Distribution of Total and Fecal Coliform Organisms From Septic Effluent in Selected Coastal Plain Soils

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THE NUMBER OF FAMILIES in the United States not serviced by sewage systems is growing because of increased suburban and rural development. In 1970 an estimated 32 million people in the United States used septic tanks and subsurface absorption fields for disposal of waste water (*1*). In addition, an unestimated number of septic systems were used primarily during the summer vacation season. Disposal of domestic wastes from individual residences is expected to become even more difficult in the future as competition for soils well suited for waste disposal increases. Since such soils are also generally prime agricultural lands, our growing population and the energy crisis will put a premium on their use for the production of food and fiber. Consequently, demand for disposal of domestic wastes in soils considered to be only marginally suited for this purpose is likely to increase. Our report concerns the horizontal and vertical distribution of total and fecal coliform densities in ground waters adjacent to septic tank drainfields—soils that are considered only marginally suited for the sanitary disposal of domestic waste. The study is part of a cooperative research program between the Virginia State Department of Health and the Research Division of the Agronomy Department of Virginia Polytechnic Institute and State University; the program has been described previously in this journel (*2*).

Septic tank effluents should be disposed of in such a way that bacteriological contamination of surface or ground waters does not result. The Federal Water Pollution Control Administration (*3*) has suggested that safe, clear, potable, aesthetically pleasing, and acceptable public water supplies can be obtained from raw surface water containing up to 10,000 total coliforms per 100 ml or 2,000 fecal coliforms per 100 ml. Desirable levels of these organisms, however, are less than 100 total coliforms or less than 20 fecal coliforms per 100 ml. It is recommended that recreation waters not exceed a log mean of 200 fecal coliforms per 100 ml and that not more than 10 percent of the total water samples during any 30-day period exceed 400 coliforms per 100 ml.

Coliforms have been used as indicators of the sanitary quality of water since about 1885, when Escherich, a pioneer bacteriologist, recoverd these bacteria from human feces. Because of the significance of various members of the coliform group, fecal organisms should be differentiated from nonfecal if one is to evaluate the change that takes place in the bacteriological quality of water as septic effluent moves through the natural soil system. Clark and Kabler (*4*) have emphasized the need not only for differentiation of the coliform subgroups, but also for selection of the appropriate subgroup for analysis. Fecal coliforms, which characteristically inhabit the intestines of warm-blooded animals, signal a recent and

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potentially dangerous source of pollution. Members of the coliform group other than fecal may be found in soils, on plants and insects, in old sewage, and in waters that have been polluted sometime in the past. Since fecal coliforms are a more reliable indicator of fecal contamination than are other coliforms, (*5*), they are used to trace the movement of bacterial pollutants from septic tank effluent through natural soil systems. In our study, both fecal coliforms and total coliforms were enumerated.

Limited research has been done on the in situ movement of pollutant microbes through natural soil systems. Many of the existing data, however, were collected without the aid of a qualified soil scientist, so that it is difficult to relate this knowledge to other soil types with similar morphological, chemical, and physical properties. Caldwell and Parr (*6*) reported that bacterial pollutants originating in a bored hole "latrine" traveled less than 1.2 m (4 ft) per day in soils of low permeability, as compared with more than 3.0 m (10 ft) per day in highly permeable soils. Stiles and Crohurst (*7*) observed that during a period of 2½ years viable bacteria from flooded trenches traveled 71 m (232 ft) in permeable soils in the direction of ground water flow. Mallmann and Mack (*8*) studied the pollution of a well that was located in a permeable soil 9.1 m (30 ft) from a septic seepage field. Bacteria introduced to the seepage field traveled 3.0 m (10 ft) in 2 days and 6.1 m (20 ft) in 3 and were still detected in the well after 10 days. More extensive information on bacterial movement through natural soil systems is available in literature reviews (*9*).

Procedures and Definitions

Location of soils. The experimental sites studied were at the western edge of the Atlantic coastal plain on private properties in Chesterfield and Spotsylvania Counties, Va. These sites were in Varina sandy loam, Goldsboro loamy sand, and Beltsville sandy loam.

Varina, which has developed in the silty and clayey sediments of the lower Atlantic coastal plain, occupies broad, gently sloping ridge tops. This soil is a moderately well-drained member of the fine-loamy, kaolinitic, thermic family of Plinthic Paleudults (*10*). The plinthite (a humus-poor, sequioxide-rich horizon that hardens irreversibly upon repeated wetting and drying) extends from approximately 100 to 195 cm and is slowly permeable to water and air. This low permeability results in a seasonally perched water table.

