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Detecting the Presence of Total Coliforms and E. coli in Private Well-Water in South Western Pennsylvania

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DETECTING THE PRESENCE OF TOTAL COLIFORMS AND E. COLI IN PRIVATE WELL-WATER IN SOUTHWESTERN PENNSYLVANIA

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By

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ABSTRACT

DETECTING THE PRESENCE OF TOTAL COLIFORMS AND E. COLI IN PRIVATE WELL-WATER IN W. PENNSYLVANIA

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Dissertation supervised by Dr. John F. Stolz

Rural private well-water quality and quantity is a global concern. It is currently a significant concern in Pennsylvania because there are no uniform statewide regulations for well construction. The aim of this study was to determine the prevalence of *E. coli* and coliforms in private well-water from a small community in Butler County, Pennsylvania. *E. coli* and coliforms were detected in water samples using EPA standard methods 9222 G. and 9222 B. Well construction, topography and distance from pollution sources (e.g. septic systems), chemical parameters, soil type, and time of year were factors considered in regard to fecal contamination. *E. coli* and coliform prevalence was 3.7% and 6.8%, respectively, for the 29 wells tested. Combinations of factors are believed to be responsible for fecal contamination of well water in this study. Overall, certain well construction criteria should be met in order to minimize risk to water quality.

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Section 1: Background

1.1 Aquifers, Geology, and Types of Wells

Rock materials may be classified as consolidated rock (e.g. sandstone, limestone or granite) or unconsolidated rock (e.g. sand, gravel or clay). Porosity and permeability are the two main characteristics of rocks that affect the presence and movement of groundwater. Consolidated rock may contain fractures, pore spaces, and spaces between layers that can, and usually do, hold water (Waller, 1988). Most bedrock also contains vertical fractures that may intersect other fractures and allow water to move across layers (Waller, 1988). Likewise, water can dissolve carbonate rocks and create vertical and horizontal solution channels. Unconsolidated material overlies bedrock and well-sorted unconsolidated material can store large quantities of groundwater (Waller, 1988).

Aquifers are defined as areas in the subsurface where water-bearing rocks readily transmit water to wells or springs (Figure 1) (Waller, 1988). Water in aquifers normally flows from areas of recharge to areas of discharge. Pressure in confined aquifers is what causes man-made water wells to fill. Ground water is slow in most areas—only moving a few feet per year—but can move several feet per day in permeable zones (Waller, 1988) as shown in Figure 2.

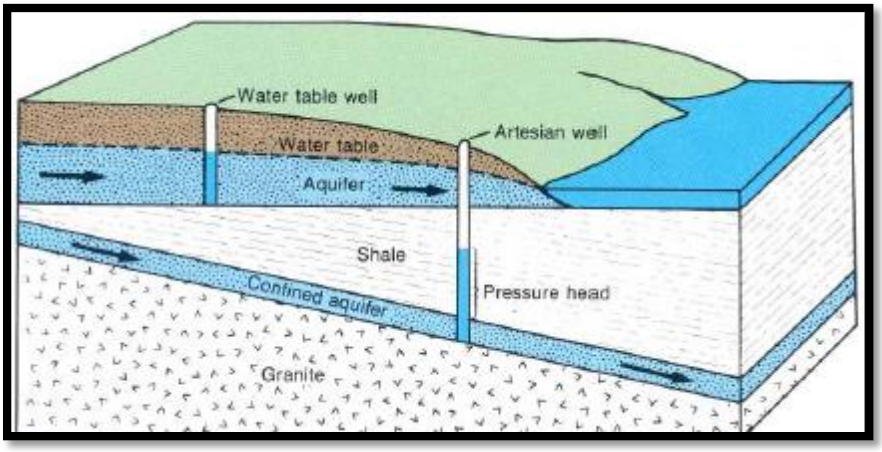

Figure 1: Types of aquifers; artesian and confined. Confined aquifers occur deeper under the surface than artesian aquifers and are confined within impermeable rock strata (Waller, 1988)

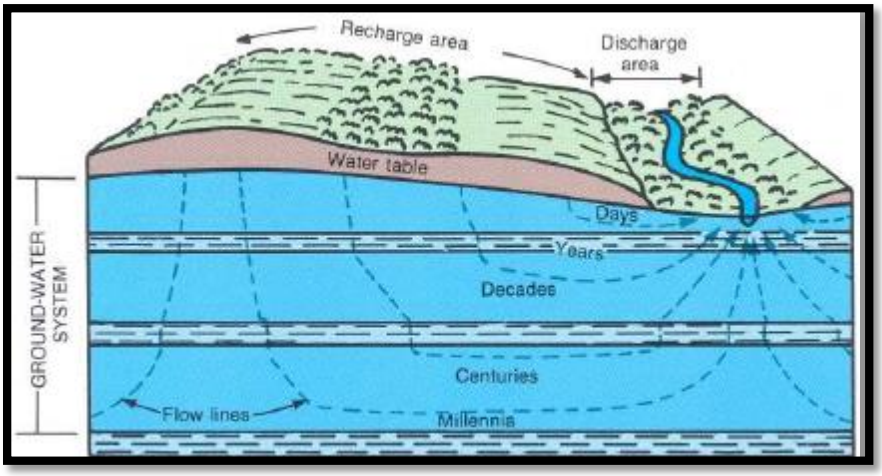

Figure 2: Recharge and discharge areas of an aquifer system. Note that different aquifer systems have different rates of groundwater movement (Waller, 1988)

Most modern wells are drilled by truck-mounted percussion (a cable-tool) or rotary drill (powered by air or hydraulics) rigs (Waller, 1988). However, dug wells are still constructed in some areas. Historically, dug wells were excavated by hand until a depth was reached where water entered the well. However, modern large-diameter wells are mainly constructed by the use of machinery. The main disadvantages of dug wells are that they are shallow and susceptible to surface contamination and drying out during periods of drought (Waller, 1988).

Driven wells are constructed by driving small-diameter pipe into shallow water-bearing sand or gravel. Again, these wells can only reach shallow groundwater sources and are

susceptible to surface contamination (Waller, 1988). Drilled wells are constructed by either percussion or rotary-drilling machines. Drilled wells that penetrate unconsolidated material require the installation of a casing to prevent the inflow of sediment and collapse (Waller, 1988). Unlike dug and driven wells, drilled wells can acquire groundwater sources more than 1000 feet deep.

1.1.1 Briefing on Well Contamination

Housing developments with small lots and individual wells built in rural areas could run into problems with groundwater yields. If the aquifer is low yielding so that pumping causes a large drawdown, a cone of depression will develop around each well. Therefore, several domestic wells close together can create a steady lowering of the water table if pumpage exceeds the natural recharge rate to the system (Waller, 1988).

Commonly tested well contaminants include natural gas, conductance (e.g. ions or salts in solution) and septic waste (e.g. fecal contamination). Small volumes of natural gas, usually methane, can be carried along with the water into wells tapping carbonate or shale rock (Waller, 1988). In old oil and gas fields, saline water may escape from improperly sealed or cased wells and contaminate freshwater aquifers. Like rainwater and snowmelt, effluent from septic systems flows down a hydraulic gradient to lower points. In some types of rock material, the leach field part of the septic system can become gradually clogged by contaminants (Waller, 1988). However, deep wells are less likely to draw in septic waste.

Chlorinating wells works well to kill bacteria at that point and time. However, if an upgradient or surface source of bacterial contamination is entering the aquifer the well draws from, then inconsistent chlorination will do little to eliminate bacterial contamination in that

well. Likewise, if high bacteria counts occur repeatedly, chemical treatment of the affected well cannot solve the problem (Waller, 1988).

Contamination of groundwater wells can occur from above or below the surface. Disruption of entire groundwater aquifers may occur from failing septic systems, manure and fertilizer applications, oil and gas drilling, and/or mining. Individual water supplies could also be contaminated via surface water, insects, or animals entering the well through an exposed well casing or loose fitting/ missing well cap. Not only are poorly contained wells susceptible to pollution, but they act as a potential pollution input source to the entire aquifer from which that well draws its water. However, surface contamination can be prevented by extending the well casing above the ground surface, installing a grout seal around the casing, and fitting a well cap on top of the well. It is also recommended that minimum distances between possible contamination sources and the well head are achieved. Minimum recommended distances to the well head from various pollution sources include; 50 feet from septic tanks; 50 ft from livestock yards or septic leach fields; 100 ft from petroleum tanks, liquid-tight manure storage, and pesticide and fertilizer storage; and 250 ft from manure stacks (CDC, 2009).

1.1.2 Briefing on Soils

Terms including permeability profile, drainage, texture, cation exchange capacity, moist bulk density, saturated hydraulic conductivity (Ksat), and available water capacity must first be described in order to understand the basics of soils. Permeability refers to the rate at which water and air move through the subsoil. It is estimated by determining texture, density, and structure of the most dense and tightest layer in the soil profile above 36 inches deep (WVU extension service). There are four ranks of permeability: (1) rapidly permeable soils have coarse or gravely subsoils with little defined structure; (2) moderately permeable soils have a medium-textured

subsoils, have good structure, break apart easily, and clay skins are absent; (3) slowly permeable soils have fairly tight, clayey subsoils that have some structure and are firm when moist and hard when dry; and (4) very slowly permeable soils have dense, heavy clay subsoils with little structure and very few visible pores (WVU extension service). Cation exchange capacity is the total amount of extractable cations held by the soil and the ability to retain cations reduces the hazard of ground-water pollution (USDA Natural Resource Conservation Service). Moist bulk density is the weight of soil per unit volume and can be used as a measure to compute shrink-swell potential, available water capacity and total pore space (USDA Natural Resource Conservation Service). A bulk density greater than 1.4 can restrict water storage and pore spaces. Saturated hydraulic gradient (Ksat) refers to the ease with which pores in a saturated soil transmit water and is of great importance in designing septic tank absorption fields (USDA Natural Resource Conservation Service). Available water capacity refers to the quantity of water than the soil is capable of storing for use by plants.

Soil drainage refers to the average wetness or dryness of a soil. It is affected by soil texture, structure, slope of the land, and absence or presence of a high water table (WVU extension service). There are four categories of soil drainage including well-drained, moderately well-drained, imperfectly-drained, and poorly-drained. Soil texture is determined by the proportion of clay, silt and sand particles. Coarse-textured soils are sandy and feel gritty; medium-textured soils contain mainly silt with smaller amounts of sand and clay and feel soft; and fine-textured soils have a high percentage of clay and less silt or sand and feel slick when wet (WVU extension service).

1.2 *E. coli* and Fecal Indicating Bacteria

E. coli is the preferred indicator of fecal contamination because it is the only member of the thermotolerant coliform group that is found in the feces of warm-blooded animals and outnumbers the other thermotolerant coliforms in both human and animal waste (Medema et al., 2003). Coliforms are a less reliable index of fecal contamination than *E. coli* even though their concentrations are directly related to *E. coli* concentrations (Payment et. al., 2003). *E. coli* is a gram-negative facultative anaerobe that is a member of the family *Enterobacteriacea*. Thermotolerant coliforms are defined as the group of coliforms able to ferment lactose at 44.5ºC. Thermotolerant coliforms are frequently reported as fecal coliforms. However, not all thermotolerant coliforms may be of fecal origin which is why it is important to confirm that they are fecal coliforms in laboratory studies involving the detection of such microbes. The genera *Escherichia, Klebsiella, Enterobacter,* and *Citrobacter* are generally accepted as making up the "total coliform" population (Clark and Pagel, 1977). Thermotolerant coliforms, other than *E. coli*, may appear in water that has been organically enriched from things such as industrial effluents or decaying plant materials and soils.

Pathogens

Pathogenic microbes can be present in both human and animal waste. Animal manure application to agricultural land is a major source of pathogenic microbes in surface and groundwater systems (Reddy et al., 1981). Pathogenic bacteria associated with agricultural waste include *E. coli*, *Salmonella, Campylobacter,* and *Shigella*. Pathogenic protozoans include *Cryptosporidium parvum* and *Giardia* (Landry and Wolfe 1999). Three general syndromes can result from infection with the pathogenic strains of *E. coli***:** enteric/ diarrhoeal disease, urinary tract infections, and sepsis/ meningitis. The most widely known pathogenic *E. coli* strain is

O157:H7 of the enterohemorrahgic *E. coli* (EHEC) group. *Escherichia coli* is the most common fecal coliform but most strains of this bacterium are non-pathogenic.

1.3 *E. coli* Survival Rates, Fate and Transport

Pathogen fate and transport in soils receiving agricultural waste is a complex issue. Landry and Wolfe (1999) concluded that the range of disciplines conducting fecal bacteria research and the large amount of literature available on the subject have made it difficult to understand the existing knowledge and apply that knowledge in the field.

1.3.1 Survival of E. coli and fecal coliforms

Gerba et al. (1975) has reported that survival times of enteric bacteria in soil and groundwater ranged from 2 to 4 months. Filip et al. (1988) observed *that E. coli* survived for over 100 days at 10ºC under simulated saturated soil conditions. As far as pathogenic *E. coli* survival is concerned, Kudva et al. (1998) found that *E. coli* O157:H7 survived for 630 days in un-aerated sheep manure stored at air temperatures below 23ºC. Using exponential regression to estimate survival times in soil, Sjogren (1994) found the probable survival times of *E. coli* to range from 20.7 to 23.3 months. Thus, detection of fecal coliforms in soil and agricultural drainage water may not represent recent contamination. This may obscure the source and extent of fecal contamination (Howell et al., 1996).

The principal factor affecting the survival of enteric bacteria in soil systems is moisture (Mubiru et al., 2000). Similarly, moisture retention is the main soil property that has the greatest impact on bacterial survival and is linked to particle size distribution and organic matter. *E. coli* also survive longer in soil at a neutral to alkaline pH as compared to acidic soils (Sjogren, 1994). Specifically, *E. coli* survival is greatest in organic soils under flooded conditions (Tate 1978).

Also, Hagedorn et al. (1978) found that *E. coli* populations were highest after a rise in the water table following major rainfall events.

1.3.2 E. coli Survival and the Q_{10} Equation

Knowing *E. coli* survival rates is important for assessing the severity of contamination that has occurred and making appropriate management decisions. Survival rates in water are dependent on temperature, pH, salinity, predation, streambed resuspension, and sunlight intensity (Blaustein et al., 2013). However, temperature is viewed as the major factor (Flint, 1987). The Q_{10} equation is often used to express the dependence of biological rates on temperature. Applying this equation normally assumes a first-order exponential die-off model. The Q_{10} temperature coefficient is used to describe the fractional change in biological rate (i.e. growth or death) in accordance with a 10^{o}C change in temperature (Blaustein et al., 2013).

In a study by Blaustein et al. (2013), inactivation rate constants were very small in pristine waters; moderate in agricultural waters and lakes; moderate to large in estuary waters and groundwater; and large in river water and wastewater . The sensitivity of the survival rates to temperature becomes low at values of Q_{10} around 1. Also, the survival potential of *E. coli* and other coliforms can be extended by low water temperature (Blaustein et al., 2013). *E. coli* survival rates within a category of waters were found to be highly variable at the same temperature. In fact, *E. coli* inactivation rates in groundwater showed one of the weakest dependencies (Q_{10}= 1.783 ± 0.702; R^2= 0.265) temperature. Pristine waters showed the highest inactivation rate temperature dependency (Q_{10}= 2.066 ±0.190; R^2= 0.939) but agricultural waters still showed a strong dependencies (Q_{10}= 1.548 ± 0.161; R^2=0.640) (Blaustein et al., 2013).

McCambridge and McMeekin (1980) showed that bacterial decline depended on the presence of both bacterial and protozoan predators. When the water temperature drops to around

5° C, *E. coli* can be driven into a viable but not culturable (VBNC) state, which allows for continuous survival without the ability to divide (Naet et al., 2006). In the non-culturable state, the cells may not be available for enumeration with growth media, but they can be resuscitated to regain that ability when the environmental stress is alleviated.

1.3.3 Transport

Globally, groundwater systems provide 25-40% of the world's drinking water (Morris et al., 2003). Traditional strategies designed to protect groundwater sources from contamination rely mainly on the effectiveness of natural attenuation of various microorganisms in soils over some distance (Taylor et al., 2004). The prediction of transport distances of microorganisms in aquifers has been determined with the colloid filtration theory. This theory is based on the assumption that colloid retention follows an invariable rate deposition on collector surfaces, while fluid-phase colloid concentrations reduce log-linearly with increasing transport distance (Lutterodt, Foppen, and Uhlenbrook, 2012). A power-law best describes the distribution of bacteria mass fraction retained in the saturated porous medium and their sticking efficiencies when transported through columns of saturated quartz sand. The net negative surface charge and low inactivation rates of *E. coli* enable long travel distances in the subsurface (Foppen and Schijven, 2006).

E. coli is a poorly adhesive organism and is more hydrophilic than hydrophobic. However, for relatively hydrophilic organisms, the major controlling factor in adhesion of bacteria is the surface charge of the minerals in the aquifer (Scholl and Harvery, 1992). Usually, when *E. coli* are introduced to aquatic environments, they gradually die and this process is accompanied by changes in their characteristics: e.g. the bacteria enter into a viable but non-culturable state.

At Darcy groundwater velocities between 0.1 and 10 m/ d and a grain size of 1mm, the diffusion and sedimentation components are the dominant bacterial transport mechanisms. When

grain size decreases to 0.02mm (the approximate value between silt and clay) diffusion, interception and straining are the dominant transport mechanisms (Foppen and Schijven 2006). Straining is defined as the trapping of bacteria in pore throats that are too small to allow passage.

For *E. coli*, which is negatively charged at typical groundwater pH levels (6-8), favorable attachment sites are positively charged. Thus, *E. coli* can attach to positively charged minerals such as goethite and carbonates like calcite (Foppen and Schijven, 2006). Sticking efficiency of *E. coli* ATCC 25922 was determined in a series of column experiments with sediments consisting of 0.18-0.50mm quartz sand, goethite-coated grains, calcite grains or grains of activated carbon by Foppen and Schijven (2006). The activated carbon experiment showed the greatest initial increase in sticking efficiency followed by the calcite and goethite experiments. Foppen and Schijeven (2006) also report that the increase in die-off rate coefficient per degree Celsius rise is apparent and comparable in most experiments (e.g. Sjogren, 1994; Rice et al., 1992; Wang and Doyle, 1998; Korhonen and Martikainen, 1991; Nasser et al., 1993; Van Donsel et al., 1967; McFeters and Stuart, 1972; Bogosian et al., 1996) and average die-off coefficient at 10^oC is $0.15d^{-1}$ and at 20^oC it is $0.50\ d^{-1}$.

Die-off rate coefficients for *E. coli* can vary depending on environmental conditions such as temperature, soil conditions, and pH. It is important to note the differences in die-off rates between groundwater spiked with raw sewage (0.09- 0.30 d^{-1}; reported by Pang et al., 2003), *E. coli* sorbed into aquifer material (2.59-4.47 d^{-1}), and groundwater alone (0.06 d^{-1}; reported by Filip et al., 1986). In instances were *E. coli* can be absorbed into aquifer material, it will die off far more rapidly than in groundwater sources within limited or no binding sites and in groundwater spiked with raw sewage. Furthermore, the effect of soil on the die-off rate (e.g. toxic substances, moisture, and/or nutrients) depends on local conditions. With regard to toxic

substances, such as Cu, Althaus et al. (1982) reported that the die-off rate coefficient for *E. coli* O157:H7 doubled for a Cu concentration of 3.91mg/L compared to 0.61mg/L.

Die-off rate coefficients are also variable in water. For example, Kudryavtseva (1972) observed a coefficient of 0.12 d^{-1} for *E. coli* in groundwater; McFeters et al. (1974) observed a coefficient of 0.77 d^{-1} for thermotolerant coliforms in well water; Keswick et al. (1982) observed a coefficient of 0.74 d^{-1} for *E. coli* strain Hfr in a rural domestic well 275 ft in depth; and Caldwell et al. (1989) observed a coefficient of 0.01 d^{-1} for sterile well water for *E. coli* ED 8654.

In coarse-grained aquifers the total retention rate coefficient is dominated by decay while the physiochemical removal processes are of secondary importance. When the grain size is reduced, the total retention rate coefficient increases due to an increase in the diffusion, interception, and straining components in the SCCE (single collector contact efficiency). Diffusion has the largest influence on total retention rate with regard to grain size. If the size of the colloid increases, then the total retention rate coefficient increases due to an increase of the sedimentation, the interception, and the straining component in the SCCE. Sedimentation, however, has the largest influence on total retention rate with regard to colloid size.

