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Evaluation of Residential Well Water Quality in Alamance County, North Carolina

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Abstract:

State-wide residential well regulations for North Carolina went into effect July 1, 2008 that mandated all new wells to undergo a permitting process that required the inspection of the well head to ensure proper sealing, and collection and analyses of well water samples for indicator microbial organisms. Prior to the new regulations, well water samples were only tested for microbial contamination upon request by well owners. The primary objective of this study was to determine if the frequency of wells that tested positive for microbial contamination was significantly different before in comparison to after the implementation of the new well regulations. A secondary goal was to gain a better understanding of the likelihood of well water contamination across Alamance County, North Carolina. Water samples from 35 wells installed after 2008 (new wells) were tested for the presence of total coliform and the frequency of contamination was calculated and compared to the results from 35 match pair samples collected from nearby wells installed between 2005 and 2008. No significant difference was found in the frequency of water samples that tested positive for microbial contamination for wells drilled after 2008 (31%) relative to wells drilled between 2005 and 2008 (29%). Furthermore, after reviewing data from 141 wells across the County, it was discovered that 34% (48 wells) contained total coliform. Therefore, adoption of a well program that includes the inspection of well installations and proper sealing of wells will not guarantee safe water. All private wells should be sampled to ensure residents that their water supply is safe.

Keywords: Water well, contamination, bacteria, health

1. Introduction:

1.1 Groundwater Supplies and Groundwater Quality:

An adequate supply of safe water is one of the most basic human needs. Groundwater, because of natural filtration process provided by soil, is typically considered safer than surface water as a water supply. However, groundwater may also become contaminated and hazardous to human health. One of the most imminent public health hazards is the presence of pathogens in water supplies. On a global scale, waterborne pathogens are responsible for an estimated 5,500 deaths every day or nearly 2 million per year (Nadakavukaren, 2006). These pathogens can originate from malfunctioning septic systems, improperly stored manure, and waste runoff. Water well construction methods, well depth, and location of wells relative to potential contamination sources are other factors which can influence well water quality. For example, Gonzalez (2008) tested 30 private wells for the presence of total coliform and *E. coli* in Estes Park Valley, Colorado and found a positive correlation between poor wellhead protection and bacterial (total coliform and *E. coli*) contamination. Gonzales (2008) also found that wells less than 60 m deep, and/or wells located within 30 m of surface waters were more likely to be contaminated.

Sixteen public water supply wells in the South Bass Island, Ohio area were sampled by the United States Environmental Protection Agency after an outbreak of *Campylobacter*, Norovirus, *Giardia* and *Salmonella* were determined to be associated with ground-water supplies (Theng-Theng et.al., 2007). Eleven of the 16 wells were positive for coliform bacteria (Theng-Theng et.al., 2007). Their results also indicated that deeper wells were less likely to be contaminated with microbial indicators. Theng-Theng et al. (2007) attributed the outbreak to multiple heavy rainfalls leading to failures in septic system wastewater treatment.

Between 1991 and 2004, the United States Geological Survey sampled 2100 private wells from 219 properties, spanning 48 states, including North Carolina. (Desimone, Hamilton, and Gillion, 2009). Their study focused on the occurrence of contamination for regional aquifers. Nearly 400 of these wells were tested for bacteriological contamination. Total coliform was found in 34% of wells sampled indicating that microbial contamination of groundwater was relatively common (Desimone, Hamilton, and Gillion, 2009).

The United States Centers for Disease Control and Prevention (USCDC) in conjunction with the state health and environmental departments of nine Midwestern states conducted a water quality survey of 5520 private wells in the early 1990's (USCDC, 1998). A coliform bacterium was found in wells at frequencies ranging from 22.8% (Wisconsin) to 58.6% (Iowa). Overall, an average of 41% of wells tested positive for coliform (USCDC, 1998). The survey showed that dug or bored wells were 10 to 15 times more likely to be contaminated with coliform bacteria or *E. coli* than the deeper drilled wells, and wells within 30 m of potential pollutant sources (septic systems, waste application fields, etc.,) were more likely to be contaminated (USCDC, 1998). Thus, the USCDC (1998) determined that proper wellhead protection, well type, and well location all play a role in keeping ground-water supplies safe for consumption.

