Relation of Bacteria in Limestone Aquifers to Septic Systems in Berkeley County, West Virginia

Water-Resources Investigations Report 00-4229

In cooperation with the
Eastern Panhandle Soil Conservation District

U.S. Department of the Interior
U.S. Geological Survey

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By Melvin V. Mathes

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U.S. Department of the Interior
Bruce Babbitt, Secretary

U.S. Geological Survey
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
11 Dunbar Street
Charleston, WV 25301

Copies of this report can be purchased from:

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
milliliter	0.0610	cubic inch

Temperature given in degrees Celsius (^{o}C) can be converted to degrees Fahrenheit (^{o}F) by using the following equation:

$$^{o}F = 1.8\ (^{o}C) + 32$$

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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Abstract

Water samples collected from 50 wells in Berkeley County, West Virginia, during June 2000 were analyzed for indicator bacteria. Of the 50 wells sampled, 62 percent (31 wells) contained total coliform bacteria, 32 percent (16 wells) contained *Escherichia coli,* and 30 percent (15 wells) contained fecal coliform bacteria. Although bacteria were present in many wells regardless of the number of septic systems in a 5-acre circular area around each well, no apparent correlation was detected between septic-system density and concentrations of bacteria colonies. There was also little difference in the frequency of total coliform bacteria detection between shallow and deep wells; however, the highest concentrations of *E. coli* and fecal coliform bacteria were found in the shallowest wells. At least one of the three bacteria types was found in samples of untreated water in 32 of the 50 wells. At 21 of the 32 wells with bacteria present, there was no treatment of the ground water to remove bacteria.

Introduction

In many residential subdivisions in the limestone terrain of Berkeley County, West Virginia, individual wells are used for domestic water supply, and septic systems with leach fields are used for waste treatment. The rapid movement of water through fractures in the underlying limestone bedrock and aquifers[1] in the county poses a high risk of contamination of the wells by bacteria from septic systems. Such aquifers underlie more than one third of the county (Shultz and other, 1995). In areas where overlying soils are thin, limestone aquifers with fractures or conduits allow rapid infiltration and lateral movement of ground water, which increases the risk of bacterial contamination of drinking-water supplies. There is a risk, therefore, that diseases may be transmitted by waste water from leach fields to nearby drinking-water wells. Newly-constructed homes with small lots could potentially have a large number of leach fields located within close proximity of drinking-water wells.

The U.S. Geological Survey (USGS), in cooperation with the (West Virginia) Eastern Panhandle Soil Conservation District, conducted a study of the relation between the presence of bacteria in water from wells completed in limestone aquifers in Berkeley County and the density of septic systems in the vicinity of the wells. This report presents the results of analyses of water samples from 50 residential drinking-water wells in Berkeley County for fecal coliform, total coliform, and *Escherichia coli (E. coli)* indicator bacteria. It describes the relation of the density of septic systems to bacteria concentrations in water samples from drinking-water wells drilled in limestone aquifers in Berkeley County. Information in this report can be used to develop standards for residential septic systems in the county to reduce or eliminate the potential

[1] Includes limestone, dolomite, and calcareous shale, but will be referred to as limestone or limestone aquifers throughout this report.

for disease transmission through water in limestone aquifers.

Background

The purpose of a septic system and leach field is to provide sufficient time and space to digest and filter disease-causing organisms so that when water returns to the environment it will not transmit them. Current (2000) West Virginia regulations for septic leach fields require a minimum area, soil depth, and percolation rate in support of the general requirement that septic systems not create a public health hazard (64 CSR 9-3.5.a). The regulations require at least three feet of soil between a leach-field trench and bedrock. The depth and percolation rate of soils overlying the fractured limestone bedrock in much of the study area are less than the minimum required for installation of septic leach fields. Many of these shallow soil zones in Berkeley County, however, are the sites of existing or proposed subdivisions that use or will use individual septic leach fields. Areas where bedrock outcrops are present may have an even greater potential for ground-water contamination of nearby wells by septic effluent.

Previous Hydrogeologic Investigations

The geology of Berkeley County was described and mapped by Grimsley (1916) and by Dean and others (1987). Lineaments that may indicate or coincide with the traces of joints or fractures in the bedrock in the county have been mapped by Hobba (1976), Taylor (1974), and Zewe (1991). Shultz and others (1995) described the geohydrology, ground-water availability, and ground-water quality of Berkeley County, with emphasis on limestone areas. They found fecal coliform bacteria present in 41 percent of wells sampled in limestone areas of Berkeley County, and that fecal contamination was more common in summer when high temperatures decreased the rate at which the bacteria died.

Topography, Ground-Water Flow, and Land Use in Berkeley County

Berkeley County encompasses 325 square miles of the eastern panhandle of West Virginia and drains entirely into the Potomac River (fig. 1). The western half of the county is underlain predominantly by shale and sandstone and only minor limestone. The eastern half of the county is in the Shenandoah Valley, and is characterized by gently rolling topography with altitudes ranging from 310 to 800 feet above sea level (Shultz and others, 1995). It is underlain predominantly by limestone and other carbonate rocks such as dolomite and calcareous shale, but also includes significant outcrops of sandstone and shale. The study area in this report is located in the limestone areas of the eastern part of Berkeley County.

