Drinking Water Quality in Rural Pennsylvania and the Effect of Management Practices

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EXECUTIVE SUMMARY

Millions of rural and suburban Pennsylvania residents rely on private wells for drinking water, and, each year, 20,000 new wells are drilled. While research has shown that many private wells in the state have failed at least one drinking water standard, Pennsylvania remains one of the few states without any private well regulations.

This study was conducted to better understand the prevalence and causes of private well contamination and to evaluate the role of regulatory versus voluntary management of private wells. It set out to determine if specific indicators, including natural factors, well construction features, and nearby land uses, could be correlated with water quality parameters in private wells.

To complete the study, the researchers enlisted the help of more than 170 Master Well Owner Network (MWON) volunteers to collect samples from 701 private wells statewide.

The findings indicated that bedrock geology was statistically significant in explaining variations in all of the water quality parameters, with the exception of arsenic. Soil moisture, at the time of sampling, was the most important factor in explaining the occurrence of bacteria in wells. Individual well construction features were not statistically important in explaining well water quality but combinations of well construction components were statistically significant in explaining both coliform and *E. coli* bacterial contamination. No specific land activities were correlated with bacterial contamination, but DNA fingerprinting of *E. coli* bacteria from wells found that the majority were from animal sources. Nitrate concentrations in wells were statistically correlated with the distance to the nearest cornfield and other crop fields. Lead contamination was found to be largely from metal plumbing components that were exposed to acidic and soft raw groundwater.

About half of the homeowner participants in this study had never had their water tested properly, which resulted in low awareness of water quality problems. MWON volunteers were generally two to three times more likely to know about a health-related pollutant in their well, suggesting that education can greatly improve awareness of problems. Overall, up to 80 percent of the well owners that were shown to have unhealthy drinking water took steps to successfully avoid the problem within one year after having their water tested.

Results from this study suggest a combination of educational programs for homeowners and new regulations to overcome the largest barriers to safe drinking water. Regulations are warranted to increase mandatory testing of private water wells at the completion of new well construction and before finalization of any real estate transaction. For existing well owners, this study demonstrated the effect education can have to increase the frequency of water testing, the use of certified labs and awareness of water quality problems.

While this study showed that education increased the use of sanitary well caps on existing wells, most well construction features need to be included at the time the well is drilled. Homeowners having new wells drilled are difficult to reach with educational programs and, as a result, the voluntary approach to encourage proper well construction has largely failed. Given the benefits of well construction and the difficulty in reaching the target audience for new wells, statewide regulations requiring well construction components appear to be warranted.

The results of this study do not make a strong case for the need for mandatory wellhead protection areas around private wells. In most cases, voluntary wellhead protection areas already existed around private wells in this study. As a result, the data seem to confirm the importance and success of de facto wellhead protection areas of 50 to 100 feet that already exist around most wells.

Overall, 63 to 78 percent of well owners were supportive of potential regulations targeting well construction, well location and well driller certification.

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INTRODUCTION

More than 3 million rural and suburban residents in Pennsylvania rely on a private well for drinking water, and about 20,000 new wells are drilled each year in the state[1] (U.S. Census Bureau, 1970, 1990). Only Michigan has a larger population served by private water supplies. Unlike residents that use community water systems, homeowners with private wells are not protected by any statewide regulations.

Despite many past attempts, (the most recent were House Bill 1591 and Senate Bill 870 in 2001), Pennsylvania remains one of the few states where well location, construction, testing and treatment are the voluntary responsibility of the homeowner. Some counties and townships have passed ordinances, and considerable educational efforts have been made to meet the demands of private well owners interested in properly managing their water supply (Mancl et al., 1989; Swistock et al., 2001).

The voluntary management of private wells is a problem because most health-related pollutants in water are symptomless. As a result, homeowners with private water supplies may be exposed unknowingly to health related pollutants unless they voluntarily have their water tested for the correct water quality parameters.

Several studies have documented the occurrence of various water contaminants in private water systems (Rowe et al., 2007; New Jersey DEP, 2004; Iowa DNR, 2004; Liu et al., 2005; Zimmerman et al., 2001). Large-scale national or statewide studies typically report that about 15 to 50 percent of private water systems fail at least one safe drinking water standard. Smaller, regional studies often report much lower or higher contamination rates. Only a few of these studies have made any attempt to determine the causes, such as natural geology, land use and well construction, of contamination of private water systems.

A significant portion of the rural population may be exposed to unhealthy drinking water unless it properly treats the water or uses bottled water. However, documenting the impact of polluted drinking water on the health of residents using private water supplies is difficult because most pollutants require long-term exposure and mimic the effects from other air- or food-borne pollutants. Those that create acute effects, such as bacteria, have symptoms similar to common viral or bacterial illnesses. A comprehensive study of 228 waterborne illnesses in the 1970's by Craun (1986) determined that residents with private or small, semi-public wells were most vulnerable to waterborne illnesses. Recent research in Pennsylvania has further documented the occurrence of disease-causing bacteria in private wells (Lindsey et al., 2002; Swistock et al., 2004).

Contamination of groundwater wells can occur from both above and below the surface. Pollution of entire groundwater aquifers may occur from failing septic systems, manure and fertilizer applications, mining, or other land uses. Individual water supplies may also be contaminated around the exposed well casing (wellhead) from surface water flowing along the well casing and/or from a loose fitting or absent well cap that allows insects, animals or surface water to directly enter the well. Thus, the wellhead area, especially in poorly constructed wells, represents a very sensitive area that can serve as an open conduit to underground aquifers that threaten nearby private and public water supplies.

Surface contamination can be prevented by extending the well casing above the ground surface, installing a cement-like grout seal around the casing, and fitting a vermin-proof or "sanitary" well cap on top of the well. Extended casings, grout seals and sanitary well caps are required in most states but they are rarely used in Pennsylvania because there are no statewide well construction regulations in the state. Recent studies on a small number of wells have demonstrated the importance of a grout seal and sanitary well cap in preventing bacterial contamination but the overall importance of wellhead versus aquifer-wide contamination remains poorly understood (Centers for Disease Control, 1998; Zimmerman et al., 2001; Swistock and Sharpe, 2005). Other issues, such as well location relative to sources of contamination and land management practices, may play an important role in contamination of private water systems. For example, a recent study by the principal investigators of 50 central Pennsylvania homes that were at least 5 years old and had a private water supply found that 24 percent had never pumped their septic tank and had experienced higher rates of water contamination (Center for Watershed Stewardship, 2005). This same study also found relationships between well water quality and well construction, land use and septic systems.

Homeowners with private wells typically neglect water supply management unless obvious water quality

[1] Based on the average annual increase in drilled wells reported between the 1970 and 1990 U.S. Census. Note: Data on the use of private water systems were not collected during the 2000 U.S. Census.

symptoms occur. Unfortunately, most health-based pollutants have no obvious tastes or odors in water. Uninformed homeowners may fail to identify dangerous problems or fall victim to scare tactics used by treatment vendors and spend thousands of dollars on unnecessary treatment equipment. In fact, a recent survey of central Pennsylvania well owners found that only 50 percent had ever tested (most just for bacteria) their wells and about 10 percent had purchased unnecessary water treatment equipment (Center for Watershed Stewardship, 2005).

Penn State Cooperative Extension has a long history of educating well owners in Pennsylvania but the large target audience has made education a difficult task (Mancl et al., 1989; Swistock et al. 2001). In an attempt to more efficiently educate well owners, the researchers received federal funding in 2004 to create the Master Well Owner Network (MWON). This program provided eight hours of training on proper water well management to over 300 volunteers from 64 counties. This program has educated thousands of private well owners in the state resulting in its expansion into Virginia, Maryland, Delaware and West Virginia.

Private wells are pervasive across the landscape of Pennsylvania, serving as important sources of water for rural and suburban homes and farms. However, poorly constructed and unmanaged water wells represent potential risks for vital groundwater aquifers and the homeowners, farmers and businesses that access them. Limited available data suggest that contamination of these water supplies is widespread but little is known about the magnitude of the problem, the causes of pollution, and policies or educational efforts that may best address the problem. The Master Well Owner Network (MWON) volunteers represented a uniquely efficient opportunity to gather important data about private water wells throughout the state to better understand the occurrence and sources of contamination and the potential impact of regulation versus voluntary education.

Goals and Objectives

This two-year study, conducted in 2006 and 2007, set out to:

- Determine the occurrence of several health-related pollutants in 700 private wells throughout the state.
- Determine if well contamination is different between wells with different types of well construction (i.e. buried casing, type of well cap, presence of grout, slope around well, etc.).
- Determine how water supply characteristics, such as proximity to polluting activities and nearby septic system maintenance, influence groundwater quality.
- Determine how frequently private wells are voluntarily tested and adequately treated for contaminants and how often homeowners voluntarily follow recommendations to solve well contamination problems.