1.2 Alamance County and Groundwater Wells:

Alamance County is located in the slate belt region of the central piedmont area of North Carolina (Figure a.). The slate belt is predominantly made up of mafic and felsic metavolcanic rock which can influence potable water quality (Anderson, 1998). Minerals found in these rocks contain magnesium and iron, which at elevated concentrations can reduce the palatability of water, cause water hardness, staining and a general reduction in aesthetics (Hammer and Hammer Jr., 2004). A more imminent public health hazard is the presence of pathogens in well water. Well water can become contaminated by inadequately treated human waste via malfunctioning septic systems, poor manure management practices, and wildlife waste. Approximately 37% of Alamance County residents rely on septic systems for wastewater treatment, 32% of the land area is in agriculture production, and there are over 19,000 livestock in the County (United States Census Bureau, 1990; NC Agriculture and Consumer Services, 2011). Thus, there are many potential pollution sources in Alamance County that could contaminate well water. Approximately 15,000 Alamance County residents rely on either drilled or dug wells as their primary source of drinking water (United States Census Bureau, 2010). Therefore, well inspections and water testing are important for the protection of public health by keeping residents informed concerning the safety of their water supply.

1.3 State and County Groundwater Well Regulations:

In 2008, the State of North Carolina implemented legislation that required each county or health district to develop a groundwater well program (NC session law 2006 202; House Bill 2873). Some counties had well regulations and programs prior to the statewide rules. The state regulations helped to standardize the permitting and inspection processes of private water wells across county lines and ensure that newly installed wells were tested for all counties. Alamance County has had a well program in place since 1990. Alamance County Environmental Health Specialists (EHS) have permitted and inspected the installation of new wells for more than two decades. However, prior to the state well program, EHS did not inspect the sanitary well seal or collect water samples for analyses unless requested by the owner. As part of the statewide well program, county EHS were required to inspect the sanitary well seal and collect water samples from newly installed drinking water wells to test for microbial indicators of drinking water contamination. Well water samples were sent to the North Carolina Public Health Laboratory (NCPHL) in Raleigh for microbial analyses. Alamance County EHS observed an apparent increase in the number of domestic single home wells that tested positive for total coliform bacteria and were unsure if the increase in well contamination was statistically significant or if the requirement to test all new wells led to more positive samples due to the increase in testing.

The main objective of this study was to determine if there was a significant difference in the frequency of microbial contamination of water for wells installed prior to the State-mandated well program of 2008 relative to post 2008. A secondary objective was to gain a better understanding of the water quality of domestic wells in the county.