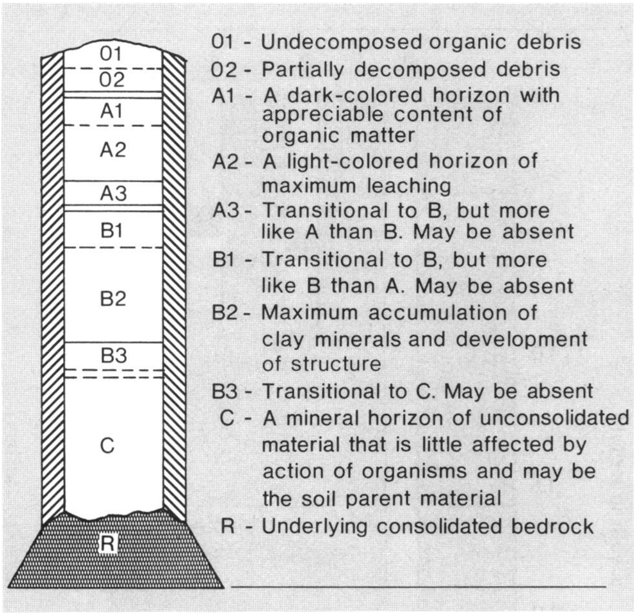
Goldsboro, which has developed in the loamy sediments of the upper and middle coastal plain terraces, occupies broad, gently sloping ridge tops and concave slopes. This soil is a well- to moderately well-drained member of the fine-loamy, siliceous, thermic family of Aquic Paleudults. A weakly developed fragipan that is moderately to slowly permeable to water is found in the lower part of the subsoil at approximately 130–150 cm. (A subsoil horizon of high-bulk density that is brittle when moist and very hard when dry is called a fragipan.) In Goldsboro, the fragipan results in a seasonally perched water table.

Beltsville, which has developed in loamy sediments, occupies broad, gently sloping ridge tops and concave toe slopes. It is a moderately well drained member of the fine-loamy, mixed mesic family of Typic Fraguidults (*10*). Beginning at a depth of about 60 cm, it extends approximately 130 cm and is only very slowly permeable to water and air.

Because the seasonal water tables of these three soils fluctuate greatly as a result of restricting layers, they are considered to be only marginally suited for the sanitary disposal of domestic waste. This fluctuation may cause untreated or partially treated waste to surface during periods of high soil moisture and may also influence the vertical and lateral distribution of biological contaminants. More detailed information on the physical, chemical, and morphological properties of these soils has been reported previously by Reneau and Pettry (*11*).

Morphological definitions. To help interpret the findings of our study, a brief statement on soil morphology may be appropriate. Soils, which comprise the surface landscape of the earth's outer crust, are in dynamic equilibrium with the environment. Since soils are natural bodies that result from the weathering action of climate, organisms, and relief on parent materials over a period of time, they are often mixed and interwoven into complex arrangements. Adjacent soils are often linked by broad transition zones. A hypothetical profile of the soils studied is presented in figure 1. A soil profile is a vertical exposure of the horizons of a soil. It displays all the principal horizons (a horizon being a layer of soil that is approximately parallel to the land surface and that differs from adjacent genetically related layers in physical, chemical, and biological characteristics). These horizons directly influence the rate of movement of septic effluent in the soil and the degree of purification this effluent undergoes as it moves through these natural soil systems.

