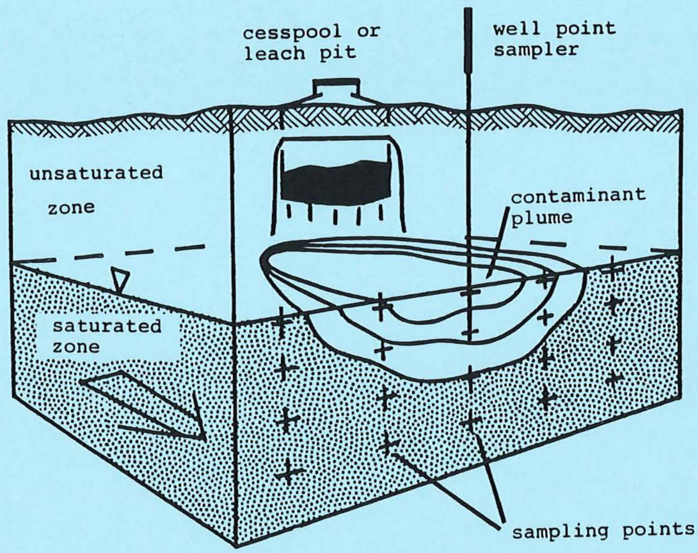
The Impact of Septic Effluent on Groundwater Quality, Buttermilk Bay Drainage Basin, Massachusetts

Part I: Indicator Bacteria



February 1989 DRAFT REPORT

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Submitted to:
The Buzzards Bay Project
U.S. Environmental Protection Agency, Region I
Massachusetts Executive Office of Environmental Affairs

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ABSTRACT

Part I: Indicator Bacteria

Buttermilk Bay, located at the head of Buzzards Bay in Bourne and Wareham, Massachusetts, has an unsewered watershed with several densely populated nearshore areas. The bay's drainage basin is underlain by highly permeable (K = 50 meters/day) sand and gravel sediments of glacial outwash origin. Septic systems are suspected to be a major source of the fecal coliform indicator bacteria which have repeatedly forced the closure of shellfish beds in the bay. The present study was undertaken to test this hypothesis.

The effluent and groundwater associated with four individual septic systems/cesspools was sampled monthly over a six month period. The 24 effluent samples had a geometric mean fecal coliform density of 115,000 colonies/100 ml; fecal streptococcus and and *Clostridium perfringens* densities averaged 19,500 and 6,700 col./100 ml, respectively. Groundwater indicator densities (in samples collected 1 meter downgradient of each system, in the core of each contamination plume as determined by well point sampling) varied with indicator type and site factors. At the one site where fecal coliform was detected, the geometric mean density was 13 col./100 ml, while the *Clostridium* averaged 23 col./100 ml. *Clostridium* was also detected at least once at the three other sites, while fecal streptococcus was never detected in any of the groundwater samples. Indicator breakthrough to the saturated zone below each system appeared to be controlled largely by the depth to water table and the effluent loading rate (volume/unit area/unit time) at each site. Horizontal transport of indicators with flowing groundwater was observed to be extremely limited. Fecal coliform levels were at or below the detection limit 2 meters downgradient of the "worst case" site. *Clostridium* densities also declined rapidly in the downgradient direction.

The public health significance of these findings, and indeed all groundwater quality studies relying upon indicator bacteria, is uncertain. Several investigators (e.g. Vaughn et al., 1983) have shown that viral pathogens can be far more mobile and persistent in the subsurface than bacterial indicators or pathogens; a groundwater sample free of fecal coliforms, for example, can contain significant numbers of viruses. Because of this fact, it is important to maintain and strengthen the existing Title V code, which regulates the design and siting of septic systems in Massachusetts. The maximum loading rates allowed by the code in highly permeable

sediments should be reduced (by requiring larger bottom and sidewall areas for absorption trenches, fields, or pits). It may be advisable to increase the depth-to-water table and setback from watercourse requirements as well. A complete understanding of septic system impact on the microbial quality of coastal waters, and the adequacy of Title V as a protection measure must await the completion of viral transport studies in the Cape Cod/Buzzards Bay region.

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1. INTRODUCTION

1.1 The Problem

Buttermilk Bay, located at the head of Buzzards Bay in southeast Massachusetts (Fig. 1), has a history of water quality problems (Buchsbaum, 1988). The bay is eutrophic, or nutrient-enriched, and since 1984 shellfishing has been restricted due to the bacterial contamination of its waters. The U.S. Environmental Protection Agency and the Masssachusetts Executive Office of Environmental Affairs, under the auspices of the Buzzards Bay Project, have sponsored a series of investigations into the bay's hydrology, hydrodynamics, and contaminant loading (Moog, 1987; Fish, 1988; Valiela and Costa, 1987; Heufelder, 1987). Because the drainage basin of the bay is unsewered throughout, and also contains several densely populated areas (Fig. 2), these investigators have suggested that domestic septic systems are a major source of the bacteria and nutrients now entering the bay. The present study was undertaken in order to test this hypothesis.

The literature concerning septic systems and their effects is large and diverse, encompassing the fields of hydrogeology, geochemistry, environmental microbiology, environmental engineering, epidemiology, and public health. A review of this literature (see Appendix A) reveals that septic systems can "fail", or negatively affect the

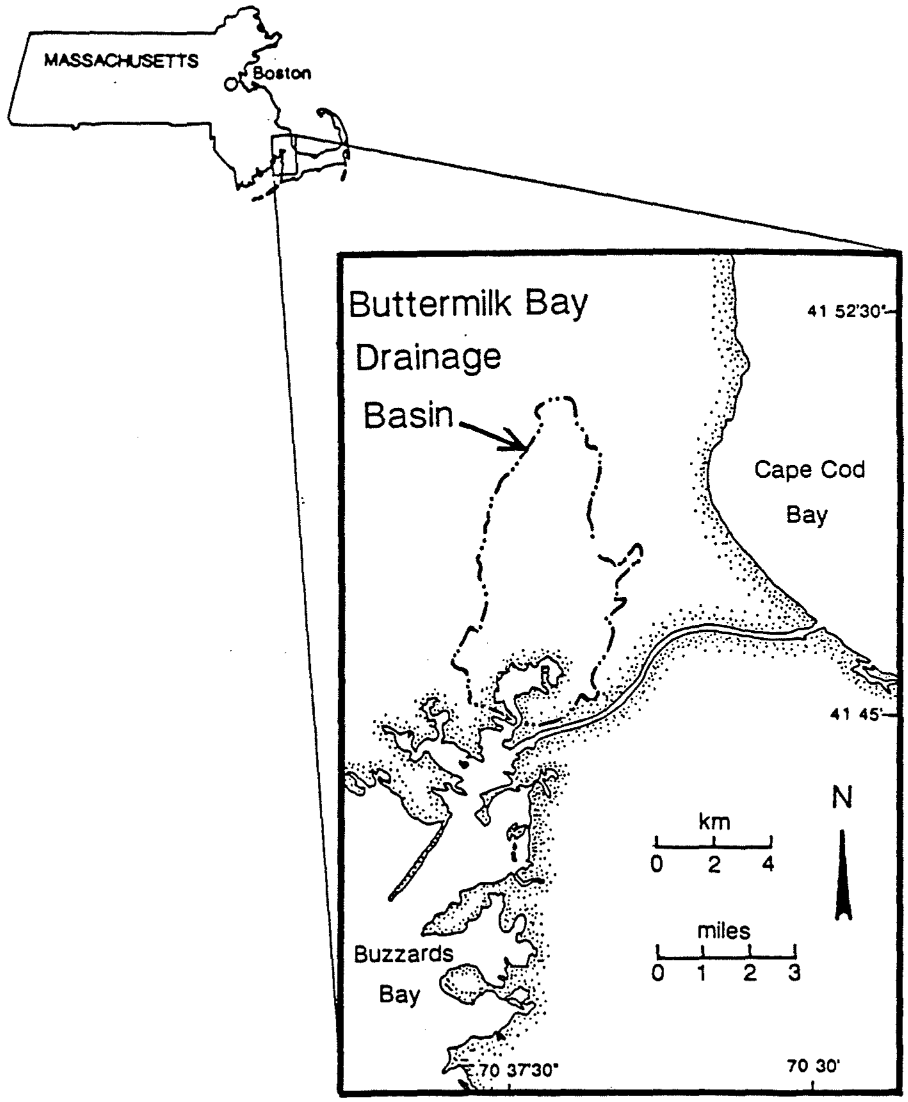


Figure 1. The location of the Buttermilk Bay drainage basin.