The capacity of a soil to remove microbes is inversely related to soil saturation and is greater in soils with high clay contents and cation exchange capacities (Reddy et al., 1981). Various column and field experiments have indicated that macropore, or non-matrix flow, is the dominant transport pathway for fecal bacteria. This means that soils more susceptible to shrinking and cracking, such as clays, could be less effective than sandy soils in limiting bacterial transport (Jamieson et al., 2002). There is some contradiction in the literature about the effectiveness of soils with clays and high cation exchange capacities at removing microbes.

Specifically, Jamieson et al. (2002) showed in laboratory experiments that soils with high clay contents are less effective at limiting bacteria survival and transport than other soils because they are susceptible to cracking and shrinking. However, cited literature (e.g. Reddy et al. 1981; Canter and Knox 1988) in their paper suggested the opposite. An alternative interpretation of this contradiction would deem soils with high clay contents and cation exchange capacities as very effective in limiting bacteria transport and survival under limited cracking or shrinking conditions. This is supported from previously referenced (e.g. Foppen and Schijven 2006) information that the dominant removal action of clay soils is straining and therefore limited cracking and shrinking conditions would increase straining

Lutterrodt, Foppen, and Uhlenbrook (2012) have investigated the sticking efficiency distribution and transport of various *E. coli* strains in natural springs in Kampala, Uganda. Transport distance of various *E. coli* strains only reached about 2.5 m with an unfavorable sticking efficiency of 0.01 under geochemical heterogeneity. However, maximum transport distance ranged from 8-23m in the absence of geochemical heterogeneity for the various *E. coli* strains. Based the assumption that the shallow aquifer in Kampala is characterized by geochemical heterogeneity, when a plume of *E. coli* would enter the pristine aquifer, it is likely that most of the bacteria would be removed. Thus, spring protection areas of only a few meters would be needed. However, in the event that the aquifer is not pristine anymore (which is the reality of the aquifer in Kampala), the 8 to 23 m range best describes the transport distance of an *E. coli* plume in the aquifer. In other words, prolonged infiltration of waste water containing *E. coli* means that part or most of the positively charged attachment sites within the aquifer media will become occupied and, thus, *E. coli* will be able to travel farther within the aquifer. Overall, transport distances needed for five log removal of bacterial cells ranged from 3 to 22 m and was

dependent on the presence of geochemical heterogeneity, the distribution of unfavorable sticking efficiencies, pore water flow velocity, and decay rate coefficient (Lutterodt, Foppen, and Uhlenbrook, 2012).

1.4 Coliform and *E. coli* Incidence Outside of Pennsylvania and Public-Water Quality Regulations

Nationally, 24 million people rely on private or individual water systems as their source of drinking water supply (Zimmerman et al., 2001). Consumption of contaminated ground water has been responsible for about 50% of all reported outbreaks of waterborne diseases in the US since the early 1900s (Zimmerman et al., 2001). According to the World Health Organization, nearly 10% of global disease could be prevented by improving water supply, sanitation, hygiene and the management of water sources (Pruss-Ustun et al., 2008). Providing sufficient amounts of quality drinking water is a necessity and protecting and maintaining a sustainable long-term supply of such resources is of national and international concern (Reid et al., 2003). Groundwater from shallow aquifers and sources is particularly susceptible to contamination from point and diffuse sources (Fuest, Berlekamp, and Klein 1998; Nolan and Stoner 2000).

A UK study by Humphrey and Cruickshank (1985) detected fecal coliforms in 62% of 55 private water supplies examined in southwest England. Similarly, Shepherd and Wyn-Jones (1997) detected fecal coliforms in 77% of 218 private water supplies in England, Wales, and Scotland. Rutter et al. (2000) demonstrated a clear regional and seasonal pattern of microbial contamination of water supplies with greatest incidence rates recorded during summer and fall. Reid et al. (2003) detected fecal contamination in 35% of their samples from private water supplies in Aberdennshire, UK. They also found seasonal changes in fecal and nitrate contamination. Coliform incidence was more than double in the latter half of the year while

nitrate concentration was greatest in the first half of the year (Reid et al., 2003). Seasonal average rainfall amount was positively correlated with coliform incidence and nitrate concentration.

1.4.1 Total Coliform Rule

The use of enteric indicator organisms to estimate the persistence and fate of pathogens in the environment is easier and more efficient for detecting pathogen presence as compared to testing for specific species (e.g. species that are not indicators) (Crane et al., 1981). Fecal coliforms are the most commonly used indicator organisms. However, the USEPA recommends that *E. coli* be used as the principle indicator organism in freshwater, instead of fecal coliforms (USEPA, 2001).

The Total Coliform Rule (TCR) was enacted by EPA on June 29, 1989 with a purpose of improving public health protection by reducing fecal pathogens to minimal levels through the control of total coliform bacteria (which may include *E. coli*). This rule establishes a maximum contaminant level (MCL) based on the presence or absence of total coliforms, modifies monitoring requirements (e.g. testing for fecal coliforms), requires the use of a sampling siting plan and sanitary surveys for systems collecting fewer than five samples per month. TCR applies to all public water systems under EPA jurisdiction.

There are various routine sampling requirements under TCR. These requirements include: total coliform samples must be collected at sites which are representative of water quality throughout the distribution system according to a written sample siting plan subject to state review and revision; each total coliform-positive sample much be tested for the presence of fecal coliforms or *E. coli*; and monthly sampling requirements must be based on population served (Appendix 1). Repeat samples are also required when a routine sample tests positive for

coliforms. The TCR requires that 3 Repeat samples must be collected within 24 hours of learning of a total coliform-positive Routine sample result. One sample must be collected from same tap as the original sample and one sample must be collected within five service connections upstream and downstream.

Compliance of the TCR is based on presence or absence of total coliforms and is determined each month that the system serves water to the public. A monthly MCL violation occurs if a system has greater than 1 Rountine/Repeat total-coliform positive sample per month (in facilities collecting less than 40 samples per month) or has greater than 5.0% of the Routine/Repeat samples test positive for coliforms (in facilities collecting more than 40 samples per month) (Appendix 1). An acute MCL violation occurs if any public water system has any fecal coliform- or E. coli-positive Repeat sample (Appendix 1).

For a monthly MCL violation, the violation must be reported no later than the end of the next business day and the public must be informed within 30 days. For an acute MCL violation, the violation must be reported to the state no later than the end of the next business day and the public must be notified within 24 hours.

The TCR was revised and its revisions enacted on February 13, 2013. One revision requires that PWSs develop a written sample siting plan that identifies the systems sample collection schedule and all sample times. Other revisions require that PWSs that have an indication of coliform contamination (e.g. as a result of coliform-positive samples or E. coli MCL violations) assess the problem and take correction action based on the severity of the problem (Appendix 1). Similarly, violations can occur if the proper assessments are not conducted. These assessments and other provisions of the Revised Total Coliform Rule can be viewed at length in Appendix 1. Again, the revisions and the TCR only apply to PWSs.

1.5 Pennsylvania Water Wells and Water Quality Studies

US Bureau of the Census (1992) shows that about 1 million households in PA rely on ground water from private on-lot wells for daily water supply and about 4 million households rely on ground water from community or public water supply systems for daily drinking water. Despite the fact that research has shown that many private water wells in Pennsylvania have failed at least one drinking water standard, Pennsylvania remains one of few states without any private well regulations. Furthermore, nationwide studies have shown that about 15-50% of private water systems fail at least one safe drinking water standard (Swistock, Clemens, and Sharpe, 2009). Pennsylvania has no statewide well-construction requirements and most drilling and testing in Pennsylvania is done with no regulatory oversight. The Pennsylvania Department of Environmental Protection (PA DEP) recommends that wells be sited uphill at least 100 ft from potential contamination sources such as septic leach fields, roads, fuels tanks, and barnyards (Zimmerman et al., 2001). PA DEP mentions barnyards because these areas are associated with a lot of manure on the ground surface that is susceptible to runoff. This runoff could carry bacteria into various water supplies such as streams and ground water. Hence, contamination of private household water wells is possible.

Bacterial contamination in Pennsylvania ground water from private wells is common but it is not known if contamination is from well-construction characteristics (e.g. bacteria enter at the well bore) or if the aquifer is contaminated. A study conducted by the Pennsylvania Department of Agriculture (2001) sampled ground water from wells completed mainly in carbonate rocks and in rocks of Triassic age**.** They found that 25 of 122 (20.1%) private wells tested positive for *E. coli* and 73 of 122 (59.8%) test positive for total coliforms, as shown in Table 1.

Table 1: Percentages of Total Coliform and E. coli detected in ground water wells sampled by PA Dept. of Agriculture (2001)

Study area	Total samples				Samples from private households		
	Number of samples	Number of wells	Percentage total coliform	Percentage *E. coli*	Number of samples	Percentage total coliform	Percentage *E. coli*
Blair County	120	118	84	48	56	86	36
Bedford County	73	73	70	37	11	73	27
Berks County	44	42	57	16	16	32	12
Lebanon County	26	26	50	12	10	40	0
Lehigh County	8	8	25	12	7	12	0
Northampton County	15	15	40	0	9	44	0
Triassic System	44	44	36	9	13	23	0

1.5.1 USGS with PaDEP Study

The United States Geological Survey (USGS) in cooperation with PaDEP conducted a study in South-Central and Southeastern Pennsylvania to determine if well water from private wells constructed with annular grout have lower incidence of bacterial contamination than wells constructed without annular grout. Wells in predominantly agricultural land-use settings were the main focus. The amount of samples taken by county, and percentage of private water wells per county in the study area is shown in Table 2. Samples were collected from September 2000 to March 2001 and they were tested for total coliforms and *E. coli* concentrations. Well characteristics, such as sanitary vs. nonsanitary, and underlying rock type, such as carbonate vs. noncarbonate, were also considered. Ideal sanitary wells are described as having grout installed along the entire annulus of casing and sealed well cap (Zimmerman et al., 2001). However, wells with sealed caps were rare, so this was left out of the definition of a sanitary well for the data. Nonsanitary wells were described as having loose dirt or fill around the annulus of casing and a loose fitting well cap (Zimmerman et al., 2001).

Table 2: U.S. Bureau of the Census (1990) information for the counties in the USGS Study area

County	Number of households	Number of households in county with private wells	Percentage of households in county with private wells
Chester	133,592	49,316	37
Cumberland	73,506	19,587	27
Dauphin	95,123	21,655	23
Lancaster	151,352	50,966	34
Lebanon	42,708	13,034	31
Montgomery	254,596	30,716	12
Perry	14,930	11,112	74
York	128,764	43,441	34
Total	894,571	239,827	

Samples were collected one time only at each site from an outside faucet that bypassed any water-treatment system. Aliquot sizes of 200 ml, 100 ml, and 10 ml were in an attempt to obtain bacteria detections and were processed immediately on site using membrane filtration techniques (Zimmerman et al., 2001). USGS researchers used standard plate count membrane-filter method for enumeration of total coliform on m-Endo media and *E. coli* on NA-MUG media. The membrane filter pore size was 0.45 micrometers. Golden-green metallic colonies represent total coliforms while dark blue fluorescent perimeters around a darker colony (only seen under UV light) represent *E. coli* (Zimmerman et al., 2001).

To ensure Quality Assurance and Quality Control, split replicate and/or sequential replicate aliquots were collected at 21 of the 78 sites. Split replicates were collected in the same bottle and then divided into subsamples for identical analysis so that the reproducibility in the sample-processing results could be assessed. Sequential replicates were collected to assess the variability among samples resulting from sample collection. There were few exceptions in the data, but typically the differences were at the detection limit (Zimmerman et al., 2001).

Results

Total coliform bacteria were found in 48 of 78 (62%) of the wells sampled and 8 of 78 (10%) samples tested positive for *E. coli*. Furthermore, 17% of the samples that tested positive for total coliforms were also positive for *E. coli*. However, neither *E. coli* nor total coliforms were detected in 30 of 78 (38%) samples. Total coliform bacteria were just as likely to be found in sanitary wells as in nonsanitary wells (60%, 65% respectively) (Zimmerman et al., 2001). Wells underlain by carbonate bedrock had the highest percentages of total coliforms detected (75%), but total coliforms were also detected in about 50% of wells underlain with noncarbonate bedrock. *E. coli* were detected in 15% of nonsanitary wells as compared to 5% of sanitary wells and were only found in wells underlain by carbonate bedrock.

Sanitary vs. Nonsanitary construction

There is no statistically significant difference in total coliform detection between sanitary and nonsanitary wells. However, *E. coli* was more likely to be found in water from nonsanitary wells than sanitary wells (Zimmerman et al., 2001).

Carbonate vs. Noncarbonate Underlying Bedrock

There is no statistically significant difference in total coliform detection between wells underlain by carbonate and noncarbonate bedrock. However, since all *E. coli* detections were found in wells underlain by carbonate rock, this may indicate a high aquifer vulnerability to *E. coli* contamination (Zimmerman et al., 2001).

Seasonal Variation

Comparisons between the bacteriological data from this study and the Lower Susquehanna River Basin National Water-Quality Assessment (LSUS NAWQA) Program show seasonal variation. The USGS study had lower concentration of bacteria than the LSUS NAWQA Program (Zimmerman et al., 2001). This is most likely attributed to the season of the

sampling period. The LSUS NAWQA Program sampled from June to August (summer months) of 1993-95 while the USGS sampled during the fall of 2000 and winter of 2001 (Zimmerman et al., 2001). During the summer months, the growing season, manure is applied to fields which may have increased the amount of *E. coli* and total coliforms present in the area around the wells.

Other Correlations between bacteria concentrations and well characteristics
Total coliform concentration increased;

- As the depth of the first water-bearing zone increased for nonsanitary wells
- As the depth of the first water-bearing zone increased for sanitary wells underlain by carbonate rock

In contrast, a negative correlation of bacteria concentrations with depth of water-bearing zones is expected (Zimmerman et al., 2001). However, water flow in carbonate rock is controlled by conduit flow which means that water produced from deeper water-bearing zones has not necessarily undergone more filtration or have a long residence time (Zimmerman et al., 2001).
Total coliform concentrations decreased;

- As the depth to water-bearing zone in sanitary wells increased.
- As the casing length increased in nonsanitary wells underlain by noncarbonate rock.

There is no statistically significant difference between wells with and without evidence of insects and the presence of bacteria for all parameters (sanitary, nonsanitary, bedrock type, etc.) (Zimmerman et al., 2001). However, the Wisconsin Department of Natural Resources (1993) has shown that insects (earwigs) can be a source of bacterial contamination in water wells.

Sanitary seals should still be recommended for the preservation of clean well water. The data set for sanitary wells with sealed well caps in this study was too small to conduct statistical

analysis on, therefore it is uncertain whether or not a sealed well cap can be correlated with the reduction or absence of total coliforms and *E. coli* in private household water wells (Zimmerman et al., 2001).

1.5.2 Center for Rural Pennsylvania Study

A study by Swistock, Clemens, and Sharpe (2009) of 700 private water wells across Pennsylvania was conducted from 2006-2007 (Figure 3). Two water samples were taken from each well; the first sample was a first-draw collection and the other sample was collected after a two minute purge. The water samples were analyzed for total coliform bacteria, *E. coli*, pH, lead, nitrate-nitrogen, arsenic, triazine pesticides, and hardness. Well characteristics were also considered. The average well depth was 172 feet and the maximum well depth was 1100 feet. Over 72% of the wells had been drilled since 1970 but only 4% had been drilled since 2005.

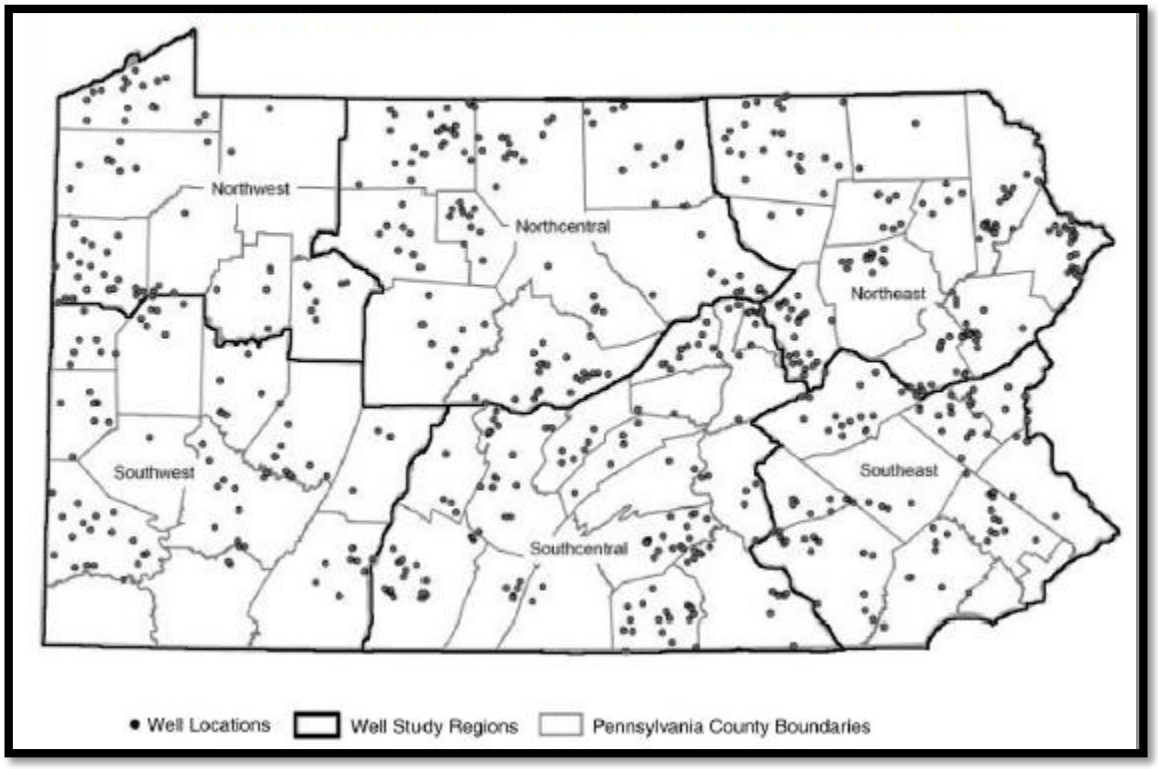

Figure 3: Center for Rural Pennsylvania Study Wells. The approximate locations of the 701 private wells sampled in 2006 and 2007 and regional boundaries (Swistock, Clemens, and Sharpe, 2009).

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. The carbonate rock type produced significantly higher bacteria levels, pH, nitrate, and hardness compared to most other rock types. Igneous rock (located in parts of southeast and southcentral Pennsylvania) was more acidic and lower in hardness compared to other rock types. Finally, sedimentary and sandstone/ shale bedrock types produced nearly identical water quality results.

TC bacteria were found in 33 percent of the sampled wells. The highest incidence of TC occurred in the southeast and southwest regions while the lowest incidence was observed in the northwest and northeast regions. Butler County is within the southwest region. *E. coli* were detected in 14% of the wells sampled. The incidence of *E. coli* in this study was greater than reported by some regional studies, such as Zimmerman et al. (2001) and Durlin and Schaffstall (2001), but less than others (e.g. Bickford et al., 1996). *E. coli* incidence showed approximately the same regional trend as TC bacteria. DNA fingerprinting indicated that the *E. coli* found in the samples was more closely related to animal sources than human sources, suggesting that most contamination has occurred from surface water near agricultural or animal-related land uses.

Of the wells that contained coliforms or *E. coli*, 84% were tested during moist conditions while only 16% were testing during dry weather. Thus, there is a strong correlation between the presence of coliforms and *E. coli* in water wells and moist soil. Overall, this study suggested that the variability of bacteria results related to weather conditions must be considered in interpreting water quality results and determining when to test the well. In this study, ANCOVA models showed near constant bacterial contamination for the three seasons (spring, summer, and fall)

that the wells were testing. Thus, season was not a statistically important factor for coliform and *E. coli* contamination or for any water quality parameter tested.

Not one individual well component (e.g. well casing, above ground well casing, grouted/ cemented casing, ground slope away from casing, and sanitary well cap) produced statistically significant results over the other, with regard to bacterial contamination. However, combinations of well construction features were significant in reducing total coliform and *E. coli* concentrations. Wells that have poor well scores (i.e. they lack appropriate construction features) are far more likely to have *E. coli* compared to wells that have more or all appropriate construction features. However, despite having a wellscore of 5 (i.e. having all appropriate construction features), coliforms and *E. coli* were still found in 28% and 8%, respectively, of the wells sampled.