Figure 1. A hypothetical soil profile

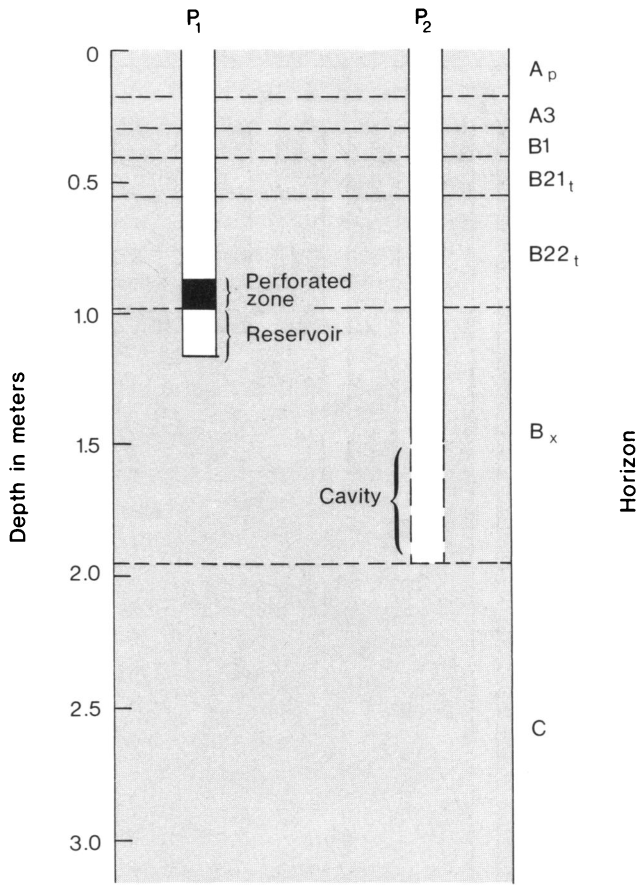


Movement of organisms. The in situ movements of pollutant organisms (total and fecal coliforms) were monitored during 1972, 1973, and 1974 by placing a series of piezometers at selected distances from the drainfields in the direction of the ground water flow, as established by equal hydraulic heads. These piezometers were installed so as to obtain samples from selected depths. The number of piezometers and the depths sampled were based on the soil properties.

To facilitate sample collection at the Varina soil location, each series of piezometers consisted of two piezometers—P1 and P2 (fig. 2). P1 was located above the restricting plinthic horizon (B_x), and P2 was located in the dense plinthic material. The piezometer in the B_x horizon was driven and a cavity excavated below the polyvinyl chloride tube. Five series were installed at distances of 0.15, 0.53, 1.27, 3.05, 6.10, and 12.0 m from the drainfield. Samples were collected on 17 dates above the restricting plinthic layer and on 7 dates within the layer. At the Goldsboro soil location, each series consisted of four piezometers (P1, P2, P3, and P4) with 10 cm perforated areas. P1 was designed to collect samples from a depth of 84–94 cm, P2 from 142–152 cm, P3 from 200–210 cm, and P4 from 422–432 cm (fig. 3). These series of piezometers were located at 0.15, 0.53, 1.51, 3.0, and 13.5 m from the drainfield. Samples were collected on 13 dates at the Goldsboro soil location. At the Beltsville soil location, each series consisted of three piezometers (P1, P2, and P3); to facilitate sample collection, P1 and P2 had perforated areas above the fragipan (B_x) and P3 was driven below the fragipan (fig. 4). A series of piezometers at this site was located between the last two drainlines, at 0.15, 0.53, and 1.5 m from the next to last drainline and at 0.5, 12.5, and 28.0 m from the drainfield. Samples were collected above the fragipan (B_x) on six dates and below the fragipan on four dates.

Samples for bacterial analysis were collected after the piezometers had been pumped dry and allowed to recharge. A hand vacuum pump was used in sample collection. After the samples were removed from the piezometer via a 1.25 cm (inside diameter) tygon tube leading to the collection vessel, they were immediately placed on ice. Bacterial analyses, in which

Figure 2. Placement of piezometers in a Varina soil containing dense, restricting plinthic horizon (Bx)



Subordinate symbols
p - horizon that has been disturbed by cultivation or pasturing
t - accumlations of translocated clays
g - horizon of intense reduction; is gray or light-colored
x - fragipan horizon with properties of firmness, brittleness, and high density

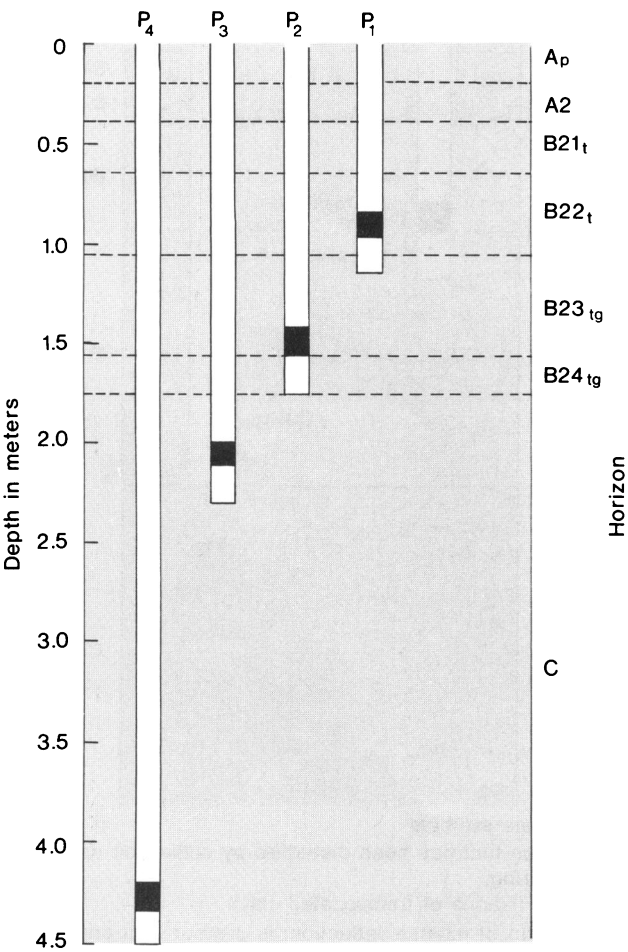
NOTE: For explanation of P, A, B, and C, see fig. 1.