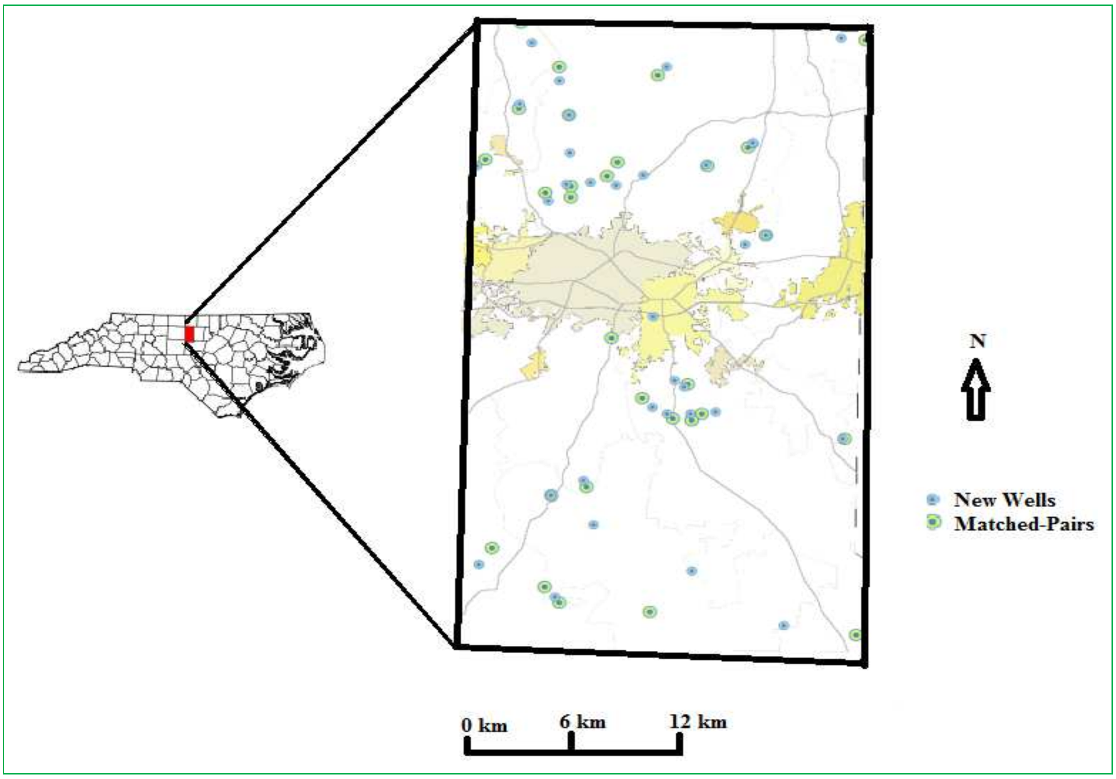

Figure a. Map of new and matched-pairs wells in Alamance County, Noth Carolina (shaded in red).

2. Materials and Methods:

2.1 Well Selection:

Water samples were collected between January 2010 and August 2010 from 141 drilled and bored wells that serve single family homes in Alamance County, NC**.** The samples were collected and analyzed either because the new statewide regulation required testing (post 2008), because a property owner requested the analyses (pre-2008), or specifically for this study as part of a matched-pairs analysis (2005-2008). Data from all the wells was reported, however, the main objective of the study was to determine if there was a significant difference in the frequency of well contamination by microbial indicators for wells installed prior to the State mandated well program in 2008 relative to wells installed after 2008. Well water analyses that were requested by property owners (pre-2008) may be more likely to test positive for microbial contamination than other wells because the owners suspected a problem with their water, and thus requested the test. Therefore, to eliminate bias, a matched-pairs study was initiated. The matched-pairs wells had to be in close proximity (same subdivision or typically within ~2 km) and age (3 years) to wells installed after 2008, to be included in the study. The well construction information, and water quality data from the new wells (2008 or newer) were compared to the well construction data and water quality for the nearby, slightly older (2005-2008), matched-pairs wells to determine if the frequency of contamination was significantly different, and if well construction characteristics influenced contamination. Water quality and well construction data from additional tested wells that were not in close proximity or age to the matched-pairs wells were also summarized to gain a broader overview of well water quality in Alamance County.

2.2 Matched-Pairs Methodology:

A list was compiled of all wells in the county that were installed between 2005 and 2008. This time frame was chosen because it was just before the implementation of the state-wide well program, and thus the age difference between new and matched-pairs wells would be minimal. Geographic Information System (GIS) was used to find geographically proximal matches of wells installed between 2005-June 2008 to wells installed post June 2008 (Figure a.). Wells installed in similar settings would be subjected to similar potential sources of contamination. Once a match was identified the owners name was found using the county tax database. Efforts were made via phone, mail, and sometimes site visits to obtain permission to sample wells. While 57 matches were selected and site visits were made to all properties, cooperation was somewhat limited. Permission was received to sample 31 separate wells installed between 2005 and June 2008 for comparison to 35 nearby wells installed after June 2008. Four of the 31 samples collected were in subdivisions where more than one well drilled after June 30, 2008 was previously sampled. Because of the close proximity of these wells a matched pairs sample was matched to more than one newly drilled well. This led to 35 matches to 35 new wells. McNemar's test was performed using *SPSS 19* (IBM, 2011) to determine if the differences in frequency of microbial contamination between wells installed pre in comparison to post June 2008 were statistically significant. Microbial contamination frequency was also reported for the other wells that were sampled, but not included in the matched-pairs analysis. There were an additional 22 new wells (installed after 2008) and 53 older wells (installed prior to 2008) with microbial data.

2.3 Well Condition and Characteristics:

Wells were categorized by depth, type, wellhead protection, and sampling location as described by Gonzales (2008). Well type was noted as either drilled or bored and then divided into three categories according to well depth; wells less than 30 m, wells between 30 and 60 m, and wells greater than 60 m. Wellhead protection classifications included poor (no grout around well and/or wellhead, less than 0.3 m above finished grade), fair (grouted well with wellhead at least 0.3 m above finished grade) and excellent (well grouted, wellhead 0.3 m above finished grade and properly sealed with vent pipe and hose bib present). Wells with poor, fair and excellent construction were assigned values of 0, 1, and 2, respectively for general comparisons. Wells were also classified as new (required to be sampled by state regulations), existing (requested to be sampled by property owners) or matched pairs (those chosen for matched pairs sampling). Each well sample was given an alphanumeric code so as to clearly identify which were new (NW1, NW2, etc,), existing (EW1, EW2, etc,) or matched pairs (MP1, MP2, etc).