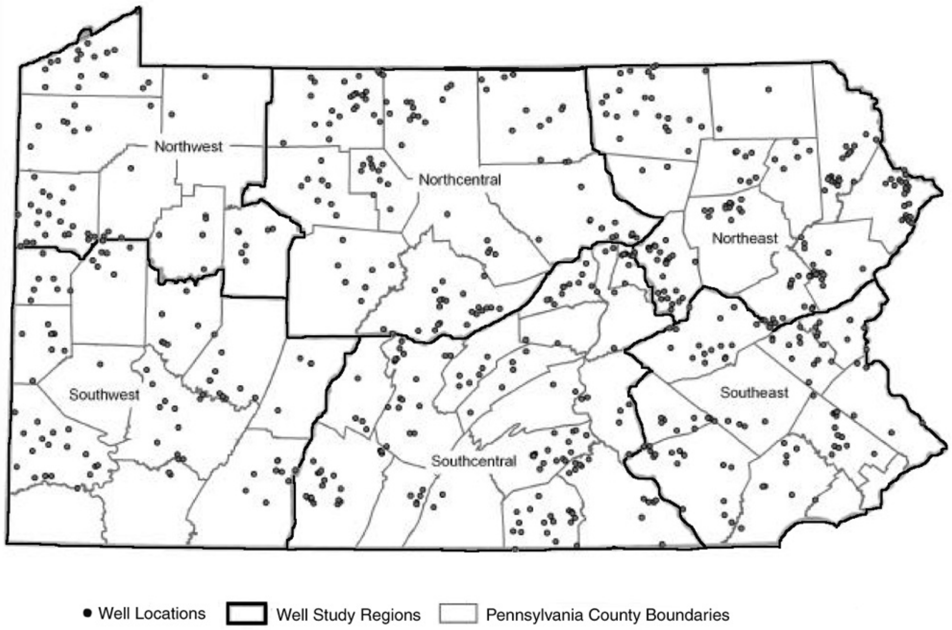
Methodology

A total of 172 MWON volunteers and Cooperative Extension staff collected samples from 450 private wells in 2006 and another 251 wells in 2007 for a total of 701 wells. The approximate locations of the wells are shown in Figure 1. Each of the MWON volunteers attended eight hours of training on private water system construction, management and testing. Most of the MWON volunteers attended training workshops during 2004 or 2005 but some were trained in 2006. The volunteers had varied backgrounds including water resource agency professionals (30 percent), professions unrelated to water (23 percent), retired (20 percent), educators (7 percent), health care professionals (5 percent), local government representatives (5 percent) and farmers (4 percent) (Clemens et al., 2007).

Of the 701 private wells, 79 were owned by existing MWON volunteers and 622 were owned by either newly trained volunteers or homeowners. For the purposes of this report, the 79 MWON volunteer wells were usually treated differently than the 622 wells owned by homeowners or newly trained volunteers because of their management history. Existing MWON volunteers would have had at least one year to improve the management of their private water well based on information they learned at their training course. Homeowner or newly trained MWON wells would be more representative of typical private wells throughout the state.

MWON volunteers were recruited to help with sample collection through email and phone calls. One month before each sample collection workshop, interested volunteers were sent sample bottles, surveys and instructions for collecting samples. Approximately one week before the respective sample collection workshops, the MWON coordinator called each volunteer to answer questions and confirm sample collection criteria and instructions. Volunteers were also encouraged to contact their MWON regional coordinator with any project questions. Coordinators were trained in early 2006 on sample and survey procedures.

Figure 1. The approximate locations of the 701 private wells sampled in 2006 and 2007, along with the regional boundaries used for statistical analyses.



Selection of all study participants was done by MWON volunteers, regional coordinators, Cooperative Extension educators or project staff. To ensure spatial distribution, volunteers maintained at least a one-mile distance between sampled wells. Volunteers were encouraged to select private wells that were familiar to them (friends, family, co-workers, etc.) to facilitate collection of water samples and water supply information in a timely and accurate fashion.

Sample and Survey Collection

Volunteers collected water samples from each well on the morning of the workshop, stored the samples on ice and returned the samples and surveys to the workshop location usually no later than noon. The training and experience of volunteers helped to ensure that samples were collected properly and that water supply information was accurately recorded on the survey.

Two water samples were collected from each home. The first was a sample of “first-draw water” (water that had been in the plumbing for at least six hours) which was tested for lead from corrosion of metal plumbing components. Volunteers collected first-draw samples from the kitchen faucet (78 percent of samples) or other faucets used for drinking water (22 percent of samples).

The second sample was analyzed for all other chemical parameters along with coliform and *E. coli* bacteria. Where only treated water was supplied to the house, samples were collected from the pressure tank or an outside hose bib. The water was allowed to run for one to two minutes prior to the sample being collected. Volunteers reported that 46 percent of the running water samples came from the kitchen faucet, 27 percent was from the pressure tank and 27 percent was from other taps (mostly outside hose bibs).

The survey forms for each water supply were divided into a homeowner and volunteer portion. The volunteers visually inspected the well, plumbing, and surrounding landscape and reported information on well construction and sources of contamination. The homeowner survey included questions about the well age, well depth, approximate yield, past water testing, known problems or symptoms, septic system characteristics, water treatment equipment, and opinions about the need for private well regulations. The surveys were returned to the drop-off location with each well sample.

Follow-Up Survey

In 2007, an additional survey was sent to each of the 450 well owners that participated in the study during 2006. The purpose of this survey was to document any actions taken by the well owner to solve water quality problems or better manage their water supply as a result of participating in the study. This follow-up survey was mailed approximately six to 12 months after the wells had been tested in 2006 to give homeowners the opportunity to take action on their well. A reminder postcard was mailed a few weeks after the survey resulting in an overall return rate of 64.2 percent (289 well owners).

Sample Analyses

Water samples were analyzed for the following eight contaminants that are likely to occur in rural and suburban areas from activities or surface water contamination.

- Total coliform bacteria are “indicators” used to determine if a pathway exists that might allow disease-causing bacteria to contaminate the water supply. *E. coli* bacteria are a subset of coliform bacteria that only occur in animal or human wastes and indicate more serious contamination.

• *E. coli* source tracking was conducted at the E. coli Reference Center at Penn State University in an attempt to determine the role of animals versus humans as a source of *E. coli* contamination in private wells.
• pH is a common measure of water quality that is often related to corrosion of plumbing system components like lead and copper.
• Lead is a dangerous metal with many health effects, especially in children. Lead usually occurs in drinking water supplies from corrosion of lead solder or lead impurities in plumbing fixtures.
• Nitrate-nitrogen is a health related pollutant that usually originates from fertilizer, manure or septic systems.
• Arsenic is a relatively new concern in drinking water with serious health effects at very low concentrations. It is thought to most often occur naturally from certain types of rocks but it can also come from treated lumber and pesticides.
• Triazine pesticides include the most common pesticides used in Pennsylvania, such as atrazine and simazine. These pesticides have serious health effects.
• Hardness is a measure of the amount of calcium and magnesium in the water. Although harmless, hardness can cause aesthetic effects including stains, damaged hot water heaters and increased soap usage. Hardness was measured primarily to determine the appropriate versus unnecessary use of water softener treatment devices since softeners are the most common water treatment device sold in Pennsylvania.

Well Owner Notification

All participants in the study received their water quality results within six weeks of their sample submissions. Individual water quality results were kept confidential and were only accessible to project personnel. All participants with a water system that failed to meet one or more drinking water standards received specific recommendations and Penn State Fact Sheets to assist them in taking action to solve their water quality problem. Homeowners were also given a phone number and email address to ask questions about their results. During the two-year study, 19 of the 701 homeowners called with follow-up questions after receiving their water test report.

Statistical Analyses

In this report, where statistical analyses were not possible, direct comparison of percentages were used rather than detailed statistical analyses. Analysis of covariance (ANCOVA) and logistic regression models were used to determine which well characteristics (geology, construction, etc.), land uses (distance to septic, farm fields, etc.) and management activities (septic system pumping frequency, etc.) were important in explaining the occurrence of the various pollutants.

Data Quality Assurance and Quality Control

This study analyzed 58 quality control samples, representing about 8 percent of the 701 private well samples analyzed. These samples were submitted to the laboratory among other samples from private wells to measure how accurate, precise and repeatable the water quality results were from the laboratory.

Overall, the results from the quality control samples indicated that water quality data collected during the study were of excellent quality.

Effect of Location and Sample Method on Bacteria

Another data quality question centered on the location and method used to collect water samples for bacteria analysis. Extra care must be taken when sampling water supplies for coliform bacteria and *E. coli* bacteria because of the risk of contaminating the sample from hands and other surfaces during collection and subsequent handling. The results of the protocol used in this research suggest that the sampling strategies, including washing the bottle three times and not flame sterilizing the end of the faucets, did not cause any systematic bacterial contamination of the samples from the 701 study wells.

Results

Well Characteristics

The characteristics of the 701 private wells sampled came from responses on the homeowner and volunteer surveys submitted for each well. Generally, well owners were very knowledgeable about their wells and most were able to provide the basic characteristics of their well. For example:

• 83 percent were able to estimate the depth of their well. The average well depth was 172 feet (median depth = 140 feet) with a maximum depth of nearly 1,000 feet.
• 88 percent knew the approximate year their well was drilled. More than 72 percent had been drilled since 1970 but only 4 percent had been drilled since 2005.
• Well owners knew their well characteristics despite the fact that very few possessed a copy of their well completion report or "well log." A copy of the well completion report should be provided to the well owner to document the well characteristics, such as depth, construction, geology, and yield.