the three-tube, multiple-tube dilution technique was used, were begun within 2 hours of collection. The confirmed test was used to measure total coliform densities. These analyses were performed by the Water and Milk Microbiology Section of the Virginia State Department of Health Laboratory, Richmond.

Results and Discussion

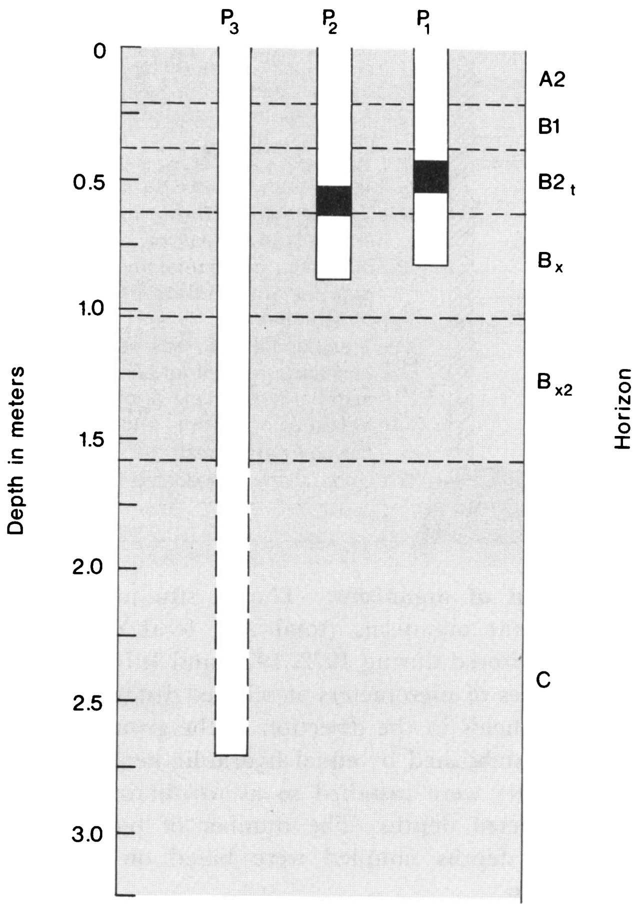
Varina location. The septic tank drainfield in the Varina soil had been in use for approximately 15 years at the time of the study. It disposed of an estimated 20 liters (0.5 gallons) per day per square meter if one assumes that each person used approximately 189 liters (50 gallons) per day. The absorption field was installed approximately 30 cm from the surface and extended to 63 cm (fig. 2).

Figure 3. Placement of piezometers in a Goldsboro soil containing restricting clayey horizons



NOTE: For explanation of symbols P, A, B, and C, see fig. 1.
For explanation of subordinate symbols p, t, g, and x, see fig. 2.

Figure 4. Placement of piezometers in a Beltsville soil containing hard, dense restricting fragipan horizon (Bx)



NOTE: For explanation of symbols P, A, B, and C, see fig. 1.
For explanation of subordinate symbols p, t, g, and x, see fig. 2.

Both total and fecal coliform counts decreased as horizontal distance from the drainfield increased (table 1 and fig. 5). Coliform counts above the plinthic horizon (P1) were reduced from an average of 5.9 total coliforms and 1.6 fecal coliforms $\times 10^6$ per 100 ml at the distribution box to 39 total coliforms and 6.9 fecal coliforms $\times 10^3$ per 100 ml at 12.0 m from the drainfield in the direction of water flow (table 1). In the very slowly permeable plinthic material (P2), the total and fecal counts were greatly reduced as compared with the indicator organism densities detected above the plinthic horizon (fig. 5). The total coliform counts ranged from an average of 13,000 per 100 ml at 0.15 m to 48 per 100 ml at a 12 m distance. Few fecal coliforms were detected in the plinthic material.

