Domestic Well Coliform Tests Results

A positive coliform test result may not always tell you what it is supposed to tell you.

By Thomas B. Atherholt, Ph.D., and Nicholas A. Procopio, Ph.D.

Contamination of groundwater by fecal wastes is a health risk due to the occurrence of pathogenic microorganisms often present in these wastes. Such contamination is usually determined by testing water for the presence of "indicator" bacteria such as total coliform (TC), fecal coliform (FC), or *Escherichia coli* (E. coli) bacteria.

Coliform bacteria are always present in untreated wastes from humans and warm-blooded animals and therefore are used to indicate the potential presence of pathogens. The U.S. Environmental Protection Agency recommends private well owners test their wells for TC bacteria, nitrates, total dissolved solids, and pH at least once a year, and more often under certain circumstances.

The state of New Jersey in 2001 passed a right-to-know law called the Private Well Testing Act. The act, which went into effect September 2002, specifies buyers or sellers in real estate transactions, as well as landlords of properties with a well not required to be tested under other state law, must test and share information regarding the quality of the source water from domestic wells (*www.nj.gov/dep/watersupply/pw_pwta.html*).

Untreated water must be tested by a state-certified laboratory for lead, mercury, arsenic, 26 volatile organic chemicals, radioactivity, nitrate, iron, manganese, pH, and coliform bacteria. In addition to address, block, and lot information, the global positioning system (GPS) coordinates of each tested well are also recorded.

As well as providing the test results to the buyer and seller, the laboratory submits all test results electronically to the New

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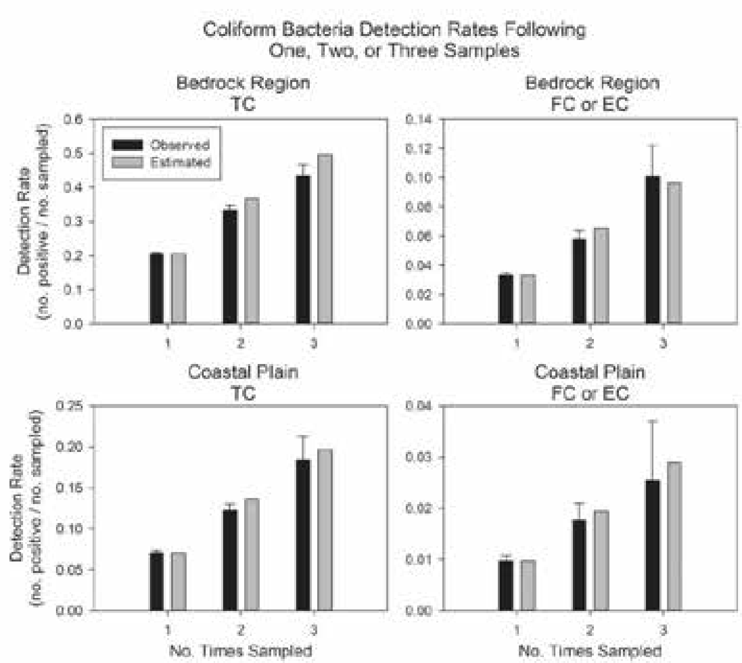

Figure 1. Observed and estimated coliform bacteria detection rates in the Bedrock Region and Coastal Plain of New Jersey. Error bars are the 95% confidence intervals. TC is the total coliform bacteria. FC or EC is the fecal coliform or E. coli bacteria. No. times sampled: 1 = wells sampled once, 2 = twice, 3 = three times. Positive = coliform bacteria detected (in any of the samples for wells sampled more than once). From Reference 1.