Ground-water flow in the limestones of Berkeley County can be diffuse flow or conduit flow. Diffuse flow occurs where significant solution enlargement of fractures has not occurred, and the flow is slow and laminar. Conduit flow usually occurs in faults, beneath losing streams, in cavernous areas, and where fractures have been enlarged by dissolution of limestone. Conduits can range from less than one inch to tens of feet in width and height, and are generally the main flow paths for ground water wherever they are present. Ground water in conduits can move rapidly and is sometimes turbulent (Shultz and others, 1995). In the 1995 study by Shultz and others, ground-water-flow velocities in limestone in Berkeley County ranged from 32 to 1,879 feet per day. These higher velocities may facilitate the transmission of bacteria and potential disease-causing organisms from waste systems to drinking-water wells.

The land use in Berkeley County is constantly changing as subdivisions become more numerous. The population of Berkeley County increased 26.7 percent from 1980 to 1990 (U.S. Department of Commerce, 1991). Shultz and others (1995) report land-use statistics compiled in 1973 for Berkeley County as 46.5 percent forest, 31.4 percent pasture, 12.9 percent cropland, 4.7 percent urban or commercial, 3.6 percent orchard, 0.7 percent barren, and 0.2 percent water. More recent studies report 13.4 percent cropland in 1989 (West Virginia Department of Agriculture, 1990). Manure applied to cropland as fertilizer may contribute bacteria to the ground-water system.

Acknowledgments

The author thanks Roger Boyer and Michael O'Donnell of the Potomac Headwaters Resource Conservation and Development Region, Inc. for overseeing and conducting a preliminary site analysis of 83 potential sampling sites, for obtaining permission to collect additional well-construction and site-analysis data at each of these sites, and for obtaining permission to sample 50 of the 83 selected sites for indicator

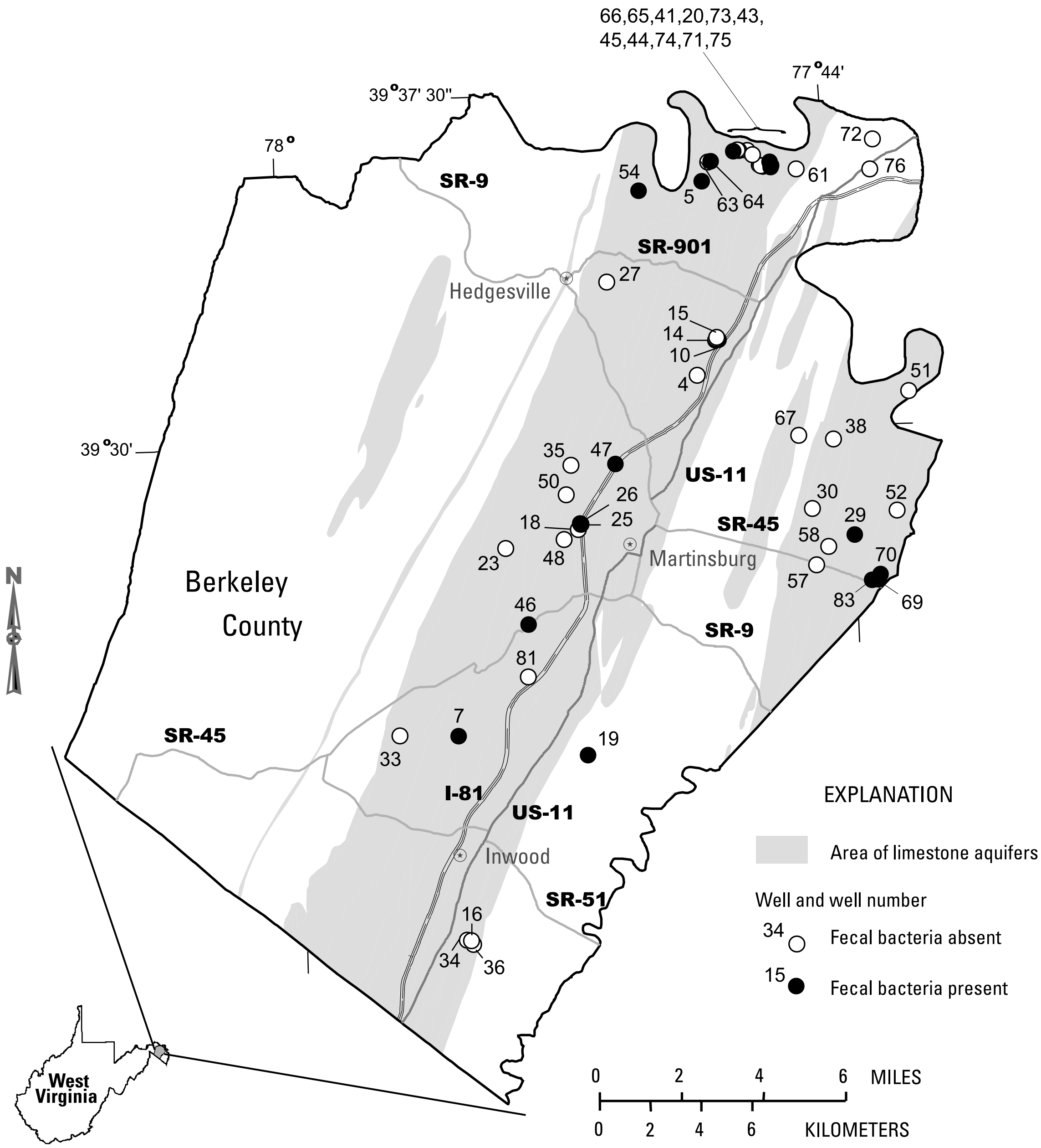

Figure 1. Location of study area, geology, and sample locations in Berkeley County, West Virginia.

bacteria. Virginia Tabb of the U.S. Natural Resources Conservation Service also helped to identify potential sampling sites. Appreciation is extended to the residents of Berkeley County who granted access to sample their wells and who provided well information.