The relatively small differences between the maximum and minimum counts and the fact that all distances with the exception of 3.05 m had median values of less than 3 demonstrate that the plinthic horizon limited the travel of the indicator organisms vertically (fig. 5). All bacterial densities of less than 0.003×10^3 (fig. 5) indicate that no coliform organisms were observed by the three-tube dilution technique. The fecal coliform counts for samples collected at 12.0 m were higher than those for samples collected at the 6.1 m distance. A possible explanation may be that because the 12.0 m samples were collected in a discharge area below the drainfield, they were more subject to contamination from the soil surface. Also, fewer observations were made at 12.0 m. The study data indicate that both total and fecal coliform densities were greatly reduced as effluent moved horizontally through this soil. These reductions were probably a result of dilution, soil filtration, and dieoff. The data demonstrate that the plinthic horizon effectively bars vertical movement of biological contaminants and reduces the total soil volume available for filtration.

Fecal coliform counts for random samples obtained from a small creek that ran adjacent to the drainfield ranged from 430 to less than 3 per 100 ml after passage through the drainfield area. Information on stream flow and source of input was not sufficient to permit discrimination between the contribution of fecal coliforms from the drainfield and the contribution from animal sources. The differences between the median coliform densities (fig. 5) and the mean coliform densities (table 1) indicate that the density distribution was skewed toward higher coliform

Table 1. Total and fecal coliforms in water samples taken at selected distances and depths in a Varina soil

Depth sampled (in relation to plinthic horizon)	*Total coliforms* [1]			*Fecal coliforms* [1]			*Observations*
	Maximum	*Minimum*	*Mean*	*Maximum*	*Minimum*	*Mean*	
			At distribution box				
....	12,000,000	46,000	5,900,000	5,000,000	21,000	1,600,000	8
			At 0.15 m from drainfield				
Above plinthic	≥2,400,000	4,300	740,000	≥2,400,000	1,100	330,000	37
In plinthic	110,000	<3	13,000	230	<3	18	16
			At 0.53 m from drainfield				
Above plinthic	≥2,400,000	2,300	520,000	≥2,400,000	300	170,000	40
In plinthic	2,400	<3	2,400	93	<3	6	17
			At 1.27 m from drainfield				
Above plinthic	≥2,400,000	300	420,000	≥2,400,000	300	170,000	40
In plinthic	430	<3	73	4	<3	3	8
			At 3.05 m from drainfield				
Above plinthic	460,000	150	130,000	240,000	150	59,000	40
In plinthic	≥24,000	<3	6,200	4,600	<3	740	17
			At 6.10 m from drainfield				
Above plinthic	≥240,000	64	37,000	110,000	<3	10,000	39
In plinthic	≥24,000	<3	3,600	930	<3	60	17
			At 12.0 m from drainfield				
Above plinthic	≥240,000	4,600	39,000	≥24,000	210	6,800	9
In plinthic	230	<3	48	230	<3	40	18

[1] Most probable number per 100 ml. NOTE: < 3 indicates no coliform organism counts by 3-tube, multiple-tube dilution technique.

densities, so that the mean value was much in excess of the median.

Goldsboro location. The 4-year old septic tank system located in the Goldsboro soil disposes of approximately 7.2 liters per day per square meter (0.17 gallons per square foot) of absorption field. The drainlines are installed about 40 cm from the surface and extend down to 76 cm (fig. 3).

Generally, total and fecal coliform counts decreased at each depth as the distance from the drainfield increased (table 2 and fig. 6). The single largest reduction in both total and fecal coliform counts occurred during the first 0.15 m of travel. At a distance of 0.15 m, the total and fecal coliform counts (table 2) had decreased from an average of approximately 3 million (in the drainline) to an average of 5 total and 2 fecal coliform $\times 10^5$ per 100 ml at the 152 cm depth. Large reductions were noted in both total and fecal coliform densities between the 0.15 and 13.5 m distance.

