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Rita M. Gergely
Iowa Department of Health

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A Comparison of Drinking Water Contamination in Buried Slab Wells, Other Large-Diameter Wells, and Drilled Wells

RITA M. GERGELY

Iowa Department of Public Health, 321 East 12th Street, Des Moines, Iowa 50319-0075

This study presents the results of a statewide water well survey conducted by the Iowa Department of Public Health from 1993 to 1995 to determine whether there were statistically significant differences between well water contamination in buried slab wells, other large-diamerer wells, and drilled wells. Wells were sampled for total coliform bacteria, fecal coliform bacteria, nitrate, and atrazine. Staff collected water samples and completed a site survey at each well, which included an interview with the occupant or owner and actual observations of the wellhead and surrounding area.

The study included 293 buried slab wells, 287 other large-diameter wells, and 445 drilled wells. Buried slab wells were significantly less likely than other large-diameter wells to be contaminated with total coliform bacteria, fecal coliform bacteria, nitrate, and atrazine. The well type (buried slab versus other large-diameter) was a more significant variable than whether the well depth was greater than 15.2 m (50 ft) for all contaminants except for total coliform bacteria. When classified by depth (less than or equal to 15.2 m (50 ft) deep or greater than 15.2 m (50 ft deep)), buried slab wells in each depth range were significantly less likely than other large-diameter wells to be contaminated by total coliform bacteria, fecal coliform bacteria, and nitrate. The rates of contamination for total coliform bacteria, fecal coliform bacteria, and atrazine were not significantly different for buried slab wells and drilled wells. In addition, the percentage of wells with a concentration of NO_3-N greater than 20 ppm or 30 ppm was not significantly different for buried slab wells and drilled wells. However, the mean concentration of NO_3-N (nitrate expressed as nitrogen) was significantly higher for buried slab wells compared to drilled wells, as was the percentage of wells with a concentration of NO_3-N greater than or equal to 3 ppm and greater than 10 ppm.

INDEX DESCRIPTORS: wells, buried slab, total coliform bacteria, fecal coliform bacteria, nitrate, atrazine, Iowa.

From 1993 to 1995, the Iowa Department of Public Health (IDPH) conducted a comprehensive survey of private water wells to determine whether there are statistically significant differences between well water contamination in buried slab wells, other large-diameter wells, and drilled wells. This survey was part of a well water study initiated by the Centers for Disease Control and Prevention (CDC) following severe flooding during the summer of 1993. CDC was concerned that flooding had contributed to the contamination of private water wells in Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, and Wisconsin. Since samples were collected nearly one year after the flooding, it was not possible to determine whether private water wells had been adversely affected by the flooding. Therefore, CDC's primary purpose was to collect data to provide a baseline for future studies of water quality in private water wells (CDC 1998). The CDC portion of the study consisted of collecting water samples from 745 wells and collecting basic construction information about the well. IDPH collected the data required for the CDC study. In addition, IDPH collected extensive additional construction information about the 745 wells in the CDC study and collected water samples and basic and additional construction information for 280 buried slab wells. IDPH collected additional construction information and included 280 buried slab wells in the study to determine whether there were statistically significant differences in the quality of water obtained from buried slab wells, other large-diameter wells, and drilled well.

TYPES OF WELL CONSTRUCTION

In this study, each well was classified as a buried slab well, other large-diameter well, or drilled well.

Other Large-Diameter Wells

Augered or bored and hand-dug wells were classified as "other large-diameter" wells. Augered or bored wells are cased with clay or concrete tile and are generally less than 30.5 m (100 ft) deep. Each tile section is roughly 0.76 m (2.5 ft) in diameter and 0.6 m (2 ft) in length. The casing is installed in sections. The joint between the sections is left unsealed to allow water to seep into the well. These wells draw water from small sand formations found in loess. The large diameter of augered wells allows them to store a large quantity of water in the well, which is necessary because these small formations do not produce enough water to supply "on demand" use. Hand dug wells are generally older and larger in diameter than buried slab wells and are usually cased with brick or stone instead of with clay or concrete tile (Iowa State University 1993a; Choquette pets. comm.). The diameter of the "other large-diameter" wells included in the study ranged from 0.25 m to 2 m (10 in to 80 in). Augered and dug wells are often contaminated with total and fecal coliform bacteria and NO_3-N since the top 3 to 4.5 m (10 to 15 ft) of casing is not sealed (Iowa State University 1993a). Figure 1 shows a typical "other large-diameter" well.