Study Methods

During the winter of 1999-2000, field personnel located and identified 83 candidate wells for potential bacteria sampling. In June 2000, water samples were collected from 50 of the 83 wells and analyzed for indicator bacteria (for site location, see fig. 1).

Selection of Sampling Sites

The criterion for selection as a candidate well was the location of the well in a residential community where sewage is treated in individual septic systems with leach fields that overlie limestone aquifers. Candidate wells were assigned to three categories of septic-system density -- high density indicates four or more septic systems per five acres, intermediate density indicates two or three septic systems within five acres, and low density indicates one or no septic systems in five acres.

In April 2000, candidate wells were inspected. Site inspections included the collection of well-construction data, well-yield information, and geologic information. At that time, the number of septic systems within a five-acre circular area surrounding each candidate well was determined, and other possible sources of fecal bacteria, such as grazing animals, gardens, and feedlots, were identified. Other possible bacteria sources were noted for 13 of the 50 wells sampled. The 50 wells selected for sampling (fig. 1, table 1) were chosen mainly on the basis of owner cooperation and the ability to collect a representative, untreated sample from the well. Wells properly sealed and grouted and with no nearby possible bacteria sources other than septic systems were given priority; but out of necessity, the wells selected for sampling include those with other nearby possible sources of fecal bacteria and a variety of well-construction characteristics. The wells sampled are clustered in certain areas of the county based on the necessities of site selection, mainly owner availability and cooperation. Of the 50 sampled wells, 16 were classified as high septic density, 21 as intermediate septic density, and 13 as low septic density.

Collection and Analysis of Samples

All wells sampled were purged until recorded measurements (made in a flow-through chamber) of water temperature, specific conductance, pH, and dissolved oxygen stabilized, indicating that fresh water was being withdrawn from the aquifer as opposed to stagnant water from the well casing and plumbing. When the purge log of recorded field measurements indicated stable conditions, two sterile bottles were filled with fresh ground water. Bacteria concentrations were determined by membrane filtration of this water and microscopic enumeration of colonies using methods described by Myers and Sylvester (1997).

Sample volumes of 20, 50, and 100 milliliters were filtered for analysis of both total and fecal coliform. Sterile dilution water was also filtered through membrane filters before (equipment blank) and after (procedure blank) the sample volumes were filtered for quality assurance. No bacteria were found on any of the fecal coliform blanks. Five of the total coliform blanks had seven or fewer colonies, and one blank had colonies too numerous to count. Several of these colonies, however, were possibly types of bacteria other than total coliforms.

All bacteria colonies were examined on each membrane filter, and all colonies of total coliform, fecal coliform, and *E. coli* were counted. Bacteria concentrations were determined from these counts by standard formulas according to procedures in Myers and Sylvester (1997). Each sample was tested for total coliform by filtering known volumes of water sample through membrane filters and placing these filters in petri dishes containing m-Endo culture media. These petri dishes were incubated at 35^{o} C for 24 hours to allow optimal growth of total coliform bacteria colonies. All filters that grew total coliform colonies characterized by a gold or green metallic sheen were transferred to NA-MUG media for further incubation for four hours at 35^{o} C.

After four hours, these filters were then inspected for *E. coli* colonies by examination under an ultraviolet light. These colonies were characterized by a dark center surrounded by a fluorescent halo. *E. coli* bacteria grow in human intestines and can be detected in water samples by simple tests. *E. coli* survive in the environment at a rate similar to pathogenic or disease-causing organisms and are therefore widely recognized as indicators of hazardous sewage contamination. *E. coli* are part of the larger fecal coliform group

Table 1. Site information and detections of bacteria for wells sampled in June 2000 in Berkeley County, West Virginia

[EC = *Escherichia Coli*; FC = Fecal Coliform; col/100 mL = colonies per 100 milliliters]