Regarding bacterial contamination, soil moisture conditions at the time of sampling were the single most important variable in explaining the occurrence of bacteria in private water wells. Also, inadequate well construction and geology was strongly correlated with the occurrence of both coliform and *E. coli* bacteria contamination in wells. Proper well construction was significant in reducing the incidence of this contamination. Furthermore, the data confirm the importance and success of wellhead protection areas of 50 to 100 feet around the wellhead to avoid well contamination from surface level activities (e.g. septic systems, dog kennels, and agricultural land use**).**

1.6 Overview on Marcellus Shale Gas Development and Water Quality Issues

The United States has numerous natural gas resources within the Barnett, Haynesville/Bossier, Antrim, Fayetteville, New Albany, and Marcellus Shale. It is estimated that the amount of recoverable natural gas from these sources could be more than 1,744 trillion cubic

feet (Tcf) (50km^3) (DOE, 2009). At the annual production rate of about 19.3 Tcf, there is enough natural gas to supply the US for the next 90 to 116 years (Kargbo et al., 2010). The focus of this section will be on Marcellus shale gas development because the Marcellus shale formation lies underneath the small rural community in this study and it is currently being developed.

The Marcellus Shale is of Devonian Age and belongs to a group of black, organic-rich shales that are common constituents of sedimentary deposits (Kargbo et al., 2010). The gas within this shale is mostly thermogenic and recent production data suggest recoverable reserves from this shale could be as great as 489 Tcf (Engelder, 2009). Also, it is not very deep in some places and averages about 1.6 miles below the surface (Kargbo et al., 2010). However, there are many environmental concerns and regulatory challenges related to natural gas extraction. The Safe Drinking Water Act excludes the regulation of hydraulic fracturing by the US Environmental Protection Agency (EPA) (Kargbo et al., 2010). This exemption has allowed the gas companies to keep the hydro fracture fluid, or "frack" fluid", formulas confidential. This exemption complicates treatment efforts by wastewater treatment plants of hydrofracture fluid. Furthermore, it would complicate cleanup efforts if some sort of accident occurred that released frack fluid into an aquifer, stream, lake, or soil.

The most important thing to realize is that modern gas wells are drilled in an unconventional way. In other words, older oil and gas wells were drilled vertically, or conventionally, while modern natural gas wells have a horizontal portion. Thus, they are unconventional. Once they reach their target vertical depth, the operator is able to drill horizontally into the shale layer. Although more technologically intensive than drilling vertically, it is more efficient in capturing natural gas because a greater area of the shale can be reached with only one surface disturbance, or well pad. Furthermore, many wells can be drilled from the

same pad. What may have took dozens of wells scattered over a few hundred acres decades ago, now only takes 1-6 wells on a few acre well pad capturing gas from a horizontal well that could be least 3000 ft long (Kargbo et al., 2010). Once the drilling and casing are completed, the well is fracked using hydraulic fracturing techniques. Fracking occurs in stages: (1) perforate the casing and cement at predetermined locations; (2) pump water-based fracturing fluids (2 to 10 million gallons of water is used) through the perforation clusters; (3) set a plug; and (4) move up the well and repeat this process at each fracturing location (Kargbo et al., 2010). It is also important to note that as much as 80% of the frack fluid is not recovered and remains within the formations.

Even though the frack fluid is mainly composed of water, there are other important ingredients; some of which may pose significant human and environmental health risks if released into the environment. Proppants (e.g. quartz sand) are needed to prevent the fractures from closing, gels (e.g. hydroxyethyl cellulose) are added to increase frack fluid viscosity and reduce fluid loss from the fracture, acids are added to remove drilling mud near the well bore, biocides prevent gas forming (e.g. H_2S) microbes from growing and contaminating the methane gas, scale inhibitors control the precipitation of carbonates and sulfates, and surfactants increase the recovery of injected fluid into the well by reducing the interfacial tension between the fluid and formation materials (Arthur, Bohm, and Layne, 2008).

The specific compounds used in this process could include hydrochloric acid, hydroxyethyl cellulose as gel, glutaraldehyde as a biocide, pertroleum distillate as a friction reducer, ammonium bisulfate as oxygen scavenger, 2-hydroxy-1,2,3-propanetricarboxylic acid for iron control, N,n-dimethyl formamide as corrosion inhibitor, methanol-based surfactants and other chemicals such as fluorocarbons, naphthalene, butanol, and formaldehyde (Arthur, Bohm,

and Layne, 2008). Most of these compounds are carcinogenic or associated with negative health effects of the eyes, skin, lungs, intestines, liver, brain and nervous system (Kargbo et al., 2010). Aside from dealing with carcinogenic compounds, other challenges that drillers in the Marcellus Shale face include: (1) disruption and alteration of subsurface hydrological condtions including the disturbance and destruction of aquifers; (2) severe ground subsidence because of extraction, drilling, and unexpected subterranean conditions; and (3) triggering small scale earthquakes (Kargbo et al., 2010).

Section 2: Specific Aims, Hypotheses

2.1 Specific Aims

The goal of this study was to determine the level of coliforms and *E. coli* in private well-water from a small rural community located in Connequessining Township, Bulter County, Pennsylvania. Marcellus shale gas development is present and expanding near this community, and within Butler County and Western Pennsylvania as a whole. This study serves a three-fold purpose: (1) to act as a water quality survey for the community; (2) identify relationships between chemical indices, well construction characteristics, geology and coliforms and *E. coli* incidence; and (3) attempt to identify any relationship between Marcellus shale gas development and fecal contamination of well-water.

2.2 Hypotheses

1) Bacteriological data will show that the incidence rate of E. coli and total coliforms will not exceed that found in previous well-water quality surveys conducted in Pennsylvania.
2) Marcellus shale gas development does not affect the incidence of fecal contamination in well-water.

Section 3: Materials and Methods

Two EPA standard methods were primarily used in this study. One method, 9222 B. Standard Total Coliform Membrane Filter Procedure, was used first to detect the presence coliforms in the samples. The other method, 9222 G. MF Partition Procedures Escherichia coli Partition Methods, was used to second to detect the presence of *E. coli* in coliform-positive samples.

3.1 Sample Collection

One-hundred mL samples were collected in triplicate using six 50 mL sterile test tubes. The samples' origin is well water used for private household uses. The water was collected from either an outside spigot or other inside faucet prior to any water treatment system (i.e. water softeners, UV treatment, or filtration). After collection, the samples were kept in a cooler (no longer than two hours) with cold packs until placed in a refrigerator in the laboratory and analyzed. The samples were never kept longer than 48 hours and most were analyzed on the same day of collection. Samples were collected from November 2012 to August 2013.

3.2 Colform Detection

3.2.1 Media Prep

Total Coliform counts were determined using standard operating procedure (SOP) 9222 B. Standard Total Coliform Membrane Filter Procedure. The media, m-Endo agar, used in this method was made in bulk and rehydrated with the proper ratios of 95% ethanol and water described on the manufacturer's label. After rehydration, the media was heated to a near boil. Then it was cooled to 45^{o}C before 5 mL was dispense into 50-mm tight fitting petri dishes and

allowed to solidify. When the petri dishes were not being used, they were wrapped in aluminum foil and kept in the refrigerator for no longer than three months.

3.2.2 Filtration

Samples were filtered using 0.45µm, black gridded, 47mm sterile Millipore filters. An absorption pad was placed over a porous plate and then the filter was placed on top of the pad grid side up. A matched funnel was placed over that and locked to the plate using a clamp. The samples were then filtered under partial vacuum. After filtration and disassembly of the apparatus, the membrane filter was transferred using sterile forceps to the appropriately labeled m-Endo agar petri dish and incubated at 35± 0.5ºC for 24 hours. Coliforms colonies are observed dark-red in color with a metallic sheen. Generally, pink, blue, white, or colorless colonies are non-coliforms.

3.2.3 Coliform and E. coli Verification

Atypical grown on m-Endo agar may appear dark-red but do not develop a metallic sheen. In order to confirm that they are coliforms, or that coliforms are present in the sample, three addition media were used to determine coliform and *E. coli* presence based on lactose fermentation and thermotolerance.

Lauryl Tryptose Broth (Ref. 224140), Brilliant Green Bile (Ref. 273000), and EC-MUG (Difco, Ref. 222100) were rehydrated using de-ionized water and then autoclaved at 121ºC for 30 minutes. Then, reusable 100mL test tubes with fermentation vials inside were autoclaved at 121ºC for 30 minutes. The media was transferred aseptically into the appropriately labeled test tubes in a manner that did not trap air bubbles within the inverted fermentation vials.

Suspected coliform colonies from membranes incubated on m-Endo agar were swabbed using sterile cotton swabs. Test tubes with lauryl tryptose broth, brilliant green bile, and EC-

MUG were inoculated simultaneously using these swabs. Note: the entire membrane was swabbed for presence-absence results in the drinking water samples. Lauryl tryptose broth and brilliant green bile tubes were incubated at 35± 0.5ºC for up to 48 h. Gas formed in lauryl tryptose broth and confirmed in brilliant green bile within 48 h verifies the colony as a coliform. EC-MUG tubes were incubated at 44.5 ± 0.2ºC for 24 h. Gas production and growth in these tubes verifies the presence of *E. coli* and thermotolerant coliforms.

3.3 *E. coli* Counts and Detection

Viable, but non-culturable bacteria are only identified in tests utilizing defined substrate techniques. These types of tests measure biochemical changes, such as hydrolysis reactions, in media rather than colony formation (Zhai et al., 1995). For this reason, total *E. coli* counts were determined after coliform counts (with M-ENDO agar) using 9222 G. MF Partition Procedure, *Escherichia coli* Partition Method. Verification of *E. coli* may be achieved for a total-coliform sample by using media containing 4-methylumbelliferyl-β-D-glucuronide (MUG). In this method, *E. coli* is defined as any coliform that produces the enzyme β-glucuronidase and hydrolyzes the MUG substrate to produce a blue fluorescence under 366nm UV light.

The nutrient agar (NA) MUG media was rehydrated with de-ionized water and autoclaved at 121ºC for 30 minutes. After autoclaving, it was allowed to cool to 45º C and 5 mL was dispensed into 50-mm petri dishes and allowed to solidify. For *E. coli* determination, coliform positive membranes filters from 9222 B. were transferred aseptically to an NA-MUG plate immediately after the incubation period for coliforms as specified in 9222 B. These plates were incubated at 35 ± 0.5ºC for 4 h. After incubation, the plates were observed under 366 nm UV light. Under this light source, *E.coli*-positive colonies will exhibit blue fluorescence around the outer edge of the colony.

3.4 Controls and Photos of Experimental Results

A river water sample from the Ohio River was used a positive control for both total coliform and *E. coli* methods. The various media from the methods above were incubated without inoculation at their respective temperatures as negative controls.

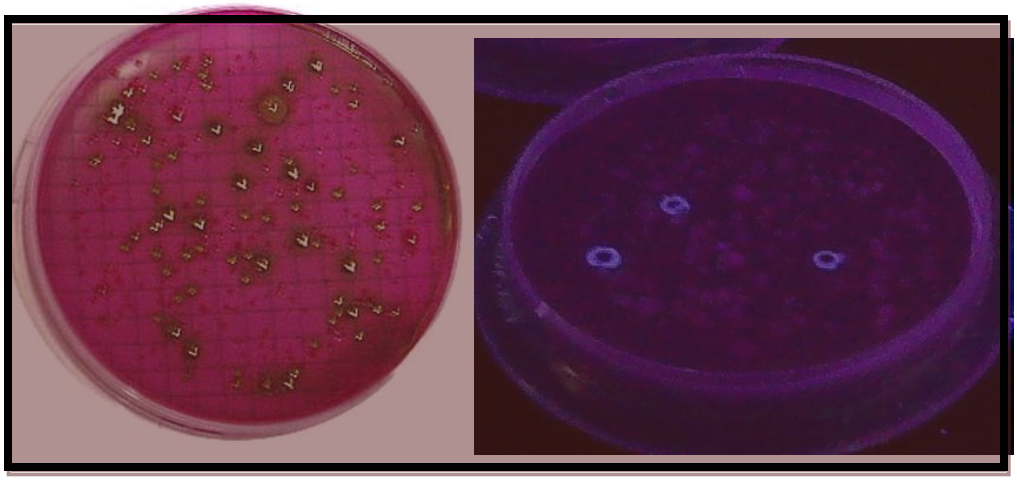

Figure 4: Photos of Total Coliform and *E. coli* Positive Samples. On the left, a total coliform positive sample on m-ENDO agar: coliform colonies have a metallic sheen. On the right, an *E. coli* positive sample on NA MUG media. Colonies with a blue fluorescent halo are *E. coli*.

Section 4 Results

4.1 Total Coliform and *E. coli* colony counts from the Study Area (small community)

A total of 29 private drinking water wells were sampled during this survey. Twenty-six of these samples were collected from the small rural community while the other three samples (MS 207, 171, and 174) were collected from houses surrounding the Bricker Well Pad (Figure 5) near the study area. Coliforms and *E. coli* were largely absent in these samples with the exception of MS119 MS199, MS233, and MS230 (Table 3). It is important to note that MS119 was taken from a spring water source on the property and not from a water well. Only 2 of 29 (6.8%) wells sampled tested positive for coliforms and only 1 of 29 (3.7%) wells sampled tested positive for *E. coli*. One well showed positive results twice (MS199 in August 2013 and MS233 in October

2013) and coliforms were detected both times. However, *E. coli* was not detected at the later date.

Eight wells were sampled at different times of year and some evidence is present to directly link coliform and *E. coli* incidence and type of season (Table 4). For example, the well that was positive for coliforms and *E. coli* was sampled in January 2013 (MS118), August 2013 (MS199), and October 2013 (MS233) with positive results occurring in August and October.

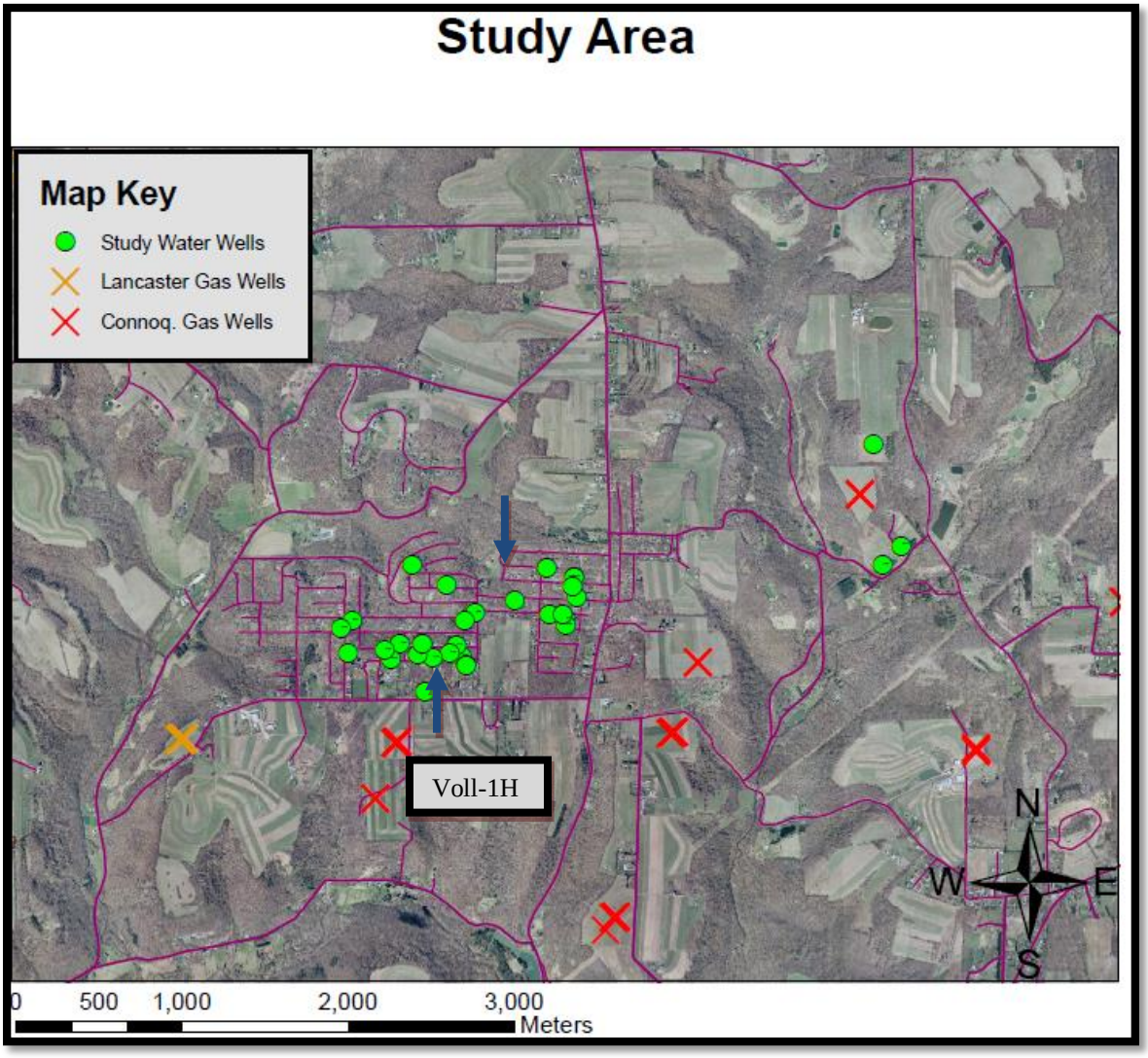

Figure 5: Aerial photograph of the Study Area. Roads, Study Water wells, and Lancaster and Connoquenessing Township gas well permits have also been plotted (see the map key). Three samples were collected outside of the community. These samples were collected from three houses around the Bricker Well Pad north east of the study area**.** Blue arrows point to the location of the coliform positive samples: the northern pointing arrow indicates MS199 and MS233 while the southern pointing arrow indicates MS230

Table 3: Study Area Well Water TC and *E. coli* counts, Well Depths, Distance to Septic. TC and *E. coli* colony results are per 100 mL. "N/T" denotes "not tested". Samples that did not produce a coliform colony were not tested for *E. coli*. "*" denotes a sample taken from a residence with four water wells on the property pooled into one source and pumped to three houses. "**" denotes a second house receiving water from the holding tank. "***" denotes samples taken from water wells near the Bricker well pad (Figure 5)

Sample Number	Sample Type	Well Type	Well Depth	Distance to Septic Tank (ft)	Coliforms	E. coli
088	Kitchen faucet	Cable tool	165	---	<1	N/T
090	Kitchen faucet	---	---	---	<1	N/T
087	Sink faucet	Cable tool	130	---	<1	N/T
093	Kitchen faucet/	---	165	---	<1	N/T
086, 116,	Kitchen	Cable tool	176	56	<1	N/T
092, 121,	Outside spigot	---	125	43	<1	N/T
089	Bathroom	---	---	---	<1	N/T
085, 114,	From pump	Cable tool	105	88	<1	N/T
117	Kitchen faucet	---	---	---	<1	N/T
119	Spring water	---	350	---	**1**	N/T
124	Basement tank	---	---	---	<1	N/T
125	Basement	Rotary	290	---	<1	N/T
126	Basement tank	Cable tool	380	---	<1	N/T
123, 200	Basement	Rotary	120	---	<1	N/T
128, 203	Kitchen faucet	---	275	---	<1	N/T
120	Well	---	---	---	<1	N/T
115, 182	Outside spigot	Cable tool	200	181	<1	N/T
158	Kitchen, from	---	175	---	<1	N/T
159**	Kitchen	---	**	75	<1	N/T
184	Kitchen	---	900	55	<1	N/T
118	Kitchen	Cable tool			<1	N/T
199					**13**	**6**
233			140	74	**3**	**0**
204*	Kitchen	Rotary	195	75	<1	N/T
		---	265a	70		
		---	140	104		
		---	265b	110		
206	Kitchen	---	300	31	<1	N/T
175	Outside Spigot	Cable tool	100	127	<1	N/T
230	Kitchen	---	125	11	**15**	**0**
232	Kitchen	---	135	148	<1	0
207***	Before filter	---	---	---	<1	N/T
171***	Outside Spigot	---	75	---	<1	N/T
174***	Outside Spigot	Cable tool	160	---	<1	N/T

Table 4: Seasonal Coliform and E. coli Variation. Well water sites within the small rural community that were sampled at different times of year.