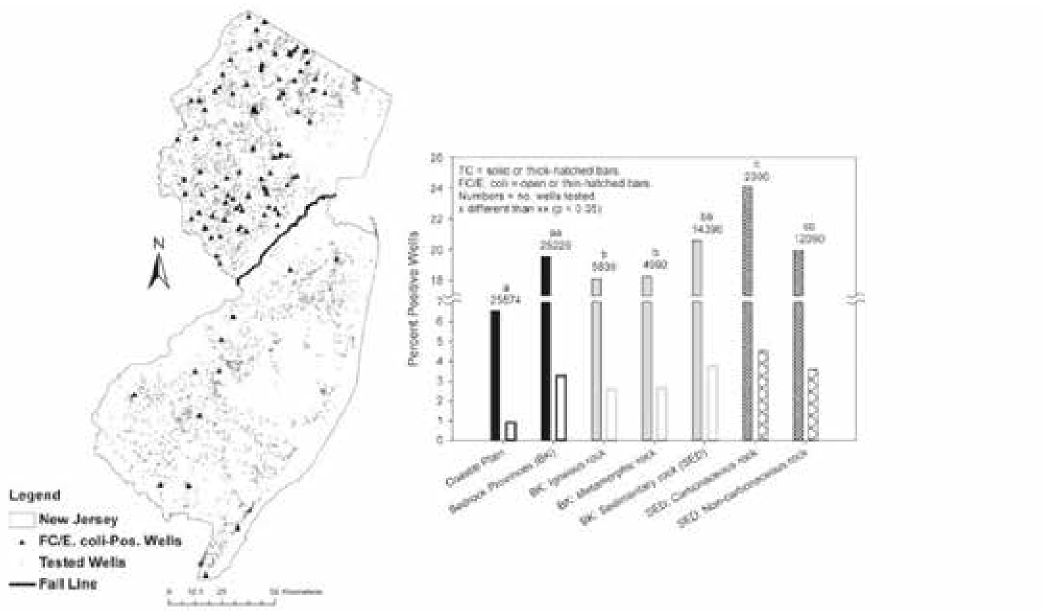

Figure 2. New Jersey map showing the first six months' data (for clarity) of tested and FC/E. coli-positive wells and graph of all data showing the percentage of TC-positive and FC/E. coli-positive wells in the indicated strata. Bars with the same single letter are not significantly different, but bars marked with a double letter differ significantly ($p < 0.05$) from bars marked with the same single letter for both TC and FC/E. coli. From Reference 2.

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Jersey Department of Environmental Protection. It has now been more than 15 years since the act went into effect and the department has accumulated water-quality data from more than 97,000 domestic wells, including coliform data submitted by 39 laboratories (30 laboratories, each analyzing 100 or more samples, contributed 99.9% of the data). We are unaware of another domestic groundwater-quality database of similar size anywhere else in the world.

The purpose of the coliform tests is to determine the sanitary status of the water. The testing requires the water is first tested for TC bacteria, and if any TC bacteria are detected, that sample is further tested for the presence of either FC or E. coli bacteria.

There are several types of TC and E. coli tests that can be used, depending on laboratory certification. Rather than sequential testing, some of the more commonly used tests analyze TC and E. coli bacteria simultaneously. Fecal wastes from warm-blooded animals contain high concentrations of all these groups of bacteria and their presence in well water is used as an indicator for the potential presence of other more dangerous pathogenic bacteria, viruses, or protozoan parasites.

Following 10 years of data collection, regional-scale analyses of the coliform data from 78,546 wells (93,787 samples including wells sampled more than once) were conducted. Between 2013 and 2017, the results of the analyses appeared in four separate articles in the National Ground Water Association's *Groundwater* and *Groundwater Monitoring & Remediation* (see References 1-4). What follows is a brief summary of some of the notable findings.

The term "detection rate" is simply the number of coliform-positive wells divided by the number of wells tested (× 100 = percent positive).

1. Repeated testing increases the likelihood that these bacteria will be detected (Reference 1).

The Private Well Testing Act database contains many properties with multiple samples from a single well. Repeat samples of coliform occur either because a property was sold more than once, or the six-month test result validity period expired.

Not surprisingly, as the number of times a well was sampled increased, the likelihood that coliform bacteria were detected in at least one of the samples was greater (Figure 1).

Often, when coliforms were detected following two or more tests, the initial test result was negative. Since coliforms typically occur in low concentrations in groundwater, and because only a small sample volume is analyzed (100 mL or 0.2 pint), contamination may often be missed after a single test or even after several tests.

2. A positive TC test result may not indicate the presence of fecal contamination in many cases (Reference 1).

In the same study, a statistical analysis determined that, statewide, if every well were sampled and analyzed 10 times, 90% of them would likely contain at least one positive TC test result and suggest fecal contamination.

If a chromogenic or enzyme substrate test method is used, and if the well is located in sedimentary rock, with a pH between 3 and 6, 90% of all such wells would have a positive test result after just five samples (see no.3).