	Within a 5-acre circle,			Bacteria concentration, col/100 mL					
Well number	Number of septic systems	Other possible sources of bacteria?	Were EC of FC detected?	*E. Coli*	Fecal Coliform	Total Coliform	Well Depth, Feet	Is the water treated before use?	Aquifer lithology
43	6	No	Yes	9	12	85	240	No	Limestone
48	6	No	No	<1	<1	3	215	No	Limestone
65	6	No	No	<1	<1	<1	360	No	Limestone
76	6	No	No	<1	<1	<1	150	No	Shale
14	5	Yes	Yes	39	37	370	93	Yes	Dolomite
70	5	No	Yes	75	59	>270	40	Yes	Limestone
73	5	No	No	<1	<1	<1	250	No	Limestone
74	5	No	Yes	1	<1	120	60	Yes	Dolomite
81	5	No	No	<1	<1	12	540	Yes	Limestone
10	4	No	Yes	<1	1	<1	82	No	Dolomite
15	4	No	No	<1	<1	2	95	No	Dolomite
20	4	No	No	<1	<1	47	220	No	Limestone
25	4	No	No	<1	<1	6	178	Yes	Limestone
57	4	No	No	<1	<1	<1	320	Yes	Limestone
64	4	No	Yes	2	<1	140	425	No	Limestone
83	4	No	Yes	<1	200	>270	90	Yes	Limestone
26	3	No	Yes	1	1	90	268	No	Limestone
29	3	Yes	Yes	<1	1	17	194	Yes	Dolomite
41	3	No	No	<1	<1	15	150	Yes	Limestone
44	3	Yes	Yes	5	2	68	325	No	Limestone
45	3	No	No	<1	<1	<1	270	No	Limestone
47	3	No	Yes	14	<1	68	250	No	Limestone
50	3	No	No	<1	<1	14	375	Yes	Limestone
61	3	No	No	<1	<1	<1	300	No	Dolomite
63	3	No	No	<1	<1	<1	160	No	Limestone
67	3	No	No	<1	<1	<1	123	No	Limestone
69	3	Yes	Yes	14	11	>270	135	No	Limestone

Table 1. Site information and detections of bacteria for wells sampled in June 2000 in Berkeley County, West Virginia —Continued

[EC = *Escherichia Coli*; FC = Fecal Coliform; col/100 mL = colonies per 100 milliliters]

Well number	Within a 5-acre circle, Number of septic systems	Within a 5-acre circle, Other possible sources of bacteria?	Were EC of FC detected?	Bacteria concentration, col/100 mL *E. Coli*	Bacteria concentration, col/100 mL Fecal Coliform	Bacteria concentration, col/100 mL Total Coliform	Well Depth, Feet	Is the water treated before use?	Aquifer lithology
71	3	Yes	Yes	4	5	6	350	Yes	Dolomite
72	3	No	No	<1	<1	21	100	No	Shale
75	3	No	Yes	3	2	89	87	No	Dolomite
4	2	Yes	No	<1	<1	17	80	No	Dolomite
18	2	No	No	<1	<1	<1	186	No	Limestone
23	2	No	No	<1	<1	<1	300	Yes	Limestone
27	2	No	No	<1	<1	120	280	No	Limestone
30	2	Yes	No	<1	<1	<1	125	No	Limestone
58	2	No	No	<1	<1	710	450	Yes	Limestone
66	2	Yes	Yes	1	<1	250	375	No	Limestone
7	1	Yes	Yes	69	170	570	28	No	Limestone
16	1	Yes	No	<1	<1	3	400	Unknown	Limestone
19	1	No	Yes	<1	1	<1	125	Unknown	Limestone
33	1	Yes	No	<1	<1	<1	82	Unknown	Limestone
34	1	No	No	<1	<1	<1	315	No	Limestone
35	1	No	No	<2	<1	9	168	Unknown	Limestone
36	1	Yes	No	<1	<1	<1	330	Unknown	Limestone
38	1	No	No	<1	<1	<1	400	No	Limestone
46	1	No	Yes	5	6	73	220	No	Limestone
51	1	No	No	<1	<1	<1	352	No	Dolomite
54	1	No	Yes	30	97	72	146	No	Limestone
5	0	No	Yes	20	<1	26	336	Unknown	Limestone
52	0	Yes	No	<1	<1	<1	Unknown	No	Limestone

of bacteria that also have been used to indicate sewage contamination. Apparent inconsistencies between fecal coliform detections and *E. coli* detections result from the use of separate filters and separate subsamples of water. It is possible to detect only one of these bacteria types, even when both are present in the source water.

Each sample was tested for fecal coliform bacteria by filtering known volumes of water sample through membrane filters and placing these filters into petri dishes containing m-FC culture media. These petri dishes were incubated at 44.5^{o} C for 24 hours to allow optimal growth of fecal coliform colonies. Fecal coliform colonies are characterized by a deep blue color.

Relation of Bacteria in Wells to Septic Systems

The presence of bacteria in water from a drinking-water well is significant, because drinking water should be free from bacteria. The standard for public supplies is no detectable *E. Coli* or fecal coliform in any sample from the drinking water and no detectable total coliform in more than 95 percent of repeated samples (United States Environmental Protection Agency, 1986).

Total coliform bacteria were detected in samples from 31 of 50 wells (62 percent), *E. coli* in 16 of 50 wells (32 percent), and fecal coliform bacteria in 15 of 50 wells (30 percent). Domestic wells that are constructed with a surface seal, concrete pad, and grouted casing will produce water less susceptible to surface contamination by fecal bacteria (fecal coliform and *E. coli*) so long as the aquifer itself is not contaminated (Eychaner, 1998). The high frequency of fecal contamination of wells in Berkeley County, however, indicates that the limestone aquifers are contaminated in many areas. The presence or absence of fecal bacteria (fecal coliform bacteria and *E. coli*) is shown for each well sampled (fig. 1). Total coliform bacteria are ubiquitous in ground water, and their presence does not necessarily indicate the presence of fecal bacteria such as fecal coliform bacteria or *E. coli* in ground water. The data show, however, that where total coliform bacteria are not found in ground water, fecal bacteria such as *E. coli* and fecal coliform bacteria are also typically not found.