Water Quantity

About 51 percent of well owners could estimate the yield of water coming from their well, with an average yield of about 18 gallons per minute (gpm). The Midwest Plan Service recommends a minimum of 6 gpm for a home water well (Midwest Plan Service, 1992) although most homes will need less than 6 gpm. In this study, nearly 70 percent of the well yields reported were greater than 6 gpm. According to well owners, well yields were not a major problem across the state.

Well Construction

MWON volunteers evaluated the construction of each well (Figure 2). Of the 701 wells, 12 percent (84 wells) were completely buried below the ground surface, often in a pit or basement. Nine percent of wells owned by an MWON volunteer were buried while 13 percent of homeowner wells were buried. This was a common practice decades ago to keep water lines from freezing. Of the 85 wells in this study that had a buried casing, most were drilled prior to 1970. Still, there were eight wells with a buried casing that had been drilled after 1990. Buried wells were most prevalent in northwest Pennsylvania, probably because wells tended to be older in that region, but there were no statistically significant differences in the occurrence of any well construction features (buried casing, sanitary well cap, grout, etc.) between the six regions of the state.

Of the homeowner wells that were visible above the ground, 16 percent had a sealed, sanitary well cap. Sanitary well caps were more than twice as likely on MWON volunteers' wells, presumably because they received a free sanitary well cap during their MWON training. About 9 percent of homeowner wells had missing well caps or miscellaneous types of caps (coffee cans, cement, ceramic, etc.). Many of the wells with miscellaneous caps were very old, hand-dug wells that were typically constructed in the early 1900s. Hand-dug wells have a large diameter hole (several feet wide) lined with stone and usually covered with a cement slab cap. Of the 701 wells sampled in this study, 6 percent were hand-dug and the remaining 94 percent were drilled.

Volunteers were asked to determine, as best as possible, if a well was grouted or if the well had a visible cement seal around the casing. Since so few wells had a well completion report, the presence of a proper grout seal that extended from the surface to bedrock was impossible to determine in most cases. Instead, grout presence had to be based on homeowner memory or visual evidence of cement or grout residual at the surface around the casing by the volunteer sampling the well (most cases).

Volunteers reported that grout or a cement seal around the well casing was present on 18 percent (120 wells) of the private wells and this percentage was similar between volunteer and homeowner wells. Grout information was available from well logs for only 19 of these wells. About 5 percent of the homeowner wells had both a sanitary well cap and evidence of grout, according to volunteers. A follow-up email survey of well owners with grouted wells found that only a handful could confirm for certain that their entire well casing was properly grouted at the time the well was drilled. Since only eight wells had been drilled after enactment of county well construction ordinances in Chester and Montgomery counties, it seems likely that the majority of the wells denoted as "grouted" in this study were only grouted along the first few feet of the casing below the ground surface instead of the entire length of the well casing as recommended.

Sloping the ground in the immediate vicinity of the well casing is recommended to prevent ponding of surface water and possible contamination of the well by surface water. Visual observation by volunteers showed that 36 percent of homeowner wells had this slope around the well. A greater percentage of volunteers' wells (54 percent) were sloped, presumably because volunteers had learned the value of sloping during their MWON training.

Figure 2. Well construction components for homeowner and MWON volunteer wells.

Well Construction Component	Percent of Homeowner Wells (n=622)	Percent of MWON Volunteer Wells (n=79)
Buried well casing	13	9
Extended casing with standard well cap	62	49
Extended casing with sanitary well cap	16	34
Extended casing with misc. or no cap	9	8
Grout or cement around casing	18	19
Ground slopes away from well	36	54

For statistical comparisons, five well construction features were combined to provide an overall well construction score or "wellscore." The wellscore was used to correlate overall well construction with water quality parameters in wells. Well construction features considered in the wellscore included:

- Casing – a drilled well with a metal or plastic casing (casing score = 1) versus a hand-dug well without a casing (casing score = 0).
- Buried – the well casing is visible above

ground (buried score =1) versus a buried well casing not visible above ground (buried score = 0).
• Grout – evidence of grout or cement around the casing at the surface (grout score = 1) versus no evidence of grout or cement around the casing (grout score = 0).
• Slope – no ground slope around the well head including wells in a depression (slope score = 0) versus wells with ground sloping away from the casing (slope score = 1).
• Well cap – a sanitary, sealed, vermin-proof type (well cap score = 1) versus an unsealed, standard or missing well cap (cap score = 0).

The wellscore for each well was the added score of the five well construction features with scores ranging from 0 (very poor construction) to five (very good construction). Of the 701 wells in this study, a breakdown of wells in each wellscore category are:

Wellscore 0 = 3 percent (no recommended well construction components);
Wellscore 1 = 10 percent (one recommended well construction component);
Wellscore 2 = 41 percent (two recommended well construction components);
Wellscore 3 = 30 percent (three recommended well construction components);
Wellscore 4 = 12 percent (four recommended well construction components); and
Wellscore 5 = 4 percent (all five recommended well construction components).

Water Treatment Equipment

Water treatment equipment was installed on many of the private wells, with 53 percent having at least one piece of treatment equipment. MWON volunteers were only slightly more likely to have treatment equipment compared to homeowners. Well owners in the northeast region of the state were significantly less likely to have water treatment equipment compared to other regions of the state; presumably because water hardness is much lower in that region, decreasing the need for water softeners.

The percent of wells that had each type of water treatment equipment is listed in Figure 3. Water softeners were the most common type of water treatment equipment, occurring in about one-third of homes with private wells in this study. Sediment filters were also quite common but the majority of sediment filters were small, cartridge filters that are installed ahead of larger, expensive units (like softeners, ultraviolet lights, etc.) to remove large sediment particles and prevent wear and tear on other treatment equipment. Only about one-third of the sediment filters appeared to be larger, multilayer (sand and gravel) filters for treating serious sediment problems. Other types of water treatment, such as oxidizing filters to remove iron, manganese and/or hydrogen sulfide gas and ultraviolet lights to kill bacteria, were far less common, occurring in less than 10 percent of the homes with private wells. The average cost of water treatment equipment and installation was $1,127 with a maximum of $7,000. These values were not adjusted for inflation because the year of installation was not measured.

Figure 3. Occurrence of water treatment equipment on wells in this study.

Type of Water Treatment Equipment	Percent of Wells with Equipment
Water softener	34
Sediment filter	21
Oxidizing filter	8
Carbon filtration	8
Ultraviolet light disinfection	7
Faucet filter (i.e. Brita®)	3
Reverse osmosis filter	3
Chlorination	2
Aeration, Acid Neutralizing Filter	1 each
Magnetic, Ozone, distillation, anion exchange	<0.5 each

Given that the most common water treatment devices listed in Figure 3 are used primarily to treat obvious aesthetic problems in water, it was not surprising that half of well owners indicated that they had installed water treatment equipment because of obvious stains, odors or tastes. The other half of well owners with water treatment owned it because they had water test reports showing a problem (32 percent) or they inherited it from a previous homeowner (20 percent).

Wastewater Treatment Characteristics

Eighty-nine percent of the homes with private wells used an on-site system for wastewater disposal. Traditional septic tanks and leach fields occurred in 72 percent of the homes. The remaining 17 percent used sand mounds (14 percent), alternative on-lot systems (2 percent), or did not know where their wastewater went (1 percent). Of those with on-lot wastewater systems, 13 percent reported problems with malfunctions. Septic system malfunction rates were similar between standard septic systems, sand mounds and alternative systems, and were also similar between regions of the state.

Septic system maintenance was determined by asking homeowners about the frequency of pumping their septic tank. The generally accepted interval for septic tank pumping is every 2 to 4 years, depending on family and septic tank size. Septic tanks pumped infrequently or not at all may cause groundwater and surface water contamination from failed leach fields. Of the 625 wells in this study with an on-lot septic system and septic tank, 28 percent were never pumped, 33 percent were pumped at an interval greater than 4 years and 39 percent were pumped at least every 3 years. Septic system age could not be used to explain the number that had not been pumped since only 2 percent were less than 4 years old.

Prevalence and Spatial Occurrence of Well Contamination

Of the parameters that were tested on each well water supply, six had primary drinking water standards (i.e. detrimental health effects are possible if standards are not met) including coliform bacteria, *E. coli* bacteria, lead, nitrate, arsenic and triazine pesticides. Hardness does not have a drinking water standard and pH has a secondary or recommended drinking water standard (for aesthetic effects on taste and corrosion).

Contamination rates in raw well water were similar between MWON volunteer wells and homeowner wells so they have been lumped together for reporting here. Overall, approximately 41 percent of the wells tested failed to meet at least one of the health-based drinking water standards. Of these wells, most (89 percent) failed only one of the drinking water standards.

Keep in mind that these results apply to raw water and do not include the effect of water treatment devices or bottled water that some well owners used to avoid health-related pollutants. In fact, roughly 25 percent of well owners with a health-related pollutant was avoiding it by using proper water treatment or by drinking only bottled water. Actions taken by wells owners, both before this study and as a result of this study, are discussed later. Details of individual contaminants are discussed below. For the regional analyses, the total number of wells sampled in each region were: northwest (61 wells), northcentral (115 wells), northeast (167 wells), southwest (98 wells), southcentral (159 wells), and southeast (101 wells).

Total Coliform (TC) Bacteria

TC bacteria were found in 33 percent of the sampled wells and were absent in 67 percent. This contamination rate is similar to past national and statewide surveys of private water systems.