Buried Slab Wells

As early as 1965, IDPH recommended the buried slab design, which is an improved augered well design (Iowa Department of Public Health 1965). In 1980, IDPH updated the buried slab design to include a pitless design (Iowa Department of Public Health 1980). The pitless design includes a pitless adaptor, which is attached to the well casing below the frost level, allowing water to be carried

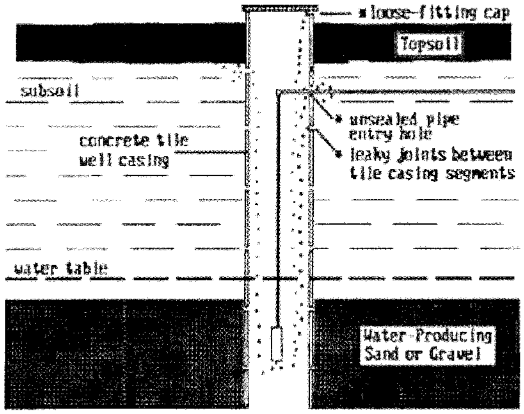

Fig. 1. Typical construction of "other large-diameter wells" (Iowa State University 1993a).

through a discharge pipe below the frost line (Nebraska Health and Human Services System 2004). This design can be used in the construction of new augered wells or in the rehabilitation of existing augered wells. It is impractical to convert hand-dug wells using the buried slab design because their brick and rock casing material is irregular and prevents the slab from fitting correctly. Therefore, the slab cannot form a watertight seal that will keep surface water and very shallow groundwater out of the well.

Two types of casing are used in buried slab well construction. Large-diameter concrete tile casing is used in the bottom of the well to allow water to seep into the well and to provide water storage capacity. For the upper 3 to 4.5 m (10 to 15 ft) of the well, a 15.2 to 20.3 cm (6- to 8-in) diameter steel or plastic casing is used, along with a standard pitless adaptor and watertight cap or a pitless unit. A transition joint constructed of concrete is positioned between the large and small diameter casings. This is called the "slab." The slab is sealed in position with cement, bentonite, or an equivalent material. The area above the slab is filled with uniformly compacted soil. This construction prevents water from getting directly into the well in the upper 3 to 4.5 m (10 to 15 ft) of the well, which greatly minimizes bacterial and chemical contamination. One potential limitation to buried-slab construction is that it can only be used when the slab is positioned above the groundwater level, so this design may not be feasible in areas with a high water table (Iowa State University 1993b). Figure 2 shows the typical construction of buried slab wells.

Drilled Wells

Drilled wells are usually cased with 10.2 to 20.3 cm (4 to 8 in) steel or plastic pipe and are up to 762 m (2,500 ft) deep, which is much deeper than buried slab wells and other large-diameter wells. These wells primarily draw water from bedrock, although some draw water from sand and gravel deposits (Iowa State University 1993a). There has been a shift toward the construction of drilled wells over the last 20 to 25 years, primarily because they produce higher volumes of water and are generally less likely to be conraminated. It is commonly believed that this is because they draw from deeper water sources that are less likely to be contaminated. However, it is also likely rhat drilled wells are better designed to prevent surface and shallow contaminarion from entering the well. One drawback to rhese deep wells is that the water may be hard or may contain undesirable concentrations of iron or sulfate (Iowa State University 1993a; Choquette pers. comm.). Figure 3 shows the typical construction of drilled wells.

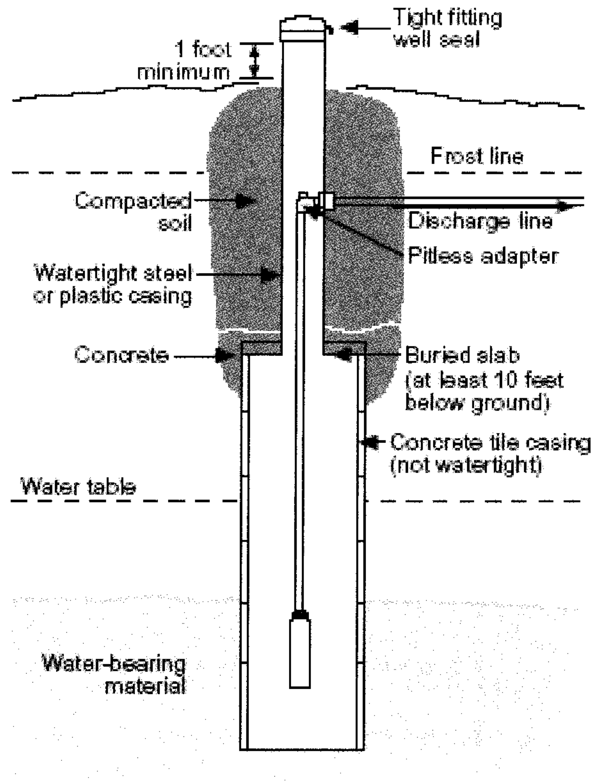

Fig. 2. Typical construction of buried slab wells (Iowa State University 1993b).

PREVIOUS STUDIES

A literature search identified 33 papers written from 1974 to 1999 that addressed the issues of well water contamination, well construction, and sources of contamination.

Two well water surveys from California and Minnesota consisted only of sampling water from selected wells since the purpose was to look only at the frequency of well water contamination. The investigators did not gather any information about well construction (Klaseus et al. 1989; Miller et al. 1990).

In six of the well water surveys, some information was gathered about well construction parameters. However, these studies did not include a complete sanitary survey of the well at the time of water sampling (Hallberg et al. 1982; Hallberg et al. 1983; Koelliker et al. 1988; Kross et al. 1990; LeMasters et al. 1989; Tjostem et al. 1977). A sanitary survey, which is a complete survey to note all possible entry points of surface contamination and to determine if all modern well construction standards are met, is necessary if valid conclusions about the relationship of well water contamination to well construction are to be drawn.