Neither the number (and percentage) of wells in which bacteria was detected nor the concentrations of bacteria in the samples could be correlated with the density of septic systems around the sampled wells (table 2). *E. coli* were present in 5 of 16 wells sampled (31 percent) from the high septic density class, 7 of 21 wells sampled (33 percent) from the intermediate density, and 4 of 13 wells sampled (31 percent) from the low density class. Fecal coliform bacteria were present in five samples (31 percent) from wells in the high septic density class, six samples (29 percent) from the intermediate density class, and four samples (31 percent) from the low density class. Total coliform bacteria were present in 11 wells (69 percent) from the high septic density class, 14 wells (67 percent) from the intermediate septic density class, and 6 wells (46 percent) from the low density class.

Scatterplots of bacteria concentration versus number of septic systems in 5-acre circular area surrounding each well do not show any graphical

Table 2. Number and percentage of wells containing bacteria for each septic density sampled June 2000 in Berkeley County

	Septic Density		
	High	**Medium**	**Low**
Number of septic systems per five acres	4-6	2-3	0-1
Number of wells sampled	16	21	13
Number of samples with *E. coli* bacteria present	5	7	4
Percent of samples with *E. coli* bacteria present	31	33	31
Number of samples with fecal coliform bacteria present	5	6	4
Percent of samples with fecal coliform bacteria present	31	29	31
Number of samples with total coliform bacteria present	11	14	6
Percent of samples with total coliform bacteria present	69	67	46

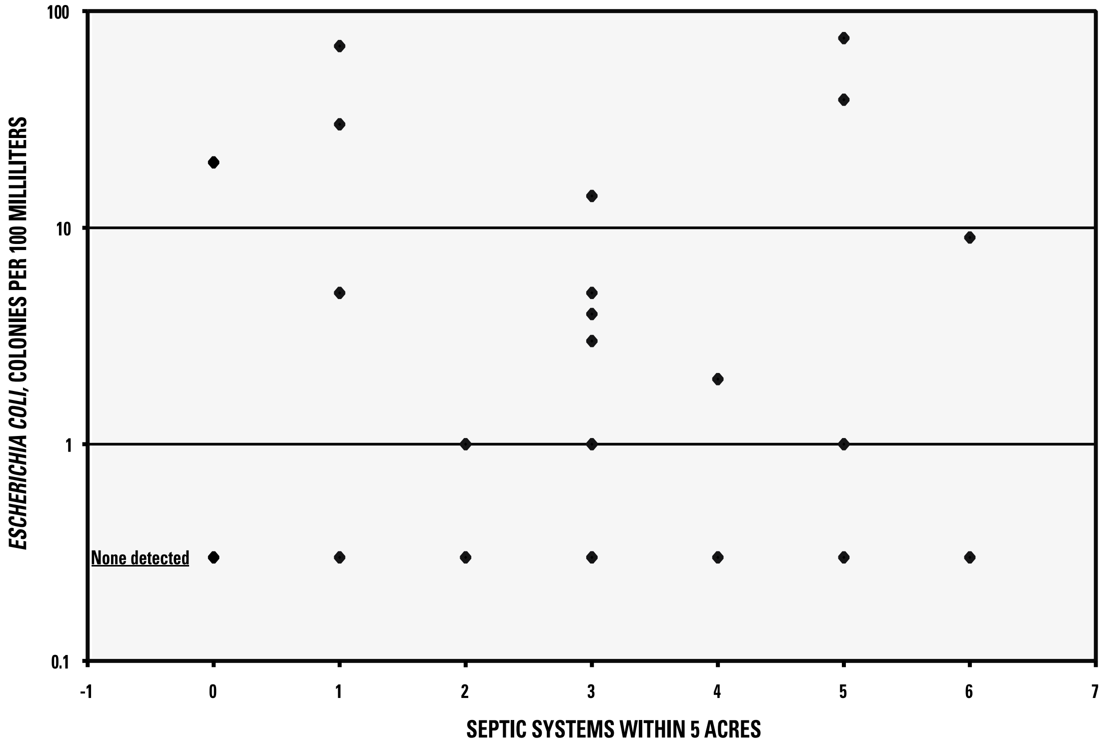

Figure 2. ***Escherichia coli*** **bacteria concentration and septic-system density of wells sampled June 2000 in Berkeley County.**

correlation between bacteria concentration and septic-system density (figs. 2-4). This lack of correlation may be a result of the inability to determine the source of water to a well. Ground-water flow velocity within limestone aquifers in the study area can range from 32 feet per day in diffuse-flow portions of the aquifer to 1,154 feet per day in conduit-flow dominated portions of the aquifer (Shultz and others, 1995). Thus, bacteria present in water samples collected from wells sampled in areas with ground-water velocities at the higher end of this range may have been transported from distant portions of the aquifer and not necessarily from the 5-acre circular area surrounding a well. Further data are needed to understand bacteria transport processes within the limestone aquifers of Berkeley County.

Scatterplots of well depth versus bacteria concentration (figs. 5-7) show little difference in the frequency of total coliform bacteria detection between shallow and deep wells. The greatest concentrations of *E. coli* and fecal coliform bacteria, however, were detected in the shallowest wells.