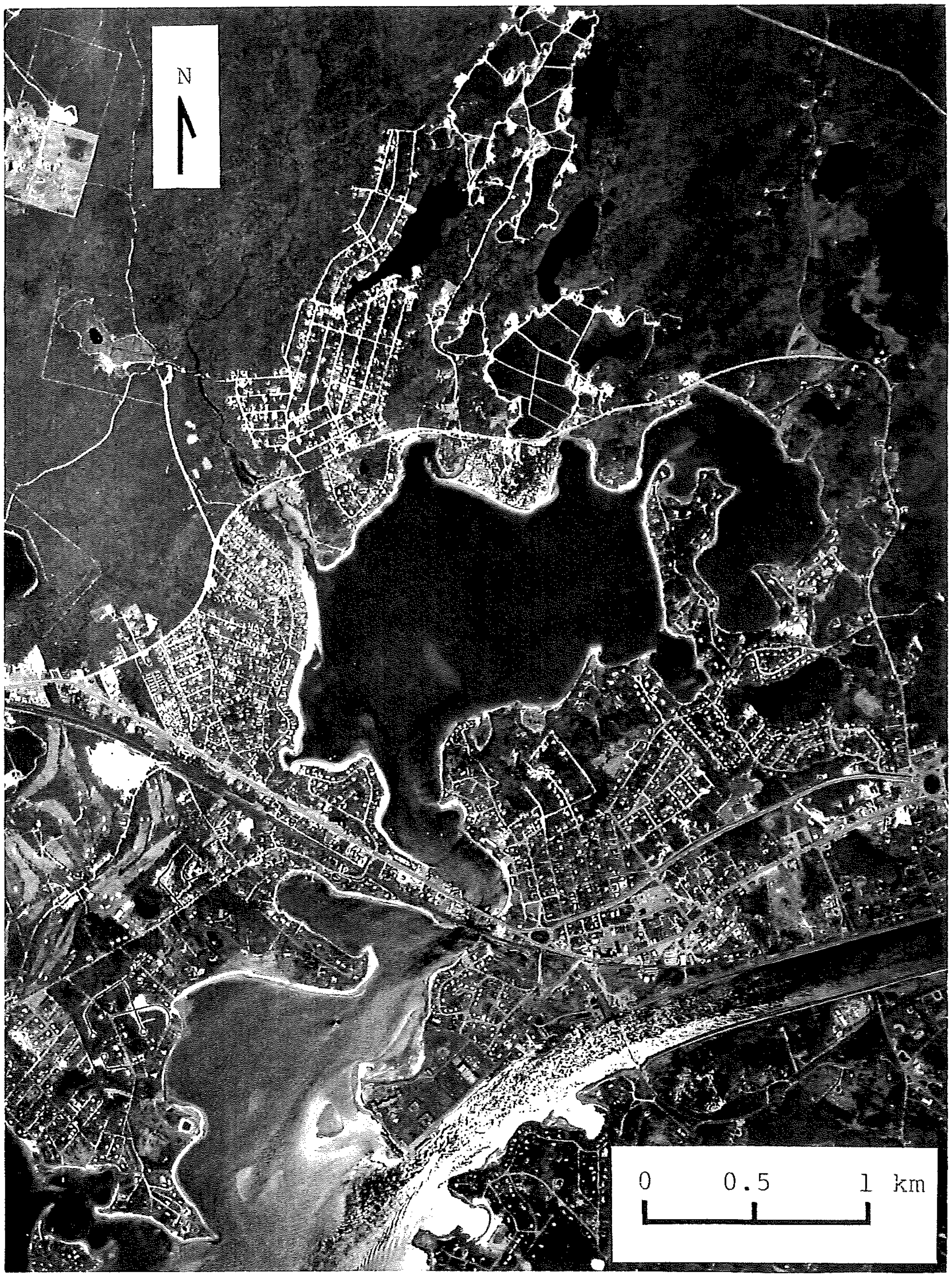


Figure 2. Buttermilk Bay and adjacent land areas. Note urbanized areas west, southeast, and north of the bay. Scrub oak/pine forest and cranberry bogs cover most undeveloped areas. (Date of photograph: 20 April, 1974.)

environment, in two distinct ways. First, septic effluent can break out at the ground surface, posing a direct threat to the public health and to surface water quality. Second, effluent can infiltrate too rapidly to the saturated zone and contaminate groundwater (Canter and Knox, 1985). Contaminated groundwater is not only a potential health threat in itself; it also poses an indirect threat to surface water quality, insofar as contaminants are transported with ambient groundwater to a downgradient stream, pond, wetland, or coastal water body.

Surface breakout of septic effluent is common in areas underlain by relatively impermeable sediments (soils and surficial deposits overlying bedrock) and/or shallow depth to water table (Duda and Cromartie, 1982; Frimpter and Fisher, 1983). Groundwater contamination from septic effluent is more likely in areas with highly permeable sediments. Both types of impact can occur at a variety of scales, ranging from the onsite or microscale, to the neighborhood or "sub-regional" scale, to the regional scale (Childs et al., 1974; Morrill and Toler, 1973; Persky, 1986; Eckhardt and Oaksford, 1988; Appendix A of this report).

1.2 Purpose and Approach of this Study

The Buttermilk Bay drainage basin is underlain by the highly permeable, glacio-fluvial deposits of the Wareham Outwash Plain (Fig. 3). In all but a few nearshore areas, the