In two water well studies, the investigators did complete sanitary surveys of each well at the time of water sampling. However, the number of properly constructed wells in each case was very small, so it was not possible to do a valid statistical analysis of the frequency of contamination in properly constructed wells versus the frequency of contamination in improperly constructed wells (Exner et al. 1985; Ridder et al. 1974).

In six studies, a complete sanitary and site survey was done at the time of water sampling, but the wells were not randomly selected. Therefore, the conclusions cannot be extended to a larger group of

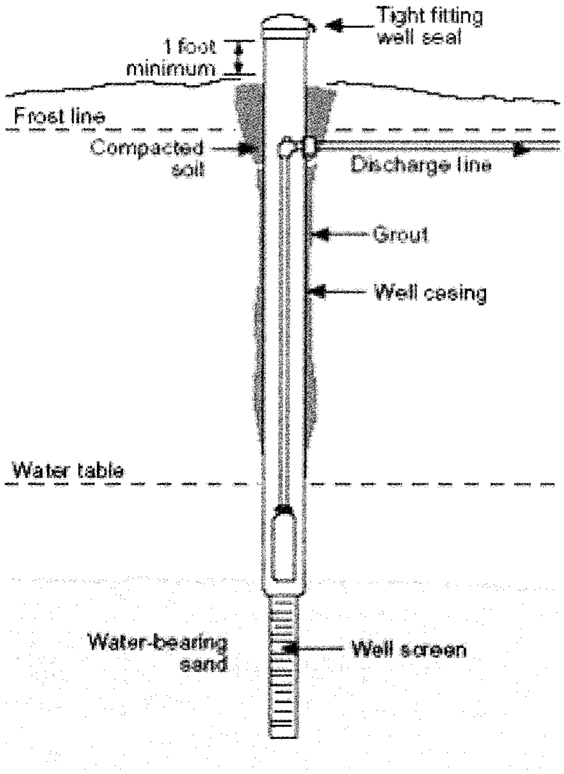

Fig. 3. Typical construction of drilled wells (Iowa State University 1993b).

wells (Conboy et al. 1999; Glanville et al. 1997; Seigley et al. 1993; Sievers et al. 1992; Townsend et al. 1995; Tuthill et al. 1998).

A number of less-comprehensive well-water surveys and studies have concluded that the detection of bacteria and pesticides in wells and NO_3-N concentrations greater than 10 ppm in wells are linked to construction deficiencies and to location of wells too close to known sources of contamination such as septic tanks, feedlots, and pesticide loading and/or mixing sites. While these studies provide useful information to consider in designing a more comprehensive well water survey, they are largely investigations of particular cases of well water contamination rather than comparisons of the frequency of contamination of improperly constructed wells to the frequency of contamination of properly constructed wells. In general, these studies did not compare properly constructed wells to those with construction deficiencies, and they did not sample an adequate number of wells to be able to draw valid conclusions about wells, well construction, and well water contamination in general (Carter et al. 1984; Conway 1981; Frank et al. 1984; Frank et al. 1987; Gopal 1987; Hallberg et al. 1987; Hogmire et al. 1990; Iowa Department of Public Health 1979; Kelley 1987; Smith et al. 1987; Tryon 1976; Walker 1973; Yates 1985).

In four studies, the wells were randomly selecred and a complete sanirary and site survey was done at the time of water sampling. However, buried slab wells were not included in these four studies (Briggins et al. 1995; Bruggeman et al. 1995; Conboy et al. 2000; Goss et al. 1998).

None of these studies included a sufficient number of buried slab wells to draw any conclusions about statistically significant differences between water well quality in buried slab wells, other large-diameter wells, and drilled wells.

CONTAMINANTS STUDIED

Four contaminants were selected to measure well water contamination: total coliform, fecal coliform, NO_3-N, and atrazine. Following is a description of each of these contaminants, including possible sources of contamination, routes of well water contamination, and the health risks associated with the contaminants.

Total Coliform Bacteria

The total coliform bacteria group is comprised of both fecal coliform and non-fecal coliform bacteria. Coliform bacteria are found in soil, surface water, and human and animal wastes (Salvato 2003). The presence of coliform bacteria in well water typically signals that water has entered the well at the ground surface or in the top 3 to 4.5 m (10 to 15 ft) of the well (Iowa State University 1993a). Total coliform bacteria do not cause disease. However, the presence of total coliform bacteria in well water indicates that organisms that do cause disease could also enter the well (Salvato 2003). Iowa's soil usually acts as an effective filter that traps bacteria and viruses as water percolates through unsaturated soil. However, some conditions in Iowa, such as shallow soil cover over an aquifer, rock outcropping (karst topography), saturated soil, or very permeable rocky or sandy soil, can result in bacteria and viruses not being effectively filtered (Iowa State University 1993a). Well construction deficiencies can also allow water to enter the well in the top 3 to 4.5 m (10 to 15 ft).