Although the fifty wells selected for sampling were chosen to minimize the number of sources of bacteria other than household leach fields within the 5-acre circular area surrounding each well, field notes indicate that 13 of the wells have possible bacteria sources other than leach fields. These possible sources include grazing animals, gardens, and some small feedlots. Total coliform bacteria were detected for 9 of these 13 wells (69 percent) as opposed to 22 of 37 wells (59 percent) with no other possible bacteria sources. *E. coli* bacteria were detected for 6 of these 13 wells (46 percent) as opposed to 10 of 37 wells (27 percent) with no other possible sources. Fecal coliform bacteria were detected for 6 of these 13 (46 percent) wells as opposed to 9 of 37 wells (24 percent) with no other possible bacteria sources. At least one of the three bacteria types was found in samples of untreated water in 32 of the 50 wells. At 21 of the 32 wells with bacteria present, there was no treatment of the ground water to remove bacteria.

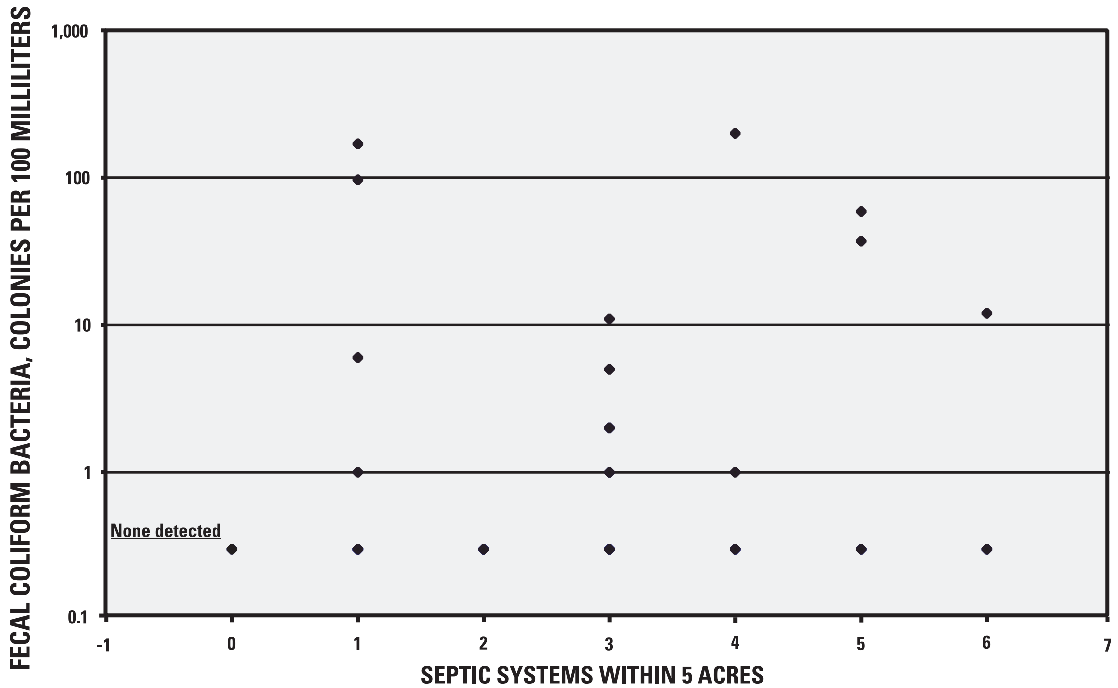

Figure 3. Fecal coliform bacteria concentration and septic-system density of wells sampled June 2000 in Berkeley County.

