA established limits on the level of contaminants in drinking water to ensure that public water systems deliver water that is safe for human consumption. These limits are known as the maximum contaminant levels (MCLs) -- the highest allowable amount of a contaminant that a public water supply can deliver to a consumer. A violation occurs when an MCL is exceeded. The MCL is 10 mg/L for nitrate and 3 ppb for atrazine (EPA, 1994). For bacteriological monitoring, the EPA established the total coliform rule, which states that any water sample that tests positive for coliform bacteria must be analyzed for fecal coliform or E. coli. A positive test result is when coliform bacteria or E. coli concentration is at least one per 100 mL of sample. A repeat test is conducted for each positive sample and samples are collected within 24 hours of a positive test result. A violation occurs when coliform bacteria or E. coli are present in both the initial and repeat sample. While these standards pertain to public water systems, they served as guidelines for assessing the quality of water collected in this survey. Thus a water sample collected from a household served by a domestic well was considered to be contaminated if coliform bacteria or E. coli concentrations were detected, if nitrate concentrations exceeded 10 mg/L, or if atrazine levels were above 3 ppb.

Statistical analysis. Odds ratios were calculated to order to determine the strength of the association between a well feature (e.g., depth, presence of cracks in casing, pesticide use near the wellhead) and the presence of contaminants in the water samples (coliform bacteria, E. coli, nitrate, or atrazine). Results for atrazine are not reported because only 0.2% of the samples had levels that exceeded the MCL. An odds ratio less than one indicates that the well feature was associated with a lower contamination rate than the wells without that feature, an odds ratio greater than one implies that the well feature was associated with a higher contamination rate, and an odds ratio of one shows that the well feature had no association with the contamination rate. To examine the association between well construction and contamination, we chose drilled wells as the reference because they constituted the largest group and had samples with one of the lowest rates of contamination.

Epi Info version 6.0 was used for the descriptive analysis and calculation of odds ratios (Dean et al., 1994). SAS version 6.10 (SAS Institute Inc., 1991) was used to run the logistic regression to examine for associations between the analytes and well depth, age, and casing diameter. ArcInfo (Environmental Systems Research Inc., 1993) and MapInfo (MapInfo Inc., 1994) were used in the descriptive analysis of the spatial distribution of the analytes. ArcInfo was also used to examine for associations between the analytes and well location, political boundaries, bodies of water, soil type, household income, and the presence of multiple analytes in water samples.

A Survey of the Quality of Water Drawn from Domestic Wells in Nine Midwest States

Table of Contents | **Introduction and Methods** | **Results** | **Discussion**
| **References** | **Appendix I** | **Appendix II**

Results

Participation

Water samples were collected from houses in 5,536 (87.9%) of the 6,298 grid points in the sampling frame (Figure 2). Water samples were not collected from 445 (7.1%) households because these houses did not have a domestic well or received water from a public water supply, or because the sampling unit was in a lake, river, swamp or mountain. In 186 (3.0%) of the households, no resident was present to give permission to collect a water sample. Residents in 131 (2.0%) households declined to participate in the survey. Of the 5,536 water samples collected, 16 (0.3%) were excluded from the analysis because they were from a cistern, spring, or community well. Thus the analysis was based upon 5,520 samples.

Figure 2. Location of sampling areas in the 1994 Midwest Well Water Survey

Analytes

Bacteria. Coliform bacteria were present in 41.3% of the water samples. The proportion of samples testing positive for coliform bacteria ranged from 22.8% in Wisconsin to 58.6% in Iowa (**Table 2**). *E. coli* was detected in 11.1% of all the samples and in 27.0% of the samples with coliform bacteria. *E. coli* was recovered only from samples testing positive for coliform bacteria because *E. coli* is a member of the coliform bacteria group and will, by itself, produce a positive total coliform result. Nebraska (2.5%) and Wisconsin (2.6%) had the lowest proportion of samples with *E. coli*, and Iowa (20.5%) and Missouri (22.6%) had the highest. The two largest groups of samples had coliform bacteria or *E. coli* densities less than 1.1/100 mL or greater than 23/100 mL (Figure 3).These values represent the lower and upper quantitative limit of the assay.

Table 2.
The percentage of water samples that tested positive for coliform bacteria and for *E. coli* and the percentage with nitrate or atrazine concentrations above the maximum contamination level for public water supplies, 1994 Midwest Well Water Survey

	Analytes				
State	**Coliform Bacteria**	***E. coli***	**Nitrate >10 mg/L**	**Atrazine > 3 ppb**	**N**
Illinois	45.9	15.4	15.3	0.0	540

Iowa	58.6	20.5	20.6	0.4	526
Kansas	48.7	16.3	24.3	0.6	716
Minnesota	27.3	04.5	05.8	0.1	718
Missouri	57.4	22.6	09.7	0.0	632
Nebraska	37.3	02.5	14.7	0.2	598
North Dakota	35.5	08.2	13.5	not tested	673
South Dakota	40.1	08.4	10.4	0.0	583
Wisconsin	22.8	02.6	06.6	0.2	534
Total	**41.3**	**11.1**	**13.4**	**0.2**	**5,520**

N = number of wells tested for coliform bacteria. A similar number of wells in each state were tested for the other analytes. Coliform bacteria or *E. coli* greater than or equal to 1.1 cfu/100 mL.