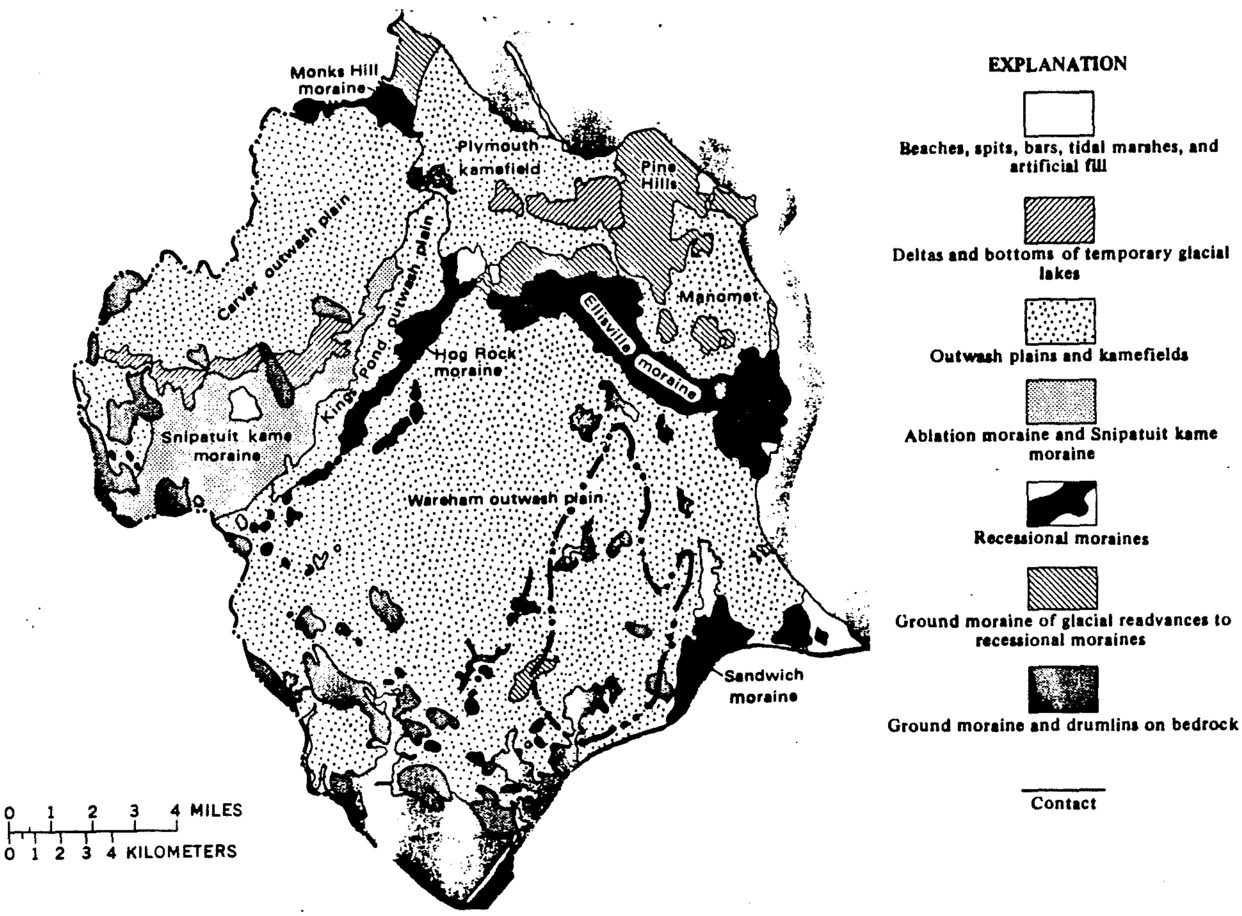


Figure 3. The surficial geology of the Buttermilk basin and surrounding areas (From Williams and Tasker, 1974).

unsaturated zone is quite thick, ranging from 5 to 15 meters (Williams and Tasker, 1974; Moog, 1987). As one might expect, surface breakout of effluent is uncommon in this hyrogeologic setting. When breakout incidents do occur, they are generally discovered and quickly corrected by local health authorities. The effects of septic effluent upon the groundwater of the basin, however, are not known. Therefore, the main purpose of this study is to monitor the groundwater impact of septic effluent in selected portions of the basin. A secondary purpose is to estimate the flux of septic-derived contaminants reaching the bay via groundwater discharge.

The approach of the study was designed in accordance with the scale considerations noted above. First, a small number of individual septic systems and sites were examined in detail, in order to assess the degree to which selected contaminants infiltrate vertically to the saturated zone under a variety of site conditions. Second, the groundwater beneath, upgradient, and downgradient of a densely populated, unsewered neighborhood just west of the bay (Indian Heights) was monitored, in order to assess the sub-regional impact of several hundred systems upon both the aquifer and the bay.

The chief microbial constituents monitored in this study were fecal coliform and *Clostridium perfringens*. Fecal streptococcus was also monitored on two sampling dates. All are normally present in the feces of humans and other warm blooded animals (Geldreich, 1977), and their occurence in ground and surface waters is associated with fecal contamination of those waters (Pipes, 1982). Of these three "bacterial indicators," only fecal coliform is routinely monitored by public health authorities responsible for shellfish waters. In Massachusetts, shellfish waters which exceed a median fecal coliform density of 14 colonies per 100 ml water sample are closed to harvesting (Commonwealth of Mass., 1985).

The first part of this report presents the methods and results of bacterial indicator monitoring conducted (at the microscale) in the Buttermilk basin. In the second part of the report, the hydrogeology of the Indian Heights sub-basin is delineated, the contaminant flux issuing from the area is modelled, and the model predictions are interpreted in the light of groundwater monitoring results obtained from this densely populated, unsewered neighborhood.

2. THE BACTERIA STUDY: METHODS

2.1 Field Methods

2.1.1 System and site selection. Four septic systems were chosen for detailed analysis. The systems are all located in the Buttermilk Bay drainage basin, are underlain by medium to coarse glacio-fluvial sand, and serve year-round households. The sites were chosen to represent the range of depth-to-groundwater conditions characteristic of the densely populated, nearshore portion of the basin. The type, age, maintenance history, physical dimensions, flow regime, and absorption area of each system were determined through direct observation and measurement, interviews with the owners, and water use records. The depth below land surface of the absorption system or cesspool base was measured with a steel rod. Maps of the sites were prepared using a compass, tape, hand level, and profiling rods. Vertical control for Sites 1-3 was provided by the U.S. Geological Survey benchmark at the northern end of the Indian Heights sub-basin, near Red Brook Road. At Site 4, elevations were determined relative to an adjacent freshwater pond, whose elevation was estimated from the USGS Sagamore Quadrangle map.

2.1.2 Monitoring well installation. First, the orientation of the groundwater contamination plume downgradient of each septic system was estimated by either detailed plume mapping or reconnaissance sampling. Then a 1.6 cm outer diameter, 0.95 cm inner diameter steel monitoring well was driven vertically through the plume core, 1 meter downgradient of the absorption system or cesspool edge. The well screen consisted of a 1 meter slotted section, with a slot width of 300 um. The screen was set vertically to coincide with the plume core. This sampling position, 1 meter downgradient of each system, was chosen to allow repeated sampling, over time, of each plume at its point of origin, before dispersion and removal processes in the saturated zone could attenuate contaminant concentrations.

2.1.3 Plume mapping. In order to obtain a fuller picture of the plume geometry at each site, the plumes were "mapped" by sampling an array of points downgradient of each system, lying in a cross section transverse to the estimated groundwater flow direction (Fig. 4). The array of points was sampled with a hand-driven, stainless steel well point sampler. Samples were drawn with a hand vacuum pump, after purging the water remaining in the sampler from the previous sampling point. The specific conductance of each sample was measured in the field with a YSI Model 33 S-C-T meter (R), which was calibrated with standard solutions, in accordance with U.S. EPA methods (1983, Method 120.1). A 2 dimensional

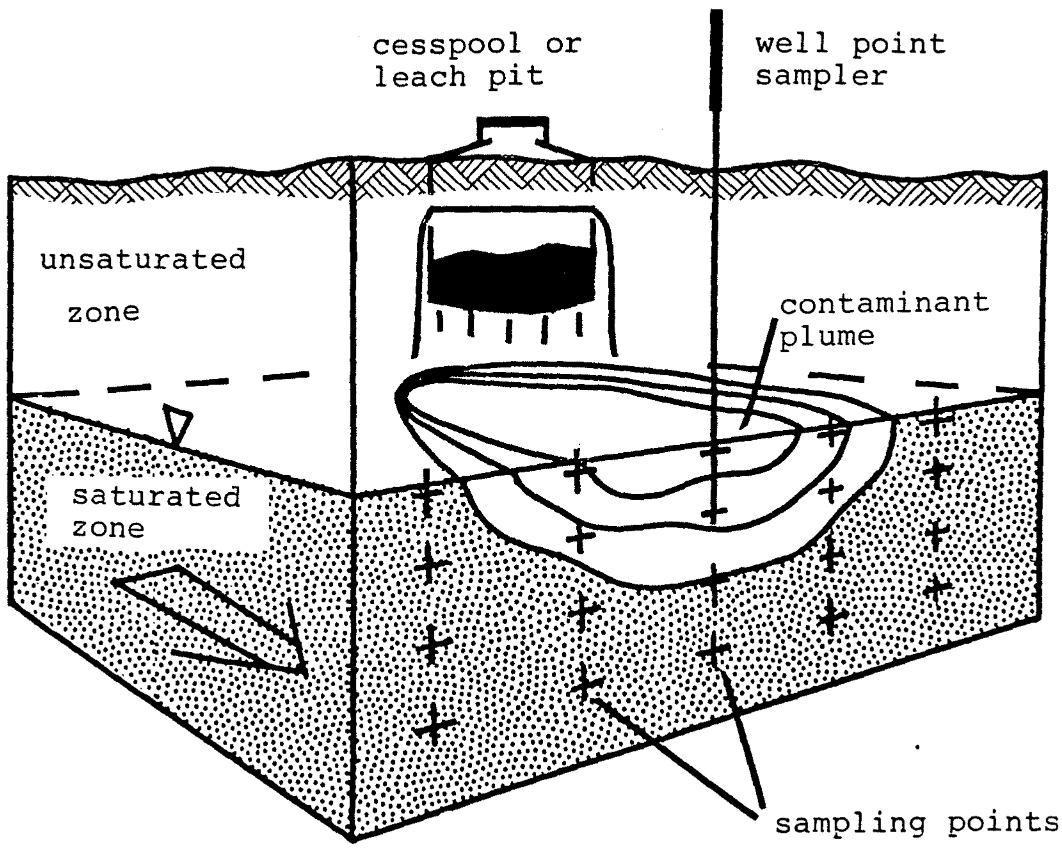


Figure 4. Array of points sampled at each site during plume mapping exercise (schematic).

plot of the conductance data was constructed with a computer using SURFER (C) contouring software.