TC bacteria occurred throughout the state but there were some regional differences. The highest incidence of TC occurred in the southeast and southwest regions while the lowest incidence was observed in the northwest and northeast regions. Statistically, the southeast region had a significantly higher occurrence of TC bacteria than the northwest or northeast regions. These regional trends are consistent with TC contamination reported by Sharpe et al. (1985).

E. coli Bacteria

E. coli (EC) bacteria should be absent from drinking water for the water to be safe to drink. EC bacteria represent a more serious contamination issue than coliform bacteria since EC bacteria can only originate from human or animal waste. In this study, EC bacteria were detected in 14 percent of the private wells. No other statewide surveys have been done to document the occurrence of EC in private wells. The incidence of EC bacteria found in this study is greater than reported by some regional studies (Durlin and Schaffstall, 2001; Zimmerman et al., 2001) but less than values reported by others (Bickford et al., 1996). EC bacteria showed similar regional trends to those found for TC bacteria.

A total of 213 distinct EC bacteria colonies from 79 different private wells were analyzed by the E. coli Reference Center at Penn State. The DNA fingerprints of each of these bacteria were statistically compared to the library of EC bacteria from known animal and human sources in an attempt to determine the relative role of animal versus human wastes in causing EC contamination of private wells. The results showed that most EC colonies were more closely related to animal sources than human sources. This suggests that most contamination occurs by surface water from nearby animal-related land activites.

pH and Lead

The pH of each sample was determined as a general indicator of the corrosion potential to correlate to lead contamination. In general, low pH water (below 7.0) tends to be “corrosive,” which means it can dissolve metals, such as copper and lead from pipes, solder or fixtures, from the plumbing system. Lead was measured in first-draw water samples from 251 wells during 2007.

Wells with a pH below the recommended level of 6.5 occurred in 18 percent of the wells tested and were most frequently found in the southeastern region. Wells with a high pH (above the recommended level of 8.5) were rare (2 percent) and occurred sporadically across all regions.

While only 18 percent of private wells were below the recommended pH standard of 6.5, it is likely that a much higher percentage of wells contained "corrosive water." Many other water quality parameters, including hardness and total dissolved solids, are important in determining the corrosion potential of water. This study did not test for all of the parameters necessary to calculate a corrosion index (known as the Langelier Saturation Index or LSI). Sharpe et al. (1985) found that, while only 18 percent of private wells were too acidic ($pH < 6.5$), a much higher percentage (59 percent) were actually corrosive to metal plumbing. In that study, corrosive water was the most common water quality found in Pennsylvania, especially in northcentral Pennsylvania where well water tended to be both acidic and soft (low hardness and total dissolved solids).

Elevated lead levels occurred in first-draw water from 12 percent of the wells that were tested during 2007. It appears that corrosion of lead from plumbing components (rather than lead from groundwater pollution) was the predominant source of lead in these well water supplies. Ninety-three percent of the wells with high lead levels had acidic water (pH below 7.0) and 80 percent also had soft water. As mentioned above, this combination of acidic, soft water causes corrosion of metals. Lead contamination was most likely in the southcentral (17 percent) and southeast (16 percent) regions and least likely in the northeast region (5 percent). These regional variations in lead are identical to those reported by Swistock et al. (1993).

The 12 percent failure rate for lead is much lower than the 19 percent reported in a study by Swistock et al. (1993). It is presumed that this reduction is a result of the 1991 Federal Lead and Copper Rule that required the use of lead-free solder and fixtures in home plumbing. Seventy percent of the homes with high lead levels had plumbing systems that were installed prior to enactment of this rule and most also had copper plumbing systems. There was only one private well with a high lead level that could not be clearly linked to corrosion of metal plumbing (i.e. a new home with plastic plumbing and alkaline water).

Nitrate

Nitrate-nitrogen occurred above the drinking water standard of 10 mg/L in only 2 percent of the private wells. Nitrate concentrations in private wells varied strongly between regions. Mean nitrate concentrations were significantly higher in the southeast and southcentral regions compared to the other four regions. Still, sporadic nitrate concentrations above 10 mg/L were found in the central and northeast regions.

The 2 percent of wells that exceeded 10 mg/L of nitrate-nitrogen was far below the 14 percent reported by Sharpe et al. (1985) and the 9 percent reported by Swistock et al. (1993). Both of these past studies had a larger proportion of samples from southeast Pennsylvania than this study and both also reported a strong regional influence on nitrate occurrence. Still, these comparisons suggest that groundwater nitrates are lower than they have been historically, perhaps due to better management of nitrogen on farms and home fertilizers resulting from education and mandated nutrient management plans. Data reported in the 2002 Census of Agriculture (the most recent census available) by the U.S. Department of Agriculture (2004) suggest that applications of nitrogen by fertilizer and manure have dropped in southern Pennsylvania since the early 1990s.

Arsenic

Only 2 percent of the wells exceeded the health-based drinking water standard of 10 mg/L for arsenic. The maximum concentration observed was 35 mg/L but the majority of wells (89 percent) had arsenic concentrations below 6 mg/L. Wells with high arsenic occurred mostly in northern Pennsylvania regions, presumably due to the geology of these areas. The three northern regions of the state had significantly higher arsenic concentrations than the southern regions with the highest occurring in the northwest region. These results are similar to results reported by the U.S. Geological Survey (2000) for 578 private wells that were sampled in southeast and extreme western Pennsylvania. Arsenic is thought to originate primarily from natural geologic sources, thus, it would not be expected to vary significantly over time.

Triazine Pesticides

Only three wells (less than 1 percent) had unsafe concentrations of triazine pesticides above 3 mg/L. Two of these wells were located in southcentral Pennsylvania and one well was located in the northeast region. Of these three wells, two homeowners were willing to have their well re-tested in 2007 using more sophisticated analyses. Those re-tests occurred in late 2007 and they did not detect pesticides in either well.

The only other survey of pesticides in private wells in Pennsylvania was conducted during 1993 in an unpublished study by Penn State University. Of 189 private wells sampled in that study, none had atrazine or simazine concentrations above the drinking water standard. Another recent study by Bartholomay et al. (2007) tested several hundred wells in Pennsylvania and found none that exceeded the drinking water standard for atrazine or its breakdown products. It should be noted that these past studies of pesticides in Pennsylvania have generally detected small concentrations of pesticides (above the detection level but below the drinking water standard). This study's testing method only provided a result of "present" or "absent" at a level above the drinking water standard. So, while the sampling shows that very few wells were above the drinking water standard, the results do not allow an estimation of the number of wells that may have triazine pesticides present at lower detectable concentrations.

Hardness

There are no health effects or drinking water standards for hardness but hard water can cause numerous aesthetic problems, especially when water is heated. Because hardness reduces corrosion of household plumbing, a level of 90 to 100 mg/L is often considered optimum to reduce corrosion while also preventing unwanted aesthetic effects. Total hardness is usually reported in one of four categories as follows: soft water has a hardness concentration of 0 to 60 mg/L; moderately hard water has a hardness concentration of 61 to 120 mg/L; hard water has a hardness concentration of 121 to 180 mg/L; and very hard water has a hardness concentration greater than 180 mg/L.

Figure 4. Variables used in ANCOVA statistical models to determine causes of contamination of private wells.

Parameter	Description	Values
Well Setting and Climate		
Geology	Type of bedrock geology	Carbonate, inter-bedded sedimentary, sandstone/shale, igneous, or conglomerate
Moisture Index	Palmer soil moisture index	-6 (dry) to +6 (wet) for two week period prior to each well sample
Region	Regional location of well	See Figure 1 for regional boundaries
Date	Date sample was collected	3/11/06 to 11/27/07
Well Characteristics/Construction		
Depth	Depth of well	Feet below ground surface
Age of Well	Years since well was drilled	Years
Casing	Present (i.e. drilled well) or absent (i.e. hand-dug well)	0 = absent 1 = present
Buried Casing	Is the well casing above or below ground (buried)	0 = buried 1 = extended above ground
Grout	Is there evidence of grout or cement around the casing	0 = no evidence of grout 1 = evidence of grout
Slope	Ground slope around the well head area	0 = well is in a depression 1 = ground slopes away from well head
Well Cap	Is the well cap sealed and vermin-proof (sanitary)	0 = non-sanitary well cap 1 = sanitary well cap
Well Score	Cumulative score of all five well construction features	0 (poor construction) to 5 (excellent construction)
Wastewater Characteristics		
Wastewater	Type of wastewater disposal	On-lot (private) or public sewer
Septic Age	Age of wastewater system	1=less than 1 year old, 2=1-5 years, 3=5-10 years, 4=more than 10 years old
Septic Tank Pumping Frequency	How often is the septic tank pumped out	1 = yearly, 2 = 2-3 years, 3 = 4 years or more, 4 = Never pumped
Nearby Land Uses		
Corn Field	Distance to nearest cornfield (as a category)	1 = <50', 2 = 50-100', 3=100'-500', 4=500'-1000', 5 = None visible
Other Crop	Distance to other crop field	Categories 1 through 5 described above
Garden	Distance to garden	Categories 1 through 5 described above
Orchard	Distance to orchard	Categories 1 through 5 described above
Mine	Distance to mine	Categories 1 through 5 described above
Gas/Oil Well	Distance to gas/oil well	Categories 1 through 5 described above
Septic	Estimated distance to septic	Distance in feet between well and septic
Dog Kennel	Distance to dog kennel	Categories 1 through 5 described above
Barnyard	Distance to barnyard	Categories 1 through 5 described above
Pasture	Distance to pasture	Categories 1 through 5 described above
Stream/Lake	Distance to surface water	Categories 1 through 5 described above
Golf Course	Distance to a golf course	Categories 1 through 5 described above
Neighbor Well	Distance to a neighbors well	Categories 1 through 5 described above

There were clear regional differences in hardness concentrations across the state. Most wells with very hard water were located in western counties or in central and southcentral Pennsylvania. Wells in the northcentral and northeast regions had significantly lower hardness concentrations (means = 70 to 90 mg/L) compared to the other four regions (means = 120 to 140 mg/L) due to the bedrock geology of these regions.