Sample Site	Sample Type	Coliforms (per 100ml)	E. coli (per 100ml)	Month Sampled
MS118	Kitchen	<1	N/T	January 2013
MS199	Kitchen	13	6	August 2013
MS233	Kitchen	3	<1	October 2013
MS086	Bathroom	<1	N/T	November 2012
MS116	Bathroom	<1	N/T	January 2013
MS161	Kitchen	<1	N/T	February 2013
MS186	Kitchen	<1	N/T	May 2013
MS092	Outside spigot	<1	N/T	November 2012
MS121	Outside spigot	<1	N/T	January 2013
MS198	Outside Spigot	<1	N/T	August 2013
MS085	From pump	<1	N/T	November 2012
MS114	Outside spigot	<1	N/T	January 2013
MS157	Outside spigot	<1	N/T	February 2013
MS123	Basement	<1	N/T	January 2013
MS200	Kitchen	<1	N/T	August 2013
MS128	Kitchen faucet	<1	N/T	January 2013
MS203	Kitchen	<1	N/T	August 2013
MS120	Sink, w/ filter	<1	N/T	January 2013
MS160	Kitchen, no filter	<1	N/T	February 2013
MS187	Well	<1	N/T	May 2013
MS115	Outside spigot	<1	N/T	January 2013
MS182	Well	<1	N/T	May 2013

4.3 Well Characteristics

Some information regarding well construction was unknown (e.g. casing length and age) by the home owner. However, this study was not designed to collect all of this data and some homeowners were unsure of how their wells were constructed, but most well depths and how the wells were bored was available for this study (Table 3). Twenty-three of 29 homeowners knew the depth of their well. Of that 23, 16 wells had depths between 100 and 200 feet. The maximum and average well depth in this study was 900 feet and 221.7 feet, respectively. With regard to how the wells were bored, 13 wells were drilled; 10 by cable tool and 3 by rotary drill. For the other 16 wells, the homeowners did not know exactly how their wells were bored but none were dug. All wells were observed to have a sanitary well cap and all but two had their casings constructed at least 8-12 inches above ground. However, the well from which samples MS086, MS116, and MS164 were taken had its cap underneath a patio stone below ground level. Also, the well that MS230 corresponds to had its well cap at ground level.

The distances between water wells and septic systems were measured for 14 wells for 11 addresses. There were more wells than addresses in this data set because one address had two wells (e.g. MS184 and MS206) and two other addresses used four wells (e.g. MS204* and MS159** from Table 3). The minimum distance recorded was 11 ft (MS230) and the average distance was 83 ft.

4.4 Geology and Soils

4.4.1 Geology

Coal has been mined in the Butler-Zelienople quadrangles country banks for many years and although some shipping mines have been operated, the coal is generally not as thick or as valuable as in other parts of Pennsylvania (DOI, 1936). The Butler and Zelienople quadrangles are part of the Appalachian Highlands which extend from the Atlantic Coastal Plain to the

Central Lowland and from Alabama to Canada. These quadrangles are on the Appalachian Plateaus which are underlain by Carboniferous rock and older strata (DOI, 1936). Lowest elevation is 860 feet above sea level in the valley of Connoquenessing Creek south west of the town of Zelienople and the highest elevation is 1560 feet above sea level east of Slippery Rock Creek. In general, the hills are composed chiefly of shale with capping ledges of sandstone. Table 5 and 6 are data from core-drill holes near the study area. The tables report the various strata and their thickness and depth. Note that coal and shale make up a large portion of the core samples and that there are many layers of each. Other non-coal/ shale layers are sandstone, clay, and limestone. Figure 6 depicts the approximate locations of the core-drill samples and Study Area.

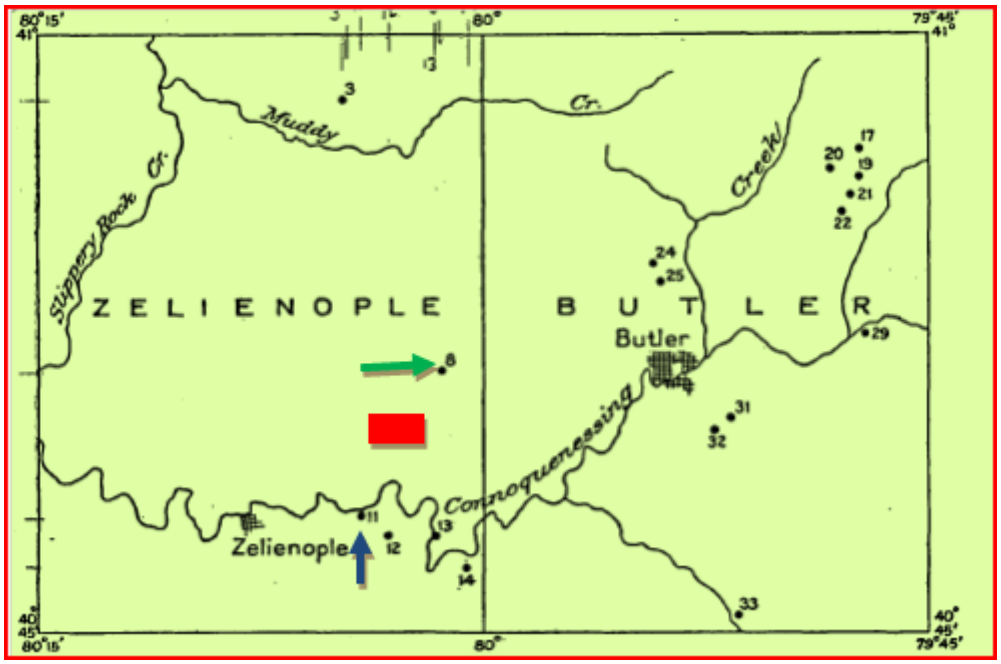

Figure 6: Map Key of the approximate locations of core-drill holes and study area. Core-drill hole #8 Connoquenessing Township marked by green arrow. Core-drill hole #11 Jackson Township marked by blue arrow. The study area is overlain with red rectangle. (DOI, 1936)

Table 5: Core-drill hole #8; Connoquenessing Township, Butler County. (DOI, 1936)

	Thickness		Depth	
	Ft.	*in.*	*Ft.*	*in.*
Surface	15	0	15	0
Soft shale	9	0	24	0
Black slate	8	10	32	10
Sandstone	55	0	87	10
Clay	2	4	90	2
Shale	25	4	115	6
Coal (Brush Creek)	1	6	117	0
Clay	3	4	120	4
Shale	14	0	134	4
Shale and sandstone	14	0	148	4
Sandstone	12	2	160	6
Clay	1	0	161	6
Variegated shale	2	3	163	9
Bastard lime	3	8	167	5
Clay	6	3	173	8
Bastard lime		4	174	0
Shale with sand streaks	17	5	191	5
Sandstone	1	6	192	11
Black shale	3	6	196	5
Coal (Upper Freeport)	1	3	197	8
Bony coal		3	197	11
Clay	2	9	200	8
Sandy shale	22	10	223	6
Black shale	11	0	234	6
Coal		5	234	11
Shale and coal streaks	6	9	241	8
Bony coal		1½	241	9½
Shale and coal	1	4	243	1½
Clay	2	0	245	1½
Sandy shale	10	1½	255	3
Sandstone and shale	8	0	263	3
Black slate	5	3	268	6
Dark shale	26	6	295	0
Black shale	10	0	305	0
Bony coal		6	305	6
Coal (Upper Kittanning)	1	10	307	4
Sulphur binder		1	307	5
Coal		8	308	1
Clay		9	308	10
Shale	9	6	318	4
Clay	2	0	320	4
Shale	20	3	340	7
Coal		2	340	9
Sandy shale	10	0	350	9
Shale		6	351	3
Bony coal		5	351	8
Coal		3	351	11
Bony coal		3	352	2
Dark shale	1	6	353	8
Sandy shale	3	5	357	1
Coal (Middle Kittanning)	1	3	358	4
Bony coal		1	358	5
Shaly clay	7	0	365	5
Sandy shale	6	0	371	5
Slate	1	0	372	5
Clay	2	0	374	5
Sandstone	11	0	385	5
Green shale	11	7	397	0
Sandy shale	14	0	411	0
Dark shale	14	4	425	4
Lime (Vanport limestone member)	10	0	435	4
Shale		1	435	5
Bone and sulphur		4	435	9
Coal (Scrubgrass)		10	436	7
Clay	4	0	440	7
Sandstone and shale streaks	10	0	450	7
Shale	1	3	451	10
Coal (Clarion)	1	6	453	4
Clay	4	0	457	4
Sandy clay	10	1	467	5
Sandstone	2	5	469	10
Shale	5	2	475	0
Coal and bone		6	475	6
Sandstone and coal spars		3	475	9
Shale and clay	5	5	481	2
Black shale		7	481	9
Clay	4	0	485	0
Sandstone with coal spars (Homewood)	41	3	527	0

Table 6: Core-drill hole #11; Jackson Township, Butler County (DOI, 1936).

Surface	10	6	10	6
Lime	1	10	12	4
Clay	2	3	14	7
Clay and sandy shale	5	5	20	0
Sandy shale	15	1	35	1
Dark shale	29	6	64	7
Coal (Upper Kittanning)	3	3	67	10
Clay	4	5	72	3
Light shale	5	7	77	10
Clay and shale	7	10	85	8
Dark shale	7	0	92	8
Shale	25	0	117	8
Bone		4	118	0
Coal (Middle Kittanning)	2	11	120	11
Clay	17	0	137	11
"Lime"	1	7	139	6
Shale	32	1	171	7
Dark shale	5	1	176	8
Shale	24	8	201	4
Lime (Vanport limestone member)		9	202	1
Shale	4	7½	206	8½
Coal (Scrubgrass)	4	2½	210	11
Clay	6	8	217	7
Sandy shale	8	3	225	10
Dark shale	4	6	230	4
Shale		11	231	3
Clay	1	4	232	7
Shale	2	2	234	9
Coal (Clarion)	1	0	235	9
Dark shale	11	5	247	2

4.4.2 Soils

According Penn State Soil Map, there are 17 different types of soils underneath the study area (Figure 7). This section will only focus on the two soil types where the coliform and *E. coli* positive samples were collected; namely HaC (MS199 and MS233) and WaB (MS230) or Hazleton channery loam and Wharton silt loam, respectively. Hazelton channery loam, 8-15% slopes is a well drained soil that has a moderately rapid permeability profile. This soil is not hydric and the bedrock depth is classified as deep with a seasonal water table greater than five feet from the surface (soil map). Wharton silt loam, 3-8% slopes is a moderately well drained soil that has a slow permeability profile. This soil is not hydric and the bedrock depth is classified as deep with a seasonal water table from 18-36 inches. Physical soil property, chemcial soil property, and suitability for septic system data for HaC and WaB soils is availabile in full in Appendix 3: Soils. A summary of bacterial contamination and soil type can be seen in Table 7.

Table 7: Soil Type vs. Positive and Negative coliform and *E. coli* samples. Note, the quantities of results refer to the number of water wells and not a specific sample (i.e. some wells were sampled more than once with the same result)

	Coliform Positive	**Coliform Negative**	***E. coli* Positive**	***E. coli* Negative**
HaC	1	5	1	5
WaB	1	2	0	2

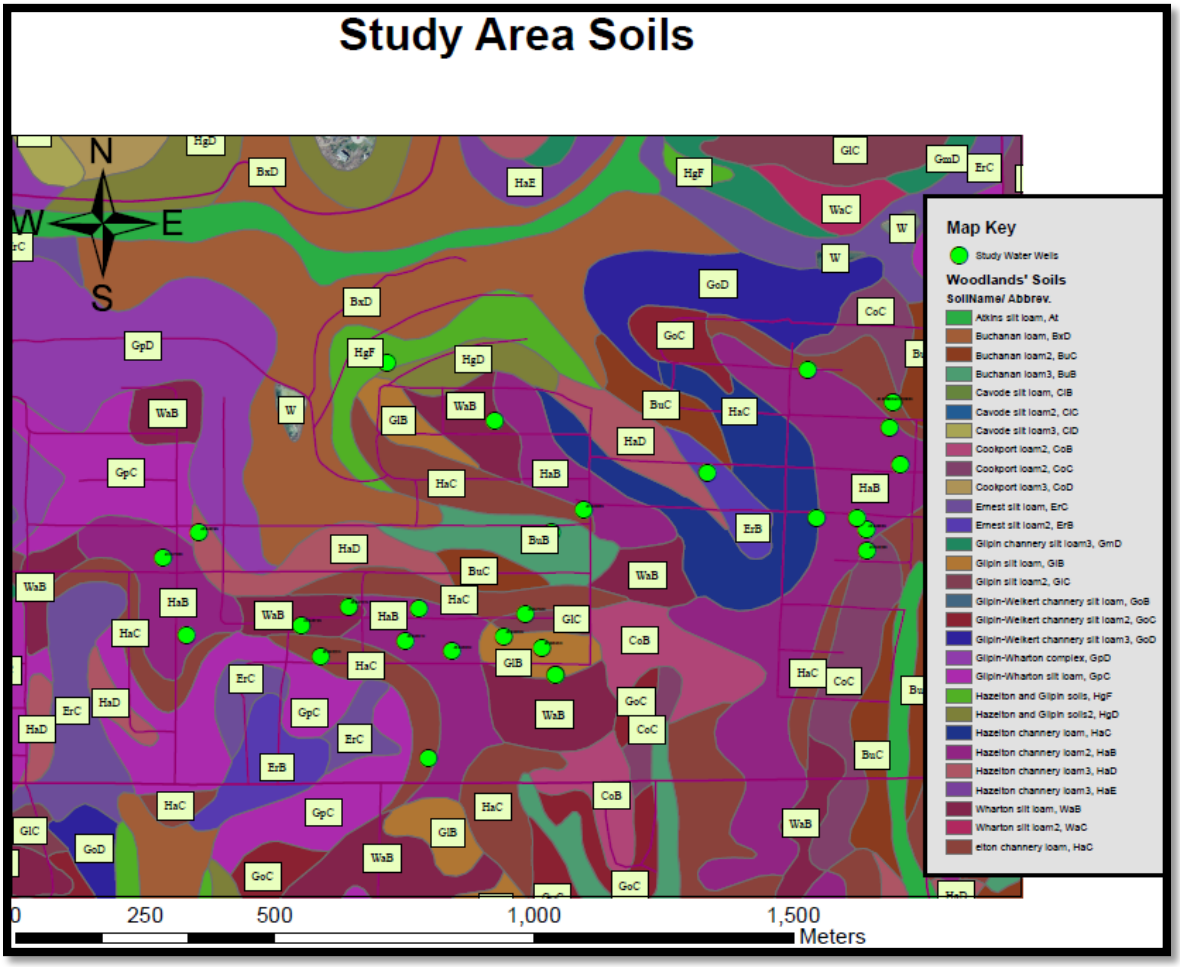

Figure 7: Soil Map of the Study Area. The map above was created using Arc Map 10.3 GIS software. Each color represents a separate soil formation. The map key on the left can be used to determine the full name of the soil formation.

Section 5: Discussion

5.1 Coliform and *E. coli* counts

The incidence of coliforms and *E. coli* in well water was far less in this study than reported in previous private well water surveys in Pennsylvania: e.g. Pennsylvania Department of Agriculture 2001 (59.8 and 20.1%); Zimmerman et al., 2001 (62 and 10%); and Swistock, Clemens, and Sharpe, 2009 (33 and 14%). Factors responsible for the low incidence of fecal bacteria may include well construction characteristics, topography and distance from pollution sources, time of year, chemical variables, and geology.

5.1.1 Well Construction Characteristics

Well construction directly impacts the water quality of the well. In fact, it is statistically significant in terms of coliform and *E. coli* incidence (Swistock, Clemens, and Sharpe 2009). A sanitary well cap was observed on all of the well heads in this study. Furthermore, all but two of the well heads were cased and constructed at least 8-12 inches above ground. These factors more than likely helped prevent bacterial contamination of the well.

Well depth also plays an important part in preventing contamination from fecal bacteria. The average depth in this study was around 50 feet greater than other studies (e.g. 170 feet reported by Zimmerman et al., 2001; and 172 feet reported by Swistock, Clemens, and Sharpe 2009). Assuming all other variables influencing fecal contamination of well water are the same in this study and those mentioned in section 1.5, then it would appear that well depth is inversely related to fecal contamination of well water based on average well depth compared to other studies.

The total coliform- and *E. coli*-positive sample (MS199) came from a well with a depth of only 140 feet. This is below the average well depth in this study and much closer to the average well depth of other studies with higher coliform and *E. coli* incidence.

5.1.2 Topography and Distance from Pollution Sources

Topography is very important in determining where and how fast water will flow. Water will flow down-gradient in a predictable manner unless other forces act on it (e.g. pressures resulting from artesian wells or springs and erosion control measures). Generally surface water will flow down-gradient especially during rainfall events. Thus, it is relatively easy to observe surface pollution flows once their source is known. For example, a groundwater or surface water source down-gradient from a barnyard or field applied with fertilizer could likely become affected by agricultural runoff.

Based on the topography of the study area, shown in Figure 8, and the lack of agricultural activities at the same elevation and in close proximity to the community's water wells, it is unlikely that agricultural runoff would affect this area. Likewise, it is unlikely that the community would be susceptible to other pollution sources from surface or some subsurface flow; unless, of course, pollution sources originated within the community and at the higher elevations of the community or the aquifer(s) under this area were contaminated.

The maximum height of the study area is approximately 1348 ft and the creek bottoms nearby are around 990 ft above sea level; thus, the difference in height from the top of the study area to a stream nearby is only 368 ft. The majority of the samples were collected from properties in the last 50 ft of elevation, as illustrated by the LIDAR data in Figure 8. These facts are important to realize because most of the water wells are between 100 and 200 ft deep and only two wells in the sample set are over 368 ft deep. Thus, many wells within our data set are tapping shallow groundwater aquifers that are probably unconfined in structure.

To date, there are no barnyards, agricultural fields, or manure storage areas within the community. The number of septic systems could become an issue for this area and it is certainly a concern for water quality. There are over 150 households (and septic systems) within a small

region and most houses sit on less than an acre of property. EPA recommends that a water well be constructed no less than 50 feet from a septic tanks, septic leach fields or barnyards. EPA also recommends a 250 ft setback from manure stacks but other sources suggest only a 200 ft setback (e.g. New York Department of Environmental Conservation). Using GIS software, a 50 ft and 200 ft buffer zone around each water well of this study was created, as shown in Figure 9. With regard to the 50 ft buffer zone, no two zones overlap. Almost all of the 200 ft buffer zones overlap but since there are no manure stacks within the study area, this zone does not have to be considered. It was only computed for informational purposes and so that one can observe that a 200 ft buffer zone around a water well is hard to obtain in a community where most property owners have less than an acre of land.

Septic systems have been identified as a potential source of fecal contamination within the community. However, a limitation of this study is that the distance from water well to septic system was not measured for every well. Nonetheless, a correlation between bacterial contamination of well waters and the distance to the septic systems was inherently obvious for one sample; e.g. MS230 was collected from a well only 11 feet from a septic system. The lack of fecal contamination in other wells that were at least 50 ft from septic systems supports reasoning for EPA's recommendation of 50ft between septic systems and water wells. The data also indicate that gradient between septic systems and water wells most likely played a factor in preventing contamination. In other words, water wells were at a lower risk of fecal contamination from septic systems if these systems were constructed down gradient from water wells. This theory was developed based on the fecal contamination found in MS199. Although the distance between the septic tank and the water well was 74 ft (and approximately 100ft from

the sand mound), the septic tank was above grade of the water well and the sand mound was constructed even higher above grade.

Achieving proper gradient may be more important than reaching a 50ft setback from septic systems. Abu-Ashour and Lee (2000) studied surface movement of a nalidixic acid resistant (NAR) *E. coli* strain during rainfall events. A 25mm (0.98 inches) rainfall event occurring two days after site inoculation resulted in the movement of the *E. coli* 20m (65.6 ft) downgradient of the source area on a 2% slope and 35m (114.5 ft) downgradient of the source area on a 6% slope. That finding is also supported by the results of this study. For example, negative coliform and *E. coli* results were obtained from MS206 and MS092 and the wells from which these samples were taken were only 31 and 43 ft away from a septic tank, respectively, but that tank was below the gradient of the water well. On the other hand, positive results found in MS199 and MS233 were from a well that was 74 ft downgradient from a septic system.