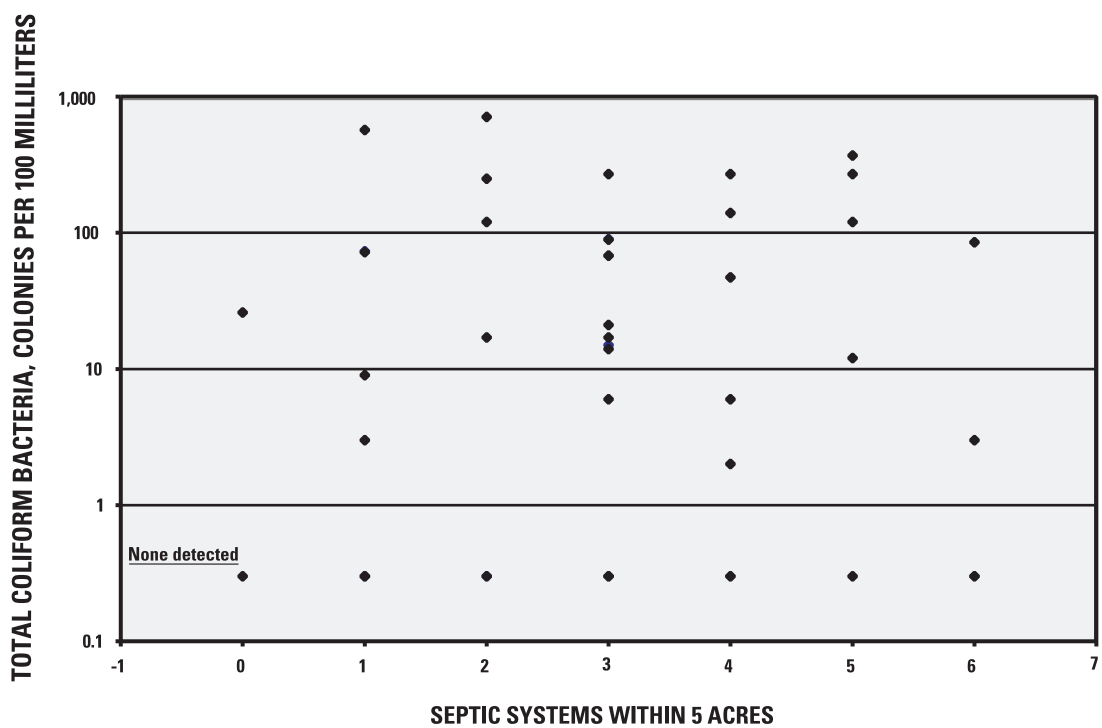

Figure 4. Total coliform bacteria concentration and septic-system density of wells sampled June 2000 in Berkeley County.

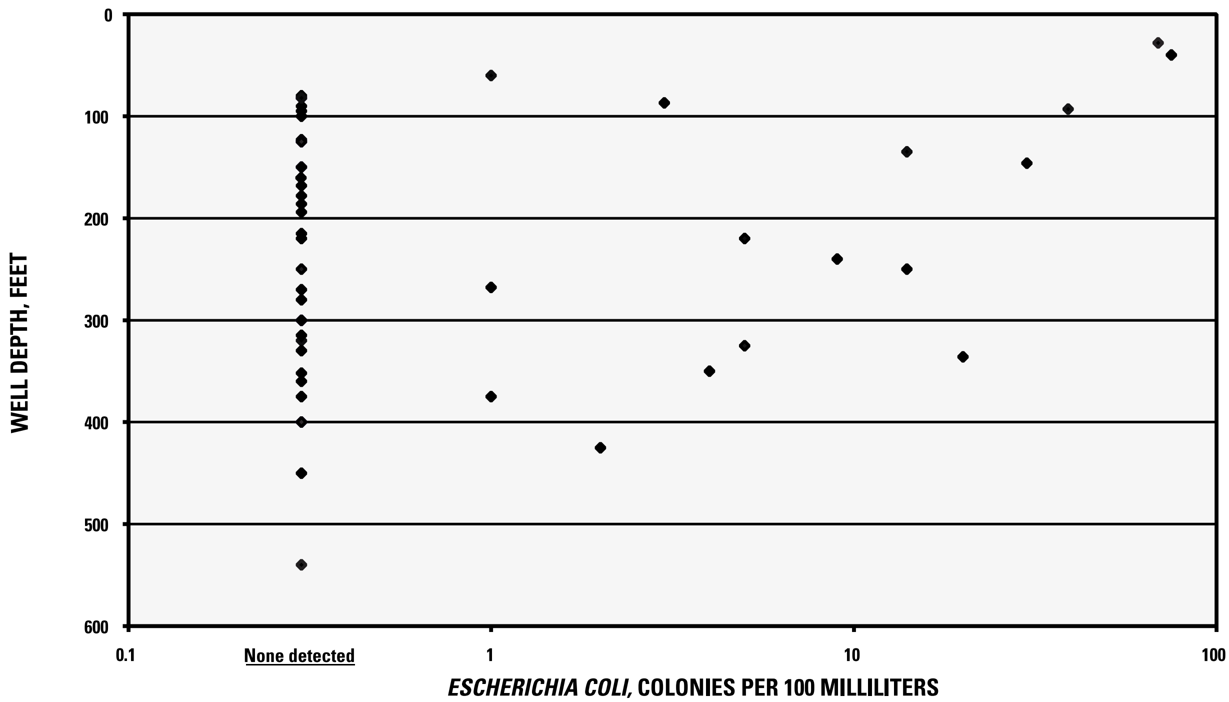

Figure 5. Depth of wells sampled and *Escherichia coli* bacteria concentrations detected June 2000 in Berkeley County.