Variables Controlling Contamination of Private Wells

Contamination of private wells can occur through the interaction of both natural and human causes. Leaching of arsenic from bedrock is an example of a natural source while leaching of bacteria from a septic system is an example of a human cause. Figure 4 shows all of the variables that were included in the ANCOVA statistical model in an attempt to explain sources of contamination in private wells. The ANCOVA model was then able to determine which variables were statistically significant in explaining water quality differences.

Climate and Other Natural Factors

Regional differences were previously reported in the summary of each water quality parameter but much of this variation can be attributed to geologic differences between the regions. In the ANCOVA models, geology was statistically significant in explaining the variation in all of the water quality parameters with the exception of arsenic. In most cases, water quality was strongly tied to geology. The geologic controls on water quality are not surprising considering that groundwater in private wells is in direct contact with the bedrock for extended periods of time. However, some of the geologic differences are probably the result of land uses that are predominant on certain types of bedrock. For example, higher nitrate levels on carbonate and igneous bedrock are likely due to the fact that these bedrock types are predominant in the regions of the state with intensive agricultural land use rather than actual differences in the bedrock chemistry.

The carbonate rock type produced the most unique water quality with significantly higher bacteria levels, pH, nitrate and hardness compared to most other rock types. A recent study of private wells in southcentral Pennsylvania also reported a higher incidence of coliform and *E. coli* bacteria in wells located in carbonate bedrock because of the close connection between carbonate aquifers and surface water (Zimmerman et al., 2001). Igneous rock, located in parts of southeast and southcentral Pennsylvania, was more acidic (lower pH) and lower in hardness compared to other rock types. This resulted in generally higher lead concentrations although this difference was not statistically significant. Sedimentary and sandstone/shale bedrock types, which are both comprised of various types of sandstone and shale, predictably produced nearly identical water quality results. These results suggest that the natural geology where a private well is drilled plays an important role in the resulting water quality, regardless of well construction and nearby land use impacts. The overall importance of geology on many water quality parameters has also been observed in testing of 5,000 private wells in New Jersey (New Jersey DEP, 2004).

Climatic conditions, such as precipitation and temperature, are thought to be important when testing pollutants in groundwater wells although limited research data are available on this subject. Contaminants originating from the ground surface, like coliform bacteria and *E. coli* bacteria, would be expected to be more prevalent during wet and warm weather since these conditions favor the growth of bacteria and wet weather promotes the movement of surface water and surface contaminants into the ground.

Of the wells that contained coliform bacteria or *E. coli* bacteria, 84 percent were tested during moist conditions, while only 16 percent were tested during dry weather. These results agree with those of Swistock and Sharpe (2005) who found that bacterial contamination of private wells in Pennsylvania was greatly reduced during an extreme drought in 2002. Short-term moisture conditions were not statistically important in explaining concentrations of nitrate, lead, pH, hardness or arsenic in private wells.

The strong relationship between bacteria levels and moisture conditions has many implications. Results of bacteria testing will likely be more variable than other water quality parameters, depending on the weather at the time of sampling. As such, the bacteria results presented here must be considered a snapshot of conditions that apply to the weather conditions that existed during the study. Conditions during 2006 and 2007 throughout Pennsylvania encompassed a range of short-term conditions from mild drought (summer 2007) to moderate wetness (fall 2006) but, overall, these two years were near climatic norms. Results from the homeowner survey and re-sampling of wells between 2006 and 2007 also elude to the variability of bacteria results. Twenty-six of the 701 well owners (4 percent) indicated they had coliform bacteria in their water well but this testing found none present. Also, some wells that contained small numbers of coliform bacteria in 2006 did not contain these bacteria when they were re-tested in 2007. The variability of bacteria results related to weather conditions must be considered when making recommendations to well owners about well testing.

Season of the year was also tested as a potential cause of water quality variations in wells. One might expect that warmer and wetter conditions during spring and summer would result in a greater likelihood of bacteria, nitrate, lead and pesticides in wells while generally drier and cooler conditions during fall might cause higher pH, hardness and arsenic as dilution from rainwater is reduced. In the ANCOVA models, season was not statistically important for any of the water quality parameters. Bacterial contamination was nearly constant among the three seasons (spring, summer and fall) that wells were tested.

Effect of Well Construction

Well construction features could play a role in the entry of some pollutants, especially those generated near the land surface, into private wells. For example, bacterial contamination of wells may occur through improper construction practices that allow surface water, insects or small mammals into the well. Sanitary well caps, grout seals and sloped ground near the casing are all used to prevent this wellhead contamination. Five separate well construction components (casing present, casing above ground, sanitary cap, grout or cement seal, slope around casing) along with the overall “wellscore” (the number of proper well construction components on the well) were included in the ANCOVA models for each water quality parameter. Additional well characteristics, including depth and age, were included in the models.

In the case of coliform and *E. coli* bacteria, individual well construction components resulted in slightly reduced contamination rates (for example, wells with sanitary well caps had slightly lower bacterial contamination rates than those with standard or missing well caps) but none of these individual components produced statistically significant results. But, combinations of well construction features were highly significant in reducing total coliform bacteria and *E. coli* bacteria. Figure 5 illustrates the effect of increasing numbers of well construction features on bacterial contamination. Note that wells with very poor construction (zero features) were twice as likely to have coliform bacteria and five times more likely to have *E. coli* bacteria compared to wells with excellent construction (five features). The contamination rates for wells with a wellscore=5 (28 percent for coliform and 8 percent for *E. coli*) are very similar to data published by Swistock et al. (2005) from sampling of 24 wells with excellent construction in eastern Pennsylvania. Other studies have demonstrated slightly reduced incidence of bacteria from grout (Zimmerman et al. 2001), sanitary well caps (Swistock et al., 2005), and cased wells versus hand-dug (Sharpe et al. 1985) but no other studies have shown a clear connection between overall well construction and bacterial contamination. These results suggest that no single well construction feature is critical to preventing surface water contamination but, clearly, combinations of features have a significant effect in preventing bacterial contamination of private wells.

Despite the importance of well construction to bacterial contamination, it was not important in explaining other water quality problems in private wells. In fact, no single well construction feature, or even the overall wellscore, was statistically significant in any other ANCOVA model. In the case of nitrate, the age of the well was statistically important and well depth was modestly significant. These factors combined suggest that older wells, which are typically shallower, are perhaps allowing shallow, nitrate-rich water to enter deeper groundwater aquifers. Other than nitrate, well depth was not statistically significant in explaining any of the water quality parameters. The overall lack of importance of well characteristics on parameters besides bacteria is not surprising given the importance of geology described earlier.

Effect of Nearby Activities

The sample collection survey completed by each MWON volunteer included estimated distances to 14 nearby activities (crop field, dog kennels, septic system, etc.) that could influence some water quality parameters in wells. Each of these distances was included in the ANCOVA models along with well construction, climate, and geology. Overall, few of these activities were statistically significant in explaining water quality in private wells.

The overall factors that control each well water quality parameter (natural factors, well construction factors, and land activities) are summarized in Figure 6 on Page 16. These results do not argue strongly for mandated or voluntary wellhead protection areas around private wells where various activities are prohibited to protect well water quality. However, these results should be interpreted with some caution. The overwhelming majority of the private wells in this study already, in effect, had a wellhead protection area of at least 50 feet. In fact, more than 70 percent of the study wells were located at least 50 feet from all of the possible polluting activities. Thus, there were relatively few wells that could be used to test the effect of each of these activities. These results, therefore, are probably indicative of the overall effectiveness of a minimum 50-foot wellhead protection area that most homeowners and/or well drillers seem to provide either by chance or as common sense.

Figure 5. The effect of increasing numbers of well construction features on coliform and *E. coli* bacterial contamination.