Figure 5. Median distribution of total and fecal coliform organisms in Varina soil solutions adjacent to drainfield area

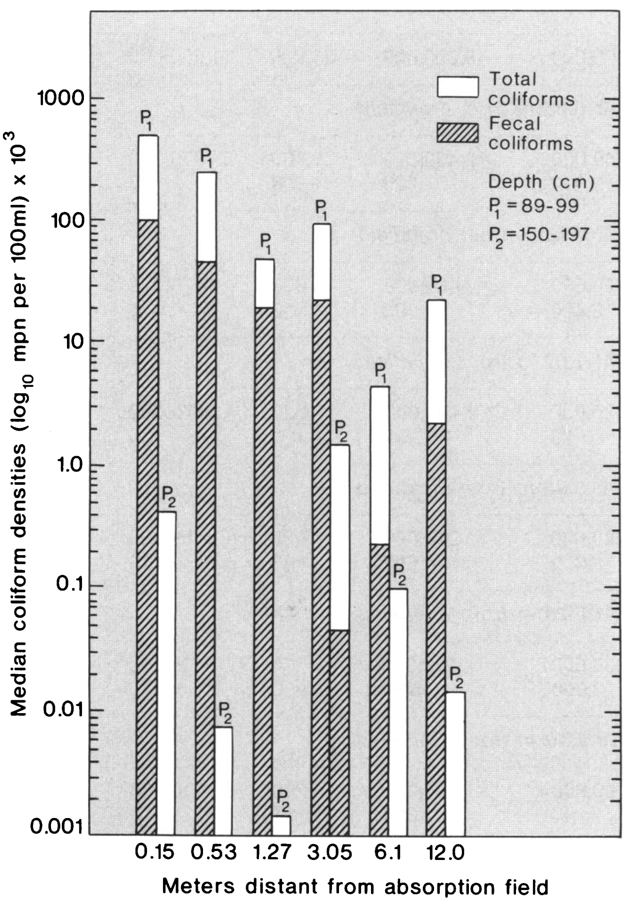
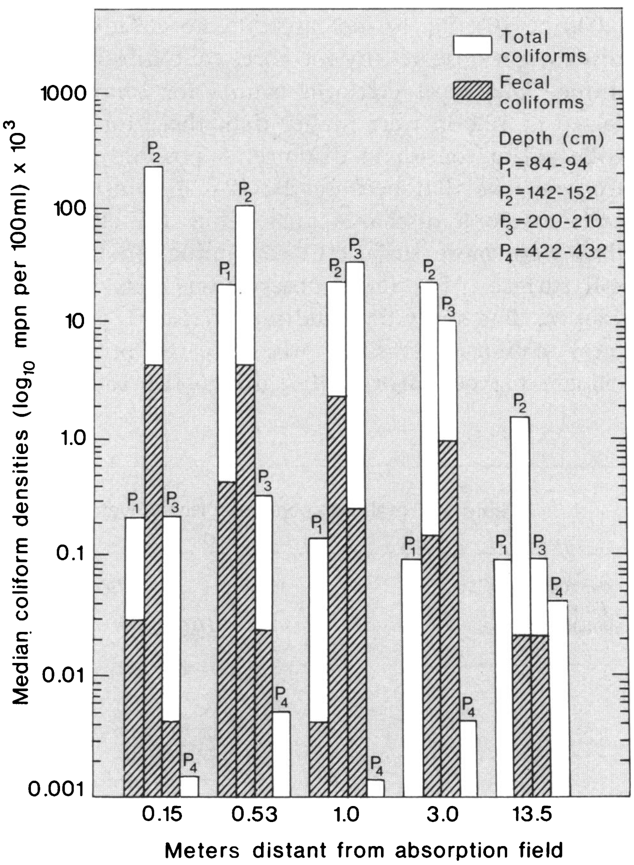


Figure 6. Median distribution of total and fecal coliform organisms in Goldsboro soil solutions adjacent to drainfield area



Total and fecal coliforms also decreased with the depth sampled (table 2 and fig. 6). The 152 cm sampling depth was consistently higher in total and fecal coliform counts than the other depths sampled, probably as a result of a weakly compacted horizon in the lower portion of the B horizon. The lowest total and fecal coliform counts were found at the 432 cm sampling depth. At this depth, few fecal coliforms were detected at the first four distances, as indicated by both the median and the average values of less than 3 per 100 ml (fig. 6 and table 2). The average value of 25 fecal coliforms per 100 ml at the 432 cm depth for the 13.5 m distance resulted from a single day's sampling which yielded 750 fecal coliforms per 100 ml (table 2). No fecal coliforms were found on the other sampling dates. Densities less than 0.003×10^3 (fig. 6) indicate that no coliform organisms were observed. Their absence probably indicates that the sample had been accidentally contaminated and that fecal coliforms did not actually move to this depth. The median value of less than 3 fecal coliforms per 100 ml for all sampling dates supports this view (fig. 6). The differences between the medial coliform densities (fig. 6) and the mean coliform densities (table 2) indicate that the density distribution was skewed toward higher coliform counts.