Fecal Coliform Bacteria

Fecal coliform bacteria are members of the total coliform group that are found in human or animal fecal waste. The presence of fecal coliform bacteria indicates that fecal material has entered the water supply. Fecal contamination represents a serious health risk because fecal material can carry pathogens that cause waterborne disease (Salvato 2003; Kross et al. 1990).

Nitrate

Nitrate is produced from the biochemical oxidation of ammonia (Salvato 2003). Soil can have a high concentration of nitrate due to human activities such as the application of fertilizers, livestock production, and domestic and commercial waste disposal. Nitrate leaches through soil into groundwater because it is an anion that is not adsorbed by soil colloids (Plaster 2002). Nitrate can also directly enter ground water aquifers through avenues such as sink holes, poorly constructed wells, and abandoned wells (Iowa State University 1993a).

The U.S. Environmental Protection Agency (EPA) has set a drinking water standard for NO_3-N at 10 ppm to protect against infant cyanosis or methemoglobinemia (blue-baby syndrome), a disorder that reduces the ability of an infant's bloodstream to carry oxygen. Low-level nitrate exposure in children has also become a concern because the reduction in the amount of oxygen delivered to various organs could contribute to developmental and neurological disorders (EPA 2003b).

Atrazine

Pesticides can enter a well directly through backsiphoning from a hose submerged in a mixing tank. Pesticides can enter a well in high concentrations if there is a spill near a well or if there is improper disposal of chemicals near the well. They may enter a well in high concentrations via backflow through plumbing or runoff to the wellhead of an improperly constructed well. At low concentrations, pesticides may enter groundwater by downward movement through the soil after application (Kross et al. 1990).

The funding for the study limited the number of laboratory analyses that could be done for pesticides. Atrazine was chosen for this study because it is the most commonly used herbicide in Iowa and the most commonly detected in past surveys (Choquette pers. comm.; Kross et al. 1990).

The drinking water standard for atrazine is 3 ppb (EPA 2003a). Laboratory animal studies suggest that exposure to atrazine above this level may result in adverse health effects, including tremors, changes in organ weights, and damage to the liver and heart. Atrazine is also a possible human carcinogen, although this has been demonstrated only through limited evidence from animal studies and inadequate data in humans (EPA 2003a).

METHODS FOR CHOOSING WELLS FOR STUDY

The first group of wells for this study was randomly selected by placing a 16.1-km by 16.1 km (ten-mile by ten-mile) grid over a map of Iowa. A 4.8 km (three-mile) radius surrounding each intersection was identified as the preferred choice for site selection. IDPH staff was instructed to identify a site within the circle, preferably as close to the intersection point as possible (CDC 1998). This systematic geographical sampling strategy was used because the state of Iowa does not maintain a list of all private water wells in the state (CDC 1998). A similar sampling strategy was used in the Iowa statewide rural well-water survey, although the sampling strategy was modified so that the results provide an estimate of the proportion of Iowa's population exposed to various drinking water contaminants and statistically significant data for each of Iowa's six hydrogeologic regions (Hallberg et al. 1990). Since the purpose was to study private water wells, the well had to be a private water well supply, meaning that it had to have less than 15 service connections and provide water to less than 25 people. In some cases, staff could not locate a private water well within a circle or residents inside the circle refused permission for the sampling. In these cases, the circle was recorded as no well available (CDC 1998).

A minimum of eight sites per county was sampled, unless the county lacked enough eligible wells. Several Iowa counties have extensive rural water systems, resulting in few eligible wells in those counties. When a county did not have eight sites identified by the grid, supplemental sites were selected anywhere in the county outside the circles. If more than one supplemental site was needed, the sites were selected from different areas in the county. Each selected well was sampled once. While water quality is better characterized by multiple samples taken over a period of time, the time and funding available for this project allowed for only one water sample per well (CDC 1998). Several other studies have relied primarily on single sample from each well (Briggins and Moerman 1995; Bruggeman et al. 1995; Hallberg et al. 1992; Kross et al. 1990; Townsend and Young 1995). This first phase of the survey was conducted from October 1993 to October 1994 (CDC 1998).

Only 13 buried slab wells were sampled during the first phase of the survey. A larger number of buried slab wells was needed to make statistically valid comparisons with drilled wells and other large-diameter wells. During the second phase of the study, IDPH staff attempted to locate and sample *all* buried slab wells in Iowa. Sites of buried slab wells were identified by surveying local health departments and well drillers in the areas of the state where large diameter wells are typically constructed. From November 1994 to June 1995, 280 additional buried slab wells were identified and sampled once. Although IDPH was unable to verify that *every* buried slab well in the state was sampled, IDPH believes that the buried slab wells sampled represent at least 80 percent of all buried slabs in the state (Choquette pers. comm.).