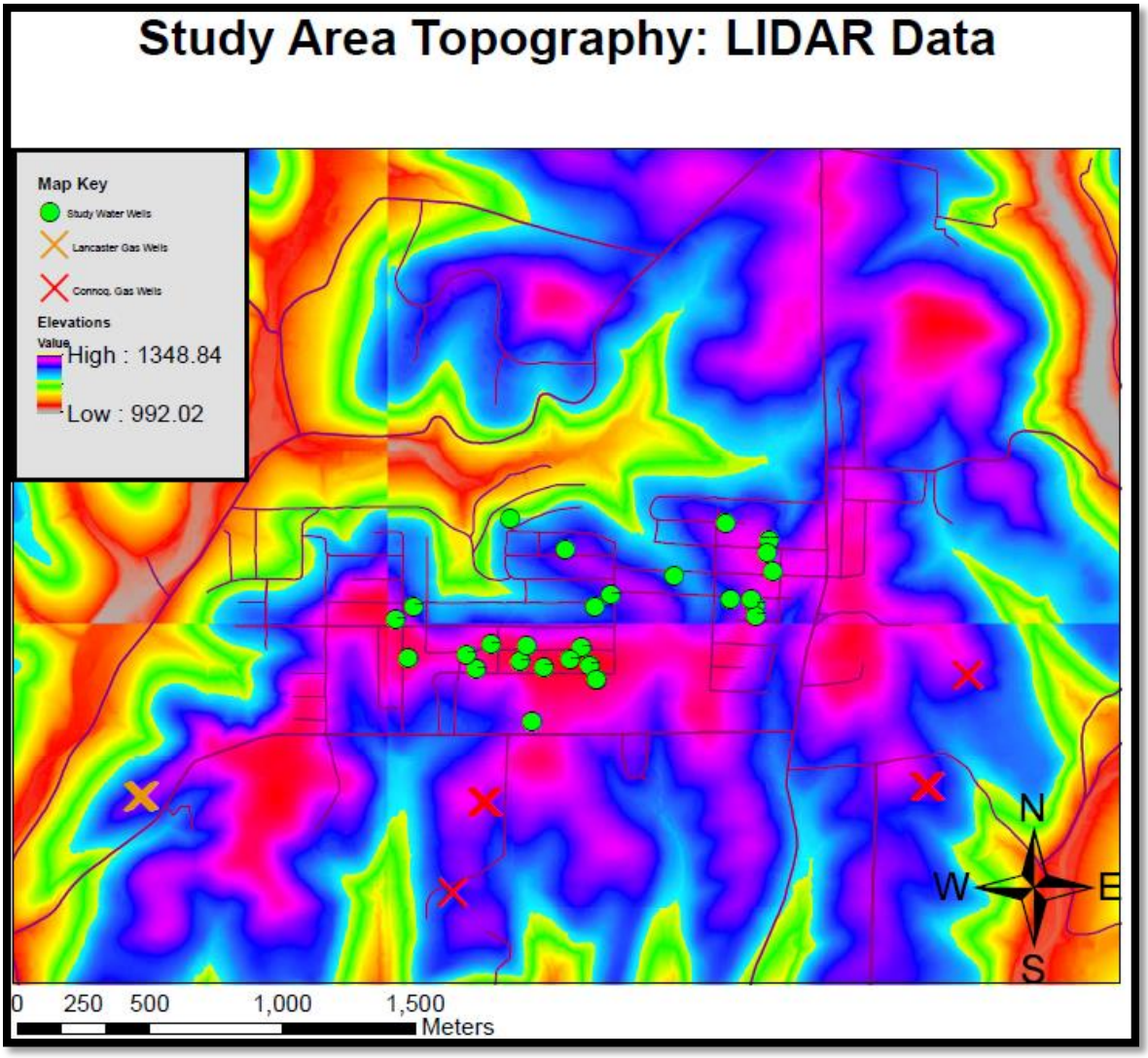

Figure 8: Study AreaTopography from LIDAR data. Pink and Blue colors are highest elevations while yellow, red and gray colors are lowest elevations. Each color represents approximately 50 feet of elevation. Notice how the majority of the study area data points are within the top 100 feet of elevation in the area. Likewise, the gas wells (marked as red and yellow "X's") are also higher in elevation than most of the surrounding area.

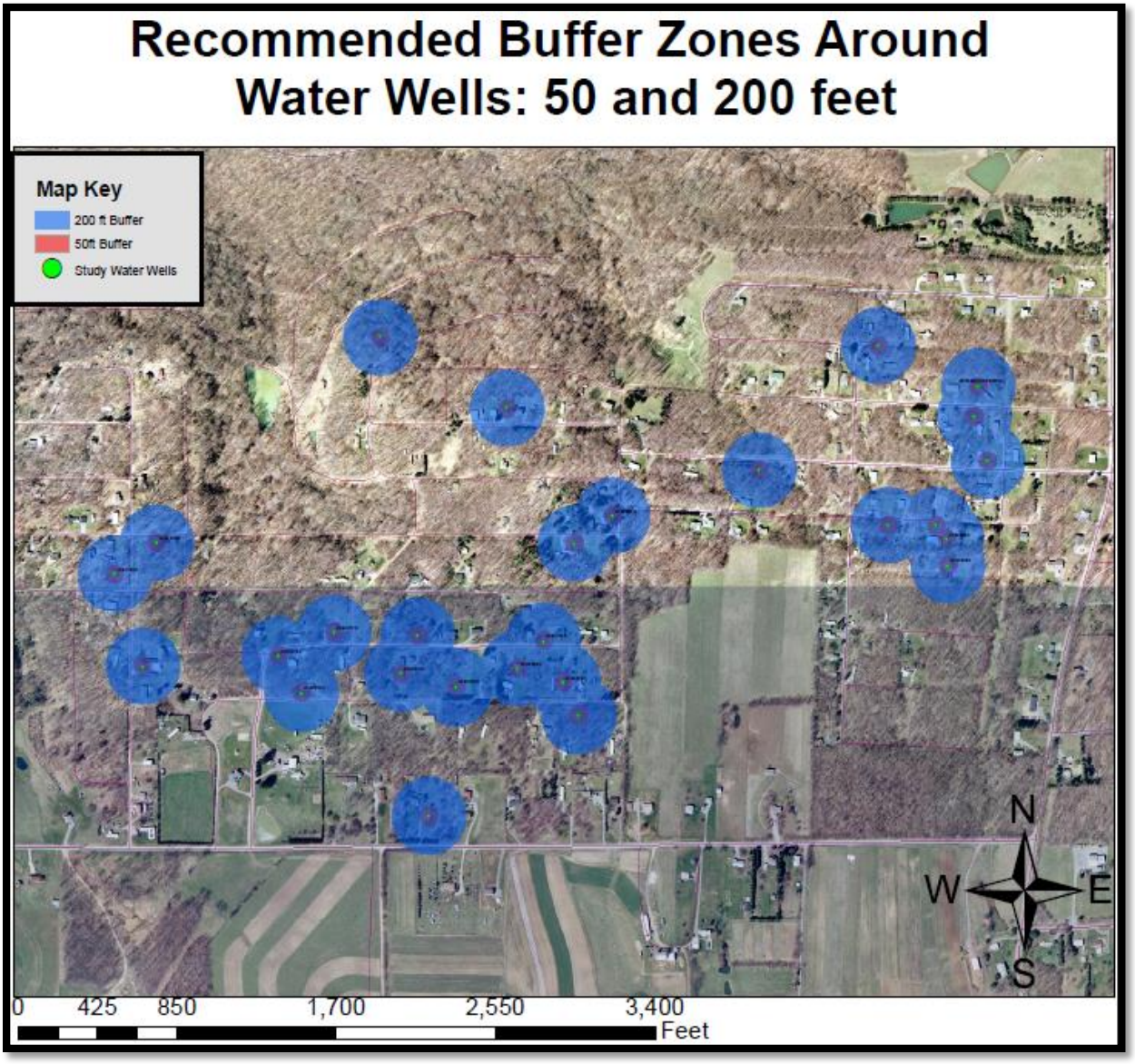

Figure 9: 50 and 200ft Buffer Zones around Water Wells. EPA recommends at least 50 feet between water wells and septic systems and 200 ft between manure stacks or fertilized agricultural areas and water wells. 50 and 200 ft buffer sounds around the study wells were created using Arc Map 10.1 GIS software.

5.1.3 Time of Year

Eight wells were sampled at different times of year. Although this was not a goal or specific aim of this study, the data set, though small, can provide some insight on seasonal fecal bacteria incidence in well water. Two coliform- and one *E. coli*-positive samples came from a well that was sampled in January, August, and October 2013. The precipitation totals for January and August were 2.37 and 2.30 inches, respectively (http://www.ncdc.noaa.gov/cdo-web/quickdata). Current precipitation data for October (up to October 28th) shows approximately 3.25 inches of precipitation. It is also important to note that above normal rainfall occurred in June (6.48inch) and July (4.98 inches) of 2013 (normal values = 3.87 and 3.76 inches) (Weather Channel, LLC).

Although soil moisture was not measured directly, it is likely soil moisture was greater than normal for that time of year due to above normal rainfall. Previous studies (Swistock, Clemens, and Sharpe 2009) have linked soil moisture to TC and *E. coli* incidence in well water and while others (Reddy et al., 1981) have attributed decreased removal of microbes by soil to soil saturation. Thus, one may be more likely to find fecal bacteria in well water during wet months as compared to dry months. With regard to MS199 this is the case. This sample was collected on August 6, 2013 which is typically a very dry time of year in Western Pennsylvania but above normal rainfall in June and July most likely kept soil moisture above normal in early August. A sample from the same well (MS118) was also collected in January 2013 with negative results. At least for this well, seasonal variation in fecal bacteria incidence has been observed. This is further supported by the colony counts. Thirteen coliform and 6 *E. coli* colonies were found in MS199. This is a significant amount of bacteria considering that the Total Coliform Rule (Appendix 1) sets the MCL drinking water standard for Public Water Systems to one coliform colony.

With regard to sample MS233 taken in October 2013, observed precipitation was only 0.50 inches above normal to date (Oct.1-24) and the September precipitation total was approximately 1.0 inch below normal. Fewer coliforms (only 3 colonies) and no *E. coli* were detected for this sample. The reduction of viable coliforms and lack of *E. coli* present still support a correlation between fecal contamination and soil moisture, time of year, and precipitation. In other words, less precipitation and seasonal transition into a dryer month(s) caused a reduction coliform and *E. coli* incidence.

5.1.4 Chemical Variables

The minimum pH value of the data set was 5.53 (MS174) and the maximum was 8.74 (MS184). The optimal pH for neutrophiles, like *E. coli*, is 7.0 (Lengeler, Drews, and Schlegel, 1999). The minimum and maximum pH of the community's well water data set was 5.53 and 8.74 (Table 8) respectively. However, the average pH was 7.37. Near optimal and certainly survivable pH conditions for *E. coli* were present in the well water samples. The minimum Specific Conductance was 116 mS/ cm (MS017) and the maximum was 1259 mS/ cm (MS124).

Specific conductance was an important variable, in terms of the growth of fecal bacteria, because salinity can be calculated from its value using the equation from P.K. Weyl (1964). The relationship between fecal bacteria survival and salinity has been well documented. Bordalo et al. (2002) have shown that the survival of fecal bacteria decreases significantly with salinity and survival in estuarine waters is much lower than in freshwater. The salinity of freshwater is nearly zero, estuaries could be between 0.5 and 35 ppt, and ocean water averages 35ppt (Levinton, 2001). The highest observed specific conductance value was 1259 µs/ cm^3 (Table 8) and the average was 510.6 µs/ cm^3. Even though salinity is measured in ppt (parts per thousand), 1259 µs/ cm^3 converts to <1 salinity unit. In the case of our well water samples, the amount of salinity

present was negligible and it would not negatively impact the growth of any fecal bacteria present.

Nitrate and Phosphate

Low concentrations of nitrate occur naturally in some uncontaminated groundwater but concentrations over 3 mg/L nitrate-nitrogen normally represent anthropogenic pollution (Madison and Brunett 1984). In a well water quality survey in Iowa by Kross et al. (1993) fecal coliforms were only found in 2.5% of samples that had greater than 10 mg/L nitrate-nitrogen. Long-term applications of P and N in chemical fertilizers and animal wastes have resulted in elevated levels of soil P and N in many locations in the United States (Lovejoy et al., 1997). Studies have identified and quantified factors that contribute to P (or phosphate) and N (or nitrate) losses in runoff such as, soil properties, crop residue cover, slope, tillage, method and timing of fertilizer application, and rainfall pattern (Alberts and Spomer, 1985; Hubbard and Sheridan, 1983; Hubbard et al., 1991; Lowrance, 1992; and Pote et al., 1996). Due to its high solubility, nitrate tends to be transported in drainage and subsurface flow. In southern Georgia, USA, Hubbard and Sheridan (1983) reported 20% loss of applied N over a 10 year period to surface runoff and subsurface flow. Of that 20%, 99% of the loss occurred in subsurface flow.

On the other hand, phosphorous is strongly bound in soil and much less mobile that nitrogen. Gburek and Sharply (1998) studied loss of P in east-central Pennsylvania and showed that P loss is controlled by runoff production zones which occur in near-stream saturated areas in a given watershed. Furthermore, P came from soils within 60 m of the stream rather than from areas around the watershed.

Zheng, Huang, and Norton (2004) conducted a laboratory study to determine how the amount of nitrate and phosphate runoff was affected by rainfall events, soil saturation, and amount of fertilizer. Their results showed that near-surface hydraulic gradients have dramatic

effects on nitrate and phosphate loss. Under low fertilizer treatment the average concentrations in surface runoff under "free drainage" and "saturated" soil conditions were 0.08 and 2.20 mg/ L NO_3 and 0.11 and 0.54 mg/ L PO_4, respectively.

Average nitrate and phosphate levels for the data set were 1.33 and 0.79 mg/L, or ppm, respectively (Table 8). These levels are comparable to the laboratory experiment conducted by Zheng, Huang, and Norton (2004) measuring NO_3 and PO_4 loss under saturated soil with small applications of fertilizer. However, it is important to note that their experiment was conducted in soil pans 45 cm long, 32 cm wide, and 35 cm deep. The amount of nitrate and phosphate found in this community's well water samples is not alarming. The MCL of nitrate in PWSs is 10mg/ L (Appendix 1); the average value of NO_3 in our data set is well below the state required MCL. Although Pennsylvania does not currently have an MCL established for phosphate, the average value of phosphate detected in the data set is very small. Adding to this observation the fact that phosphate is far less mobile than nitrate in the soil and in subsurface flow, one can conclude that the amount of phosphate observed is not negatively impacting water quality.

However, the purpose of discussing nitrate and phosphate concentrations was to observe if agricultural runoff, which would by nature contain fecal bacteria, had contaminated any well water within the data set. The small observed nitrate and phosphate concentrations mean that it is highly unlikely that agricultural runoff has contaminated the well water and the observed concentrations are simply background values. Thus, one would not expect to find fecal bacteria in the well water. In other words, any fecal bacteria found most likely did not originate from an agricultural source (i.e. fertilizer). This is especially the case for the only fecal coliform-positive sample (MS199). The amount of nitrate detected in this sample was only 0.20 mg/L and the amount of phosphate in the sample was below the detection limit.

Table 8: Chemical variables. "SpC" is specific conductance measured in µs/ cm^3. "TDS" is Total Dissolved Solids measured in ppm. "TOC" is Total Organic Carbon measured in ppm. (Alawattegawa 2013).

Sample #	Date	pH	SpC	TDS	Fl	Cl	Br	NO_3	PO_4	TOC
MS119	1/15/13	6.01	315	204.8	0.67	34.72	bdl	25.9	bdl	21.4
MS128	1/16/13	6.81	283.7	184.4	5.97	9.46	bdl	0.33	bdl	31.4
MS203	8/6/13	7.22	277.8	180.6	0.07	11.74	bdl	1.88	bdl	na
MS159	2/25/13	7.94	414.9	269.7	1.49	33.29	0.17	0.67	bdl	26.9
MS204	8/6/13	6.68	358.8	233.2	0.03	36.79	bdl	0.63	bdl	na
MS055	9/5/12	6.91	333.5	216.8	0.10	37.51	0.21	0.30	bdl	24.9
MS058	9/5/12	6.59	408.5	265.5	0.13	44.65	bdl	1.07	bdl	113.9
MS053	9/5/12	8.49	757.0	492.1	0.23	45.79	0.31	0.75	0.22	53.4
MS184	5/6/13	8.74	788	512.2	4.73	42.92	0.87	bdl	0.32	45.6
MS206	8/6/13	8.55	772	501.8	0.52	47.13	bdl	1.50	bdl	na
MS174	4/17/13	5.53	441.5	286.9	2.22	44.58	0.61	bdl	bdl	42.8
MS021		7.9	412	267.8	na	56.31		1.10		na
MS158	2/25/13	7.59	265.1	172.3	6.54	24.41	bdl	1.80	0.43	9.72
MS052	9/5/12	6.73	452.9	294.4	n.a.	63.49	bdl	1.10	bdl	24.3
MS120	1/15/13	6.91	485	315.3	5.54	64.71	bdl	1.05	bdl	22.9
MS160	2/25/13	8.33	620	403.0	5.49	35.29	0.27	0.40	bdl	44.4
MS187	5/6/13	6.67	483.9	314.5	2.75	67.70	0.53	0.65	bdl	19.6
MS205	8/6/13	7.36	392.3	255.0	0.05	69.10	bdl	2.24	bdl	na
MS089	11/7/12	7.79	358.3	232.9	3.02	9.85	bdl	1.26	0.41	44.9
MS171	4/17/13	7.14	377	245.0	4.36	12.80	0.41	bdl	bdl	39.4
MS090	11/7/12	7.42	480.4	312.3	0.68	65.71	0.09	1.21	0.60	28.1
MS183	5/6/13	7.1	1092	709.8	1.64	233.7	3.20	bdl	bdl	31.6
MS124	1/16/13	6.88	1259	818.4	5.87	271.9	bdl	1.13	bdl	31.8
MS115	1/15/13	8.12	931	605.2	0.38	156.4	bdl	bdl	bdl	35.5
MS182	5/6/13	8.28	960	624	4.12	169.7	1.74	0.22	bdl	31.0
MS202	8/6/13	7.98	1155	750.8	0.19	187.6	0.98	1.09	bdl	Na
MS015	10/22/11	7.58	463	301.0	na	222.6	1.39	1.60		na
MS017	10/22/11	8.18	116	75.4	na	44.92	0.32	0.24		na
MS050	9/5/12	8.05	965.0	627.3	0.20	143.7	bdl	1.87	0.23	39.3
MS051	9/5/12	7.20	294.7	191.6	0.13	1.75	bdl	0.32	bdl	39.0
MS073	10/4/12	7.37	313.3	203.6	2.26	1.64	bdl	0.08	bdl	34.7
MS085	11/7/12	7.57	270.1	175.6	1.00	1.69	bdl	0.43	2.26	41.2
MS098	12/7/12	7.45	326.2	212.0	0.15	1.44	bdl	0.05	0.15	42.1
MS114	1/15/13	7.23	334.4	217.4	6.07	1.67	Bdl	0.30	Bdl	39.7
MS142-1	1/29/13	7.55	329.5	214.2	0.30	1.15	0.53	0.10	bdl	39.6
MS142-2	1/29/13	7.61	333.1	216.5	4.23	1.19	0.58	0.17	bdl	38.4
MS143	1/30/13	7.26	338.3	219.9	1.52	1.08	0.57	0.17	bdl	40.4
MS146-1	1/29/13	n.a	n.a	n.a	0.16	7.92	bdl	4.93	bdl	n.a

MS146-2	1/29/13	n.a	n.a	n.a	0.17	6.14	bdl	4.04	bdl	n.a
MS157	2/25/13	7.76	287.8	187.1	0.77	1.29	0.05	0.00	bdl	30.8
MS165-1	3/20/13	7.65	316.7	205.8	6.52	1.44	bdl	0.85	bdl	38.4
MS165-2	3/20/13	7.66	305.6	198.6	1.59	1.55	bdl	0.56	bdl	34.4
MS093	11/7/12	7.73	360.3	234.2	4.38	7.93	bdl	1.14	1.30	46.0
MS064	9/14/12	7.42	533	346.5	4.27	34.77	bdl	0.64	bdl	35.0
MS125	1/16/13	7.11	518.2	336.8	0.05	19.44	0.19	0.16	bdl	61.2
MS065	9/14/12	7.43	656	426.4	4.52	84.99	bdl	1.15	bdl	30.8
MS068	9/14/12	7.64	907	589.6	1.15	144.7	bdl	1.04	bdl	29.6
MS086	11/7/12	7.31	894.0	581.1	2.95	155.0	bdl	0.69	1.29	41.9
MS101	12/7/12	7.09	790.0	513.5	1.88	118.7	0.88	bdl	bdl	34.1
MS116	1/15/13	7.1	752	488.8	0.50	128.19	bdl	0.90	bdl	34.0
MS144	1/23/13	7.24	866	562.9	3.56	140.6	2.20	bdl	bdl	30.5
MS145	1/30/13	7.19	477.3	310.2	3.03	40.98	1.07	bdl	bdl	33.9
MS161	2/25/13	7.8	696	452.4	5.78	108.8	0.91	0.43	bdl	16.6
MS166	3/20/13	7.54	1094	711.1	6.17	215.7	bdl	2.08	bdl	30.7
MS201	8/6/13	7.4	747	485.6	0.04	117.3	0.33	n.a.	bdl	na
MS074	10/4/12	7.39	332.3	216.0	5.28	6.87	bdl	bdl	bdl	43.4
MS092	11/7/12	7.51	313.7	203.9	4.44	5.60	0.07	0.43	1.28	41.5
MS121	1/15/13	7.49	302	196.3	0.30	2.79	bdl	0.21	bdl	34.4
MS198	8/6/13	7.02	346.4	225.2	0.12	6.08	bdl	0.41	bdl	na
MS071	10/4/12	8.05	305.7	198.7	4.49	6.05	bdl	0.08	bdl	23.9
MS118	1/15/13	7.31	303.6	197.3	5.65	3.40	bdl	0.20	bdl	33.4
MS199	8/6/13	6.72	299.5	194.7	0.06	3.78	bdl	2.10	bdl	na
MS126	1/16/13	6.64	424.7	276.1	6.72	9.40	bdl	0.32	bdl	42.0
MS123	1/15/13	6.82	557	362.1	3.50	65.84	bdl	0.66	bdl	33.3
MS127	1/16/13	6.67	541.8	352.2	0.16	59.58	bdl	0.42	bdl	35.5
MS200	8/6/13	6.53	529	343.9	0.11	62.03	bdl	0.67	bdl	na
MS087	11/7/12	7.29	296.5	192.7	0.30	17.18	0.43	0.64	1.19	32.2
MS088	11/7/12	7.46	382.3	248.5	1.24	18.96	0.14	1.02	0.62	39.9
MS175	4/17/13	6.98	312	202.8	5.79	5.90	0.44	bdl	bdl	33.2
MS207	8/6/13	7.24	143.7	93.4	0.01	0.66	bdl	0.05	bdl	na
MS117	1/15/13	7.64	807	524.6	4.87	17.53	Bdl	0.84	Bdl	97.8
MS230	10/24/13	---	---	---	Bdl	167.68	0.90	Bdl	Bdl	24.52
MS232	10/24/13	---	---	---	Bdl	12.84	Bdl	0.56	Bdl	13.17
MS233	10/24/13	---	---	---	bdl	4.17	bdl	0.40	bdl	28.81
	Min	5.53	116	75.4	0.01	0.660	0.05	0	0.145	9.71
	Max	8.74	1259	818.3	6.72	271.8	3.20	25.8	2.262	113.
	Avg.	7.36	510.6	331.9	2.34	56.64	0.69	1.33	0.792	36.3

5.1.5 Geology and Soils

Although it is unclear if soil type is the primary reason for fecal contamination or lack thereof in this community, there are various characteristics of soils that must be considered before ruling out soil type as a partial cause for well water contamination. These characteristics include suitability for septic system, cation exchange capacity, moist bulk density, saturated hydraulic conductivity (Ksat), and available water capacity.