Where site conditions allowed, the Geonics 16R (R) Very Low Frequency electromagnetic (VLF-EM) terrain resistivity instrument was also used to locate the core of each plume (See Appendix B for an explanation of this geophysical technique). Both of these methods exploit the fact that the total dissolved solids concentration (and therefore specific conductance) of sewage contaminated groundwater considerably exceeds that of uncontaminated groundwater in the stratified drift aquifers of the Cape Cod region (LeBlanc, 1984; Frimpter, 1987).

2.1.4 Groundwater and effluent sampling. Groundwater samples from each well, and effluent samples from the tank associated with each septic system were collected monthly between December 1987 and June 1988, using the following procedure:

1) Autoclaved, 0.64 cm polyethylene tubes were installed in each well and tank on the first sampling date. They served as dedicated samplers for the duration of the study. All sampling of effluent and groundwater, and all purging of the monitoring wells was performed with a gaged, hand-operated vacuum pump through these samplers.

2) Prior to sampling, the water level in each well was measured as follows. First, the sampling tube was raised

above the air-water interface. Then the tube was pumped while being lowered, 1 cm at a time, toward the interface. As soon as the interface was reached (as shown by the sudden response of the gage needle), the position of the pre-marked tube was noted relative to the land surface datum. The depth-to-groundwater below land surface datum was then determined, to the nearest centimeter. The depth to the absorption system (or cesspool) base at the site in question was subtracted from this figure to obtain the infiltration distance.

3) After the water level was measured, the monitoring well was purged by pumping approximately 3 bore volumes from the well. Two groundwater samples were then collected, in accordance with the methods of McNabb and Mallard (1984). The first was drawn into an autoclaved, 250 ml glass bottle, stored in the dark at 4 degrees C, and transported promptly to the laboratory for bacterial analysis (see Laboratory Methods, below). Analyses were commenced within 4 hours of collection. The second was drawn into an acid-washed glass bottle, transferred to an acid-washed, 200 ml plastic bottle, and stored in the same manner during transport to the laboratory for nutrient analysis (see Part II of this report). The specific conductance of the sample remaining from the second withdrawal was measured in the field with the YSI meter. The effluent samples were collected and

stored in the same fashion, with the exception of the purging step. At no time did either effluent or groundwater samples come into physical contact with the hand pump.

2.2 Laboratory Methods

All bacterial analyses were performed at the Barnstable County Health and Environmental Department under the supervision of the second author. In order to insure comparability, all methods used were identical to those of Heufelder (1987). Fecal coliform densities were obtained using the standard "Modified A-1 Test," a multiple tube fermentation technique, in conjunction with a standard Most Probable Number Table (American Public Health Assoc., 1985). *Clostridium perfringens* densities were obtained with the membrane filter technique developed by Bisson and Cabelli (1979). Fecal streptococci were enumerated according the methods of the APHA (1985).

Because the fecal coliform group includes some species of non-fecal origin (notably *Klebsiella*), the fecal coliform samples were further differentiated to determine their *Escherichia coli* density by adding MUG (4 Methylumbelliferyl-beta-D-glucuronide) to the nutrient broth. *E. Coli* produces an enzyme which hydrolyzes MUG into a fluorogenic product. *E. coli* presence was confirmed by observation under ultraviolet light.

3. SITES, SYSTEMS, AND PLUMES: RESULTS AND DISCUSSION

3.1 System and Site Characteristics

Many factors control the degree to which an individual septic system will affect the groundwater in its vicinity (Appendix A, Fig. A-3). Some of these factors relate to the characteristics of the site, others to the quality of the effluent, and still others to the system's design and manner of operation.

The sites and systems examined in this study have two major features in common: site geology and year-round operation. They also differ in several important respects (Table 1, Figures 5-8). The system at Site 2 is a tank/leach trench combination; the remainder are cesspools, which are quite common in the older neighborhoods of the Buttermilk Bay drainage basin. System ages and maintenance practices vary considerably, as do the effluent loading rates and infiltration distances. The sites also differ in their proximity to the bay or other surface water bodies, and in surface slope. Breakout of effluent at the ground surface was never observed, even at sites with steep slopes in the downgradient direction (Sites 1 and 2).

System Characteristic	Site 1	Site 2	Site 3	Site 4
Type	cesspool	tank & leach field	cesspool	cesspool
Age (yrs)	27	10	30	75
Pump-out frequency	once per year	once per year	twice per year	once per two years
Mean flow rate (L/day)	428	304	520	340
Absorption system area (m2)	6.59	14.85	2.74	4.48
Mean effluent loading rate (cm/day)	6.49	2.05	19.0	7.58
Mean depth to water table (m)	4.02	4.20	3.11	0.99
Depth to bottom of absorption system (m)	2.25	0.70	2.30	1.80
Mean infiltration distance (m)	1.77	3.50	0.81	0
Sediment type	med. to coarse sand	med. to coarse sand	med. to coarse sand	med. to coarse sand

Notes:
Flow rate estimated from water use records, except at Site 4, where per capita use of 170 L/day was assumed.
Absorption area = bottom area + saturated sidewall area.
Loading rate = mean flow rate divided by absorption area.
Depth to water table was measured monthly in monitoring well.
Mean infiltration distance = mean depth to water minus depth to bottom of absorption system.