Figures 4, 5, and 6 show the statewide distribution of buried slab wells, other large-diameter wells, and drilled wells, respectively. This information shows that a disproportionate number of buried slab wells were located in Cass, Dallas, Guthrie, Polk, Warren, and Webster counties. Since well drillers working in these areas favored the

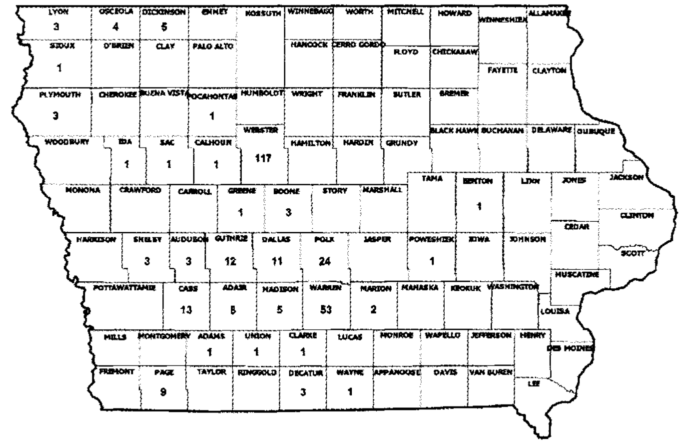

Fig. 4. Number of buried slab wells sampled by county (total 293).

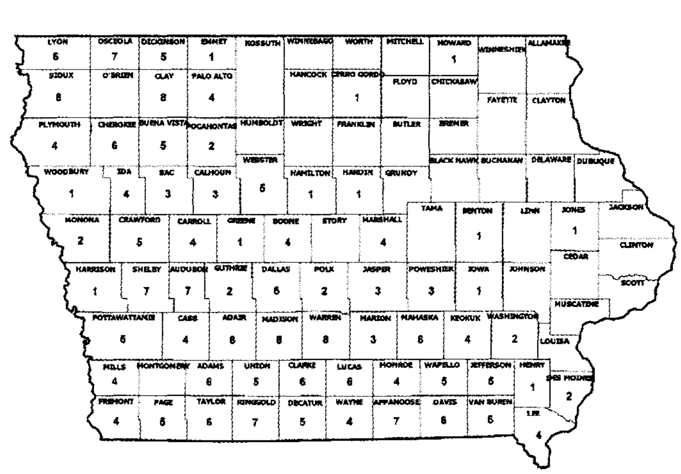

Fig. 5. Number of other large-diameter wells sampled by county (total 287).

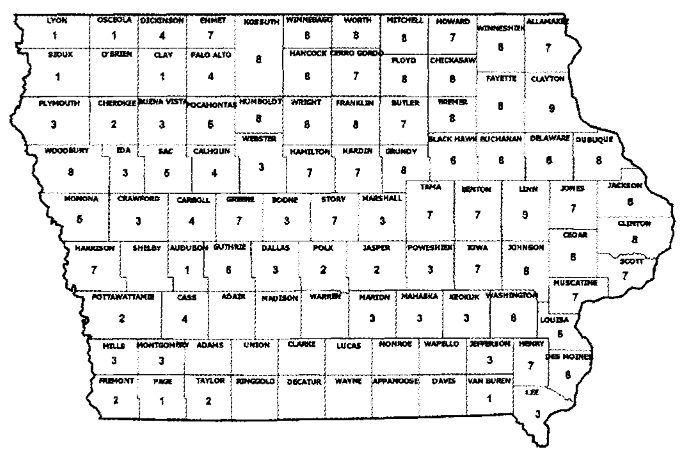

Fig. 6. Number of drilled wells sampled by county (total 445).

use of buried slab well construction, most of the buried slab wells in Iowa were located in these counties.

WATER WELL SURVEY

IDPH developed a site survey that included an interview of the occupant or owner and actual observations of the wellhead and surrounding area. The 112-question survey was an in-person questionnaire, with IDPH staff asking questions of the occupant or owner and recording their answers onto the questionnaire. After completing the interview of the participant, IDPH staff visually inspected the wellhead and surrounding area to more accurately determine any well deficiencies. Staff was extensively trained to identify well deficiencies and provided technical assistance on improving the condition of the well if any deficiencies were found (Choquette pers. comm.).

WATER SAMPLING METHODS

Staff took the water sample from a faucet inside the house that was routinely used to obtain drinking water. Staff did not sample water from a faucet being treated by a water treatment system since improper maintenance of the system can lead to the growth of bacteria. Improper maintenance of the water system can also cause a spike of chemicals if an overloaded filter dumps part of its contaminant load. Staff removed all aeration devices, sanitized the tap with sodium hypochlorite, and ran the water for five minutes before taking the sample. All samples were placed on ice until they could be delivered to the analytical laboratory (CDC 1998).

LABORATORY ANALYTICAL METHODS

The University Hygienic Laboratory in Iowa City, Iowa conducted all laboratory analyses for samples collected in Iowa. Samples were analyzed for total coliform bacteria and fecal coliform bacteria within 30 hours of sample collection. A 10-fermentation tube assay (Colilert®, IDEXX 1994) was used to measure the concentration of total coliform bacteria and fecal coliform bacteria in the water samples (CDC 1998). An automated, colorimetric, cadmium reduction method (APHA 1992) was used to measure NO_3-N concentrations. The detection limit was 0.01 ppm (CDC 1998). An enzyme-linked immunosorbent assay was used to measure atrazine (Ohmicron 1995). The detection limit was 0.05 ppb (CDC 1998).