According to reports generated by Penn State Soil Map, from USDA Natural Resources Conservation Services, found in Appendix 3, the HaC soil types scores poorly in terms of suitability for septic system construction. The reports were generated for 5 different variations of septic systems. The major limiting factors include slope (too steep) for all systems, and bedrock above 72' and slow percolation for subsurface sand systems (Appendix 3). Limiting factors for conventional septic ground beds or trenches, e.g. "leachfields", included slope and bedrock depth but fast percolation was a major limiting factor. Similarly, the soil reports indicated that WaB soil types score poorly in terms of suitability for septic system construction. It is very limited for all types of septic systems. The major limiting factors included bedrock depth, slow percolation, seasonably high water tables, and slope for all systems (Appendix 3).

Despite the fact that the HaC and WaB soil types are about equally limited in suitability for septic systems, there are great differences between their physical and chemical properties. For example, WaB has more clay (up to 35% at certain depths) than HaB. Also, Ksat is significantly higher for HaC but WaB has a slightly greater available water capacity. In other words, water flows easier through pore spaces in HaC but WaB holds more water. This is likely due to the larger percentage of clay in WaB. Bulk densities are comparable between soil types but the bulk density for WaB reaches 1.60 at some depths. Again, this is due to the percentage of clay translating into smaller pore spaces for water to pass through. Cation exchange capacity

cannot be measured for HaC because it has a pH of less than 5.5. Therefore, an adjusted parameter, e.g. effective cation exchange, was used. The effective cation exchange of HaC was approximately half that of WaB. Thus, HaC could pose a hazard for groundwater quality if contaminates were introduced to the soil (i.e. fertilizer, septic waste, etc.) (soil map report).

Thus far, this section has analyzed two soil types to form a better understanding of why bacterial contamination occurred in wells constructed in these soils. This analysis has led to the hypothesis that septic systems constructed in HaC soil types, or introduction of pollutants in this soil type could pose great risk to well water and/or groundwater. Despite coliform contamination reported in a well constructed in a WaB formation, Ksat, bulk density, and [effective] cation exchange capacities would render a lower risk to well water quality from pollutants (namely bacteria) in this soil.

Even though soil properties may deem HaC suspect for groundwater contamination and both HaC and WaB unsuitable for septic systems, 5 water wells in HaC soil types and 2 water wells in WaB soil types were negative for fecal contamination in this study. Based on this observation, one can only postulate that while soil type may influence fecal contamination of well water, other factors are involved. The lack of fecal contamination detected in this study indicated that the aquifer(s) under the study area are most likely pristine and the aquifer material and soils at least hold the ability to prevent fecal bacteria from moving between water wells. This theory is supported by differences in fecal contamination between MS200 and 199. Both samples were collected on August 6, 2013 within 30 minutes of each other but total coliforms (including *E. coli*) were detected in MS199 and not MS200. The distance between the water wells from which these samples were collected is approximately 250 ft and both wells are within the same elevation color, as shown in Figure 8. Also, MS199 was taken from a well in a HaC soil type

while MS200 was from a well in a WaB soil. Thus, fecal contamination of MS199 was from a localized source.

5.1.6. A Final Word on the Fecal Contamination of the Study Area

Samples MS233 and MS230 were collected on October 24, 2013. The homeowner from where samples MS118, 199, and 233 came from had informed us that their septic tank was pumped approximately two weeks ago and that upon that maintenance it was discovered that the pump for the sand mound was not connected. In other words, the pump inside the septic tank, used to pump liquid waste into the sand mound, had not been working for months. Thus, excess liquid waste in the septic tank leached out into the soil without proper filtration and percolation in the sand mound. Despite the large distance between the septic system and the water well, liquid waste most likely infiltrated the ground water source feeding the water well. The fact that the water well was below grade from the septic system may have increased the distance the liquid waste traveled and certainly put the water well at a greater risk of contamination. Furthermore, above normal rainfall occurred prior to collecting sample MS199. Therefore, existing contamination would have most likely migrated farther in the soil from the septic to the water well.

In this study many factors influencing fecal contamination of well water have been addressed including well construction characteristics, topography and distance from pollution sources, time of year and precipitation, chemical variables and soil type. There was a lack of fecal contamination detected in this study which may have contributed to a lack of substantial evidence linking one common factor to coliform and *E. coli* incidence in well water. However, it seems that one factor is not uniformly responsible for fecal contamination but multiple factors acting together are responsible. This is evident when examining the positive samples; for

simplicity, “well1” will refer to MS199 and MS233 and “well2” will refer to MS230. For example, Well1 was constructed in soil with low effective cation exchange capacity but Well2 was constructed in close proximity to a septic system and its well cap was at ground level.

Another combination of factors for fecal contamination is evident for Well1. Above normal rainfall combined with an improperly functioning septic system above grade of the well contributed to fecal contamination of Well1. The combination of grade and rainfall negated the fact that Well1 was still 74 ft from the septic system.

5.2 The Need of Private Well Water Regulations in Pennsylvania

Pennsylvania and Alaska are the only states that do not regulate private water well construction for household use. EPA only has authority to regulate public water systems including groundwater wells used for public water supply. Thus, water wells for private use are only able to be regulated at the state or local government level. However, EPA does make recommendations on setbacks from pollution sources. These recommendations are reported in EPA (2002) and are identical to those reported by CDC (2009) in section 1.1.1; e.g. 50 feet from septic tanks and livestock yards, and 250 feet from manure stacks. Also, EPA encourages water testing for not just fecal contamination, but water quality in general. Furthermore, Pennsylvania Department of Environmental Protection (PA DEP) offers an informative webpage (PA DEP and Private Well Water) on private water wells describing well contaminants, water testing, publications, and recommendations on well construction.

Despite the fact that Pennsylvania DEP makes recommendations on well construction, no such laws are in place to ensure proper construction of water wells unlike other states whose regulations are similar to Pennsylvania’s “recommendations”. For example, under New York State Residential Code: Subsection P2602.1.1 and Appendix 5-B requires that water wells be

located at minimum distances from various known contamination sources, as shown in Table 9, and not subject to flooding or surface water contamination.

Table 9: New York State required setbacks of various pollution sources from private water wells. "*" denotes separation distances from contaminant sources need to be significantly increased if the contaminant source is located upgradient from a well or if aquifer water enters the well at less than 50-feet below grade. Source: NYS DEC http://www.health.ny.gov/environmental/water/drinking/regulations/fact_sheets/fs6_guidance_for_code_enforcement_officials.htm.

Contaminant Source	Distance (Feet)*
Land application or storage of manure	200
Seepage pit	150
Absorption (leach or tile) field or bed	100
Septic tank, aerobic unit, watertight effluent line to distribution box	50
Stream, lake, watercourse, drainage ditch, or wetland	25

Additional well construction details verified upon review of the NYS Department of Environmental Conservation (DEC) Completion Report include: (1) well depth needs to be shown and casing extended at least 12 inches above grade and 19 feet below grade; (2) well cap tightly sercured to the casing and it must be watertight and vermin-proof; (3) grout is placed to fill annular space around casing for wells in sand or gravel; (4) grading the surround area to eliminate ponding around the well head; (5) well yield and pump are recorded.

New York is not the only state with extensive and specific regulations regarding private water well construction. It was used above as an example of water well regulations because it neighbors Pennsylvania and the NYS DEC provides an easily readable and accessible webpage on New York regulations. Links to the other 47 states' water well regulation online resources can be found in Appendix 2: Table 1.

5.2.1 Why should private water well construction be regulated in Pennsylvania?

The answer to the question of regulation is inherently obvious in the results of the Pennsylvania Water Quality Studies discussed in section 1.5 of this document. Coliforms and *E. coli* were found in a large amount of samples (up to 60%) in those studies. Considering the MCL

of fecal coliforms for PWSs in Pennsylvania is zero, the risk to human health from some private water wells (e.g. coliform- and *E. coli*-positive wells) is great and certainly unacceptable in terms of public drinking water standards. However, proper construction of water wells can greatly reduce or eliminate the risk of fecal bacteria contamination.

5.3 Marcellus Shale Drilling, Fecal contamination, and Water Quality Sampling

The debate on the environmental safety of shale gas extraction has focused on gas migration to shallow groundwater sources (Osborn et al., 2011) and the atmosphere (Jiang et al., 2011) as well as the potential for the contamination from hydraulic fracturing fluids and/or produced water and brines during drilling, transport and disposal (Dresel and Rose 2010; Rowan, Kirby and Kraemer 2011; Gregory, Vidic and Dzombak 2011; and Hayes 2009). Recent analysis of northeastern Pennsylvania inorganic well water geochemistry from active drilling areas was not significantly different when compared to non active areas and historical values (Osborn et al., 2011). Despite this finding, reports of changes in drinking water quality blamed on shale gas development have increased (Warner et al. 2012). These same types of reports have also been heard from the study area and homeowners have specifically reported changes in water quality as activity on the surrounding natural gas well-pads increased.

Potential pathways for gas migration include advective transport through sedimentary rock, fractures and faults, and abandoned wells or open boreholes (Myers 2012). Pathways for gas suggest, by default, pathways for fluids and contaminants if a gradient exists. Vertical hydraulic gradients up to a few percent exist throughout the Marcellus shale region (TAL 1981).

In Pennsylvania, more than 180,000 wells had been drilled prior to any requirement for documenting their location (Davies 2011). The result of this is many unknown wells, and their

depths, and many improperly abandoned wells (i.e. gas and oils wells that were not properly plugged with cement or cased after abandonment).

A range of interpretative simulations suggest transport times of contaminants from fractured shale could be decreased from geologic time scales to as few as tens of years (Myers 2012). In other words, evidence for potential vertical contaminant flow is strong and Myers (2012) also reports that there are no current monitoring systems in place to detect contaminant transport.

5.3.1 Surface Water Contamination

The rapid growth and expansion of US gas drilling has made regulation difficult; in Pennsylvania alone, there were more than 1400 drilling violations between January 2008 and October 2010 (PADEP 2010). Of those violations, nearly half dealt with surface-water contamination and included direct discharge of pollutants, improper erosion control, or failure to properly contain wastes (Entrekin et al., 2011).

Produced waters pose a threat to surface waters because they can contain elevated levels of metals, brines, organics, and radionuclides that occur naturally in deep groundwaters (Entrekin et al., 2011). Onsite waste impoundments or evaporation ponds could overflow, spill, or leach into groundwater and contaminate nearby streams.

A study model by Rozell and Reaven (2012) demonstrated that the greatest potential contamination risk to water sources is associated with the disposal of hydraulic fracturing wastewater and that a best-case scenario would still render a release of at least 200 m^3 of contaminated fluids from a single gas well. Releases from transportation spills, well casing leaks, leaks through fractured rock, and drilling site discharge were all calculated to be less than 1 m^3. Thus, they pose significantly less risk for water contamination.

5.3.2 FracFocus and DEP Pre-drill Testing

In 2011, the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission jointly launched an online registry for chemicals used in hydraulic fracturing, called FracFocus. This website is a repository for information of specific chemicals and components, and their quantities, used in fracking individual gas and oil wells across the US. Gas and oil well operators can upload this information and there are currently 55,978 gas and oil wells registered on www.FracFocus.org. This resource is useful for EPA and others conducting research on impacts of unconventional shale gas development. Also, it serves as a "for your information" source for property owners and those who have signed gas leases. An example of a Hydraulic Fracturing Fluid Product Component Information Disclosure report can be found in Appendix 4. Note, the report is for the Voll-1H gas well located just south of the study area (Figure 5).

The Pennsylvania Department of Environmental Protection (PA-DEP) has also provided recommendations on which water quality parameters to measure for oil and gas pre-drill testing. These analytes include: (1) inorganics—alkalinity, chloride, conductivity, hardness, oil and grease, pH, sulfate, total dissolved soilids, and total suspended solids; (2) trace metals—barium, calcium, iron, magnesium, manganese, potassium, sodium, and strontium; (3) organics—ethane and methane; and (4) microbes—total coliforms and *E. coli*. However, PA-DEP suggests that the minimum parameters tested include pH, total dissolved solids, iron, manganese, sodium, ethane and methane. The parameters for minimum testing were chosen because they could reflect changes in water quality induced by drilling activities, especially in the case of methane and ethane.

5.3.3 Fecal Contamination and Gas Drilling Operations near the Study Area

When water quality issues surrounding unconventional gas development and hydraulic fracturing are illustrated, coliforms and *E. coli* are most likely the last thing discussed, if at all.

EPA's "Study of the potential impacts of Hydraulic Fracturing on drinking water sources: Progess Report" for 2013, a 268 page document, does not even mention the word bacteria, coliform, or *E. coli*. A reason for the lack of concern for fecal contamination of well water from unconventional shale gas development could be that shale gas development does not influence coliform and *E. coli* incidence in well water. A brief review of the literature does not support or refute such a claim. However, this study was conducted in an area with rapid unconventional shale gas development and the incidence of coliforms and *E. coli* were far less than other studies conducted across Pennsylvania before unconventional shale gas extraction took place. Regardless, this study alone does not provide substantial evidence to link reduced coliform and *E. coli* incidence with unconventional shale gas development.

Fecal contamination from gas development may also not be of concern because if some effluent rich in fecal bacteria from drilling operations, aside from onsite Port-o-Johns, had contaminated surface or groundwater sources, then that effluent would most likely contain either hydraulic fracturing chemicals, brines from subsurface formations, or a combination of both. In other words, if carcinogenic chemicals or effluents with high salinity and total dissolved solids infiltrated groundwater or surface water sources, then fecal contamination of those sources as a result of the effluents would be of little concern. This is the more obvious explanation for why fecal contamination of groundwater is of little concern when discussing water quality and shale gas development.

However, there are possible scenarios that could increase coliform and E. *coli* incidence. For example, if onsite freshwater impoundment ponds became contaminated with fecal bacteria from onsite sources and those impoundments leaked thousands of gallons of contaminated water, then it would be possible that a plume of fecal bacteria could infiltrate an aquifer or well water

source close by (e.g. less than 250 ft from the edge of the spill). The likelihood of this scenario is probably minute. A similar, but still unlikely, scenario involving the release of effluent from water lines to and between gas wells could also pose risk to nearby well water and groundwater sources if water in the lines were rich in fecal bacteria. An alternative premise of both scenarios is that uncontaminated water spilled or leaked over possible pollution sources such as fertilized fields or septic systems which then contaminated well water.

Evidence for why produced waters from nearby drilling has not infiltrated the Study Area Well Water

There is a lack of chemical data to support the conclusion that hydraulic fracturing fluids or brines have infiltrated the well water of the study area. Salinity, total dissolved solids, pH, conductivity, and bromide are all within normal ranges and do not suggest contamination from drilling.

5.4 Future Research Directions

5.4.1 Fecal Source Tracking

Humans and animal species may contain both different numbers and different ratios of *E. coli* and enterocci, even though data is contradictory (Field 2004; Fogarty et al., 2003; Weaver et al., 2005). Thus, it is uncertain on how to estimate the exact contribution of fecal indicating bacteria from mixed sources. *E. coli* and enterococci can survive, grow, and establish populations in environments outside of the intestine. However, genetic evidence has shown that fecal indicating bacteria (FIB) populations found in the natural environment are not related to animal or human sources, but are instead unique environmental strains (Kinzelman et al., 2004; McLellan, 2004; Power et al., 2005).

E. coli and enterococci are not well correlated with pathogenic *Salmonella* spp., *Campylobacter* spp., *Cryptospiridium* and *Giardia* spp, and human enteroviruses (Lamarchand and Lebaron, 2003). The poor correlation of FIB with viruses is of particular concern because viruses are infectious in low doses, linked with both acute and chronic disease, and related frequently in swimmer-associated illnesses (Fong and Lipp, 2005). In a Connecticut pond with wild animal but no human fecal contamination, Calderon et al. (1991) found an increased rate of gastrointestinal illness in swimmers but FIB was strongly correlated with numbers of swimmer not with FIB or rainfall. Thus, they concluded that the illnesses were caused by swimmer-to-swimmer transmission.

The entire premise of fecal source tracking relies on the assumption that some characteristics associated with feces unequivocally identifies a particular feces type or host source and that this trait can be detected and indentified in water (Field and Mansour, 2007). Methods for fecal source identification can be grouped mainly into culture-based and culture-independent methods but some methods also require a library, or database, to compare samples to (Field and Mansour, 2007).

Culture-based, library-dependent methods include: antibiotic resistance; other phenotypic methods (i.e. carbon-source utilization profiling (CUP)); DNA fingerprinting (i.e. ribotyping, REP-PCR, and related methods). Culture-based, library-independent methods include bacteriophage methods and bacterial methods (i.e. using the ratio of atypical colonies to total coliform colonies from a membrane filter assay to differentiate between human and agricultural fecal impacts (Booth and Brion, 2004)). Culture-independent, library-independent methods include chemical and viral methods.

Culture-based methods for FIB are relatively inexpensive, low-tech, and provide enrichment steps that increase the numbers of target organisms. However, the use of FIB may come at a disadvantage because it may not provide diversity and host-specific population structure needed for source tracking (Field and Mansour, 2007). Also, many pathogens are difficult to grow and the composition of microbial communities changes drastically when cultured (Field and Mansour, 2007). A "culture bias" must be considered in culture-based fecal source identification, especially for attempts to use these methods quantitatively.

Library-based methods are labor intensive and require extensive sampling to prepare the library and test environmental isolates. Culture-independent molecular methods have an important advantage of sampling the entire population present in the sample with no culture bias and do not require a library. Furthermore, they can use difficult-to-grow microbes. These methods work better to detect bulk or community samples rather than samples from single individuals. Even though libraries are not need for every location, validation with local samples is required when the methods are applied in new locales (USEPA, 2005).