Figure 3. Coliform bacteria and E. coli concentration of well water samples collected in the 1994 Midwest Well Water Survey

Nitrate. Of the 5,500 samples submitted for nitrate analysis, 65.4% were above the limit of detection, 31.8% were above 3 mg/L, and 13.4% were above 10 mg/L. The mean nitrate level was 8.4 mg/L (SD = 16.9 mg/L) and ranged from nondetectible (less than 0.01 mg/L) to 266 mg/L. Minnesota (5.8%) and Wisconsin (6.6%) had the lowest proportion of samples with nitrate levels above 10 mg/L, and Iowa (20.6%) and Kansas (24.6%) had the highest. Twenty samples were not tested for nitrate because of insufficient volume of sample, loss of sample in transit, or a laboratory error.

Atrazine. Eight of the nine states collected water samples for atrazine testing. This herbicide was not measured in the samples collected in North Dakota because of low use in the state. Of the 4,828 samples tested for atrazine, 13.6% were above the limit of detection and 9 samples (0.2 %) were above 3.0 ppb. The mean atrazine concentration was 0.40 ppb (SD = 1.3 ppb) and ranged from nondetectible (less than 0.05 ppb) to 29.0 ppb.

Samples with multiple contaminants. There were 208 samples (3.8%) that contained coliform bacteria, *E. coli*, and elevated nitrate levels. Samples from bored wells had the highest rate (20.0%), followed by those from dug (16.9%), drilled (1.4%) and driven (0.3%) wells. Of the samples with elevated nitrate levels, coliform bacteria were present in 67.8% and *E. coli* in 28.1% of the samples (Table 3). *E. coli* was present in 27.0% of the samples with coliform bacteria.

Table 3. Coliform Bacteria, *E. coli* and nitrate in samples from the 1994 Midwest Well Water Survey

	***E. coli* - Number of samples**		**Nitrate- Number of samples**	
	absent	**present***	**< or = 10 mg/L**	**> 10 mg/L**

Coliform Bacteria absent	3238	0	2987	238
present	1666	616	1774	501
E. coli absent	--	--	4354	531
present	--	--	407	208

*>= 1.1. cfu/100mL

Well construction and contaminated water samples

Drilled wells were the most common construction type throughout the nine states, with dug wells a distant second (**Table 4**). Dug and bored wells were primarily in Illinois and Iowa, wells with a buried slab were mainly in Illinois, and driven wells were most commonly found in Wisconsin.

Table 4. Construction methods used to build wells in 1994 Midwest Well Water Survey

State	Construction Method (percent)							
	Drilled	Dug	Driven	Bored	Buried slab	Other	Unknown	Total
IL	54.4	24.4	6.5	6.5	6.5	0.7	0.9	540
IO	60.3	10.6	2.5	20.7	1.3	4.0	0.6	526
KS	79.9	17.7	0.8	0.1	0.1	1.0	0.3	716
MN	80.8	6.1	8.5	2.4	0.0	0.6	1.7	718
MO	72.6	12.7	7.3	5.9	0.5	0.2	0.9	632
NE	91.1	1.8	1.7	0.0	0.3	0.2	4.8	598
ND	83.5	11.4	3.7	0.4	0.1	0.3	0.4	673
SD	82.3	7.7	5.7	1.4	0.0	2.1	0.9	583
WI	83.0	2.1	12.7	0.0	0.0	0.4	1.9	534
Total	77.0	10.6	5.4	3.8	0.9	1.0	1.4	5520

Wells in the survey had features similar to wells built by the same construction method. For example, most bored, buried slab, dug, and driven wells were shallow; dug wells were typically 2 to 4 feet wide and lined with concrete tile; drilled and driven wells were deeper and had small diameter steel or plastic casings (**Table 5**).

Table 5. Construction features of wells in the 1994 Midwest Well Water Survey

Construction type	Age (years)	Depth (feet)	Casing Diameter (inches)	Casing Type (percent)
Bored	15-40	30-53	20-36	concrete tile (91.9)
Buried slab	4-18	35-60	24-36	concrete tile (58.1)
Drilled	10-30	75-220	4-6	steel (63.5)
Dug	35-75	20-40	24-48	brick (56.9)
Driven	11-40	20-56	1-2	steel (84.6)

Ranges are the values for the 25% and 75% quartiles

When compared with samples from drilled wells, water samples from bored or dug wells were 10 to 15 times more likely to contain coliform bacteria or *E. coli* and 4 to 6 times more likely to have nitrate concentrations above 10 mg/L (**Table 6**). Water samples from wells with buried slabs were four times more likely to have coliform bacteria or *E. coli*. Water samples from driven wells, however, were less likely to have these bacteria than were samples from drilled wells. The odds ratios for atrazine were not calculated because only 9 samples exceeded 3 ppb, the MCL for public water systems.

Table 6. Well construction type and the risk of having coliform bacteria, *E. Coli* or nitrate in water samples collected in the 1994 Midwwest Well Water Survey

Well Type	Coliform Bacteria		*E. coli*		Nitrate	
	Odds ratio	*(95% Confidence Interval)*	*Odds ratio*	*(95% CI)*	*Odds ratio*	*(95% CI)*
Drilled	1.00	Referent	1.00	Referent	1.00	Referent
Bored	11.77	(7.79-17.88)	12.60	(9.18-17.30)	5.93	(4.37-8.04)
Buried slab	4.71	(2.44-9.22)	4.01	(1.79-8.71)	1.17	(0.76-3.96)
Dug	10.33	(8.17-13.14)	15.47	(12.46-19.21)	4.02	(3.31-5.02)
Driven	0.45	(0.33-0.61)	0.56	(0.26-1.13)	1.26	(0.86-1.83)

Coliform bacteria or *E. coli* greater than or equal to 1.1 cfu/100 mL
Nitrate concentration greater than 10 mg/L
CI = confidence interval

Water from wells with a brick or concrete casing (typical of dug, bored, and buried slab wells) was more likely to contain coliform bacteria, *E. coli*, or elevated nitrate levels than did water from wells with a steel casing (**Table 7**). Water from wells with a plastic casing was less likely to contain coliform bacteria or *E. coli* than water from wells with a steel casing. Results from samples collected from wells with steel casings were chosen as the referent because they constituted the largest category.