Beltsville location. The septic system in the Beltsville soil, a system that had been in service for 9 years at the time of the study, received an estimated 750 liters (200 gallons) per day of domestic wastes. This system disposes daily of approximately 8 liters per square meter (10.17 gallons per square foot) of subsurface absorption field. The subsurface drainlines had been placed immediately above a fragipan situated at a depth of approximately 65 cm (fig. 4). There was a wooded area adjacent to the drainfield in the direction of the ground water flow.

Total and fecal coliform densities decreased as distance from the drainlines above the fragipan increased (fig. 7 and table 3). The total and fecal coliforms above the fragipan (P1 and P2) were greatly reduced at both 12.5 and 28.0 m from the drainfield. Even though mean total coliform densities above the

Table 2. Total and fecal coliforms in water samples taken at selected distances and depths in a Goldsboro soil

Depth sampled (cm)	Total coliforms [1]			Fecal coliforms [1]			Observations
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	
	In drainline						
....	24,000,000	<3,000	3,500,000	24,000,000	150	3,100,000	9
	At 0.15 m from drainfield						
84–94	2,300	43	660	300	<3	55	10
142–152	≥2,400,000	2,100	930,000	1,100,000	<3	110,000	11
200–210	39,000	<3	5,300	6,200	<3	490	13
422–432	1,500	<3	190	<3	<3	<3	13
	At 0.52 m from drainfield						
84–94	≥240,000	61	70,000	93,000	<3	20,000	8
142–152	≥2,400,000	24,000	550,000	240,000	11	52,000	10
200–210	23,000	<3	3,400	930	<3	120	12
422–432	4,300	<3	360	7	<3	<3	13
	At 1.5 m from drainfield						
84–94	930	<3	260	30	<3	11	5
142–152	≥2,400,000	90	290,000	240,000	4	36,000	11
200–210	≥2,400,000	230	350,000	240,000	<3	37,000	12
422–432	≥24,000	<3	1,800	93	<3	7	13
	At 3.0 m from drainfield						
84–94	4,600	4	970	30	<3	6	5
142–152	≥2,400,000	160	290,000	240,000	4	29,000	11
200–210	≥2,400,000	4	200,000	43,000	<3	8,500	13
422–432	93	<3	12	4	<3	<3	12
	At 13.5 m from drainfield						
84–94	≥24,000	9	4,500	39	<3	6	7
142–152	≥24,000	200	9,300	9,300	<3	1,100	11
200–210	≥24,000	15	4,100	2,100	<3	210	12
422–432	11,000	<3	1,300	750	<3	68	12

[1] Most probable number per 100 ml. NOTE: < 3 indicates no coliform organism counts by 3-tube, multiple-tube dilution technique.

fragipan decreased from 45 × 10³ per 100 ml at a depth of 45–53 cm and from 27 × 10³ per 100 ml at a depth of 54–64 cm to less than 4,300 per 100 ml at 12.5 and 28.0 m, the largest reductions were in the fecal coliform densities. The fecal coliform counts were reduced from an average of approximately 32 × 10³ ml above the fragipan adjacent to the drainfield to less than 1,300 per ml at 12.5 m and to 100 per 100 ml at 28.0 m (table 3).

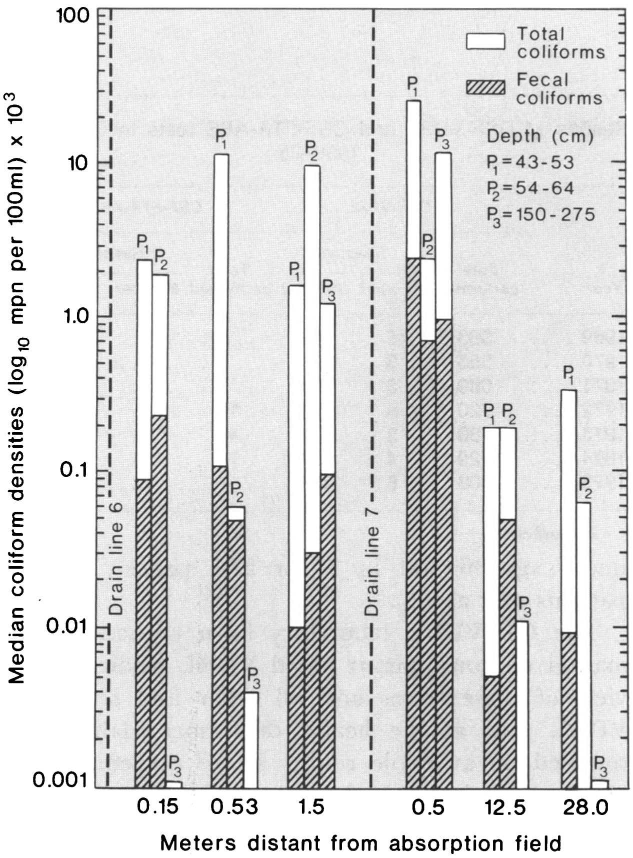
The total and fecal coliform counts were greatly reduced below the fragipan (P3) as compared with the counts detected above it (fig. 7 and table 3). The high fecal coliform densities between drainline 6 and 7 and around drainline 7 (fig. 7) were probably the result of seepage down the edge of the piezometer, since the other piezometers driven through the fragipan gave no indication of fecal bacterial contamination. All the piezometers with the exception of these two had median values of less than 3 (fig. 7), indicating that generally no fecal coliforms were observed. As a rule, total coliform densities below the fragipan were less than 100 per milliliter, and only limited fecal coliforms were present. Movement of effluent was primarily in a horizontal direction along