However, markers for only a few animal species are available and wildlife species are poorly represented (Field and Mansour, 2007). More and different target genes are needed. Antibiotic resistance methods can discriminate between human and non-human sources. Also, they can identify human, agricultural, and wild type species. They perform very well are successful for testing blind samples. Upon brief review of the methods, an antibiotic resistance method would be a best fit for the next research step of this study because it can differentiate between human and non-human sources. Thus, the source of fecal contamination could be determined more accurately and quickly.

Section 6 Conclusions

6.1 Fecal Contamination of Well Water in the Study Area

This study has examined many variables influencing fecal contamination of well water including well construction characteristics, topography and distance from pollution sources, time of year and precipitation, chemical parameters of well water, and soil type. Furthermore, this study has used two separate methods of detection for *E. coli* and used chemical parameters to roughly determine possible sources of fecal contamination. Overall, it would appear that no single variable can be held responsible for directly influencing fecal contamination by itself. In fact, multiple variables (e.g. soil type, precipitation, and well construction characteristics) acting together and in different combinations affect coliform and *E. coli* incidence in well water. Also, septic systems have been identified as the most likely source of fecal contamination within the study area and should remain a concern for future water quality in this community.

Based on chemical data, hydraulic fracturing fluids, brines and/or produced waters from unconventional shale gas extraction are not believed to have infiltrated well water in the study area. Thus, it is uncertain as to whether or not unconventional shale gas development affects coliform and *E. coli* incidence in well water even though incidence rates in this study were far less than other Pennsylvania studies conducted before unconventional gas extraction took place in the state.

The Responsibility of Gas Drillers

The mixed uncertainty of well water contamination from unconventional shale gas development should render groundwater monitoring a necessity. It should be the responsibility of the operators to monitor groundwater quality in areas where shale gas wells are dense. Alternatively, it should be the financial responsibility of the operators to have groundwater quality monitored by an appropriate government agency or private entity.

6.2. Recommendations for Water Well Construction, Placement, and Owners

Based on the results of this study, other studies, and other state regulations on well construction a new water well should;

- Be drilled at least 200 ft and cased at least 12 inches above grade and 20 feet below grade
- Have a sanitary well cap
- Be at least 50-75 feet from a septic system and 200 feet from manure fields or barnyards
- Be tested by a certified lab for pH, conductivity, salinity, coliforms and *E. coli,* iron, manganese, total dissolved solids, methane and ethane before use, 1 month after drilling, before and after any type of oil and gas development in the area, and once changes in water quality occur

Similarly, septic system design should be carefully planned out based on soil type and gradient/ distance from a water well. Also, the septic system should be checked yearly, at a minimum, to ensure proper function.

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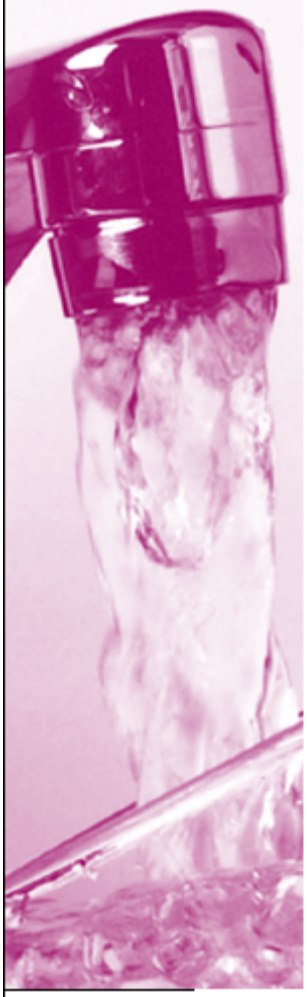
Appendix 1: Total Coliform Rule, Revised Total Coliform Rule, and Pennsylvania MCLs 2012

EPA
United States Environmental Protection Agency



Total Coliform Rule: A Quick Reference Guide

Overview of the Rule

Title[1]	Total Coliform Rule (TCR) 54 FR 27544-27568, June 29, 1989, Vol. 54, No. 124[2]
Purpose	Improve public health protection by reducing fecal pathogens to minimal levels through control of total coliform bacteria, including fecal coliforms and *Escherichia coli* (*E. coli*).
General Description	Establishes a maximum contaminant level (MCL) based on the presence or absence of total coliforms, modifies monitoring requirements including testing for fecal coliforms or *E. coli*, requires use of a sample siting plan, and also requires sanitary surveys for systems collecting fewer than five samples per month.
Utilities Covered	The TCR applies to all public water systems.

Public Health Benefits

Implementation of the TCR has resulted in . . .	► Reduction in risk of illness from disease causing organisms associated with sewage or animal wastes. Disease symptoms may include diarrhea, cramps, nausea, and possibly jaundice, and associated headaches and fatigue.

What are the Major Provisions?

ROUTINE Sampling Requirements

- Total coliform samples must be collected at sites which are representative of water quality throughout the distribution system according to a written sample siting plan subject to state review and revision
- Samples must be collected at regular time intervals throughout the month except groundwater systems serving 4,900 persons or fewer may collect them on the same day.
- Monthly sampling requirements are based on population served (see table on next page for the minimum sampling frequency).
- A reduced monitoring frequency may be available for systems serving 1,000 persons or fewer and using only ground water if a sanitary survey within the past 5 years shows the system is free of sanitary defects (the frequency may be no less than 1 sample/quarter for community and 1 sample/year for non-community systems).
- Each total coliform-positive routine sample must be tested for the presence of fecal coliforms or *E. coli*.
- If any routine sample is total coliform-positive, repeat samples are required.

REPEAT Sampling Requirements

- Within 24 hours of learning of a total coliform-positive ROUTINE sample result, at least 3 REPEAT samples must be collected and analyzed for total coliforms:
  - One REPEAT sample must be collected from the same tap as the original sample.
  - One REPEAT sample must be collected within five service connections upstream.
  - One REPEAT sample must be collected within five service connections downstream.
  - Systems that collect 1 ROUTINE sample per month or fewer must collect a 4th REPEAT sample.
- If any REPEAT sample is total coliform-positive:
  - The system must analyze that total coliform-positive culture for fecal coliforms or *E.coli*.
  - The system must collect another set of REPEAT samples, as before, unless the MCL has been violated and the system has notified the state.

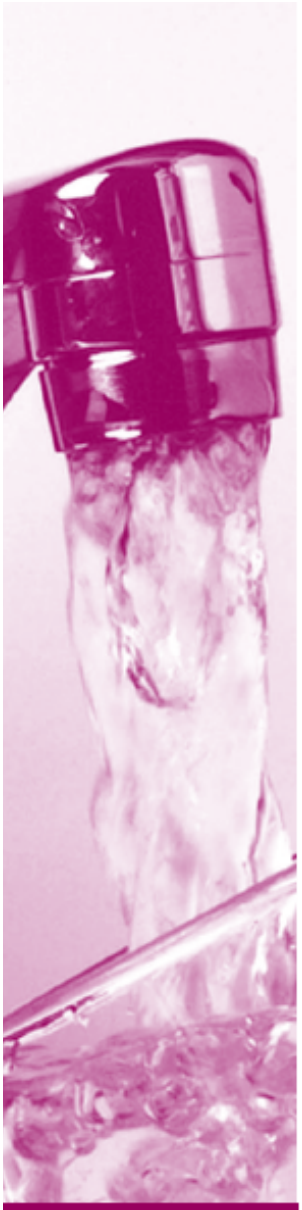
Additional ROUTINE Sample Requirements

- A positive ROUTINE or REPEAT total coliform result requires a minimum of five ROUTINE samples be collected the following month the system provides water to the public unless waived by the state.

[1] This document provides a summary of federal drinking water requirements; to ensure full compliance, please consult the federal regulations at 40 CFR 141 and any approved state requirements.

[2] The June 1989 Rule was revised as follows: Corrections and Technical Amendments, 6/19/90 and Partial Stay of Certain Provisions (Variance Criteria) 56 FR1556-1557, Vol 56, No 10.

Note: The TCR is currently undergoing the 6 year review process and may be subject to change.



For additional information on the TCR

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA web site at http://water.epa.gov/drink; or contact your state drinking water representative.

Public Water System ROUTINE Monitoring Frequencies

Population	Minimum Samples/ Month	Population	Minimum Samples/ Month	Population	Minimum Samples/ Month
25-1,000*	1	21,501-25,000	25	450,001-600,000	210
1,001-2,500	2	25,001-33,000	30	600,001-780,000	240
2,501-3,300	3	33,001-41,000	40	780,001-970,000	270
3,301-4,100	4	41,001-50,000	50	970,001-1,230,000	300
4,101-4,900	5	50,001-59,000	60	1,230,001-1,520,000	330
4,901-5,800	6	59,001-70,000	70	1,520,001-1,850,000	360
5,801-6,700	7	70,001-83,000	80	1,850,001-2,270,000	390
6,701-7,600	8	83,001-96,000	90	2,270,001-3,020,000	420
7,601-8,500	9	96,001-130,000	100	3,020,001-3,960,000	450
8,501-12,900	10	130,001-220,000	120	≥ 3,960,001	480
12,901-17,200	15	220,001-320,000	150		
17,201-21,500	20	320,001-450,000	180		

*Includes PWSs which have at least 15 service connections, but serve <25 people.

What are the Other Provisions?

Systems collecting fewer than 5 ROUTINE samples per month . . .	Must have a sanitary survey every 5 years (or every 10 years if it is a non-community water system using protected and disinfected ground water).**
Systems using surface water or ground water under the direct influence of surface water (GWUDI) and meeting filtration avoidance criteria . . .	Must collect and have analyzed one coliform sample each day the turbidity of the source water exceeds 1 NTU. This sample must be collected from a tap near the first service connection.

** As per the IESWTR, states must conduct sanitary surveys for community surface water and GWUDI systems in this category every 3 years (unless reduced by the state based on outstanding performance).

How is Compliance Determined?

- Compliance is based on the presence or absence of total coliforms.
- Compliance is determined each calendar month the system serves water to the public (or each calendar month that sampling occurs for systems on reduced monitoring).
- The results of ROUTINE and REPEAT samples are used to calculate compliance.

A Monthly MCL Violation is Triggered if:

A system collecting fewer than 40 samples per month . . .	Has greater than 1 ROUTINE/REPEAT sample per month which is total coliform-positive.
A system collecting at least 40 samples per month . . .	Has greater than 5.0 percent of the ROUTINE/REPEAT samples in a month total coliform-positive.

An Acute MCL Violation is Triggered if:

Any public water system . . .	Has any fecal coliform- or *E. coli*-positive REPEAT sample or has a fecal coliform- or *E. coli*-positive ROUTINE sample followed by a total coliform-positive REPEAT sample.

What are the Public Notification and Reporting Requirements?

For a Monthly MCL Violation	► The violation must be reported to the state no later than the end of the next business day after the system learns of the violation. ► The public must be notified within 30 days after the system learns of the violation.
For an Acute MCL Violation	► The violation must be reported to the state no later than the end of the next business day after the system learns of the violation. ► The public must be notified within 24 hours after the system learns of the violation.
Systems with ROUTINE or REPEAT samples that are fecal coliform- or *E. coli*-positive . . .	Must notify the state by the end of the day they are notified of the result or by the end of the next business day if the state office is already closed.

Office of Water (4606) EPA 816-F-01-035 http://water.epa.gov/drink Rev. March 2010

EPA
United States
Environmental Protection
Agency

Revised Total Coliform Rule: A Quick Reference Guide

Overview of the Rule

Title*	Revised Total Coliform Rule (RTCR) 78 FR 10269, February 13, 2013, Vol. 78, No. 30
Purpose	Increase public health protection through the reduction of potential pathways of entry for fecal contamination into distribution systems.
General Description	The RTCR establishes a maximum contaminant level (MCL) for *E. coli* and uses *E. coli* and total coliforms to initiate a "find and fix" approach to address fecal contamination that could enter into the distribution system. It requires public water systems (PWSs) to perform assessments to identify sanitary defects and subsequently take action to correct them.
Utilities Covered	The RTCR applies to all PWSs.

* This document provides a summary of federal drinking water requirements; to ensure full compliance, please consult the federal regulations at 40 CFR 141 and any approved state requirements.

Public Health Benefits

Implementation of the RTCR will result in:

- A decrease in the pathways by which fecal contamination can enter the drinking water distribution system.
- Reduction in fecal contamination *should* reduce the potential risk from all waterborne pathogens including bacteria, viruses, parasitic protozoa, and their associated illnesses.

Critical Deadlines and Requirements

For Public Water Systems

Before April 1, 2016	▶ PWSs must develop a written sample siting plan that identifies the system's sample collection schedule and all sample sites, including sites for routine and repeat monitoring. ▶ PWSs monitoring quarterly or annually must also identify additional routine monitoring sites in their sample siting plans. ▶ Sample siting plans are subject to state review and revision.
Beginning April 1, 2016	PWSs must comply with the RTCR requirements unless the state selects an earlier implementation date.

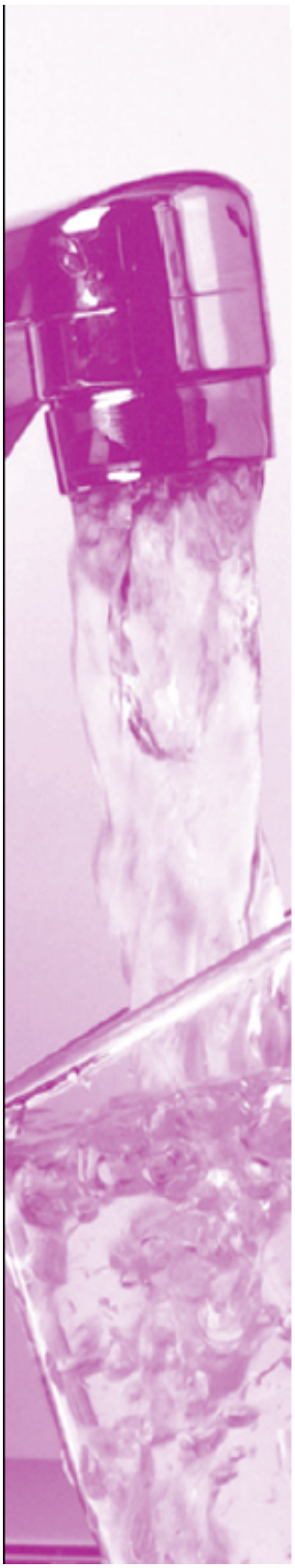
For State Drinking Water Agencies

By February 13, 2015	State submits final primacy program revision package to the EPA Region, including: ▶ Adopted State Regulations. ▶ Regulation Crosswalk. ▶ 40 CFR 142.10 Primacy Update Checklist. ▶ 40 CFR 142.14 and 142.15 Reporting and Recordkeeping. ▶ 40 CFR 142.16 Special Primacy Requirements. ▶ Attorney General's Enforceability Certification. NOTE: EPA regulations allow states until February 13, 2015, for this submittal. An extension of up to 2 years may be requested by the state.
Before February 13, 2015	State must submit a primacy program revision extension request if it does not plan to submit the final primacy program revision package by February 13, 2015. The state extension request is submitted to the EPA Region including all of the information required in 40 CFR 142.12(b): ▶ A schedule (not to exceed 2 years) for the submission of the final primacy program revision package. ▶ Justification that meets the federal requirements for an extension request. ▶ Confirmation that the state is implementing the RTCR within its scope of its current authorities and capabilities. ▶ An approved workload agreement with the EPA Region.
No later than February 13, 2017	For states with an approved extension, submit complete and final program revision package by the agreed upon extension date.

What are the Major Provisions?

Routine Sampling Requirements

- Total coliform samples must be collected by PWSs at sites which are representative of water quality throughout the distribution system according to a written sample siting plan subject to state review and revision.
- For PWSs collecting more than one sample per month, collect total coliform samples at regular intervals throughout the month, except that ground water systems serving 4,900 or fewer people may collect all required samples on a single day if the samples are taken from different sites.



Routine Sampling Requirements (cont.)

- Each total coliform-positive (TC+) routine sample must be tested for the presence of *E. coli*.
- If any TC+ sample is also *E. coli*-positive (EC+), then the EC+ sample result must be reported to the state by the end of the day that the PWS is notified.
- If any routine sample is TC+, repeat samples are required.
  - PWSs on quarterly or annual monitoring must take a minimum of three additional routine samples (known as additional routine monitoring) the month following a TC+ routine or repeat sample.
- Reduced monitoring may be available for PWSs using only ground water and serving 1,000 or fewer persons that meet certain additional PWS criteria.

Repeat Sampling Requirements

Within 24 hours of learning of a TC+ routine sample result, at least 3 repeat samples must be collected and analyzed for total coliform:	► One repeat sample must be collected from the same tap as the original sample. ► One repeat sample must be collected from within five service connections upstream. ► One repeat sample must be collected from within five service connections downstream.
	► The PWS may propose alternative repeat monitoring locations that are expected to better represent pathways of contamination into the distribution system.
If one or more repeat sample is TC+:	► The TC+ sample must be analyzed for the presence of *E. coli*. ► If any repeat TC+ sample is also EC+, then the EC+ sample result must be reported to the state by the end of the day that the PWS is notified. ► The PWS must collect another set of repeat samples, unless an assessment has been triggered and the PWS has notified the state.

Assessments and Corrective Action

The RTCR requires PWSs that have an indication of coliform contamination (e.g., as a result of TC+ samples, *E. coli* MCL violations, performance failure) to assess the problem and take corrective action. There are two levels of assessments (i.e., Level 1 and Level 2) based on the severity or frequency of the problem.

Purpose of Level 1 and Level 2 Assessments	To find sanitary defects at the PWS including: ► Sanitary defects that could provide a pathway of entry for microbial contamination, or ► Sanitary defects that indicate failure (existing or potential) of protective barriers against microbial contamination. *Guidance on how to conduct Level 1 and Level 2 Assessments and how to correct sanitary defects found during the Assessments can be found at:* http://water.epa.gov/lawsregs/rulesregs/sdwa/tcr/regulation_revisions.cfm.
Deadline for Completing Corrective Actions	When sanitary defects are identified during a Level 1 or Level 2 Assessment, they should be corrected as soon as possible to protect public health. The PWS must complete corrective actions by one of the following timeframes: ► No later than the time the assessment form is submitted to the state, which must be within 30 days of triggering the assessment, or ► Within state-approved timeframe which was proposed in the assessment form.

Level 1 Assessments

Conducting Level 1 Assessments	► Performed by the PWS owner or operator each time a Level 1 Assessment is triggered.
	► Upon trigger of a Level 1 Assessment, the Level 1 Assessment form must be submitted within 30 days to the state.
Level 1 Assessment Triggers	Level 1 Assessment is triggered if any one of the following occurs: ► A PWS collecting fewer than 40 samples per month has 2 or more TC+ routine/repeat samples in the same month. ► A PWS collecting at least 40 samples per month has greater than 5.0 percent of the routine/repeat samples in the same month that are TC+. ► A PWS fails to take every required repeat sample after any single TC+ sample.

Level 2 Assessments

Conducting Level 2 Assessments	► Performed by the state or state-approved entity each time a Level 2 Assessment is triggered. ► The PWS is responsible for ensuring that the Level 2 Assessment is conducted regardless of the entity conducting the Level 2 Assessment.
	► Upon trigger of a Level 2 Assessment, the Level 2 Assessment form must be submitted within 30 days to the state.
Level 2 Assessment Triggers	Level 2 Assessment is triggered if any one of the following occurs: ► A PWS incurs an *E. coli* MCL violation. ► A PWS has a second Level 1 Assessment within a rolling 12-month period. ► A PWS on state-approved annual monitoring has a Level 1 Assessment trigger in 2 consecutive years.

For additional information on the RTCR:

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA website at http://water.epa.gov/lawsregs/rulesregs/sdwa/tcr/regulation_revisions.cfm; or contact your state drinking water representative.

Seasonal System Provisions

The RTCR defines seasonal systems and specifies additional requirements for these types of PWSs:

- A seasonal system is defined as a non-community water system that is not operated as a PWS on a year-round basis and starts up and shuts down at the beginning and end of each operating season.

Start-up Procedures for Seasonal Systems	At the beginning of each operating period, before serving water to the public, seasonal water systems must: ► Conduct state-approved start-up procedures. ► Certify completion of state-approved start-up procedures. ► An exemption from conducting state-approved start-up procedures may be available for seasonal systems that maintain pressure throughout the distribution system during non-operating periods.
	Examples of state-approved start-up procedures, which need to be completed prior to serving water to the public, may include one or more of the following: ► Disinfection. ► Distribution system flushing. ► Sampling for total coliform and *E. coli*. ► Site visit by state. ► Verification that any current or historical sanitary defects have been corrected.
Routine Monitoring for Seasonal Systems	► The baseline monitoring frequency for seasonal systems is monthly. ► A reduced monitoring frequency may be available for seasonal systems that use ground water only and serve fewer than 1,000 persons.