Table 7. Casing material and the risk of having coliform bacteria, *E. coli* or nitrate in water samples collected from wells in the 1994 Midwestern Well Survey

	Coliform Bacteria		***E. coli***		**Nitrate**	
Casing Material	*Odds Ratio*	*(95% Confidence Interval)*	*Odds Ratio*	*(95% CI)*	*Odds Ratio*	*(95% CI)*
Steel	1.00	Referent	1.00	Referent	1.00	Referent
Brick	18.85	(12.82-27.85)	21.68	(16.53-28.44)	5.56	(4.24-7.29)
Concrete	7.30	(5.88-9.06)	6.44	(5.08-8.17)	5.56	(4.45-6.94)
Plastic	0.80	(0.69-0.92)	0.41	(0.28-0.60)	1.55	(1.25-1.92)

Coliform bacteria or *E. coli* greater than 1.1 cfu/100 mL
Nitrate concentration greater than 10 mg/L
CI = confidence interval

Table 8 contains the adjusted odds ratios for well diameter, age, and depth that are corrected for the effect of the two other well features. Coliform bacteria or *E. coli* were 4 to 5 times more likely to be present in water samples from wells with a casing diameter greater than 6 inches. Samples from wells older than 25 years or shallower than 100 feet had a modestly increased chance of containing coliform bacteria, *E. coli* or elevated nitrate than did samples from newer or deeper wells.

Table 8. Adjusted odds ratios of well characteristics associated with coliform bacteria, *E. coli* or elevated nitrate in water samples collected in the 1994 Midwest Well Water Survey

	Coliform Bacteria		***E. coli***		**Nitrate**	
Well Feature	*Odds ratio*	*(95% Confidence Interval)*	*Odds Ratio*	*(95% CI)*	*Odds ratio*	*(95% CI)*
Diameter (> 6 inches)	4.3	(3.7-5.1)	5.3	(4.2-6.7)	2.2	(1.8-2.8)
Age (> 25 years)	2.1	(1.8-2.4)	2.5	(2.0-3.1)	1.3	(1.1-1.7)
Depth (< 100 feet)	1.6	(1.4-1.9)	2.2	(1.7-2.9)	2.2	(1.8-2.9)

Coliform bacteria or E. coli greater than 1.1 cfu/100 mL
Nitrate concentration greater than 10 mg/L
OR = odds ratio, adjusted for the two other features; CI = confidence interval

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Pitless adapters were installed in 44.2% of the wells and backflow devices were in 20.7% of the wells, and they significantly reduced the risk for contamination (**Table 9**). Sealed wells also decreased the risk for contamination, whereas a cracked casing or open lid significantly increased this risk. Dug wells (46.0%) had the most openings or cracks, followed by bored wells (40.0%), drilled wells (15.4%) and driven wells (11.0%).

Table 9. Selected well characteristics and coliform bacteria, *E. coli*, or nitrate in water samples collected in the 1994 Midwestern Well Water Survey

	Coliform Bacteria		***E. coli***		**Nitrate**	
Well Feature or Condition Present	*OR*	*(95% CI)*	*OR*	*(95% CI)*	*OR*	*(95% CI)*
Pitless adapter	0.36	(0.31-0.40)	0.20	(0.16-0.25)	0.45	(0.37-0.54)
Backflow devices	0.64	(0.56-0.74)	0.63	(0.50-0.81)	0.79	(0.64-0.98)
Cap	0.40	(0.33-0.50)	0.38	(0.29-0.49)	0.05	(0.04-0.05)
Standard cap	0.39	(0.34-0.44)	0.12	(0.10-0.14)	0.41	(0.34-0.49)
Sanitary cap	0.37	(0.31-0.45)	0.32	(0.27-0.40)	0.51	(0.43-0.61)
Sealed	0.34	(0.30-0.38)	0.27	(0.22-0.33)	0.41	(0.34-0.49)
Open lid	2.96	(2.56-3.42)	3.63	(3.00-4.40)	2.17	(1.80-2.61)
Cracked casing	4.46	(3.49-5.72)	7.21	(5.60-9.28)	2.21	(1.67-2.91)

Coliform bacteria or *E. coli* greater than 1.1 cfu/100 mL
Nitrate concentration greater than 10 mg/L
OR = odds ratio, the referent group for each feature were wells that did not have that specific feature;
CI = confidence interval

Sanitary survey

The sanitary survey revealed that potential contamination sources were commonly found within 100 feet of the well head (**Table 10**). Septic tanks and lateral fields, structures that contain human fecal material, were the most common pollution sources. Less than 1% of the wells had a sewage lagoon, silage storage, agricultural drain, or sink hole within 100 feet. One-fourth of the wells had a contamination source within 100 feet and were down gradient from that pollution source.

Table 10. Domestic wells with potential contamination sources or conditions within 100 feet of the well head, 1994 Midwest Well Water Survey

Source Well	**Source within 100 feet of the Number of Wells**	**Percent**
Septic Well	1669	31.9
Lateral Field	932	18.1
Outhouse	153	2.9
Down gradient from pollutant	1378	25.7

Surface Water	534	12.7
Abandoned Well	617	11.9
Flood plain	348	7.0
Cistern	489	9.4

The frequency that a contaminant was found in water samples from wells with a pollutant source within 100 feet was compared with the frequency of that contaminant in samples from wells with the same type of pollutant source more than 100 feet from the well (**Table 11**). Septic tanks within 100 feet of a well were associated with coliform bacteria and *E. coli* in water samples, whereas lateral fields and outhouses showed no association. A well down gradient from a pollution source was associated with presence of coliform bacteria, *E. coli*, and elevated nitrate levels. A cistern within 100 feet of a well was associated with coliform bacteria in water samples.