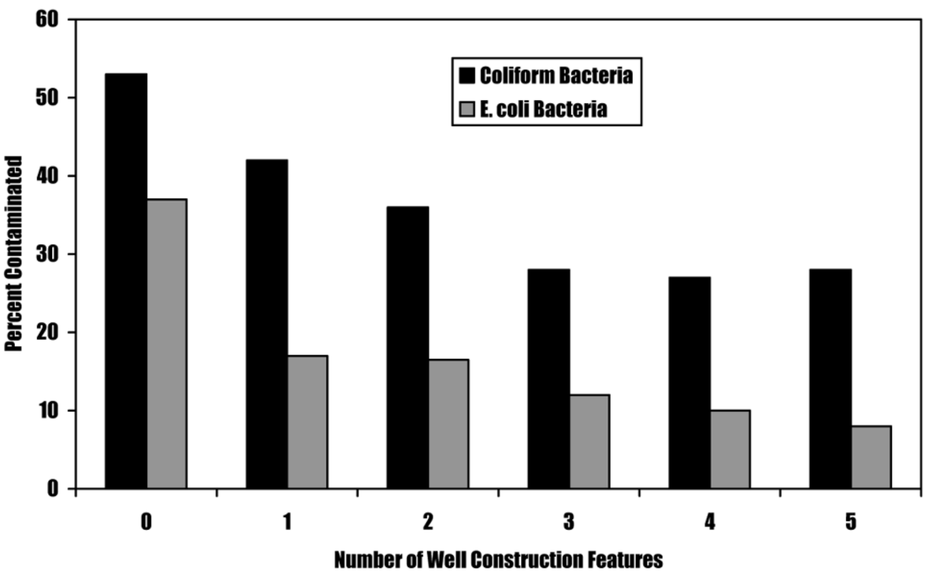


Figure 6. A summary of statistically significant variables ($p<0.05$) in ANCOVA models for each water quality parameter.

Parameter	Statistically Important Variables
Coliform bacteria	Geology, Wellscore[1], Soil Moisture
E. coli bacteria	Geology, Wellscore, Soil Moisture
Nitrate	Geology, Cornfield and Other Crop Field Distance, Well Age (Well Depth)[2]
pH	Geology
Lead	Geology, Household Plumbing[3]
Hardness	Geology
Arsenic	No Significant Variables

[1]Wellscore = number of recommended well construction features (0 to 5). [2] Well Depth p-value was 0.08 indicating that the Well Age correlation is probably related to a combination of age and depth (i.e. older wells were shallower). [3] Lead is highly correlated with plumbing system characteristics and water pH (an index to corrosion) which is related to geology.

Voluntary Water Well Management

In the absence of statewide regulations for well construction and/or maintenance, education plays an important role in promoting proper management of private water supplies. However, while education can create awareness of problems and management strategies, it can only be successful if well owners translate this knowledge into action, such as by testing their well water or installing treatment systems, when problems are identified. If it is found that well owners are generally maintaining their wells properly, then it can be argued that regulations are less necessary to protect the health of well owners.

Water Testing

Most agencies recommend having private wells tested by a state-certified laboratory annually for coliform bacteria and every few years for other contaminants. The 622 homeowners that participated in this study had rarely followed these recommendations. In fact, three-fourths of homeowners had either tested their water quality just once (44 percent) or had never had their drinking water tested (30 percent). It is important to note that these estimates may be high since most of these well owners were familiar with MWON volunteers who may have previously encouraged them to have their water tested. Trained MWON volunteers themselves were more likely to have their water tested more frequently than uneducated homeowners but some had still not had their water tested.

Of the 74 percent of homeowners that indicated their water had been tested at least once in the past, only about half had used a state-certified laboratory (Pennsylvania Department of Environmental Protection lab or state-certified commercial lab). The remainder was tested by either water treatment vendors or the use of home water testing kits. MWON volunteers, on the other hand, were much more likely (69 percent) to use certified water labs. Overall, about half of the homeowner participants in this study had never had their water tested properly (either never tested or only testing was a non-certified lab) while fewer MWON volunteers (30 percent) had failed to have their water tested properly.

The frequency of water testing did vary somewhat by regions of the state. Private well owners in the southeast region of the state were significantly more likely to have their well tested and also to use a certified testing laboratory compared to other regions of the state. The reasons for this difference are not clear but could be related to the better availability of water laboratories or greater concerns of threats to private water systems in this region.

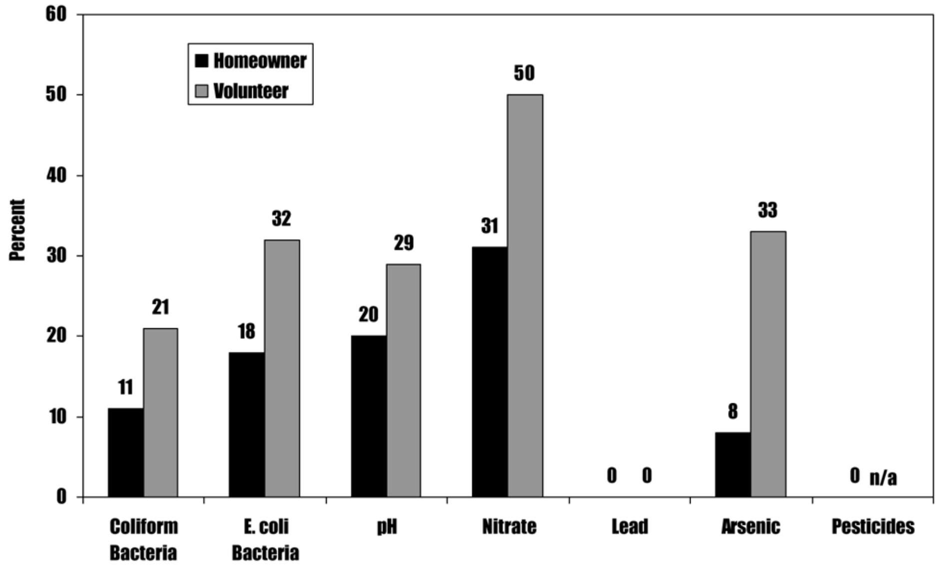
Water Quality Awareness

For the purposes of this discussion, the term "awareness" refers to a well owner's knowledge of his/her water well quality prior to participating in this study. Given the low percentage of homeowners that had previously tested their well water quality, it would be expected that few were aware of the water quality problems in their own well. This was generally true for health-based pollutants that have no obvious symptom (taste, odor, etc.) in water. Figure 7 illustrates the percent of homeowners and MWON volunteers that were already aware of each pollutant that existed in their well before participating in this study.

In Figure 7, the 11 percent awareness value for homeowners with coliform bacteria means that, of the 203 homeowner wells that were found to contain coliform bacteria, only 11 percent of those well owners were already aware of this contamination prior to participating in this study. In all cases, awareness of contamination among homeowners was below 31 percent, with the highest awareness occurring for parameters that are more often routinely tested by water laboratories (nitrate, pH, bacteria). MWON volunteers were generally two to three times more likely to know about a health-related pollutant in their well suggesting that education can greatly improve awareness of problems.

Naturally, homeowners are more aware of water pollutants that only affect taste, or cause stains or odors

Figure 7. Percent of homeowners versus MWON volunteers who were aware that each pollutant occurred in their well prior to the study. "N/A" indicates that no MWON volunteers had wells that tested positive for pesticides.



because the effects are obvious. For example, nearly 50 percent of homeowners with very hard water identified it as a problem with their water supply. Iron was also reported as a problem by 21 percent of the study participants. Although this study did not measure iron to confirm it's presence, the 21 percent that reported having it in their water agrees with the percentage found to actually have high iron by Sharpe et al. (1985) suggesting a high awareness of this problem.

Solving Water Quality Problems

The goal of any drinking water education program is to facilitate actions taken by the audience to correct water quality problems and, ultimately, to increase the percentage of participants that avoid unsafe drinking water. Actions taken by well owners to solve problems could include using a new water source (bottled water), maintaining the water supply to remove contaminants (shock chlorinating a well to kill bacteria), removing a source of contamination (moving a dog kennel away from a well), or installing a continuous water treatment device to remove the pollutant. In this study, there were several measures that provided some evidence of the willingness of well owners to take actions to properly manage their well and the effectiveness of these actions given some awareness of the problems and potential solutions. Actions that homeowners could take to solve water quality problems were provided in Penn State Cooperative Extension fact sheets that were enclosed with each water test report.

One measure of the success of education is to compare actions taken by MWON volunteers who had attended an eight-hour training workshop with homeowners who did not receive this training. MWON volunteers were much more likely to have a sanitary well cap on their well and the ground sloping away from the well casing in all directions to prevent surface water contamination. Both of these actions were stressed during their volunteer training workshop and, in fact, those completing the training were given a sanitary well cap for their home well. Additional information on actions taken and their effect on drinking water quality were measured through the follow-up survey and re-testing of a subset of wells.

Follow-Up Survey Results

Measurement of actions taken by homeowners to solve or treat water quality problems was accomplished through a follow-up survey of the 450 well owners that participated in the study in 2006. A summary of the nearly 300 responses to this follow-up survey is shown in Figure 8. About half of the respondents took an

Figure 8. Percent of private well owners that took various actions to improve their private well as a result of having their well tested (based on the follow-up survey sent to the 450 well owners that participated in 2006).

Action Taken	Percent of Homeowners with No Water Quality Problems	Percent of Homeowners with Water Quality Problems	Overall Percent
New water well or use of bottled water	4	18	9
Water treatment	7	25	13
Well rehabilitation[1]	15	54	29
Removing sources of pollution[2]	13	13	13
Additional water testing	2	19	8
Totals	33	76[3]	48

[1] Includes shock chlorination, sanitary well cap installation, extending well casing above ground, sloping ground to prevent contamination, or grouting around existing well casing. [2] Includes reduced chemical and fertilizer use, removing animals from near well, diverting runoff or maintaining septic system. [3]Some homeowners took more than one action.