Other Provisions for the State Drinking Water Agency

Special Monitoring Evaluation	The state must perform a special monitoring evaluation at all ground water systems serving 1,000 or fewer persons during each sanitary survey to review the status of the PWS and to determine whether the sample sites and monitoring schedule need to be modified.

Major Violations

***E. coli* MCL Violation**	A PWS will receive an *E. coli* MCL violation when there is any combination of an EC+ sample result with a routine/repeat TC+ or EC+ sample result:

***E. coli* MCL Violation Occurs with the Following Sample Result Combination**

Routine	Repeat
EC+	TC+
EC+	Any missing sample
EC+	EC+
TC+	EC+
TC+	TC+ (but no *E. coli* analysis)

Treatment Technique Violation	A PWS will receive a Treatment Technique violation when any of the following occur: ► Failure to conduct a Level 1 or Level 2 Assessment within 30 days of a trigger. ► Failure to correct all sanitary defects from a Level 1 or Level 2 Assessment within 30 days of a trigger or in accordance with the state-approved timeframe. ► Failure of a seasonal system to complete state-approved start-up procedures prior to serving water to the public.

Key Points for Public Water Systems to Remember

Find and correct sanitary defects as soon as you become aware of them.

- This can help reduce *E. coli* MCL violations, which trigger a Level 2 Assessment.
- This can help reduce TC+ sample results, which may trigger a Level 1 Assessment.

Make sure to collect all routine and repeat samples as required.

- Timely and correct monitoring can help reduce triggering a Level 1 or Level 2 Assessment because:
  - Failure to conduct repeat monitoring triggers a Level 1 Assessment.
  - A Level 1 Assessment triggered twice within a certain timeframe triggers a Level 2 Assessment.

Table 1: Drinking Water Standards for maximum contaminant levels (MCLs) for inorganic compounds. Effective 2-16-2012 from the Pennsylvania Department of Environmental Protection (PADEP). MFL= million fibers per liter.

FEDERAL CONTAMINANT ID NUMBER	CONTAMINANT	MCL (mg/L)
1074	Antimony	0.006
1005	Arsenic	0.05 through 12/31/2004 0.010 on and after 01/01/2005
1094	Asbestos	7 MFL
1010	Barium	2
1075	Beryllium	0.004
1015	Cadmium	0.005
1020	Chromium	0.1
1024	Cyanide (as free Cyanide)	0.2
1025	Fluoride	4.0
1030	Lead	0.015
1035	Mercury	0.002
1036	Nickel	0.1
1040	Nitrate	10 (as N)
1041	Nitrite	1 (as N)
	Total Nitrate and Nitrite	10 (as N)
1045	Selenium	0.05
1052	Sodium	160
1085	Thallium	0.002

Table 2: Secondary Drinking Water Standards. Effective 2-16-2012 from the Pennsylvania Department of Environmental Protection. SMCL= maximum contaminant level.

FEDERAL CONTAMINANT ID NUMBER	CONTAMINANT	SMCL (mg/L)*
1002	Aluminum	0.2
1017	Chloride	250
1022	Copper	1
1025	Fluoride	2.0
1028	Iron	0.3
1032	Manganese	0.05
1050	Silver	0.1
1055	Sulfate	250
1095	Zinc	5
1905	Color	15 color units
1920	Odor**	3 (threshold odor number)
1925	pH	6.5 - 8.5
1930	Total Dissolved Solids	500
2905	Foaming Agents	0.5

Appendix 2: State Regulations of Private Water Wells

Table 3: Links to online resources on state regulations of private water wells.

State	State Online Resource to Private Well Water Regulations
AL	http://www.aces.edu/waterquality/faq/faq_list.php3?Code=303
AK	N/A
AZ	http://www.azwater.gov/AzDWR/Watermanagement/Wells/default.htm
AR	http://www.arkansas.gov/awwcc/
CA	http://www.water.ca.gov/groundwater/well_info_and_other/well_standards.cfm
CO	http://water.state.co.us/groundwater/BOE/Pages/BOERules.aspx
CT	http://www.darienct.gov/filestorage/104/114/163/4423/Microsoft_Word_-_Approved_Well_Regulations__03-29-2010_.pdf
DE	http://www.dnrec.delaware.gov/wr/Information/faqs/Pages/WaterSupplyFAQs.aspx
FL	https://www.flrules.org/gateway/ChapterHome.asp?Chapter=62-532
GA	http://www.hallcounty.org/files/pdfs/devserv/envhealth/WellRegulations.pdf
HI	http://www2.ctahr.hawaii.edu/oc/freepubs/pdf/HH-9.pdf http://www.state.hi.us/dlnr/cwrm/regulations/hwcpis04.pdf
ID	http://www.deq.idaho.gov/water-quality/ground-water/private-wells.aspx
IL	http://www.ilga.gov/commission/jcar/admincode/077/07700920sections.html
IN	http://www.in.gov/idem/4281.htm
IA	http://www.iowadnr.gov/InsideDNR/RegulatoryWater/PrivateWellProgram.aspx
KS	http://www.kdheks.gov/waterwell/
KY	http://water.ky.gov/Fact%20Sheets/Groundwater%20protection%20--%20wells.pdf
LA	http://www.deq.louisiana.gov/portal/Portals/0/RemediationServices/Water%20Wells%20Rules_regs_and_standards.pdf
ME	http://www.maine.gov/dhhs/mecdc/environmental-health/eohp/wells/mewellwater.htm
MD	http://www.mde.state.md.us/programs/Water/BayRestorationFund/OnsiteDisposalSystems/Pages/WellConstruction.aspx
MA	https://malegislature.gov/Laws/GeneralLaws/PartI/TitleII/Chapter21G/Section20
MI	http://www.michigan.gov/deq/0,1607,7-135-3313_3675_3694---,00.html
MN	http://www.health.state.mn.us/divs/eh/wells/
MS	http://www.msdh.state.ms.us/msdhsite/_static/30,0,76,225.html
MO	http://www.dnr.mo.gov/pubs/pub2175.pdf
MT	http://dnrc.mt.gov/wrd/water_op/bwwc/
NE	http://water.unl.edu/web/wells/regulations
NV	http://water.nv.gov/programs/wd/wdregs.pdf
NH	http://des.nh.gov/organization/divisions/water/dwgb/well_testing/index.htm\ http://des.nh.gov/organization/commissioner/legal/rules/documents/env-dw301.pdf
NJ	http://www.nj.gov/dep/watersupply/pw_pwta.html
NM	http://www.nmenv.state.nm.us/fod/LiquidWaste/well.testing.html
NY	http://www.health.ny.gov/environmental/water/drinking/regulations/fact_sheets/fs6_guidance_for_code_enforcement_officials.htm
NC	http://ehs.ncpublichealth.com/oswp/wells-faq.htm
ND	http://www.ndhealth.gov/wq/gw/pubs/WellTestingBrochure.pdf http://www.legis.nd.gov/information/acdata/pdf/33-18-01.pdf?20130930230153
OH	http://www.dnr.state.oh.us/water/maptechs/wellogs/appNEW/
OK	http://www.dep.state.fl.us/legal/Rules/groundwater/62-532/62-532.pdf
OR	http://www.deq.state.or.us/wq/dwp/wellowners.htm
PA	N/A
RI	http://www.dem.ri.gov/programs/benviron/water/permits/privwell/
SC	https://www.scdhec.gov/environment/water/dwrw.htm
SD	http://denr.sd.gov/des/dw/privatewell.aspx
TN	http://tn.gov/sos/rules/1200/1200-04/1200-04-09.pdf

TX	http://www.tdlr.state.tx.us/wwd/wwd.htm
UT	http://extension.usu.edu/waterquality/htm/agriculturewq/riskwater/
VT	http://healthvermont.gov/enviro/ph_lab/water_test.aspx#two
VA	http://www.vdh.state.va.us/environmentalhealth/onsite/regulations/PrivateWellInfo/
WA	http://www.ecy.wa.gov/programs/wr/wells/wellhome.html
WV	http://www.wvdhhr.org/phs/water/index.asp
WI	http://dnr.wi.gov/topic/wells/homeowners.html
WY	http://seo.wyo.gov/ground-water/water-well-construction

Appendix 3 Soils: HaC and WaB

Physical Soil Properties

Butler County, Pennsylvania

Map symbol and soil name	Depth	Sand	Silt	Clay	Moist bulk density	Saturated hydraulic conductivity	Available water capacity	Linear extensibility	Organic matter	Erosion factors			Wind erodibility group	Wind erodibility index
										Kw	Kf	T		
	In	*Pct*	*Pct*	*Pct*	*g/cc*	*micro m/sec*	*In/In*	*Pct*	*Pct*					
HaC:														
Hazleton	0-6	---	---	7-18	1.20-1.40	14.11-42.34	0.10-0.14	0.0-2.9	2.0-4.0	.17	.28	3	6	48
	6-36	---	---	7-18	1.20-1.40	14.11-141.14	0.08-0.12	0.0-2.9	0.0-0.5	.15	.20			
	36-54	---	---	5-15	1.20-1.40	14.11-141.14	0.06-0.12	0.0-2.9	0.0-0.5	.15	.20			
	54-58	---	---	---	---	3.00-42.34	---	---	---	---	---			

Figure 1: HaC Physical Soil Properites (USDA Natural Resources Conservation Service)

Chemical Soil Properties

Butler County, Pennsylvania

Map symbol and soil name	Depth	Cation-exchange capacity	Effective cation-exchange capacity	Soil reaction	Calcium carbonate	Gypsum	Salinity	Sodium adsorption ratio
	In	*meq/100 g*	*meq/100 g*	*pH*	*Pct*	*Pct*	*mmhos/cm*	
HaC:								
Hazleton	0-6	---	2.9-6.6	3.6-5.5	0	0	0.0	0
	6-36	---	1.4-3.6	3.6-5.5	0	0	0.0	0
	36-54	---	1.0-3.0	3.6-5.5	0	0	0.0	0
	54-58	---	---	---	0	0	0.0	0

Figure 2: HaC Chemical Soil Properties (USDA Natural Resources Conservation Service)

Selected Soil Interpretations

Butler County, Pennsylvania

[The information in this table indicates the dominant soil condition but does not eliminate the need for onsite investigation. The table shows only the top five limitations for any given soil. The soil may have additional limitations]

*This soil interpretation was designed as a "limitation" as opposed to a "suitability". The numbers in the value columns range from 0.01 to 1.00. The larger the value, the greater the potential limitation.

Map symbol and soil name	Pct. of map unit	Septic System Sand Mound Bed or Trench (PA) *		Septic System Subsurface Sand Filter Bed (conventional) (PA) *		Septic System Subsurface Sand Filter Trench (standard) (PA) *	
		Rating class and limiting features	Value	Rating class and limiting features	Value	Rating class and limiting features	Value
HaC:							
Hazleton	80	Moderately limited		Very limited		Very limited	
		Too steep	0.85	Bedrock, above 72"	1.00	Bedrock, above 72"	1.00
		Potential fast percolation 12-20"	0.26	Too steep	1.00	Slow percolation 12-36"; see criteria	0.94
				Slow percolation 12-36"; see criteria	0.94	Slope	0.46
				Potential fast percolation 36-60"	0.02	Potential fast percolation 36-60"	0.02

Figure 3: HaC suitability for sand-type septic sytems. (USDA Natural Resources Conservation Service)

Selected Soil Interpretations

Butler County, Pennsylvania

[The information in this table indicates the dominant soil condition but does not eliminate the need for onsite investigation. The table shows only the top five limitations for any given soil. The soil may have additional limitations]

*This soil interpretation was designed as a "limitation" as opposed to a "suitability". The numbers in the value columns range from 0.01 to 1.00. The larger the value, the greater the potential limitation.

Map symbol and soil name	Pct. of map unit	Septic System In Ground Bed (conventional) (PA) *		Septic System In Ground Trench (conventional) (PA) *	
		Rating class and limiting features	Value	Rating class and limiting features	Value
HaC:					
Hazleton	80	Very limited		Very limited	
		Bedrock, above 60"	1.00	Bedrock, above 60"	1.00
		Too steep	1.00	Fast percolation >12"	1.00
		Fast percolation >12"	1.00	Slope	0.46

Figure 4: HaC suitability for convention septic systems (non-sand type). (USDA Natural Resources Conservation Service)

Physical Soil Properties

Butler County, Pennsylvania

Map symbol and soil name	Depth	Sand	Silt	Clay	Moist bulk density	Saturated hydraulic conductivity	Available water capacity	Linear extensibility	Organic matter	Erosion factors			Wind erodibility group	Wind erodibility index
										Kw	Kf	T		
	In	*Pct*	*Pct*	*Pct*	*g/cc*	*micro m/sec*	*In/In*	*Pct*	*Pct*					
WaB:														
Wharton	0-9	---	---	15-25	1.10-1.30	4.23-14.11	0.16-0.20	0.0-2.9	1.0-4.0	.37	.37	4	4	86
	9-46	---	---	15-35	1.20-1.50	0.42-4.23	0.12-0.16	3.0-5.9	0.3-1.0	.24	.28			
	46-69	---	---	20-50	1.20-1.60	0.42-4.23	0.08-0.12	3.0-5.9	0.0-0.5	.17	.24			
	69-75	---	---	---	---	0.00-14.11	---	---	---	---	---			
Brinkerton	0-8	---	---	15-30	1.20-1.40	4.23-14.11	0.18-0.24	0.0-2.9	1.0-4.0	.32	.32	3	5	56
	8-21	---	---	20-40	1.20-1.50	4.23-14.11	0.14-0.18	3.0-5.9	0.1-1.0	.37	.37			
	21-42	---	---	15-35	1.60-1.80	0.42-2.33	0.08-0.12	3.0-5.9	0.0-0.5	.32	.37			
	42-65	---	---	15-25	1.40-1.55	0.42-4.23	0.14-0.18	0.0-2.9	0.0-0.5	.20	.28			

Figure 5: WaB Physical Soil Properties (USDA Natural Resources Conservation Service)

Chemical Soil Properties

Butler County, Pennsylvania

Map symbol and soil name	Depth	Cation-exchange capacity	Effective cation-exchange capacity	Soil reaction	Calcium carbonate	Gypsum	Salinity	Sodium adsorption ratio
	In	*meq/100 g*	*meq/100 g*	*pH*	*Pct*	*Pct*	*mmhos/cm*	
WaB:								
Wharton	0-9	18-32	6.0-14	5.1-6.2	0	0	0.0	0
	9-46	12-20	3.0-7.0	4.0-5.5	0	0	0.0	0
	46-69	14-24	4.0-9.0	4.5-5.5	0	0	0.0	0
	69-75	---	---	---	0	0	0.0	0
Brinkerton	0-8	18-26	---	5.1-7.1	0	0	0.0	0
	8-21	14-24	3.0-7.4	4.5-6.0	0	0	0.0	0
	21-42	14-24	3.0-7.4	4.5-6.0	0	0	0.0	0
	42-65	12-22	---	5.1-6.5	0	0	0.0	0

Figure 6: WaB Chemcial Soil Properties (USDA Natural Resources Conservation Service)

Selected Soil Interpretations

Butler County, Pennsylvania

[The information in this table indicates the dominant soil condition but does not eliminate the need for onsite investigation. The table shows only the top five limitations for any given soil. The soil may have additional limitations]

*This soil interpretation was designed as a "limitation" as opposed to a "suitability". The numbers in the value columns range from 0.01 to 1.00. The larger the value, the greater the potential limitation.

Map symbol and soil name	Pct. of map unit	Septic System Sand Mound Bed or Trench (PA) *		Septic System Subsurface Sand Filter Bed (conventional) (PA) *		Septic System Subsurface Sand Filter Trench (standard) (PA) *	
		Rating class and limiting features	Value	Rating class and limiting features	Value	Rating class and limiting features	Value
WaB:							
Wharton	80	Very limited		Very limited		Very limited	
		Seasonal high water table	1.00	Seasonal high water table	1.00	Seasonal high water table	1.00
		Slow percolation 12-20"	0.79	Bedrock, above 72"	1.00	Bedrock, above 72"	1.00
		Slope	0.35	Slow percolation 12-36"; can not use system	1.00	Slow percolation 12-36"; can not use system	1.00
				Slow percolation 36-60"	1.00	Slow percolation 36-60"	1.00
				Slope	0.72	Slope	0.08
Brinkerton	2	Very limited		Very limited		Very limited	
		Seasonal high water table	1.00	Seasonal high water table	1.00	Seasonal high water table	1.00
		Slope	0.35	Slow percolation 12-36"; can not use system	1.00	Slow percolation 12-36"; can not use system	1.00
				Slow percolation 36-60"	1.00	Slow percolation 36-60"	1.00
				Slope	0.72	Slope	0.08

Figure 7: WaB suitability for sand-type septic sytems (USDA Natural Resources Conservation Service)

Selected Soil Interpretations

Butler County, Pennsylvania

[The information in this table indicates the dominant soil condition but does not eliminate the need for onsite investigation. The table shows only the top five limitations for any given soil. The soil may have additional limitations]

*This soil interpretation was designed as a "limitation" as opposed to a "suitability". The numbers in the value columns range from 0.01 to 1.00. The larger the value, the greater the potential limitation.

Map symbol and soil name	Pct. of map unit	Septic System In Ground Bed (conventional) (PA) *		Septic System In Ground Trench (conventional) (PA) *	
		Rating class and limiting features	Value	Rating class and limiting features	Value
WaB:					
Wharton	80	Very limited		Very limited	
		Seasonal high water table	1.00	Seasonal high water table	1.00
		Slow percolation >12"	1.00	Slow percolation >12"	1.00
		Slope	0.72	Potential bedrock near 60"	0.27
		Potential bedrock near 60"	0.27	Slope	0.08
Brinkerton	2	Very limited		Very limited	
		Seasonal high water table	1.00	Seasonal high water table	1.00
		Slow percolation >12"	1.00	Slow percolation >12"	1.00
		Slope	0.72	Slope	0.08

Figure 8: WaB suitability for convention septic systems (non-sand type). (USDA Natural Resources Conservation Service)

Appendix 4: FracFocus Reports

Hydraulic Fracturing Fluid Product Component Information Disclosure

Fracture Date	1/6/2011
State:	Pennsylvania
County:	Butler
API Number:	37-019-21674
Operator Name:	Rex Energy
Well Name and Number:	Voll 1-H
Longitude:	-80.0547259
Latitude:	40.8387035
Long/Lat Projection:	NAD83
Production Type:	Gas
True Vertical Depth (TVD):	5,469
Total Water Volume (gal)*:	3,336,471

Hydraulic Fracturing Fluid Composition:

Trade Name	Supplier	Purpose	Ingredients	Chemical Abstract Service Number (CAS #)	Maximum Ingredient Concentration in Additive (% by mass)**	Maximum Ingredient Concentration in HF Fluid (% by mass)**
Water	Rex	Base Fluid	Water	7732-18-5	100.00%	94.68860%
Sand (Proppant)	Unimin Corp.	Proppant	Silica Sand	14808-60-7	99.90%	4.11580%
			Aluminum Oxide	1344-28-1	0.10%	0.48700%
Acid (Hydrochloric)	Bayer	Acidizing	Hydrochloric Acid	7647-01-0	32.00%	0.33620%
FRP-121	SNF Inc.	Friction Reducer	Anionic water-soluble polymer	25085-02-3	99.90%	0.03110%
EC6116A	Nalco Co.	Bacteriacide	Dibromoacetonitrile	3252-43-5	1-5%	0.00070%
			2,2-Dibromo-3-nitrilopropionamide	10222-01-2	10-30%	0.00881%
			Polyethylene Glycol	25322-68-3	40-60%	0.01270%
Scalehib-100	Clearwater Int.	Scale Inhibitor	Ethylene Glycol	107-21-1	30-60%	0.01570%
NCL	Clearwater Int.	Clay Control	Ethylene Glycol	107-21-1	30-60%	0.06500%
LEB 10X	Clearwater Int.	Gel Breaker	Ethylene Glycol	107-21-1	30-60%	0.00001%
Unigel CMHPG	Hercules	Friction Reducer	carboxymethylhydroxypropyl guar blend	39421-75-5	95.00%	0.00070%
Unihib A	Clearwater	Acid inhibitor	Dibromoacetonitrile	3252-43-30	20-40%	0.00010%
			Dibrom-3-nitnlpropion	1022-01-2	20-0%	0.00010%
			Ethylene Glycol	107-21-1	20-40%	0.00010%