Table 11. Possible contamination sources or conditions within 100 feet of a domestic well and presence of coliform bacteria, *E. coli*, or elevated nitrate levels in water samples collected in the 1994 Midwest Well Water Survey

	Coliform Bacteria		***E. coli***		**Nitrate**	
Contamination source	**OR**	**(95% CI)**	**OR**	**(95% CI)**	**OR**	**(95% CI)**
Septic Tank	1.22	(1.07-1.37)	1.32	(1.09 - 1.61)	1.10	(0.92- 1.320)
Lateral Field	0.82	(0.71-0.94)	0.77	(0.61-0.98)	0.77	(0.62-0.96)
Outhouse	0.87	(0.61-1.22)	1.13	(0.67-1.88)	0.79	(0.46-1.35)
Down gradient	1.23	(1.09-1.40)	1.38	(1.07-1.80)	1.59	(1.34-1.89)
Surface water	1.11	(0.93-1.31)	1.24	(0.96-1.60)	1.10	(0.86-1.40)
Flood plain	0.90	(0.76-1.19)	0.92	(0.63-1.32)	1.02	(0.73-1.41)
Abandoned well	0.75	(0.63-0.90)	0.63	(0.46-0.86)	0.85	(0.65-1.10)
Cistern	1.64	(1.36-1.99)	1.21	(0.90-1.61)	1.28	(0.98-1.66)

Coliform bacteria or E. coli greater than 1.1 cfu/100 mL
Nitrate concentration greater than 10 mg/L
OR = odds ratio, adjusted for the two other features; CI = confidence interval

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Pesticides, manure, and fertilizers are often applied near wells and most of the applications occurred within the past 5 years (**Table 12**). When applications within the previous 5 years and within 100 feet of the wellhead were examined, the presence of coliform bacteria, E. coli, or elevated nitrate levels in water samples was associated with the use of these agricultural products (**Table 13**). This association was examined by comparing the contamination rate of samples from wells with applications within 5 years and 100 feet of the wellhead to the rate of samples from wells that had no applications or applications more than 5 years before the survey and beyond 100 feet of the wellhead. Pesticide use was associated with coliform bacteria, E. coli, and elevated nitrate levels in well water samples. The use of manure doubled the likelihood of an elevated nitrate level. The use of fertilizers increased the chance of detecting coliform bacteria and doubled the likelihood of an increased nitrate level.

Table 12. Application of agricultural chemicals near wells, 994 Midwest Well Water Survey

	Agricultural Product Applied		
Usage	**Pesticide (N = 5353)**	**Manure (N=5386)**	**Fertilizer (N= 5386)**
Ever used	41.8	29.7	52.0
In past 5 years	38.3	24.2	51.6
Within 100 ft	15.8	09.9	17.5
In past 5 years and within 100 ft	14.3	07.8	11.4

Table 13. Application of agricultural chemicals in the prior 5 years and with 100 feet of the well and the presence of coliform bacteria, *E. coli*, or elevated nitrate levels in water samples collected in the 1994 Midwest Well Water Survey

	Pesticide		**Agricultural Product Manure**		**Fertilizer**	
Analyte	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Coliform Bacteria	1.30	(1.11-1.61)	1.08	(0.88-1.61)	1.34	(1.11- 1.61)
E. coli	1.30	(1.03-1.65)	1.32	(0.98-1.63)	1.26	(0.96 -1.65)
Nitrate	1.67	(1.35-2.07)	1.95	(1.50-2.53)	1.90	(1.50 -2.41)

OR = odds ratio, CI = confidence interval. The wells with no application or applications more than 5 years ago and beyond 100 feet from the well head served as the referent group.

Diarrhea and contaminated water samples

The 5,520 wells in the survey provided water for 17,385 people. Of the 15,978 people who drank well water, 458 (2.9%) reported three or more watery stools in a 24-hour period within the 2 weeks before a sample was collected from their well. People over 17 years of age (70.8%) were the largest group who drank well water (**Table 14**).

Table 14. Ingestion of well water and diarrheal rate among residents of households served by a domestic well

	Under 6	Ages 7-17	Over 17	Total
Number who drank well water	11,315	3,547	1,116	**15,978**
Number who reported a diarrheal episode	306	100	52	**458**
Diarrheal rate (episodes/person/year)	0.70	0.73	1.21	**0.75**

The incidence of people reporting a diarrheal episode was not significantly associated with the presence of coliform bacteria or *E. coli* in water samples (OR = 1.15, 95% CI, 0.98-1.34 for coliform bacteria; OR = 1.13, 95% CI, 0.88-1.45 for *E. coli*). The incidence of households with at least one family member reporting a diarrheal episode was also not significantly associated with the presence of coliform bacteria or *E. coli* in water samples (OR = 1.16, 95% CI, 0.87-1.54 for coliform bacteria; OR = 0.88 95% CI, 0.56-1.38 for *E. coli*). All well types had similar rates of illness. There were 175 children younger than 6 years who lived in the 110 households that had well water with nitrate levels over 10 mg/L.