METHODS OF DATA ANALYSIS

Data analysis was done using Version 4.0.4 of JMP from the SAS Institute. Descriptive statistics such as mean, median, and confidence interval were used to characterize the depth of each of the three types of wells (buried slab, other large diameter, and drilled), the slab depth for buried slab wells, and the concentration of NO_3-N found in each of the three types of wells. Chi-square and ANOVA were used to determine whether there was a significant difference between the types of wells for the following variables:

- Mean well depth.
- Whether the well depth was greater than 15.2 m (50 ft).
- Whether total coliform bacteria were present.
- Whether fecal coliform bacteria were present.
- Mean concentration of NO_3-N.
- Whether the concentration of NO_3-N was greater than or equal to 3 ppm (level that indicates human activity) (Kross et al. 1990).
- Whether the concentration of NO_3-N was greater than 10 ppm (Maximum Contaminant Level (MCL) set by the U. S. Environmental Protection Agency for public water supplies) (EPA 2003b).
- Whether the concentration of NO_3-N was greater than 20 ppm.
- Whether the concentration of NO_3-N was greater than 30 ppm.
- Whether the concentration of NO_3-N was greater than 50 ppm.
- Whether atrazine is present.

ANOVA was used for the mean well depth and the mean concentration of NO_3-N since these parameters are continuous variables. Chi-square was used for the other parameters since they are categorical variables. The likelihood ratio version of the Chi-square statistic was used since the results would then be comparable with the maximum likelihood estimation strategy used in logistic regression (Shelley pers. comm.). Each comparison was tested to the null hypothesis of no difference in values. If the p-value for the analysis was less than or equal to 0.05, the difference in values was considered to be statistically significant. Smaller p-values were considered to indicate a higher level of significance. The percent variation explained by a parameter was represented by the value of R^2 from Chi-square and adjusted R^2 from ANOVA. Logistic regression was used to evaluate the relative significance of the well type compared to whether the well depth was greater than 15.2 m (50 ft). The parameter with the lower p-value was considered to be the most significant.

The severity of NO_3-N contamination in a well is often characterized as being two times the MCL, three times the MCL, or other multiples of the MCL. Therefore, the levels of 20 ppm, 30 ppm, and 50 ppm NO_3-N were chosen to characterize the severity of NO_3-N contamination because they were multiples of 10 ppm. The level of 50 ppm was used only for buried slab wells and other large-diameter wells because only one drilled well had a NO_3-N level greater than 50 ppm.

BURIED SLAB WELLS COMPARED TO OTHER LARGE-DIAMETER WELLS

Table 1 is a comparison of whether the well depth is greater than 15.2 m (50 ft), the mean well depth, and rates of contamination for 293 buried slab wells and 287 other large-diameter wells. For each comparison, the p value and the percentage of variation that is explained by the well type (buried slab versus other large-diameter) are shown. The percentage of variation explained by the well type is not shown if the p value is not significant (greater than 0.05). Buried slab wells have a greater mean well depth than other large-diameter wells and are more likely to have a depth greater than 15.2 m (50 ft). Other large-diameter wells were significantly more likely than buried slab wells to be contaminated by total coliform bacteria, fecal coliform bacteria, NO_3-N, and atrazine. The well type explained 7 to 28.5 percent of the variation in well water contamination, with the largest amount of variation explained for total coliform bacteria and atrazine.

Two reports from the Iowa state-wide rural well-water survey concluded that most of the difference in rates of well water contamination were attributed to well depth rather than to well construction factors or sources of contamination (Hallberg et al. 1992; Kross et al. 1990). Another Iowa study revealed that well depth was strongly correlated to NO_3-N concentrations, but not to atrazine detections (Glanville et al. 1997), while a study of wells in Ontario and Zimbabwe showed that well type was more significantly related to whether a well was contaminated by fecal coliform bacteria than well depth (Conboy and Goss 2000). A study of wells in Nova Scotia concluded that the type of well construction was more significantly related than well depth to whether a well was contaminated by coliform bacteria and NO_3-N, but that atrazine contamination was not significantly related to well depth or well type (Briggins and Moorman 1995). Table 2 reports the results of logistic regression modeling to determine the relative significance of the well type and whether the well depth is greater than 15.2 m (50 ft) for buried slab wells compared to other large-diameter wells. For all contaminants except total coliform bacteria, the well type was a more significant

Table 1. Characteristics of buried slab wells compared to other large-diameter wells.

Characteristic	Buried Slab Wells	Other Large-Diameter Wells	p Value	Percent Variation Explained by Well Type
Number of Wells Sampled	293	287	—	—
Well Depth >15.2 m (50 ft)	57%	17.75%	<0.0001	16.5%
Mean Well Depth	19.5 m (63.9 ft)	12.9 m (42.2 ft)	<0.0001	13.5%
Presence of Total Coliform Bacteria	37%	92%	<0.0001	28.5%
Presence of Fecal Coliform Bacteria	6%	44%	<0.0001	19.5%
Mean NO_3-N	4.7 ppm	15.9 ppm	<0.0001	8.5%
NO_3-N ≥ 3 ppm	33%	73%	<0.0001	12%
NO_3-N > 10 ppm	13%	44%	<0.0001	11%
NO_3-N > 20 ppm	4%	25%	<0.0001	11%
NO_3-N > 30 ppm	3%	16%	<0.0001	9%
NO_3-N > 50 ppm	1%	6%	0.0004	7%
Presence of Atrazine	7%	13%	0.0095	25%

Table 2. Modeling of well type and well depth for 293 buried slab wells compared to 287 other large-diameter wells.