2.4 Sample Collection:

Samples were taken directly from the wellhead when applicable. If the wellhead did not have a faucet, then the sample was taken from an outside house faucet. In a few instances samples were requested by homeowners to be taken from inside the home. For all samples, hoses, aerators and strainers were removed from the faucet prior to taking the sample. All faucets used for sampling were first sanitized on the inside and the outside with an alcohol swab and then tested for the presence of chlorine. If chlorine was absent the inspector ran the water for 3-5 minutes and then filled the sample bottle. Once the bottle was full the lid was immediately sealed, without touching the interior of the cap or container. The samples were placed in a cooler with ice until they returned to the office.

2.5 Sample Analyses:

All samples were analyzed within 24 hours of sampling by a certified lab technician at the North Carolina Public Health Laboratory (NCPHL) in Raleigh or by Alamance County Environmental Health Specialists. The NCPHL uses the *Colilert method* (IDEXX, 2011) when testing for total coliform. All laboratory results were sent back to ACEHD via the courier. The samples collected for the matched pair's survey were tested also using *Colilert* methods (IDEXX, 2011) at the Alamance County Environmental Health building. For quality control, duplicate samples were collected with samples being sent to NCPHL in Raleigh for analyses (3 samples) and the other to ACEHD (3 samples) for analyses and comparison. Blanks (de-ionized water) were also run for every 5 samples collected in the field.

3. Results and Discussion:

Table 1: Matched-pairs wells data for wells that tested negative and positive for total coliform. Wellhead condition poor (0), fair (1), excellent (2) and undetermined (-). Distance from well to septic system and watercourse.

Negative for Coliform				
Well ID	**Well Depth (m)**	**Well Head Condition**	**Septic (m)**	**Watercourse (m)**
MP2	182.9	0	30.5	30.5
MP3	91.4	2	30.5	30.5
MP4	67.1	1	27	30.5
MP5	189	2	30.5	30.5
MP6	74.7	2	30.5	30.5
MP7	158.5	0	30.5	30.5
MP8	36.6	2	30.5	30.5
MP12	132.6	2	30.5	30.5
MP13	93	2	30.5	30.5
MP14	128	0	30.5	30.5
MP16	91.4	-	30.5	24
MP19	61	2	30.5	30.5
MP20	219.5	0	30.5	30.5
MP23	36.6	2	30.5	30.5
MP24	43.3	1	30.5	30.5
MP25	103.6	-	30.5	30.5
MP26	57.9	2	30.5	30.5
MP27	49.7	1	30.5	30.5
MP28	38.1	0	30.5	30.5
MP29	36.6	2	30.5	30.5
MP30	152.4	2	30.5	30.5
MP31	61	1	26	30.5
MP3	91.4	2	30.5	30.5
MP20	219.5	0	30.5	30.5
MP26	57.9	2	30.5	30.5
Avg	98.9	1.3	30.2	30.2
S.D.	58.3	0.9	1.1	1.2

Positive for coliform				
Well ID	**Well Depth (m)**	**Well Head Condition**	**Septic (m)**	**Watercourse (m)**
MP1	103.6	2	30.5	30.5
MP9	109.7	2	30.5	28
MP10	49.7	2	30.5	30.5
MP11	79.2	0	30.5	30.5
MP15	36.6	2	30.5	30.5
MP17	54.9	2	30.5	30.5
MP18	36.6	2	30.5	30.5
MP21	109.7	2	30.5	30.5
MP22	153.9	2	30.5	30.5
MP11	79.2	0	30.5	30.5
Avg	81.3	1.6	30.5	30.2
S.D.	38.1	0.8	0	0.8

Table 2: New wells data for wells that tested negative and positive for total coliform. Wellhead condition poor (0), fair (1), and excellent (2). Distance from well to septic system and watercourse.

Negative for Total Coliform				
Well ID	**Well Depth (m)**	**Well Head Condition**	**Septic (m)**	**Watercourse (m)**
NW1	43.6	2	30.5	30.5
NW4	36.6	2	30.5	30.5
NW5	67.1	2	22.9	30.5
NW6	68.6	2	30.5	30.5
NW7	121.9	2	30.5	30.5
NW8	141.7	2	30.5	30.5
NW9	112.8	2	30.5	30.5
NW10	45.7	2	30.5	30.5
NW11	36.6	2	30.5	30.5
NW14	67.1	2	30.5	30.5
NW18	115.8	2	30.5	30.5
NW19	99.1	2	30.5	30.5
NW20	68	2	30.5	21.3
NW21	89.9	2	30.5	30.5
NW22	97.5	2	30.5	30.5
NW23	48.8	2	30.5	30.5
NW24	152.4	2	30.5	30.5
NW25	79.2	2	30.5	30.5
NW27	36.6	2	30.5	30.5
NW28	74.7	2	30.5	30.5
NW30	121.9	2	30.5	21.3
NW31	48.8	2	30.5	30.5
NW34	43.6	2	30.5	30.5
Avg	79	2	30.2	29.7
S.D.	35.5	0	1.6	2.7