Table 3. Total and fecal coliforms in water samples taken at selected distances and depths in a Beltsville soil

Depth sampled (cm)	Total coliforms [1]			Fecal coliforms [1]			Observations
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	
			In drainline				
....	240,000	110,000	230,000	230,000	230	230	4
			At 0.15 m from drainline 6				
43–53	9,300	930	3,500	1,500	4	370	6
54–64	≥240,000	160	43,000	4,300	30	1,000	6
150–275	9	<3	3	<3	<3	<3	5
			At 0.53 m from drainline 6				
43–53	29,000	230	13,000	2,300	<3	580	5
54–64	9,300	40	2,900	900	<3	260	7
150–275	≥24,000	<3	5,000	11,000	<3	<3	5
			At 1.5 m from drainline 6				
43–53	2,400	4	1,200	430	<3	100	4
54–64	≥240,000	290	47,000	110,000	4	12,000	8
150–275	≥24,000	<3	10,000	230	<3	95	5
			At 0.5 m from drainline 7				
43–53	≥240,000	430	45,000	46,000	150	8,000	8
54–64	110,000	21	27,000	15,000	<3	32,000	8
150–275	≥24,000	4	12,000	4,600	4	2,100	5
			At 12.5 m from drainline 7				
43–53	2,400	<3	500	430	<3	110	8
54–64	≥24,000	15	4,300	930	<3	1,300	8
150–275	93	<3	25	4	<3	<3	5
			At 28.0 m from drainline 7				
43–53	4,600	4	840	430	<3	70	8
54–64	≥24,000	<3	3,300	430	<3	67	8
150–275	230	<3	75	4	<3	<3	5

[1] Most probable number per 100 ml. NOTE: < 3 indicates no coliform organism counts by 3-tube, multiple-tube dilution technique.

Figure 7. Median distribution of total and fecal coliform organisms in Beltsville soil solutions adjacent to drainfield area



the surface of the fragipan. Both total and fecal coliform counts were greatly reduced in the first 13 m of horizontal travel, probably a result of dilution, soil filtration, and dieoff. Few organisms were present below the very slowly permeable fragipan. The low coliform densities that were enumerated below the fragipan were probably a result of driving piezometers through this horizon rather than the migration of coliforms to deeper depths.

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SYNOPSIS

RENEAU, R. B., Jr. (Virginia Polytechnic Institute and State University), PETTRY, D. E., SHANHOLTZ, M. I., GRAHAM, S. A., Jr., and WESTON, C. W.: *Distribution of total and fecal coliform organisms from septic effluent in selected coastal plain soils. Public Health Reports, Vol. 92, May–June 1977, pp. 251–259.*

Distribution of total and fecal coliform bacteria in three Atlantic coastal plain soils in Virginia were monitored in situ over a 3-year period. The soils studied were Varina, Goldsboro, and Beltsville sandy loams. These and similar soils are found extensively along the populous Atlantic seaboard of the United States. They are considered only marginally suitable for septic tank installation because the restricting soil layers result in the subsequent development of seasonal perched water tables. To determine both horizontal and vertical movement of indicator organisms, samples were collected from piezometers placed at selected distances and depths from the drainfields in the direction of the ground water flow.

Large reductions in total and fecal coliform bacteria were noted in the perched ground waters above the restricting layers as distance from the drainfield increased. These restricting soil layers appear to be effective barriers to the vertical movement of indicator organisms. The reduction in the density of the coliform bacteria above the restricting soil layers can probably be attributed to dilution, filtration, and dieoff as the bacteria move through the natural soil systems.