Coliform bacteria were present in water drawn from domestic wells throughout the nine-state region. Southern Illinois, Missouri, Iowa, and Kansas had a higher proportion of wells with these bacteria (**Figure 4**). Regions with a higher percentage of water samples containing E. coli were more limited and included southern Illinois, the Missouri-Iowa border, and eastern Kansas (**Figure 5**). Regions with a higher percentage of water samples containing elevated nitrate levels were southern Illinois, Iowa, northern Missouri, and Kansas (**Figure 6**). Atrazine was commonly detected in Illinois, Wisconsin, and Kansas (**Figure 7**).

Figure 4. Coliform bacteria in water samples collected from the 1994 Midwest Well Water Survey

Figure 5. E. coli in water samples collected from the 1994 Midwest Well Water Survey

Figure 6. Nitrate levels in water samples collected from the 1994 Midwest Well Water Survey

Figure 7. Atrazine levels in water samples collected from the 1994 Midwest Well Water Survey

Dug and bored wells are in a band that stretched from southern Illinois to the Iowa-Missouri border and then splits into eastern Kansas and north into northwestern Iowa (**Figure 8**). This distribution is similar to the spatial patter of water samples with E. coli. Spatial analysis did not reveal a significant relationship between well contamination and soil type, snowfall from the preceding winter, household income, or counties declared eligible for federal disaster assistance.

Figure 8. Distribution of wells construction of wells in the 1994 Midwest Well Water Survey

A Survey of the Quality of Water Drawn from Domestic Wells in Nine Midwest States

Discussion

In the 1994 Midwest Well Water Survey, coliform bacteria, *E. coli*, nitrate, and atrazine were present in many water samples collected from households with a domestic well. Most of the samples with these pollutants were from old and shallow-dug or bored wells with a large-diameter brick or concrete tile casing. An opening in the well; a septic tank within 100 feet; a well down gradient from a pollutant source; and recent use of fertilizers, pesticides, or manure near the well each had a modest detrimental effect on water quality. A pitless adapter or a backflow device reduced the risk for contamination.

Several other studies measured coliform bacteria and nitrate in water from domestic wells. In a nation-wide survey of 2,654 rural wells, coliform bacteria were present in 78% and fecal coliforms were present in 12% of the samples (EPA, 1984b). Regional surveys in Iowa (Seigley et al., 1993) and Nebraska (Exner and Spalding, 1985) reported the presence of coliform bacteria in 78% and 47%, respectively, of the dug wells and 80% of bored wells sampled in Iowa. A nation-wide survey reported that 9% of 3,351 households with water wells and 1% of public wells in agricultural areas had nitrate levels above the EPA MCL of 10 mg/L (Mueller et al., 1995). Nitrate concentrations in 599 domestic wells in the midcontinental United States exceeded 3 mg/L in 29% of the samples and were over 10 mg/L in 6% of the samples (Mueller et al., 1992). In 686 rural wells, nitrate levels were greater than 10 mg/L in 18% of the samples collected in Iowa (Kross and Selim, 1992) and 22% of the 201 wells tested in Missouri (Sievers and Fulhage, 1992). These results were similar to those from the 1994 Midwest Well Water Survey - 41.3% for coliform bacteria, 11.1% for *E. coli*, and 13.4% for nitrate levels above 10 mg/L.

A review of studies that measured atrazine in public and private wells reported a range of 0.7 to 18.0% for the detection of this herbicide in the midcontinental states (Burkart and Kolpin, 1993). The wide range of detection was attributed to differences in laboratory reporting limits, well selection criteria, geography, and time of collection. Atrazine was detected in 0.7% in rural domestic wells in a national sampling of over 1,300 wells (EPA, 1992a). In 26,909 samples from wells that were tested for pesticides by state laboratories because of a request by the well owner or enforcement action by the state, atrazine was detected in 1,512 (5.6%) samples and exceeded the MCL in 172 (0.6%) samples (EPA, 1993). The 1994 Midwest Well Water Survey reported similar results for detection (13.6%) and the amount of samples above 3 ppb (0.2%).

The 1994 Midwest Well Water Survey and other studies reported the presence of coliform bacteria or *E. coli* in water from domestic wells. Because these bacteria serve as indicators of increased risk for diarrheal diseases, higher diarrheal rates would be expected for the people drinking water with these bacteria. However, the rate of diarrheal episodes reported by the people in the survey (0.75 per person per year) was similar to the endemic rate of gastrointestinal illness reported in other studies (Hodges et al., 1956; Monto and Koopman, 1980; Payment et al., 1991). In addition, in 1993 and 1994, only seven reports of waterborne outbreaks due individual wells were reported to the CDC (CDC, 1996). Not everyone who drinks water with coliform bacteria or *E. coli* will develop diarrhea. Coliform bacteria are sensitive indicators for pollution and are a poor predictor for diarrhea. Coliform bacteria are ubiquitous in the environment. Both coliforms and *E. coli* generally do not cause gastroenteritis in healthy people. When these bacteria are detected in a water sample, microorganisms that cause gastroenteritis may not be present. Even if pathogenic bacteria are present, a person may not ingest an infective dose or may be immune to the organisms. Finally, the coliform standard (less than one coliform per 100 mL of water) includes a margin of safety.

Domestic wells in this survey had a higher "noncompliance rate" for coliform bacteria than community water systems. In 1994, 1% of the community water systems serving 25 to 500 people violated treatment technique requirements and 8% violated MCL standards (EPA, 1995). The treatment technique requirements usually relate to the presence of coliform bacteria or *E. coli*, and the MCL violations usually relate to chemicals such as nitrate and atrazine that exceed their regulatory level. In the Midwest Well Water Survey, 41% of the samples contained coliform bacteria, 11% contained *E. coli*, and 13% contained nitrate levels above 10 mg/L. Survey participants were informed of the test results of their well water.