Inevitably, the more one tests a well, the more likely it is to be positive for TC. It is difficult to envision all or most domestic wells containing fecal contamination, which this

Table 1
Coliform Bacteria Detection Rate Differences Between the Bedrock and Coastal Plain Regions of NJ

Method[a]	No. Labs[b]	No. Wells Tested	No. Positive	Detection Rate[c]	p[d]	Individual Lab Detection Rates[c] Median	Range
Total coliform bacteria							
NJ							
All labs, all methods	39	50,800	6615	0.130		0.103	0.000–0.500
Labs-100[e]; all methods	26	50,558	6585	0.130		0.108	0.018–0.277
Bedrock Provinces							
Labs-100; all methods	16	24,906	4879	0.196		0.192	0.041–0.278
Labs 100-CS	11	18,520	3940	0.213		0.200	0.049–0.278
Labs-100-FERM	2	2009	253	0.126		0.157	0.119–0.195
Labs-100-MF	5	4107	642	0.156		0.168	0.040–0.217
Coastal plain							
Labs-100; all methods	17	25,382	1657	0.065	*	0.070	0.015–0.198
Labs 100-CS	7	8246	752	0.091	*	0.098	0.063–0.198
Labs-100-FERM	2	1033	29	0.028	*	0.030	0.026–0.035
Labs-100-MF	9	16,103	876	0.054	*	0.046	0.015–0.094

[a]CS, chromogenic substrate; FERM, fermentation; MF, membrane filtration.
[b]Several labs used more than one method.
[c]Detection rate × 100 = Percent Positive Wells.
[d]Significance testing of the differences between the Bedrock and Coastal Plain areas using the Chi-square test corrected for continuity (Yates). *$p < 0.0001$.
[e]Labs-100: labs testing 100 or more wells in the indicated area.

analysis implies. It has been known for many years that many of the bacteria that comprise the TC group of coliforms are derived from non-fecal sources (e.g., soil). As such, the FC or E. coli tests are considered more reliable indicators of fecal waste contamination (but see no. 6).

3. The vulnerability of a well depends on the geological formation in which the well is located (References 2, 3).

Wells located in the bedrock of the northern half of the state (sedimentary, igneous, or metamorphic rock formations) had a rate of coliform contamination three times higher than wells located in the unconsolidated matrices (layers of sand, silt, and clay) of the southern coastal plain. Wells in aquifers located in either igneous or metamorphic rock were more vulnerable than wells located in sand; wells located in sedimentary rock, especially dolomite or limestone, were more vulnerable still (Figure 2). The pH of the well water was also a factor, either increasing or decreasing vulnerability depending on the geology (see Reference 2).

4. Coliform detection rates also depend on the laboratory used and the analytical methods that a laboratory uses (References 2, 3).

Even though each laboratory analyzed a unique set of wells, by comparing detection rates of individual labs in similar geologies, it was determined there were sometimes large inter-laboratory differences in detection rates.

It was determined the type of test used resulted in different detection rates. Regarding TC bacteria tests, since the chromogenic or enzyme substrate (CS) type of TC tests (e.g., Colilert®) detect a larger population of TC bacteria than do either the fermentation (FERM) or membrane filtration (MF) type of TC tests, the TC detection rates were always higher using a CS test than using either the FERM or MF tests (Table 1).

5. The amount and timing of precipitation prior to sampling also influences the coliform detection rate (Reference 3).

Recent precipitation may influence and ultimately increase coliform detection rates. It was determined 10 days of antecedent precipitation was an optimal period influencing coliform detection rates in domestic wells and a statistically significant increase in TC and FC or E. coli detection rates occurred following a total of 35 mm (1.4 in) and 54 mm (2.1 in), respectively, of cumulative precipitation over the previous 10 days.

The developed model incorporated 10 days of cumulative precipitation data as well as geologic setting, season, laboratory analysis method for coliform bacteria, pH, and nitrate concentration. It was also determined, for this type of analysis, multisensor precipitation estimate (MPE) data available from the National Weather Service was as reliable and easier to use than actual precipitation data from NWS on-the-ground monitoring stations.

6. FC or E. coli bacteria in well water may or may not be derived from a fecal source (Reference 4).

One of the more significant findings of these studies was a confirmation of some earlier studies from other investigators showing a seasonality to the coliform detection rates and patterns in temperate climate regions. A warm-weather increase in all coliform detection rates was observed each year (Figure 3).

We determined the seasonal pattern was most likely the result of seasonal changes in groundwater extraction volumes and temperature-driven changes in the concentration of surface or near-surface coliform sources.