Contaminant	Source	p Value
Presence of Total Coliform Bacteria	Well type.	<0.0001
	Whether well depth greater than 15.2 m (50 ft).	<0.0001
Presence of Fecal Coliform Bacteria	Well type.	<0.0001
	Whether well depth greater than 15.2 m (50 ft).	0.3299
Mean NO_3-N	Well type.	<0.0001
	Whether well depth greater than 15.2 m (50 ft).	0.2490
NO_3-N ≥ 3 ppm	Well type.	<0.0001
	Whether well depth greater than 15.2 m (50 ft).	0.0009
NO_3-N > 10 ppm	Well type.	<0.0001
	Whether well depth greater than 15.2 m (50 ft).	0.2371
NO_3-N > 20 ppm	Well type.	<0.0001
	Whether well depth greater than 15.2 m (50 ft).	0.8748
NO_3-N > 30 ppm	Well type.	<0.0001
	Whether well depth greater than 15.2 m (50 ft).	0.7922
NO_3-N > 50 ppm	Well type.	0.0007
	Whether well depth greater than 15.2 m (50 ft).	0.1620
Presence of Atrazine	Well type.	0.0167
	Whether well depth greater than 15.2 m (50 ft).	0.2455

predictor of whether the well was contaminated than whether the well depth was greater than 15.2 m (50 ft).

One report from the Iowa state-wide rural well-water survey concluded that rates of contamination were similar for wells of various construction types when classified by well depth (Kross et al. 1990). Table 3 is a comparison of well construction factors and rates of contamination for 122 buried slab wells and 188 other large-diameter wells that were less than or equal to 15.2 m (50 ft) deep. For each comparison, the p value and the percentage of variation that is explained by the well type (buried slab versus other large-diameter) are shown. The percentage of variation explained by the well type not shown if the p value is not significant (greater than 0.05). This shows that, among wells that are less than or equal to 15.2 m (50 ft) deep, other large-diameter wells were significantly more likely than buried slab wells to be contaminated by total coliform bacteria, fecal coliform bacteria, and NO_3-N.

Table 4 is a comparison of well construction factors and rates of contamination for 168 buried slab wells and 51 other large-diameter wells that were greater than 15.2 m (50 ft) deep. For each comparison, the p value and the percentage of variation that is explained by the well type (buried slab versus other large-diameter) are shown. The percentage of variation explained by the well type is shown only if the p value is significant (less than or equal to 0.05). This shows that, among wells that are greater than 15.2 m (50 ft) deep, other large-diameter wells were significantly more likely than buried slab wells to be contaminated by total coliform bacteria, fecal coliform bacteria, and NO_3-N.

BURIED SLAB WELLS COMPARED TO DRILLED WELLS

Table 5 is a comparison of well construction factors and rates of contamination for 293 buried slab wells and 445 drilled wells. For each comparison, the p value and the percentage of variation that is explained by the well type (buried slab versus drilled) are shown. The percentage of variation explained by the well type is shown only if the p value is significant (less than or equal to 0.05). This shows that the rate of contamination by total coliform bacteria, fecal coliform bacteria, and atrazine were not significantly different for buried slab wells and drilled wells. The percentages of wells with concentrations of NO_3-N greater than 20 ppm and greater than 30 ppm were not significantly different for buried slab wells and drilled wells. The mean concentration of NO_3-N was significantly higher for bur-

Table 3. Characteristics of buried slab wells compared to other large-diameter wells for wells less than or equal to 15.2 m (50 ft) deep.

Characteristic	Buried Slab Wells	Other Large-Diameter Wells	p Value	Percent Variation Explained by Well Type
Number of Wells Sampled	122	188	—	—
Presence of Total Coliform Bacteria	53%	95%	<0.0001	25%
Presence of Fecal Coliform Bacteria	8%	43%	<0.0001	13%
Mean NO_3-N	5.7 ppm	16.5 ppm	<0.0001	6%
NO_3-N ≥ 3 ppm	48%	73%	<0.0001	5%
NO_3-N > 10 ppm	16%	46%	<0.0001	8%
NO_3-N > 20 ppm	5%	26%	<0.0001	9%
NO_3-N > 30 ppm	2.5%	16.5%	<0.0001	8.5%
NO_3-N > 50 ppm	0%	6%	0.0004	12%
Presence of Atrazine	8%	14%	0.0996	*

*Not given because $p > 0.05$

Table 4. Characteristics of buried slab wells compared to other large-diameter wells for wells greater than 15.2 m (50 ft) deep.