The higher "noncompliance rate" of water samples from domestic wells may be due in part to a more stringent definition for a contaminated sample than for public water systems. In this survey, a contaminated water sample was defined as one that contained more than 1 coliform bacteria per 100 mL. When coliform bacteria is detected in public water systems, repeat samples are collected to verify the presence of coliform bacteria or *E. coli*. If either bacteria is present in a repeat sample, the public water system is in violation of EPA guidelines. Repeat samples were not routinely collected in the survey but all water samples were tested for *E. coli*, and as noted above, 11% tested positive. Since coliform bacteria are common in the environment, the proportion of samples containing *E. coli* may be a better representation of the degree of contamination measured by a single-sample survey. Bacterial contamination usually results from the lack of proper disinfection of a well following repair or construction, failure to seal the annular space between the drill hole and the outside of the casing, failure to provide a tight sanitary seal, or wastewater pollution of the well through polluted strata or a fissured or channeled formation.

Site characteristics and well features and construction affect water quality. A survey of 231 domestic wells in Iowa showed that well depth, location, and construction type, and nearby pollution sources affect the quality of the water drawn from these wells (Seigley et al., 1993). A state-wide survey in Iowa demonstrated that well depth and construction type had a strong association with contamination (Hallberg et al., 1992). Deficiencies in well construction were common among 268 household and stock wells in Nebraska (Exner and Spalding, 1985). In this survey, the wells least likely to contain contaminants met all the criteria for construction. In the 1994 Midwest Well Water Survey, samples from wells that were older or shallower or had a large-diameter brick or concrete casing usually contained higher levels of coliform bacteria, *E. coli*, and nitrate. These are features of dug and bored wells, which also had a higher frequency of cracks in the sanitary seals, grouting, or casing than drilled wells. These conditions allow material to enter the well and seepage of surface water.

Although the 1993 floods were the reason this survey was conducted, the lack of sufficient preflood water quality data on the sampled wells prohibited assessment of the effect of the flood on ground water quality. In addition, because the survey was conducted 1 year after flood waters receded, data from this survey may not reflect conditions directly related to the flood. A study by the USGS showed that groundwater quality was affected by the 1993 midwest flood (Koplin et al., 1996). In that survey, water samples were taken in July and August 1993, and levels of various pollutants were compared with preflood values. The concentration of herbicides showed a 20% increase in water samples collected in areas severely affected by floods. Water in shallow wells more quickly reflected changes in water quality because of to changes in recharge from the 1993 flooding.

Limitations of the Survey

1. The survey was observational and did not address causation. Statistical associations between pollution indicators and well features or conditions does not prove that one factor causes the other.

2. The survey used a single sample to provide information on coliform bacteria, *E. coli*, nitrate, and atrazine. However, a single sample does not define a contaminated water system or aquifer. Repeat samples should be taken to verify the presence of these contaminants.

3. The absence of coliform bacteria or *E. coli* in a single water sample does not assure that a water supply is free of coliform bacteria. A history of water samples with no coliform bacteria or E. coli, an absence of nearby pollution sources, and a properly constructed and maintained water well system are better indicators.

4. Samples were collected at the point of use (usually the kitchen faucet) and reflect the quality of the water that passed through existing holding tanks, treatment systems, and distribution pipes, rather than just the quality of the water drawn from the well.

5. The survey cannot answer whether the flooding was directly responsible for contamination of the wells. Limited data was available on the water quality of the wells in the survey before the 1993 floods. The survey was conducted 1 year after the floods, too late to measure the direct effect of the flood on bacterial and chemical water quality.

6. The wells in the survey may not be representative of all the wells in each state. Samples were collected from households at the intersections of a 10 mile grid although the 1990 US Census show that private wells are not evenly distributed spatially. Consequently, areas with a high density of wells will be under sampled and areas with a low density of wells will be over sampled. In addition, each well did not have an equal chance of being sampled.

7. Because of the small number of samples collected in each county and the resultant lack of statistical power, comparisons can not be made between of within counties.

Conclusions

1. Forty-one percent of the water samples collected from households with a domestic well contained coliform bacteria in excess of one per 100 mL. Eleven percent of the samples

contained *E. coli* in excess of one per 100 mL. Nitrate concentrations above 10 mg/L were present in 13.4% of the samples and atrazine concentrations above 3 ppb were present in 0.2 % of the samples.

2. The most notable factors associated with the presence of coliform bacteria, *E. coli*, or nitrate levels above 10 mg/L were related to well construction and the condition of the well. Samples with these pollutants were more likely to come from households with old, shallow, large-diameter dug or bored wells with tile or brick casings than the small-diameter drilled or driven wells with a steel or plastic casing. A cracked casing or opening in the well greatly increased the risk for contamination. A pitless adapter or backflow device reduced the likelihood of contamination.

3. Samples from wells located near pollution sources were slightly more likely to contain pollutants. The application of agricultural chemicals, the presence of septic tanks or cisterns within 100 feet of the well, and a well that was down gradient from a pollution source had a modest detrimental effect on the quality of water.

4. People who drank water with coliform bacteria or *E. coli* had a similar rate of self-reported diarrhea as people who drank water that did not contain these bacteria. There are several possible explanations for this result. Coliform bacteria and *E. coli* are sensitive measures of pollution but are weak predictors of diarrheal episodes. In healthy people, these bacteria generally do not cause gastroenteritis. When they are detected in a water sample, microorganisms that cause gastroenteritis may or may not be present. Even when pathogenic bacteria are present, a person may not ingest an infective dose or may be immune to the organisms. In addition, the criteria of more than one coliform per 100 mL of water for unacceptable water includes a wide margin of safety.