As previously stated, it has been known for many years members of the TC group of bacteria can have non-fecal as

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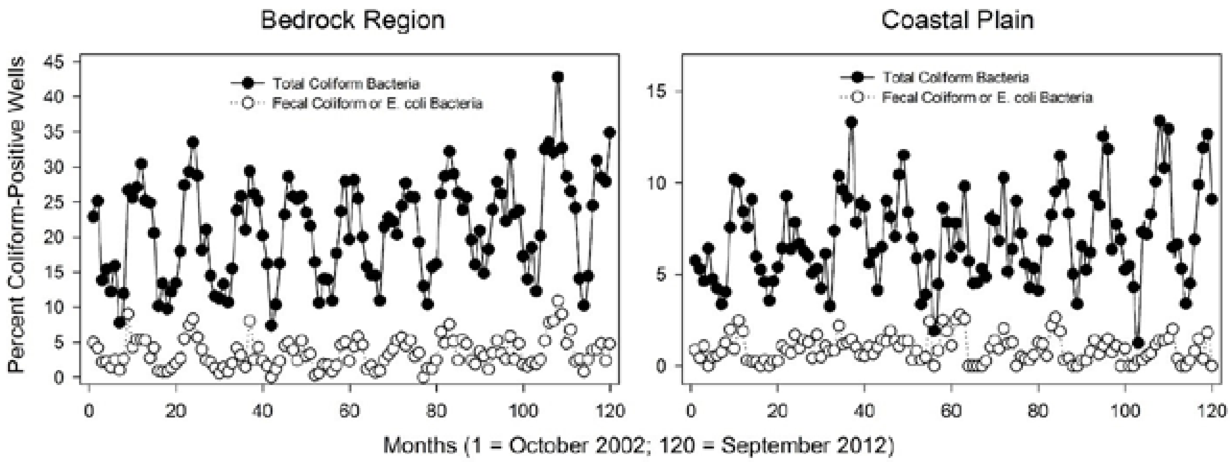

Figure 3. Percentage of New Jersey wells in which coliform bacteria were detected each month in the Bedrock and Coastal Plain regions. From Reference 4.

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well as fecal origins. However, historically speaking, the FC and E. coli groups were considered fecal-specific. That is, if either FC or E. coli bacteria were detected in a well, the water was said to contain fecal contamination.

But recent studies from several other research groups have demonstrated some members of the FC and E. coli groups of bacteria also have a non-fecal origin (or else were originally derived from a fecal source but have over time become environmentally adapted) (References 5, 6).

Therefore, FC or E. coli bacteria detected in untreated water from domestic wells may be from fecal wastes or they may be from non-fecal sources such as soils, sediments, and perhaps even vegetation. The problem is the type of coliform source (fecal or non-fecal) and hence the sanitary significance of the test result cannot be determined.

The findings of these studies indicate there can be big differences in the vulnerability of a domestic well to coliform contamination due to geology, precipitation, timing of the test, and other factors described above (as well as a few other factors not available in this database such as well depth).

From these data, a predictive model was developed to estimate the likelihood of coliform occurrences (Reference 3). The model provides useful guidance for other practitioners in evaluating the likelihood of coliform bacteria, especially in data-poor areas. These findings may apply to areas outside of New Jersey with similar geologies for use in educational outreach opportunities in areas with higher likelihoods of coliform exposure and to tailor coliform testing procedures with respect to antecedent precipitation conditions.

These findings show additional research is needed to find ways to differentiate fecal from non-fecal coliform sources.

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These studies also add further weight to the accumulating evidence (References 5 and 6) that better indicators are needed to identify fecal pollution in general, and human and domestic-animal fecal pollution in particular, in groundwater.

References

1. Atherholt, T.B., L.R. Korn, J.B. Louis, and N.A. Procopio. 2015. Repeat sampling and coliform bacteria detection rates in New Jersey domestic wells. *Groundwater Monitoring & Remediation* 35, no. 2: 70-80.
2. Atherholt, T.B., R.T. Bousenberry, G.P. Carter, L.R. Korn, J.B. Louis, M.E. Serfes, and D.A. Waller. 2013. Coliform bacteria in New Jersey domestic wells: Influence of geology, laboratory, and method. *Groundwater* 51, no. 4: 562-574.
3. Procopio, N.A., T.B. Atherholt, S.M. Goodrow, and L.A. Lester. 2017. The likelihood of coliform bacteria in NJ domestic wells based on precipitation and other factors. *Groundwater* doi: 10.1111/gwat.12518.
4. Atherholt, T.B., N.A. Procopio, and S.M. Goodrow. 2017. Seasonality of coliform bacteria detection rates in New Jersey domestic wells. *Groundwater* 55, no. 3: 346-361.
5. Luo, C., S.T. Walk, D.M. Gordon, M. Feldgarden, J.M. Tiedje, and K.T. Konstantinidis. 2011. Genome Sequencing of Environmental *Escherichia coli* Expands Understanding of the Ecology and Speciation of the Model Bacterial Species. In *Proceedings of the National Academy of Sciences USA* 108, no. 17: 7200-7205.
6. Sadowsky, M.J., and R.L. Whitman. 2011. *The Fecal Bacteria*. Washington D.C.: ASM Press. WWJ

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