Positive for Total Coliform				
Well ID	**Well Depth (m)**	**Well Head Condition**	**Septic (m)**	**Watercourse (m)**
NW2	121.9	2	30.5	30.5
NW3	54.9	2	30.5	30.5
NW12	152.4	2	30.5	30.5
NW13	121.9	2	30.5	30.5
NW15	42.7	2	30.5	30.5
NW16	109.7	2	30.5	30.5
NW17	54.9	2	29	30.5
NW26	37.5	2	30.5	30.5
NW29	73.2	2	30.5	30.5
NW32	42.7	2	30.5	30.5
NW33	92.4	2	30.5	15.2
NW35	30.5	2	30.5	30.5
Avg.	77.9	2	30.4	29.2
S.D.	40.6	0	0.4	4.4

3.1 Well Contamination:

A total of 141 wells were sampled between January and August 2010 for microbial analyses including 57 new wells (installed after June 2008) and 84 existing wells (installed before June 2008). Thirty five, close proximity matches (2005-2008) were found for 35 of the 57 new wells installed after 2008 for the main comparison.

Ten of 35 samples (~29%) from wells drilled between 2005 and 2008 (matched-pairs) were positive for total coliform, while 11 of 35 wells (~31%) drilled after June 30, 2010 (matched-pairs) tested positive (Tables 1-2). McNemar's tests showed that 15 of the 35 matched wells did not have the same test results (new well was positive but matched-pair negative, or vice-versa) and no statistically significant ($p < 0.05$) differences in the frequency of total coliform contamination of wells in the matched pairs study were observed (Table 3). The two-tailed P value was 1 and the odds ratio was 1.143 with a 95% confidence interval extending from .362 to 3.702. All blank samples were negative total coliform and all duplicate samples analyzed by ACHD and NCPHL were also negative for total coliform.

3.2 Well Construction Data:

The well head condition for most of the matched-pairs and new wells were either excellent (2) or fair (1) (Table 1 and 2). The mean well condition score for the matched-pairs wells that tested negative for coliform (1.3 ± 0.9) was similar to the mean well conditions for positive wells (1.6 ± 0.8) (Tables 1 and 2). Only two of the matched-pairs samples that were positive for total coliform had poor wellhead construction, the other 8 had excellent wellhead construction (Tables 1). The 25 samples absent for coliform came from 6 wells with poor wellhead construction, 4 with fair wellhead construction, 13 with excellent wellhead construction, and two undetermined (Table 1). All new wells had excellent well construction (Table 2), but more than 30% were still positive for total coliform contamination.

The mean depth of matched-pairs wells that tested positive for total coliform was 81.3 ± 38.1 m, and the mean depth of matched-pairs wells that tested negative was 98.9 ± 58.3 m (Table 1). The new wells that tested positive for coliform had a mean depth of 79 ± 35.5 m, while the new wells that tested negative had a mean depth of 77.9 ± 40.6 m (Table 2). However, no significant ($p < 0.05$) differences were found when comparing the depths of wells that were contaminated, to well depths that were not contaminated (Figure b).

Table 3. Cross tabulation of total coliform data from new wells and matched-pairs.

		New Wells		
		Absent	Present	Total
Matched-Pairs Wells	Absent	17	8	25
	Present	7	3	10
Total		24	11	35