Characteristic	Buried Slab Wells	Other Large-Diameter Wells	p Value	Percent Variation Explained by Well Type
Number of Wells Sampled	168	51	—	—
Presence of Total Coliform Bacteria	25%	84%	<0.0001	20%
Presence of Fecal Coliform Bacteria	4%	41%	<0.0001	24%
Mean NO_3-N	4.0 ppm	17.4 ppm	<0.0001	11.5%
NO_3-N ≥ 3 ppm	22%	74.5%	<0.0001	16.5%
NO_3-N > 10 ppm	10%	41%	<0.0001	11%
NO_3-N > 20 ppm	4%	25.5%	<0.0001	13%
NO_3-N > 30 ppm	3%	15.7%	0.0023	9.5%
NO_3-N > 50 ppm	2%	10%	0.0160	8.5%
Presence of Atrazine	5%	13%	0.0613	*

*Not given because $p > 0.05$

Table 5. Characteristics of buried slab wells compared to drilled wells.

Contaminant	Buried Slab Wells	Drilled Wells	p Value	Percent Variation Explained by Well Type
Number of Wells Sampled	293	445	—	—
Presence of Total Coliform Bacteria	37%	40%	0.4256	*
Presence of Fecal Coliform Bacteria	6%	6%	0.7849	*
Mean NO_3-N	4.7 ppm	2.4 ppm	<0.0001	2%
NO_3-N ≥ 3 ppm	33%	19%	<0.0001	2%
NO_3-N > 10 ppm	13%	7%	0.0093	1.5%
NO_3-N > 20 ppm	4%	3%	0.2718	*
NO_3-N > 30 ppm	3%	1%	0.1067	*
Presence of Atrazine	7%	8%	0.5750	*

*Not given because $p > 0.05$

ied slab wells, as were the percentages of wells with concentration of NO_3-N greater than or equal to 3 ppm and greater than 10 ppm. This is likely because buried slab wells draw water from shallower depths where the concentration of NO_3-N is likely to be higher than it is in drilled wells that draw water from deeper aquifers (Conboy and Goss 1999; Townsend and Young 1995).

OTHER LARGE-DIAMETER WELLS COMPARED TO DRILLED WELLS

Table 6 is a comparison of rates of contamination for 287 other large-diameter wells and 445 drilled wells. For each comparison, the p value and the percentage of variation that is explained by the well type (other large-diameter versus drilled) are shown. The percentage of variation explained by the well type is not shown if the p value is not significant (greater than to 0.05). The rate of contamination by total coliform bacteria, fecal coliform bacteria, all NO_3-N variables, and atrazine was significantly greater for other large-diameter wells than for drilled wells. This is consistent with the findings of a report from the Iowa state-wide rural well-water survey (Kross et al. 1990).

CONCLUSIONS

The most significant findings of this study were:

1. Buried slab wells were significantly less likely than other large-

Table 6. Characteristics of other large-diameter wells compared to drilled wells.

Contaminant	Other Large-Diameter Wells	Drilled Wells	p Value	Percent Variation Explained by Well Type
Number of Wells Sampled	287	445	—	—
Presence of Total Coliform Bacteria	92%	40%	<0.0001	23.5%
Presence of Fecal Coliform Bacteria	44%	6%	<0.0001	20%
Mean NO_3-N	15.9 ppm	2.4 ppm	<0.0001	15%
NO_3-N $\geq$ 3 ppm	73%	19%	<0.0001	22%
NO_3-N > 10 ppm	19%	7%	<0.0001	19%
NO_3-N > 20 ppm	25%	3%	0.0001	16.5%
NO_3-N > 30 ppm	16%	1%	<0.0001	16.5%
Presence of Atrazine	13%	8%	0.0205	1%

diameter wells to be contaminated with total coliform bacteria, fecal coliform bacteria, NO_3-N, and atrazine. The well type (buried slab versus other large-diameter) was a more significant variable than whether the well depth was greater than 15.2 m (50 ft) for all contaminants except for total coliform bacteria. When classified by depth (less than or equal to 15.2 m (50 ft) deep or greater than 15.2 m (50 ft) deep), buried slab wells were significantly less likely than other large-diameter wells to be contaminated by total coliform bacteria, fecal coliform bacteria, and NO_3-N.

2. There was no significant difference between buried slab wells and drilled wells in the rates of contamination by total coliform bacteria, fecal coliform bacteria, and atrazine. In addition, there was no significant difference between buried slab wells and drilled wells in the percentages of wells with concentrations of NO_3-N greater than 20 ppm and greater than 30 ppm. Buried slab wells had a significantly higher mean concentration of NO_3-N, as well as significantly higher percentages of wells with concentration of NO_3-N greater than or equal to 3 ppm and greater than 10 ppm.
3. Other large-diameter wells were significantly more likely than drilled wells to be contaminated by total coliform bacteria, fecal coliform bacteria, all NO_3-N variables, and atrazine.

FURTHER INFORMATION

This article is an excerpt of a larger creative component prepared by Rita Gergely in partial fulfillment of the requirements for a Master of Agriculture degree at Iowa State University in Ames, Iowa. A copy of the complete report can be obtained by contacting Rita Gergely at the Iowa Department of Public Health.

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