Table 1. System and Site Characteristics, Sites 1-4

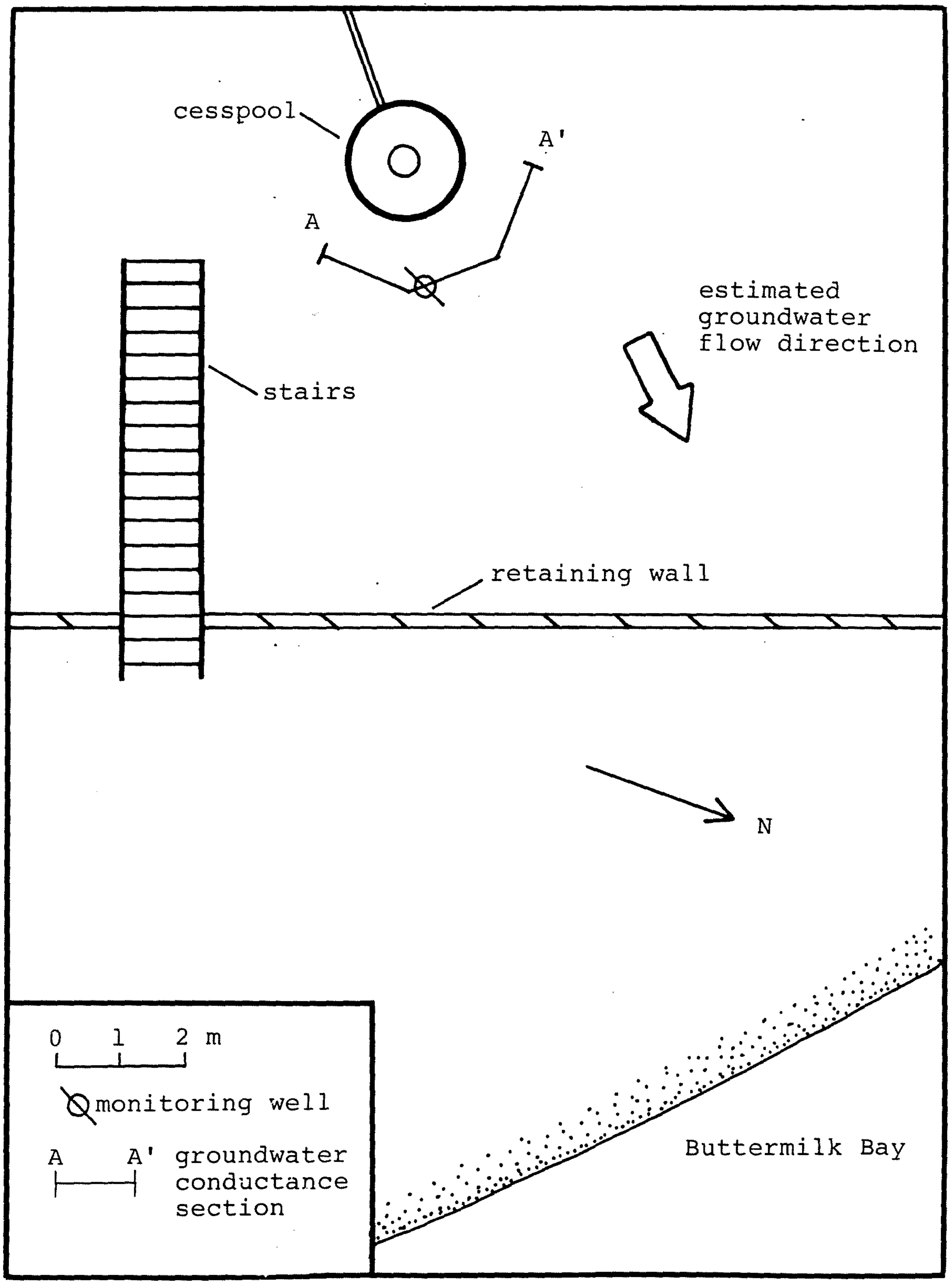


Figure 5. Plan view, Site 1

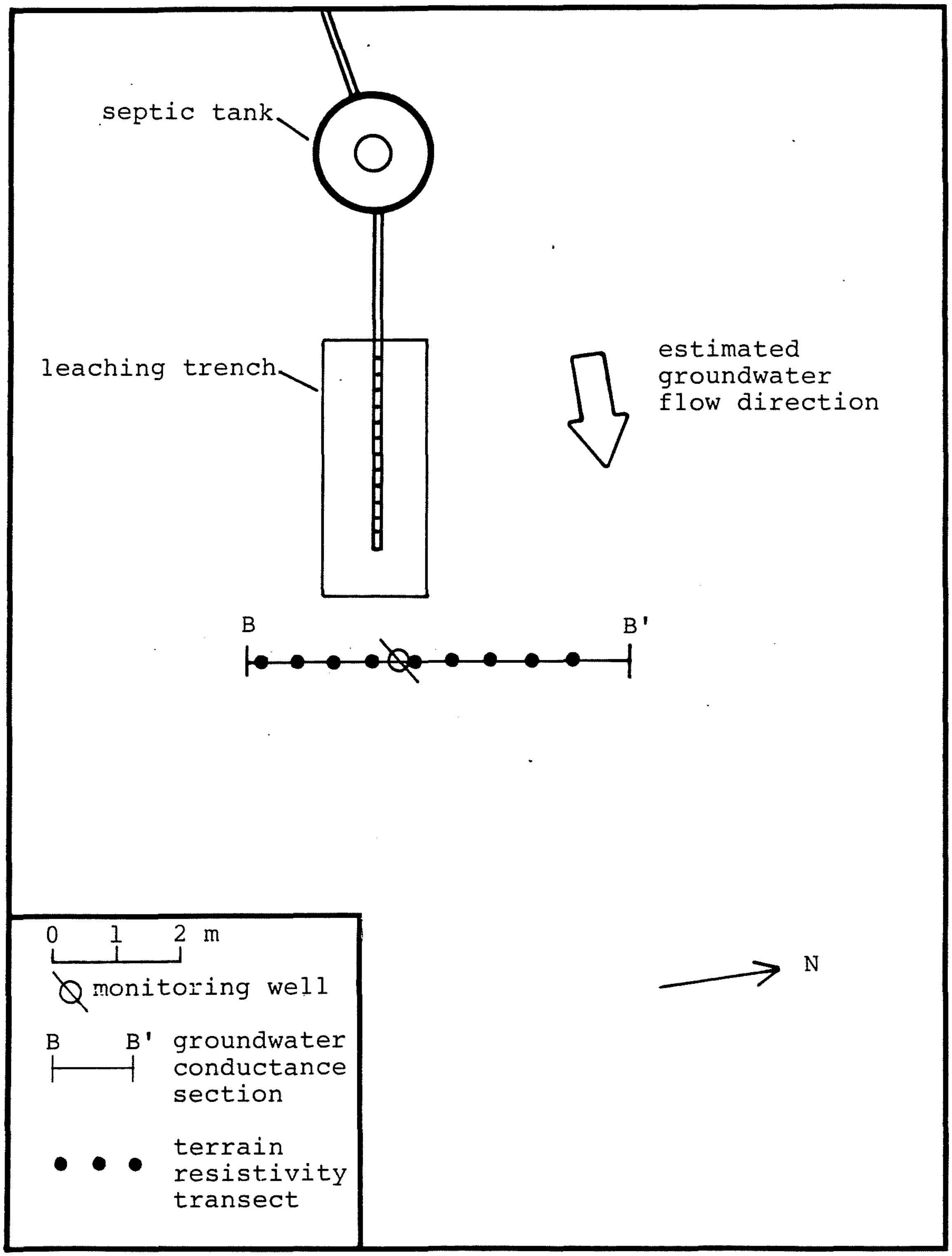


Figure 6. Plan view, Site 2

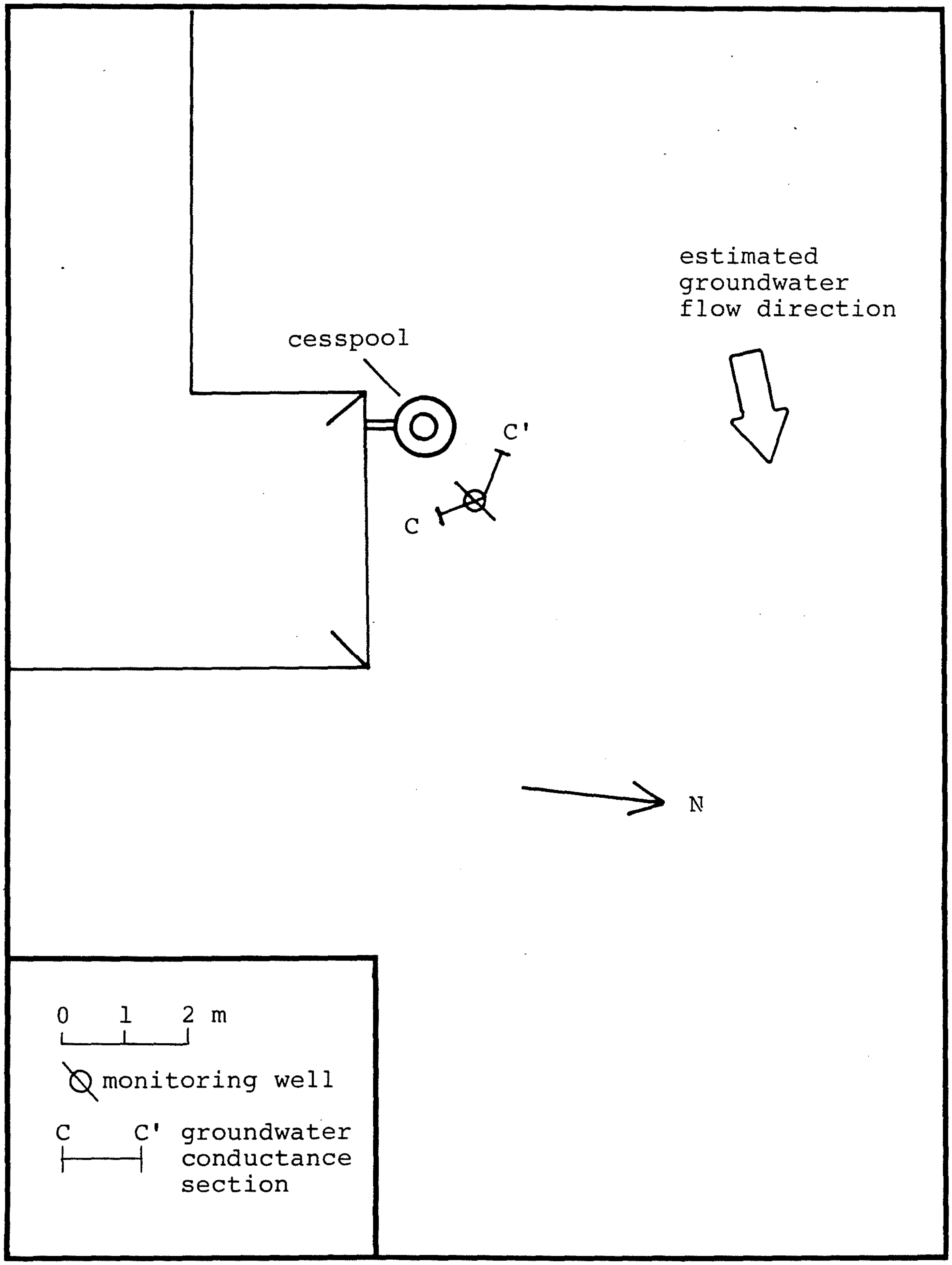


Figure 7. Plan view, Site 3

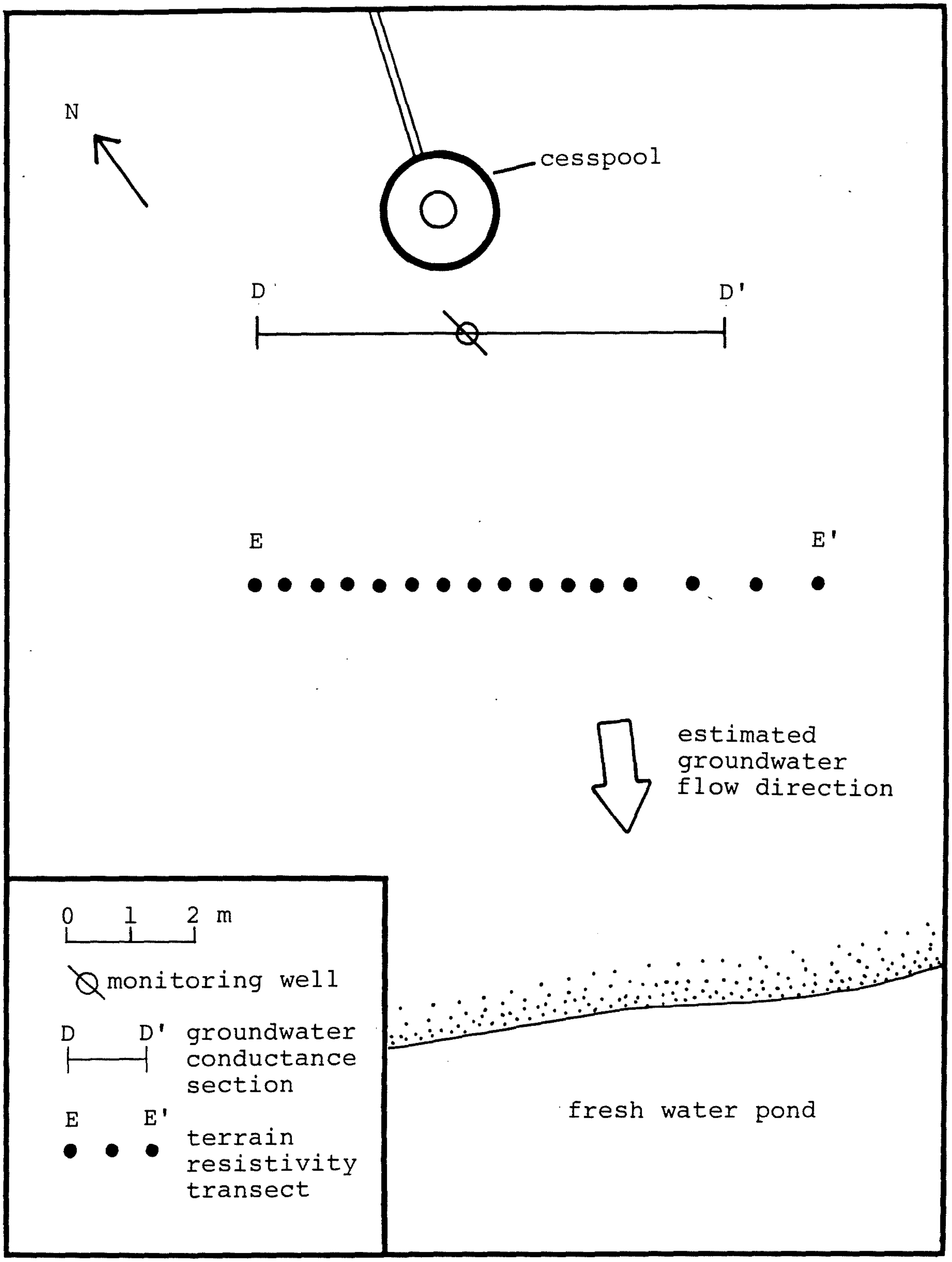


Figure 8. Plan view, Site 4

3.2 Plume Geometry:

Groundwater contamination plumes are three-dimensional bodies. Complete characterization requires a three dimensional sampling effort throughout the aquifer volume affected by the plume. Data concerning a parameter of interest, such as specific conductance, are usually displayed in plan view, in longitudinal cross section, and in one or more transverse cross sections (c.f. LeBlanc, 1984). Because of the number of sites involved, complete plume characterization was not attempted here. Instead, the plume associated with each site was mapped in transverse section on a single date, 1 meter downgradient of each cesspool or absorption system. At Sites 1, 3, and 4, the plume mapping exercise was conducted at the close of the monitoring period, in order to confirm the results of reconnaissance sampling conducted before the installation of the monitoring wells at each site. At Site 2, the plume was mapped before the installation of the well. The results of the mapping effort are presented below.

3.2.1 Sites 1, 3, and 4. The specific conductance distribution at these sites (all served by cesspools) shows a strong vertical gradient and little or no transverse gradient (Figs. 9, 11 and 12). Conductance is greatest at the water table, and declines rapidly with depth. At any given depth, conductance is fairly constant across the width of the section. This pattern suggests that groundwater flow is largely radial