Recommendations

1. Inform people that rely on dug or bored wells for their drinking water about the potential hazards of ingesting water from these wells.

2. Routinely test water from domestic wells for coliform bacteria, *E. coli*, and nitrate. Monitoring of other chemicals should be based upon an assessment of potential contamination. Most states require testing for coliform bacteria before a new well is used and before transfer of ownership of land that contains a well. The EPA recommends users of household wells to test for bacteria once a year, quarterly if any changes in the water=s taste, odor, or color occurs, and after heavy rainfall or floods (EPA, 1990). The EPA suggests annual testing for nitrate, when coliform bacteria are found in the water, and after repairs to the well, pump, storage tank and piping.

3. Properly disinfected a well as soon as possible when a repeat sample confirms the presence of coliform bacteria or *E. coli*. Water samples should be negative for coliform bacteria before providing water for consumption. As a safeguard, well water used for drinking or food preparation should be boiled or an alternative safe water supply used until satisfactory results are obtained. Wells that fail to respond to proper disinfection procedures should be evaluated and corrected for deficiencies in location or construction, and, when necessary, replaced with a well that meets the state=s well code. Connection to a community water system

should be considered if a suitable well cannot be drilled.

4. Do not give water with nitrate-nitrogen levels exceeding 10 mg/L to infants under 6 months of age, either directly or in formula. A sanitary survey should be performed to identify potential sources of nitrate that could contaminate the groundwater and to evaluate the condition of the well. If removing the nitrate sources or repairing the well fails to lower the nitrate level of the water below 10 mg/L, the well user should consider using other safe sources of water, treating the water, drilling a new well, or connecting to a community water system.

5. Evaluate domestic wells providing water that exceeds the health limits for synthetic chemicals. Connection to a rural or community water system should be considered if reconstruction, replacement, or treatment is not feasible.

6. Develop, maintain, and evaluate programs that monitor domestic wells. These may include periodic tests for water quality and sanitary surveys, technical assistance and educational programs for well drillers, owners, and consumers of well water, and efforts to identify and seal abandoned wells. In 1990, 46 states licensed or registered water well drillers and 42 states established construction standards for new water wells. However, once a well is constructed and its water is declared potable, domestic well water systems are subject to few regulations.

7. Encourage domestic well owners to routinely maintain their wells. Maintenance involves the early detection and correction of problems that could impair water quality and well performance. Well owners can schedule sanitary surveys to assess existing and potential health hazards and to evaluate the present and future importance of these hazards. Records should be kept of well construction, repairs, pumping tests, and tests of water quality.

8. Protect the wellhead and aquifers from contamination. Mitigation of contaminated aquifers is expensive, inefficient, and unreliable. Failure to provide adequate protection may expose the consumers of the water to agents of waterborne diseases.

9. Enhance waterborne disease surveillance. State and county laboratories can share information on the water samples submitted by well owners with state and local health departments. This information can be used to characterize the domestic well water systems in the United States.

Centers for Disease Control and Prevention (CDC) ... National Center for Environmental Health (NCEH)

A Survey of the Quality of Water Drawn from Domestic Wells in Nine Midwest States

Table of Contents | Introduction and Methods | Results | Discussion
| References | Appendix I | Appendix II

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Centers for Disease Control and Prevention (CDC) ... National Center for Environmental Health (NCEH)

Table of Contents | Introduction and Methods | Results | Discussion
| References | Appendix I | Appendix II

A Survey of the Quality of Water Drawn from Domestic Wells in Nine Midwest States:

Data Collection Form
Appendix 1- Page 1

see also: Appendix 1- Page 3

Appendix I - Data Collection Form Used in the Survey of

Data Collection Form - Survey of Well Contamination
Midwestern States Affected by 1993 Flooding

Do NOT survey well if chlorinated within last 4 days!

Study Sample Code (1-2) ____ - (4-6) ____ - (8-12) ________ (State - County - Well Number)

State Sample # (14-24) ________

Well sampled: __Yes __No (26)

If not sampled, check most appropriate reason:
__Refusal(s) (R) __No well at location (W) __No resident(s) available (S) (28)

Latitude/longitude ☐☐ (42-43) ☐☐ (44-45) ☐☐ (46-47) / ☐☐☐ (49-51) ☐☐ (52-53) ☐☐ (54-55)

Person collecting sample: ________ (57-

Date & time of sample collection: (71-78) __/__/__ MM DD YY (80-83) __ __ hour min (24-hour time)

Contact person: (85-100) ________ **Phone** (___) (AC) - (101-112) ___ - ___

Location of well (address/distance from permanent markers): (113-1

Well depth (feet) ________ (171-173)

Well currently used for drinking water __Yes __No (174)

Standing surface-water within 100' during/after flood NA (A) Yes No (175)

Important!
Water samples mu

Centers for Disease Control and Prevention (CDC) ... National Center for Environmental Health (NCEH)

A Survey of the Quality of Water Drawn from Domestic Wells in Nine Midwest States:

Data Collection Form
Appendix 1- Page 2

see also: Appendix 1- Page 3

Contamination Midwestern States Affected by 1993 Flooding

Data Collection Form - Survey of Well Contamination
Midwestern States Affected by 1993 Flooding

page 2

Study Sample Code ____ - ____ - ________ (State - County - Well Number)

State Sample # ______________

Well capped: __ Yes __ No __ ND (ND = Not Determined) (261)

[Key N for ND below]

Lid setting on top of casing: (check one)