Figure 9. The overall effect of actions in reducing exposure to water contaminants in this study.

Contaminant	Percent avoiding contaminant before this study	Percent starting or improving on their avoidance of contaminant[1]	Total avoiding contaminant 6-12 months after testing[2]
Coliform bacteria	33	44	50
E. coli bacteria	42	69	71
Nitrate	12	50	62
Lead	0	75	75
Arsenic	20	80	80

[1] Includes use of bottled water and/or installation of proper treatment equipment. Results for coliform bacteria and *E. coli* include an additional 10 percent removal based on the effectiveness of other actions (shock chlorination, sanitary well cap, etc.) estimated from the re-sampling of 60 wells. [2] Note that the total avoiding a contaminant (column three) does not sum from columns one and two because some well owners simply improved on actions that were already having an effect.

action to better manage their private well as a result of participating in this study. Homeowners with wells that failed at least one drinking water standard were more than twice as likely to take corrective actions on their water supply compared to homeowners that had no water quality problems. Overall, an impressive 76 percent of homeowners with wells that failed at least one health-based drinking water standard took at least one action (some took numerous actions) to correct or better manage the problem.

Effect of Actions on Bacterial Contamination

Sixty wells that tested positive for coliform bacteria in 2006 were re-sampled in 2007; 32 homeowners had taken at least one action, such as shock chlorination, installing a sanitary well cap or removing the source of contamination, to solve their wells' bacteria problem.

While many homeowners took recommended actions to remove bacteria from their drinking water well, of greater interest is how successful these actions were in eliminating bacteria from these wells. Of the 32 wells where homeowners took actions, 21 still contained coliform bacteria representing a 35 percent success rate.

Given the variability of bacteria in wells in response to moisture conditions discussed earlier, it could be expected that some wells with bacteria would test negative one year later simply due to changing weather conditions or other factors. Of the 28 wells that contained coliform bacteria in 2006 where homeowners did not take action to eliminate bacteria, 21 still contained coliform bacteria when re-tested in 2007. Thus, even in wells without any actions taken, 25 percent did not contain bacteria one year later. A notable difference between these wells and the wells where actions were successful in eliminating bacteria was the bacteria concentrations. Wells that tested negative for bacteria without any actions by the homeowner had very low pre-existing bacteria concentrations (average = 3 colonies per 100 mL).

The re-sampling of wells with coliform bacteria between 2006 and 2007 results in a very conservative estimate of the overall success of actions (shock disinfection, sanitary well caps, etc.) in removing bacteria from wells (10 percent) as the difference in success rates between those that took actions (35 percent) and those that did not take actions (25 percent). A similar success rate of 10 percent was found for removal of *E. coli* bacteria from contaminated wells in this study. The 10 percent success rate shown in the retesting is similar to the 15 percent success reported by Swistock and Sharpe (2005) in a study of 17 wells that were shock chlorinated and fitted with sanitary well caps.

The survey data compiled during the overall study showed that well owners who were aware of a health-based pollutant in their water were very likely to avoid the problem. For example, over 75 percent of the well owners that knew they had *E. coli* bacteria had already installed a disinfection treatment system or were using bottled water. The barrier to avoidance of contaminated well water on a large scale was the large percentage of well owners that were not aware of problems due to inadequate water testing.

The well owners that participated in this study were made aware of problems that occurred in their water supply. But, would this awareness translate into actions to avoid exposure to health-based pollutants? The data presented in Figure 9 illustrate the overall impact of this well testing study on reduced exposure of homeowners to health-based water pollutants. The first column shows the percent of well owners that had each contaminant and were avoiding the problem prior to this study. Keep in mind that many of the well owners that were avoiding contaminants prior to this study were only doing so inadvertently. For example, well owners using only bottled water because their well water tasted bad would also be avoiding coliform bacteria even if they did not know it occurred in their well. The second column shows the percent of well owners that started or improved on a method to avoid exposure to each pollutant as a result of this study. For example, some well owners that were originally using bottled water installed water treatment to improve water quality after receiving their water test report. The final column shows the percent of homeowners that were avoiding the problem six to 12 months after this study. Note that the percent avoiding water quality problems increased dramatically in each case. Pollutants with more severe or better documented impacts on human health, like lead, arsenic and *E. coli* bacteria, had the highest avoidance rates at the end of this study. Pollutants like coliform bacteria and nitrate, which have relatively low risk or only affect certain portions of the population, had slightly lower avoidance rates. Since relative risk information was given to each well owner in the Penn State Cooperative Extension fact sheets included with each water test report, it is not surprising that well owners responded with greater actions for pollutants with greater risks. For pollutants that were not health-related, like hardness, the percent that chose to avoid the problem generally dropped to near or below 50 percent (data not shown).

It is important to note that many well owners took actions in an attempt to avoid exposure to pollutants that could not be clearly linked to a reduced exposure to that pollutant. For example, while only 50 percent of well owners with coliform bacteria were successfully avoiding bacterial contamination by the end of this study, many of the remaining 50 percent had at least taken some action to try to avoid the problem. As a result, the percent of homeowners that took no action at all was generally quite low ranging from 8 percent for *E. coli* bacteria to 20 percent for various other pollutants. In most cases, the homeowners that did not take any action may have made this choice because of lower perceived risk. For example, those that did not take action to remove coliform bacteria nearly always had low bacteria counts less than 10 colonies per 100 mL and those that did not take action to remove *E. coli* always had just 1 colony per 100 mL of water.

Unnecessary Water Treatment

The principal investigators have worked with private well owners in Pennsylvania for several decades and often encounter homeowners that have been sold unnecessary water treatment equipment. Data collected during this study provides some insight about the use of water treatment equipment in Pennsylvania.

Of the 701 homes participating in this study, 288 employed a total of 372 water treatment systems. Of these systems, 18 percent were considered unnecessary based on water testing conducted during the study and information provided by homeowners. This study demonstrated that 58 homes, or 8 percent, had water treatment equipment that was apparently not needed. This figure agrees with recent data gathered in central Pennsylvania (CWS, 2005). Information provided by homeowners suggests they are often unaware of their specific needs with regard to water treatment. Specific examples of questionable water treatment equipment installations are described below:

- 46 homeowners with “soft” raw well water had a water softener installed. Nineteen of those homes had zero hardness, indicating that the water sample was taken post-treatment. Iron was a problem for an additional nine homes, which may have been the reason for using this type of water treatment equipment. Of the remaining 18 homes, three indicated the equipment existed when they purchased the home, nine indicated it was installed because of past water test results, and six listed various reasons that did not warrant this type of treatment equipment.
- 50 homeowners had an ultraviolet light installed on their water system to kill bacteria but 48 percent (24 systems) showed no bacteria present in their water. Of the 24 homes that did not have bacteria present, seven had the equipment because it already existed in their home when it was purchased, seven had it because of water testing they did in the past, and the remaining 10 homeowners had various reasons that did not justify using an ultraviolet light.
- 16 homes treated their water with chlorination systems. Most of these homeowners had a bacteria problem or indicated their water was high in iron or hydrogen sulfide (which can both be treated with chlorine). The remaining three homeowners did not need chlorine although one thought he had a bacteria problem. Of the three homes with unnecessary chlorination systems, two installed the equipment due to the results of previous water testing and one installed it due to taste or odor problems.
- Another 20 water treatment systems were found to be unnecessary based on the problems reported by the homeowner or by the water testing done in this study. Equipment that appeared to be unnecessary included oxidizing filters, nitrate removal systems, acid neutralizing filters and magnetic treatment devices.

Well Owner Opinions

A final portion of the survey provided to each well owner included opinion questions about perceived threats to their water supply, opinions of well regulations, and use of other sources of drinking water.

Most well owners were very satisfied with their private water well. Eighty-four percent were not willing to pay even $10 per month to have access to public water. A total of 16 percent were willing to pay some monthly fee to have public water including $10 (2 percent), $20 (6 percent), and $30 or more (8 percent).

Well owners were generally concerned about their water quality but less so about their water quantity. Sixty-four percent were very or somewhat concerned about water quality in their well while only 39 percent were similarly concerned about the amount of water their well supplies. Well owners were most concerned about new housing developments as a threat to their water supply. Thirty-five percent of well owners ranked new housing developments as the biggest threat. Agriculture (16 percent), oil and gas drilling (13 percent), mining (11 percent) and highways (4 percent) were the other common responses for threats to private wells. There were obvious regional differences in these responses with agricultural concerns centered in southcentral Pennsylvania, mining concerns mostly in western Pennsylvania and oil and gas concerns mostly in northern and western counties.