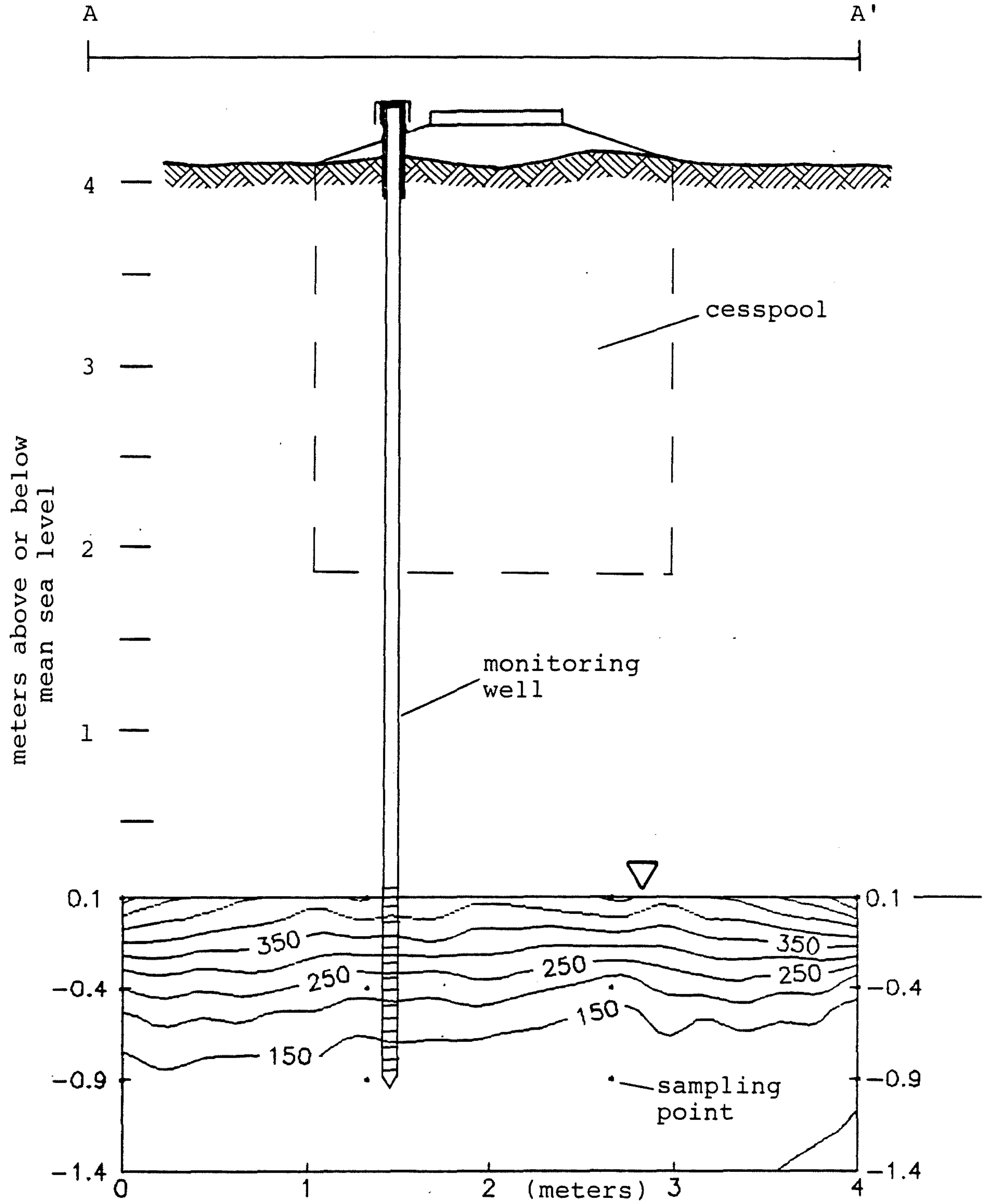


Figure 9. Groundwater specific conductance at Site 1, one meter downgradient of cesspool (microsiemens/cm), 21 October, 1988. (See Fig. 5 for location of section.)

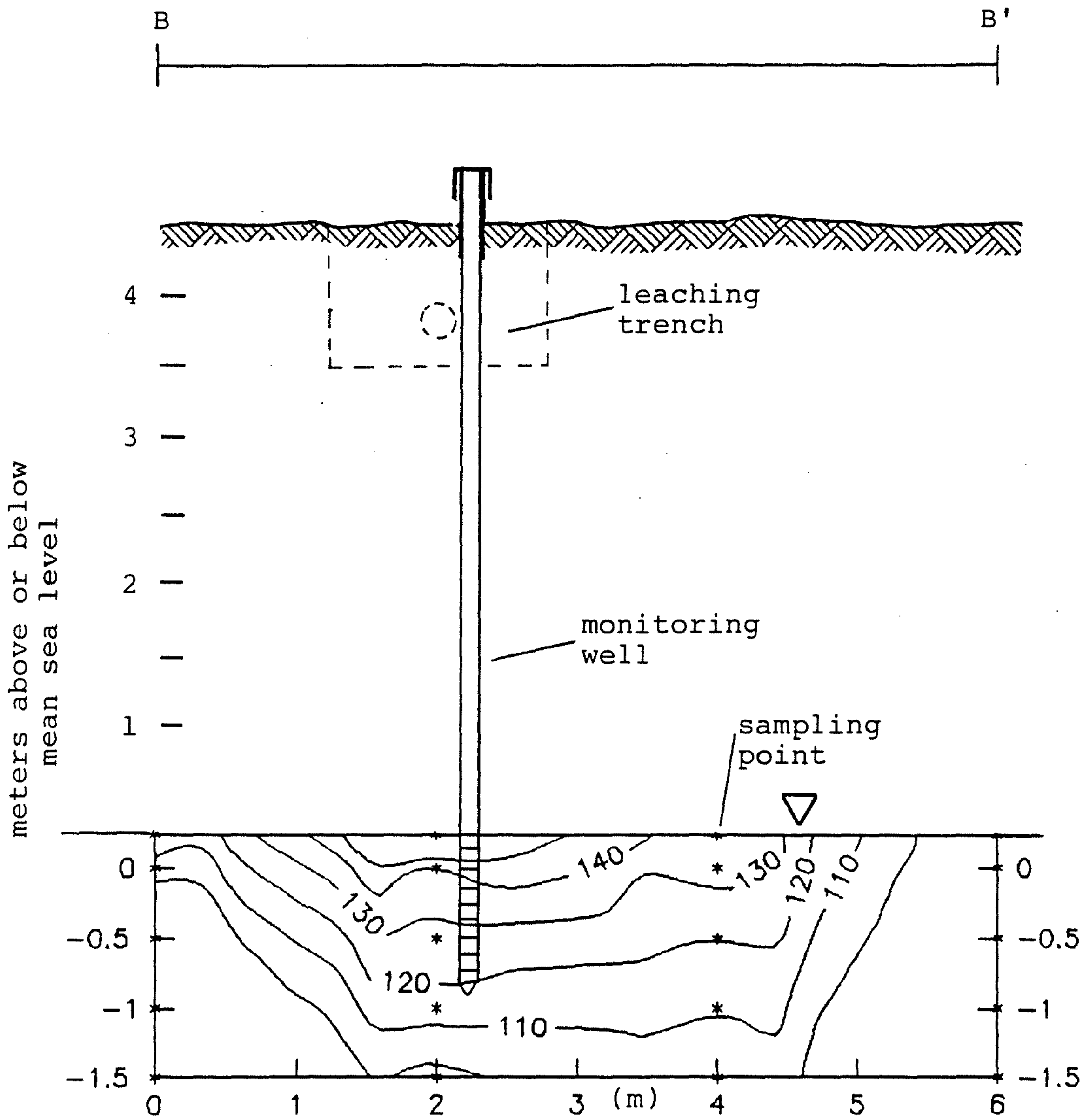


Figure 10. Groundwater specific conductance at Site 2, one meter downgradient of leaching trench (μS/cm), 17 October, 1987. (See Fig. 6 for location of section.)