__ Wood - solid sheet (S) __ Wood - boards (B) __ Concrete (C) __ Metal (M) Other ________ (O) (262)

Cap secured to top of casing on the outside (standard cap)? __ Yes __ No __ ND (263)

Cap secured to top of casing on the inside (sanitary seal)? __ Yes __ No __ ND (264)

Is the well vented? __ Yes __ No __ ND (265) If so, does the vent have a screen? __ Yes __ No (266)

Are there any openings between the lid and the casing? __ Yes __ No __ ND (267)

Are there any holes or cracks in the casing? __ Yes __ No __ ND (268)

Is there a tight seal with a grommet, caulking, or conduit (to the electric source) where electric line inlet goes through the cap? __ Yes __ No __ ND (269)

Is there a standard pitless adaptor? __ Yes __ No __ ND (270)

Type of pump: (check one)

__ Deep jet pump (D) __ Shallow jet pump (H) __ Pump jack/hand pump (P)
__ Submersible pump (U) __ Centrifugal pump (C) __ Turbine pump (T) Other ________ (O) (271)

Location of pump: (check one) __ In the well (W) __ In pumphouse (H) __ In well pit (P) Other ______ (O) (272)

Is the well located down slope from any possible contamination sources within 100 feet? __ Yes __ No (273)

Are any back-flow prevention assemblies present? __ Yes __ No (274)

How far does the well casing extend above ground level: feet inches

A Survey of the Quality of Water Drawn from Domestic Wells in Nine Midwest States:

Data Collection Form
Appendix 1- Page 3

see also: Appendix 1- Pages 1 and 2

Data Collection Form - Survey of Well Contamination
Midwestern States Affected by 1993 Flooding

Study Sample Code ____ - ____ - ________
(State - County - Well Number)

State Sample # ________

Number of adults and children currently living in household . __ adults (>17) (302-303) __ Children (6-17) (305-306) __

Of those living in household, how many adults and children are currently drinking water from the well (do not count if all drinking water is boiled). __ adults (>17) (311-312) __ Children (6-17) (314-315) __

Of those drinking water from the well, how many have had diarrhea (3 or more loose or watery stools in one 24-hour period) in the last 2 weeks? __ adults (>17) (320-321) __ Children (6-17) (323-324) __

Commercial fertilizers ever used __Yes __No (329)

Distance used/mixed from well ______ feet (331-335) Date last used ____ Month (337-338)

Manure ever used __Yes __No (342)

Distance used/stored from well ______ feet (343-347) Date last used ____ Month (349-350)

Pesticides ever used __Yes __No (354)

A Survey of the Quality of Water Drawn from Domestic Wells in Nine Midwest States

Appendix II - Definitions

Aquifer - a natural underground layer of porous, water-bearing materials which yields a large amount of water. They serve to store and transport water.

Coliform bacteria - all aerobic and facultative anaerobic, gram-negative, non-spore forming, rod shaped bacteria which ferment lactose with gas production within 48 hours at 35EC. E. coli is a member of the coliform bacteria.

Domestic well - a well with less than 15 service connections to households or regularly serves less than 25 people daily.

Down gradient - the direction that ground water flows: similar in concept to downstream for surface water, such as a river.

Drinking water - water that can be used for drinking, cooking, and washing and not cause adverse health effects.

Ground water - water below the water table.

Maximum Contaminant Levels - the maximum permissible level of a contaminant in water which is delivered to the free flowing outlet of the ultimate user of a public water system. This level is not associated with adverse health effects.

Monitoring - routine, standardized measurement and observation.

Most probable number - a mathematical estimate of the mean density of bacteria in a sample. This is based on the number of positive samples.

Odds ratio - is calculated by dividing the ratio of the odds of exposure (or well feature) among cases (or contaminated wells) to odds of exposure (or well feature) among controls (or uncontaminated wells). In regards to the well survey, the odds ratio reveals the strength of the association between a well feature (i.e., construction, design, condition, location, etc.) and presence of contaminants in the well water sample (coliform bacteria, E. coli, nitrate, or atrazine). An odds ratio less than one indicates that the well feature is associated with lower contamination rate; an odds ratio greater than one implies that the well feature is associated with a higher contamination rate; an odds ratio of one shows that the well feature is not associated with the contamination rate.

Public water supply - a system for the provision to the public of piped water for human consumption, if such system has at least 15 service connections or regularly serves an average of at least 25 individuals daily for at least 60 days of the year.

Sanitary survey - an onsite review of the water source, facilities, equipment, operation and maintenance of a water system for the purpose of evaluating the adequacy of such source, facilities, equipment, operation and maintenance for producing and distributing safe drinking water, and to evaluate potential sources for pollution of ground water.

Service connection - the junction between the water main and the line from the household served by the water purveyor.

Water supply system - the collection, treatment, storage, and distribution of potable water from source to consumer.

Wellhead - the portion of the well that projects above the ground surface.

Well construction types-

- **bored** - an auger bores a cylindrical hole into the earth. After water is reached, the well is usually cased with tile, steel pipe or other suitable material.
- **buried slab** - a transition joint that connects a large-bore diameter casing (>12 inches) to a small-bore diameter casing (<12 inches). This joint allows a standard casing to extend from the slab to the surface.
- **drilled** - a percussion or rotary tool digs the hole and a steel or plastic casing is placed into the hole.
- **driven or sandpoint** - a series of tightly coupled pipe lengths which are fitted with a well point at the lower end and driven into the ground. When the point reaches the water table, water flows into the pipe through the screened openings on the well point.
- **dug** - made by excavating a hole several feet in diameter to a depth just below the water table. The circular hole is usually lined with rocks, brick, wood, or concrete pipe to prevent cave-ins.