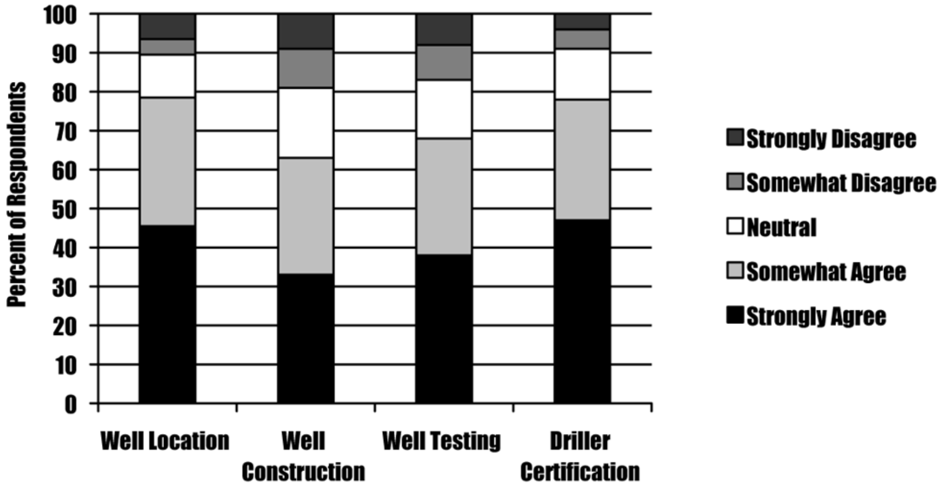
Fourteen percent of well owners use bottled water as their sole source of drinking water. Another 30 percent occasionally drink bottled water at home. Bottled water use was significantly higher in the northcentral region of the state and significantly lower in the southcentral region.

Nine percent of well owners use roadside springs for their drinking water; 8 percent occasionally and 1 percent for all of their drinking water. Roadside spring use was strongly regional with more well owners in the northcentral and northwest regions using them compared to other regions.

Four questions on the survey asked well owners their opinions about proposed private well regulations in Pennsylvania, as follows:

- (Well Location) There should be a statewide regulation on the location of new water wells that includes the minimum distance a new well can be drilled from existing wells, septic systems and other sources of contamination.
- (Well Construction) There should be a statewide regulation that requires certain well construction components on new wells (such as a sealed well cap and cement-like seal or grout around the casing) to prevent well contamination even if it adds $500 to $1,500 to the cost of a new well.
- (Well Testing) There should be a statewide regulation requiring private water wells to be tested for certain pollutants prior to the sale of the home to a new owner even if it adds several hundred dollars to the cost of a home sale.
- (Driller Certification) There should be a statewide regulation requiring that professional water well drillers be periodically certified by passing a competency exam.

Figure 10. Well owner opinions of potential private well regulations in Pennsylvania.



A summary of opinions from homeowners is given in Figure 10. MWON volunteers are not included in this summary since they were nearly unanimous in their support of these measures as a result of their volunteer training.

Well owners were generally supportive of all potential well regulations with 63 to 78 percent strongly or somewhat agreeing with the statements above. The greatest support was for proper location of new wells and well driller certification. In general, the northeast region of the state had the most favorable opinion of the proposed regulations while the northwest and southwest regions of the state were the least in favor of any well regulations.

Well owners that have a question or problem related to their well were most likely to seek assistance from private water labs (22 percent), Penn State Cooperative Extension (19 percent), a well driller (11 percent) or the Pennsylvania Department of Environmental Protection (11 percent).

The well owner opinions, including support for private well regulations, found in this study mirror results found from an online survey of 865 private well owners from 63 counties in Pennsylvania conducted by the researchers in 2006.

Conclusions

Data from this study provide a wealth of information on the incidence of pollutants in private water wells throughout Pennsylvania, the causes of contamination, and the ability of well owners to detect and solve water quality problems voluntarily.

About 41 percent of samples from the private wells tested in this study failed at least one safe drinking water standard. Overall, the prevalence of contamination was stable or declining compared to past results for the parameters measured in this study. Lead contamination appeared to be declining in response to the 1991 Federal Lead and Copper Rule while nitrate contamination was reduced from the early 1990s, presumably due to reduced applications of nitrogen through fertilizers and manures.

Of the 28 variables measured for each well, the results demonstrated that natural variables, such as the type of bedrock geology where the well was drilled, were important in explaining the occurrence of most pollutants in wells. Soil moisture conditions at the time of sampling were the single most important variable in explaining the occurrence of bacteria in private wells. Man's activities, however, were also responsible for the increased incidence of some contaminants. Inadequate well construction was strongly correlated with the occurrence of both coliform and *E. coli* bacteria in wells. Nearly all lead contamination could be attributed to the historical use of lead plumbing components and the occurrence of naturally corrosive groundwater. Increased nitrate concentrations were strongly related to the location of the well in comparison to nearby agricultural fields. Overall, these results suggest that naturally occurring groundwater is not always safe for human consumption and man's current and past activities have worsened the situation for some pollutants.

Unsafe levels of these pollutants in wells can be addressed through maintenance, water treatment devices, bottled water or new sources of water. But a major barrier to successful avoidance of problems that was identified in this study was simply creating awareness of problems through water testing. Most health-related pollutants do not have obvious symptoms (tastes, odors, etc.) so few wells have been properly tested. The results indicate that only about half of well owners have had their well water tested by a certified laboratory and, in many cases, they have not been thoroughly tested. The lack of testing by well owners is not for a lack of concern over their water quality, but instead, a lack of awareness and understanding of what testing should be done.

Overcoming the barrier to water testing is especially critical because results from this study have clearly demonstrated that well owners are willing to take actions to solve water quality problems. The great majority of well owners that were told of health-related water quality issues in their water supply had voluntarily solved the problem within one year.

Policy Considerations

To ensure safe drinking water for private water system owners in Pennsylvania, the state should consider using a combination of educational programs for homeowners and new regulations. The combination of these two approaches will make certain that existing well owners will become aware of water quality issues and proper management of wells while future well owners will be protected from poorly protected wells or lack of knowledge. Specific policy recommendations are addressed below.

Well Testing

One of the most revealing results from this study was the lack of voluntary water testing done by private water well owners and the resulting lack of awareness of health-related water quality problems. Several states now require testing of private water wells during real estate transactions but, in Pennsylvania, water testing is entirely the voluntary responsibility of a well owner. Well owners could benefit from a combination of educational programs and regulations targeting water testing. Requiring well owners to have their water tested routinely is not practical or enforceable given the large target audience in Pennsylvania. Instead, a better approach would be to require all homes with a private water well to be tested by a certified laboratory at the completion of new well construction and before finalization of any real estate transaction. Additional educational programs for the remaining well owners that do not buy or sell their home regularly are also needed (see Existing Well Owner Education on the next page).

Well Construction

The importance of well construction has been considered self-evident among groundwater experts as a means to prevent surface water (and associated pollutants) from entering groundwater aquifers. In fact, the state association of professional well drillers (Pennsylvania Ground Water Association) has supported well construction standards for many years and most states currently have well construction standards. By sampling a large number of wells with diverse settings and construction, the researchers were able to document the significant benefit of proper well construction in reducing the incidence of both coliform and *E. coli* bacteria in wells. While this study showed that education increased the use of sanitary well caps on existing wells, most well construction features need to be included at the time the well is drilled. Homeowners having new wells drilled are difficult to reach with educational programs and, as a result, the voluntary approach to encourage proper well construction has largely failed. Given the benefits of well construction and the difficulty in reaching the target audience for new wells, statewide regulations requiring well construction components appear to be warranted. This study clearly demonstrated that the majority of well owners (>60 percent) were in favor of well construction and location standards.

Wellhead Protection

In comparison to natural influences and well construction features, nearby land-uses were less important in explaining contamination of private wells. For example, the distance to a nearby on-lot septic system and the frequency of septic tank pumping were not statistically significant in explaining the occurrence of bacteria or nitrate in private wells. Instead, nearby sources of animal waste appeared more important in contributing to bacterial contamination of wells. A notable exception to the lack of importance of nearby land-uses was the strong correlation between the distance to nearby agricultural fields and nitrate concentrations in wells. Given the conservative nature of nitrate (ability to move long distances through soil and rock), this correlation is understandable. Overall, the results of this study do not make a strong case for the need for wellhead protection areas around private wells. However, the researchers recommend that the determination for the location of new water wells should still be considered very important. In most cases, voluntary wellhead protection areas already existed around the private wells in this study as a result of common sense location of wells used by well drillers and homeowners. The fact that few wells were located very close (<50 feet) to sources of contamination made it difficult to determine if minimum wellhead protection areas are warranted. The connection between contaminated wells and nearby land-use activities may be underrepresented in this study since the vast majority of homeowners did not have wells located in close proximity to activities that generate pollution. As a result, the data seem to confirm the importance and success of de facto wellhead protection areas of 50 to 100 feet that already exist around most wells.

Existing Well Owner Education

The aforementioned regulations and educational programs are largely focused on new well construction or change in ownership of existing private wells. There is also a clear need for an educational component on improving drinking water quality for homeowners with existing private wells. This study has very clearly demonstrated the effect that education can have to increase the frequency of water testing, the use of certified labs and awareness of water quality problems. Related to this was the impressive percentage (>75 percent) of well owners that were willing to take action to treat their water or use bottled water once they were aware of a health-related problem in their water and the large percentages (50 to 80 percent) that were able to avoid unsafe water through voluntary actions taken during the study. A well designed and collaborative education program to deliver unbiased education to well owners could be successful if adequately funded. Such a program should be coordinated among government agencies and businesses that were identified by well owners as important sources of information (water testing labs, Penn State Cooperative Extension, well drillers and Pennsylvania Department of Environmental Protection). A specific component to this educational effort should be an emphasis on bacteria testing during wet weather conditions to improve detection of wells with bacteria problems.

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