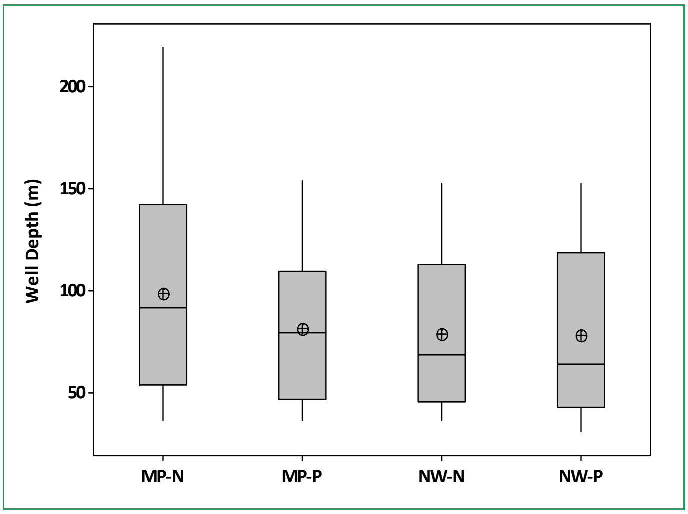

Figure b. Well depths of matched-pairs wells that tested negative (MP-N) and positive (MP-P) for coliform and new wells that tested negative (NW-N) and positive (NW-P) for coliform.

3.3 Other Well Samples But Not Included In Matched-Pairs Analysis:

For the 53 existing (pre-2008) wells that were sampled but not included in the matched-pairs analysis, nearly 34% (18 wells) tested positive for total coliform. Twenty-nine of these were from wells without records on file, indicating that they must have been drilled prior to inception of County wide regulations in 1990. For the 22 wells installed after 2008 that were sampled and not included in the matched-pairs study, 9 wells (41%) were positive total coliform. Overall, for the 141 wells sampled (existing, matched-pairs, new, new non-matched pairs, existing non-matched pairs) 48 wells (34%)

were positive for total coliform, indicating that coliform contamination was common, and consistent among the various age groups (matched-pairs 29%, new 31%, new non-matched pairs 41%, and existing non-matched pairs wells 34%).

The mean setback distances from septic systems and water courses to all comparison group wells were nearly identical and ranged from 29.2 ± 4.4 m for new wells that tested positive for coliform, to 30.5 ± 0 m for matched-pairs wells that were positive for total coliform (Tables 1-2).

3.4 *Project Objectives:*

The main objective of the matched pairs study was to see if the water quality of wells drilled prior to the 2008 mandated rules were more likely to be contaminated than those drilled after the 2008 rules. The results of the study showed no significant difference in the frequency of well water contamination for pre (29%) relative to post (31%) implantation of the state regulations. Statistical analysis showed that 15 of the 35 matched wells did not have the same test results. This indicates that for Alamance County, if there are two wells in close proximity and one tests positive for microbial indicators, it does not mean that the adjacent well will also test positive. Also, information concerning water quality of newly drilled wells may not necessarily give us reliable information about older wells in the same geographical area. There are site specific conditions which can influence well contamination, possibly during construction. More importantly though, the data indicates that well bacterial contamination is common (34% of all wells tested) across Alamance County and that all wells should be routinely tested to help inform residences of possible public health threats related to water supply.

3.5 Well Contamination Factors:

In this study a correlation between bacterial contamination and poor wellhead construction was not discovered. However, this was not the case in other similar studies (Theng-Theng et al., 2007; Gonzales, 2008). The parameters and variables of each comparison study are slightly different which may account for the difference in results. In both the South Bass Island (Theng-Theng et. al, 2007) and the Estes Park Valley (Gonzales, 2008) studies, the samples were collected from wells that were drilled or bored. Most of the bored wells tested were 15m deep or less and improperly sealed. In this study all wells sampled were at least 30 m deep, and none were bored wells. Although a significant difference was not found between each matched pairs comparison group, the wells that tested negative for microbial indicators had a mean well depth that was deeper than the wells that tested positive.

Another factor in the Estes Park Valley study was the distance to the Big Thompson River. In our matched pairs study the mean distances to watercourses were all greater than 29 m, while many wells in the Estes Park Valley study (Gonzales, 2008) were within 15 m of a watercourse, possibly increasing the risk for contamination due to flooding. The South Bass Island study (Theng-Theng et. al, 2007) also took place after several large rainfalls which may have lead to septic system malfunctions and contamination of nearby, shallow wells. The mean setback distances from septic systems to wells in Alamance County were greater than 30 m, thus providing a relatively large buffer between potential sources of contamination and wells. The Estes Park Valley and South Bass Island studies were also conducted in different geological settings (more permeable soils), and that may have also been a contributing factor to the water quality outcomes of their studies.

4. Conclusions:

The results of this study support the need for well water quality sampling because even new, inspected wells often test positive for microbial contamination, and may pose threats to public health. Overall, more than 1/3rd of the 141 wells tested were positive for total coliform, and thus water from these wells may be hazardous to public health.

5. Acknowledgements:

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