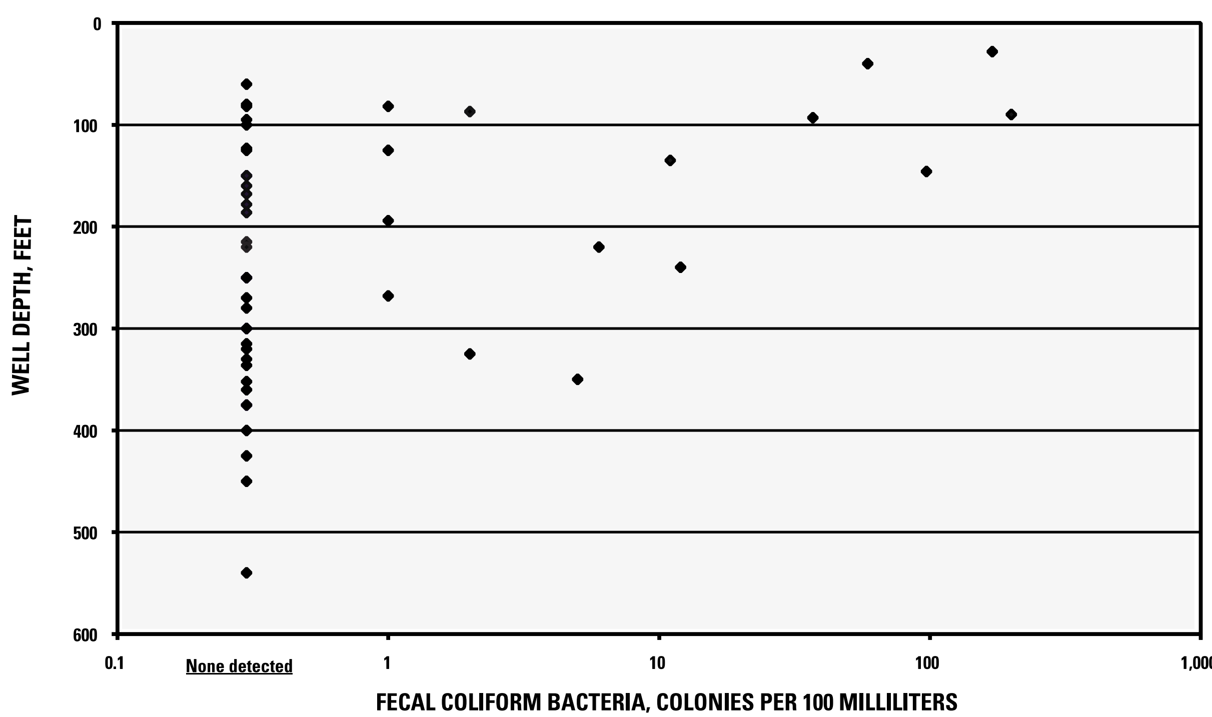

Figure 6. Depth of wells sampled and fecal coliform bacteria concentrations detected June 2000 in Berkeley County.

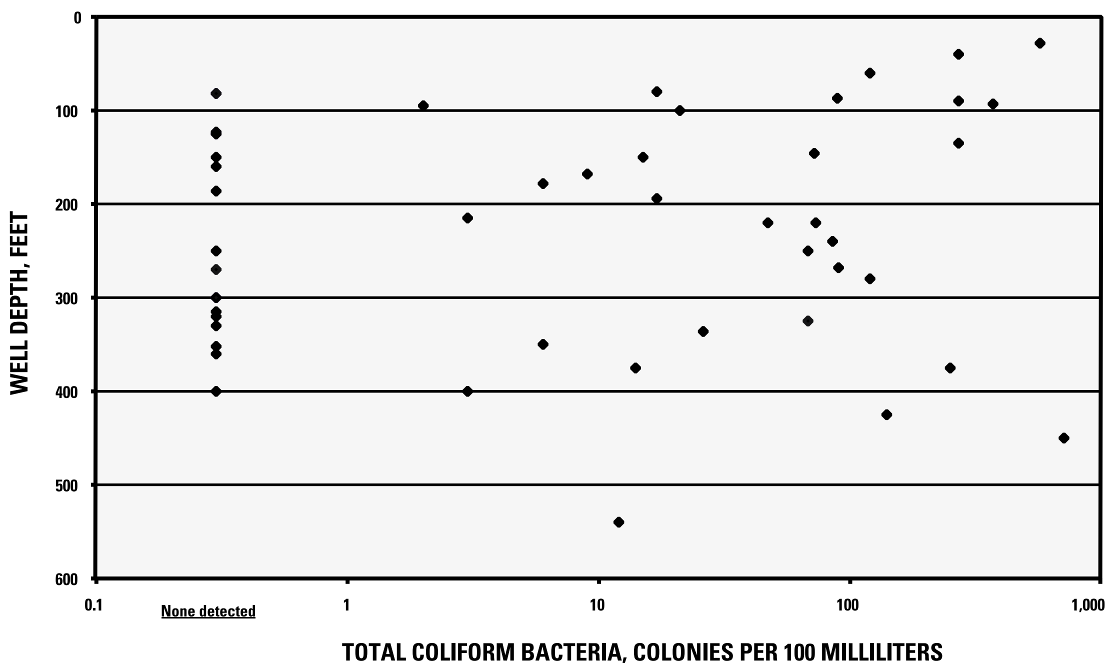

Figure 7. Depth of wells sampled and total coliform bacteria concentrations detected June 2000 in Berkeley County.

Summary and Conclusions

Of 50 wells sampled for fecal coliform, total coliform, and *E. coli* bacteria in Berkeley County, West Virginia, 62 percent (31 wells) contained total coliform bacteria, 32 percent (16 wells) contained *E. coli*, and 30 percent (15 wells) contained fecal coliform bacteria, indicating probable bacterial contamination of portions of the limestone aquifers in which the wells are completed. Bacteria were found in many wells regardless of the number of septic systems in a 5-acre circular area around each well. No apparent correlation was found between septic-system density and concentration of colonies detected. The rapid rate of ground-water flow within the limestone aquifers and the complexity of structural controls on ground-water movement through the limestone aquifers may mask the effect of septic systems on the microbiological quality of ground water. There is also little difference in the frequency of total coliform bacteria detection between shallow and deep wells; however, the greatest concentrations of *E. coli* and fecal coliform bacteria occurred in the shallowest wells. At least one of the three bacteria types was found in samples of untreated water in 32 of the 50 wells. At 21 of the 32 wells with bacteria present, there was no treatment of the ground water to remove bacteria, indicating that additional well owners might wish to consider some type of treatment, such as chlorination or ultraviolet lights, to effectively kill bacteria in ground water before use.

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