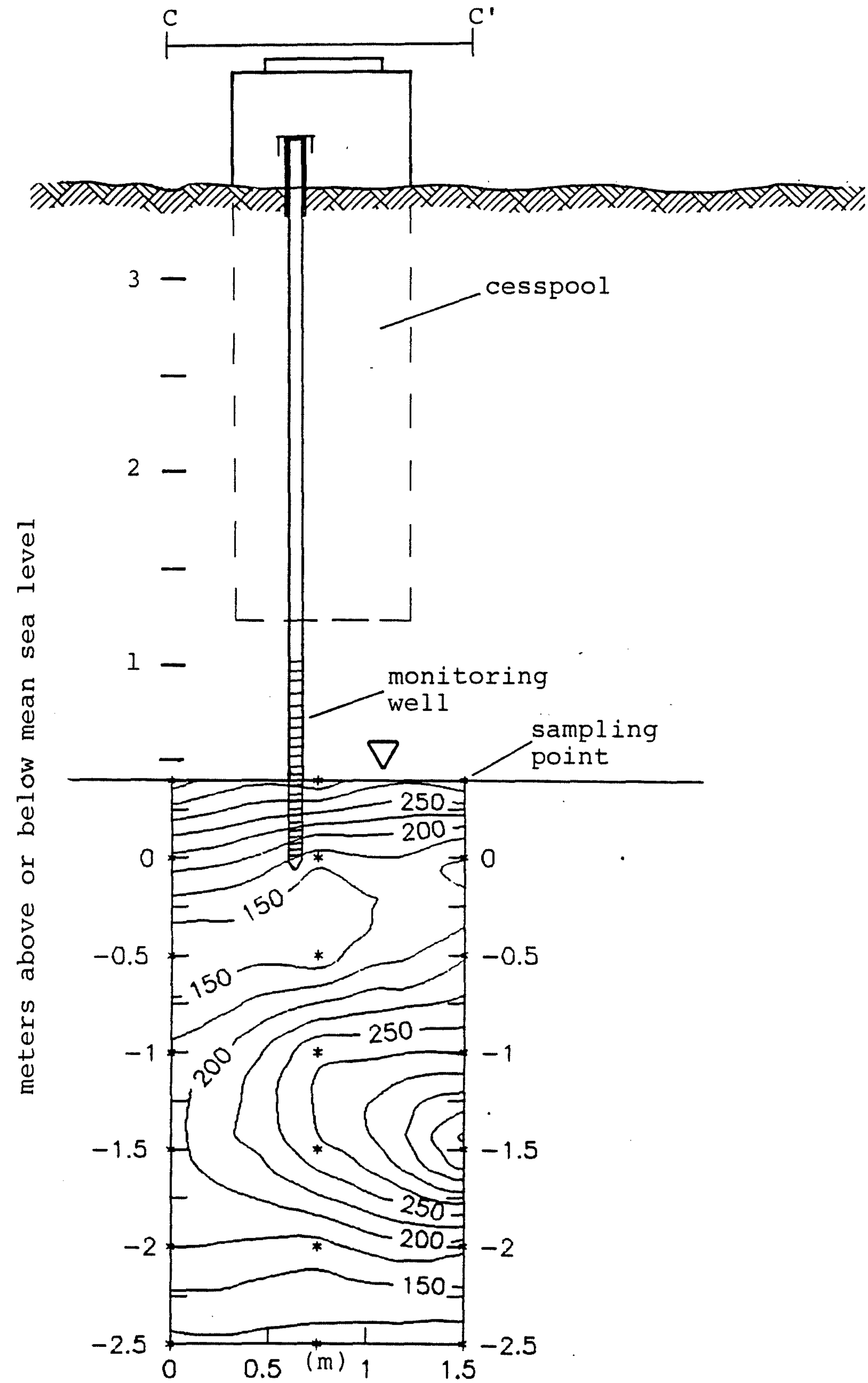


Figure 11. Groundwater Specific conductance at Site 3, one meter downgradient of cesspool (μS/cm). (See Fig. 7 for location of section.)

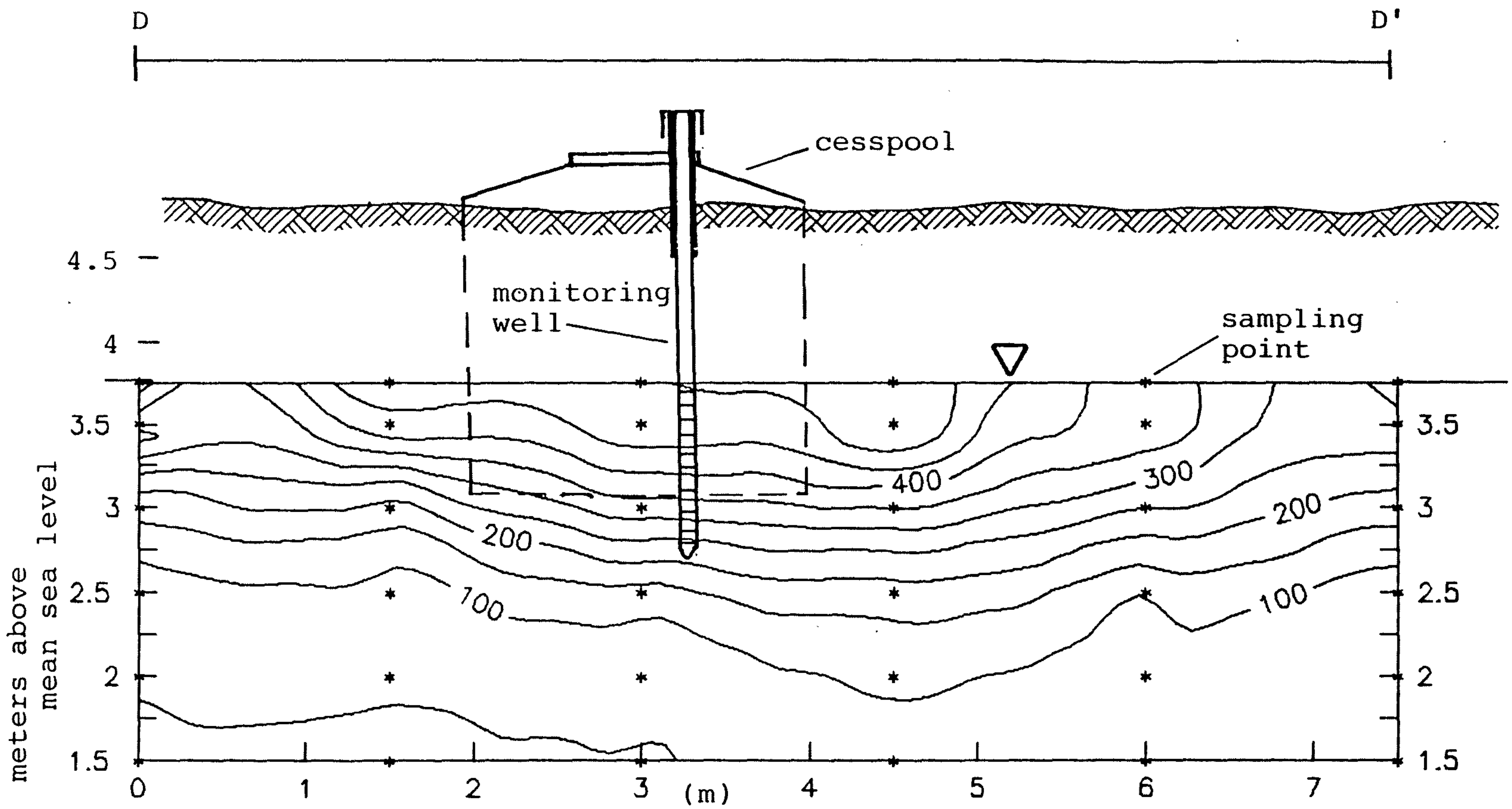


Figure 12. Groundwater specific conductance at Site 4, one meter downgradient of cesspool (µS/cm), 18 November, 1988. (See Fig. 8 for location of section.)

in the immediate vicinity of the cesspools. Such a flow pattern probably results from effluent-induced mounding of the water table below the cesspools, though mounding was not measured directly. Because of this flow pattern, the vertical positions of the monitoring well screens at these sites appear to be more critical than their transverse positions, for the purpose of sampling the most concentrated portion of the plumes.

Site 4 is the only cesspool site with even a slight transverse specific conductance gradient (Fig. 12). This is partly an artifact of the sampling design, since the Site 4 section is wider than the sections at Sites 1 and 3. Because of this slight gradient, the monitoring well at Site 4 (which was positioned on the basis of reconnaissance specific conductance sampling at the water table downgradient of the cesspool) misses the exact core of the plume. Therefore, contaminant concentrations in samples from this well may slightly underestimate the peak contaminant concentrations associated with this plume.

It should be noted that conditions at the Site 3 ground surface precluded the sampling of a wider array of points. Therefore, the Site 3 cross section (Fig. 11) is narrower than the remaining cross sections. The Site 3 section also shows a second conductance plume centered about 2 meters below the water table. This plume probably comes from a neighboring cesspoool located about 25 meters directly upgradient of the Site 3 section.

3.2.2 Site 2. At Site 2, both vertical and transverse gradients were observed in the conductance data (Fig. 10). This is probably due to the near absence of radial flow at the site, which is served not by a cesspool or leach pit, but by a leach trench oriented roughly parallel to the groundwater flow direction, and normal to the transverse section (Figure 6). The well screen at Site 2 was installed in the core of the plume as shown, after the conductance section was compiled.

3.2.3 VLF terrain resistivity mapping. VLF is commonly used to delineate large plumes of conductive groundwater, such as those associated with sanitary landfills (Greenhouse and Harris, 1983). For example, Grady and Haeni (1985) used an extensive 2 dimensional grid of stations spaced 35 meters apart to map a 270,000 m^2 area downgradient of the Farmington, CT landfill. In the present study, we deployed the instrument at a much finer scale. A (1 dimensional) transect of stations, spaced approximately 0.5 meters apart, was occupied in an effort to predict the position of plume cores downgradient of septic systems at two sites.

At Site 2, a trough in apparent terrain resistivity directly overlies the center of mass of the conductance plume, though apparently not the point of peak conductance (Fig. 13).

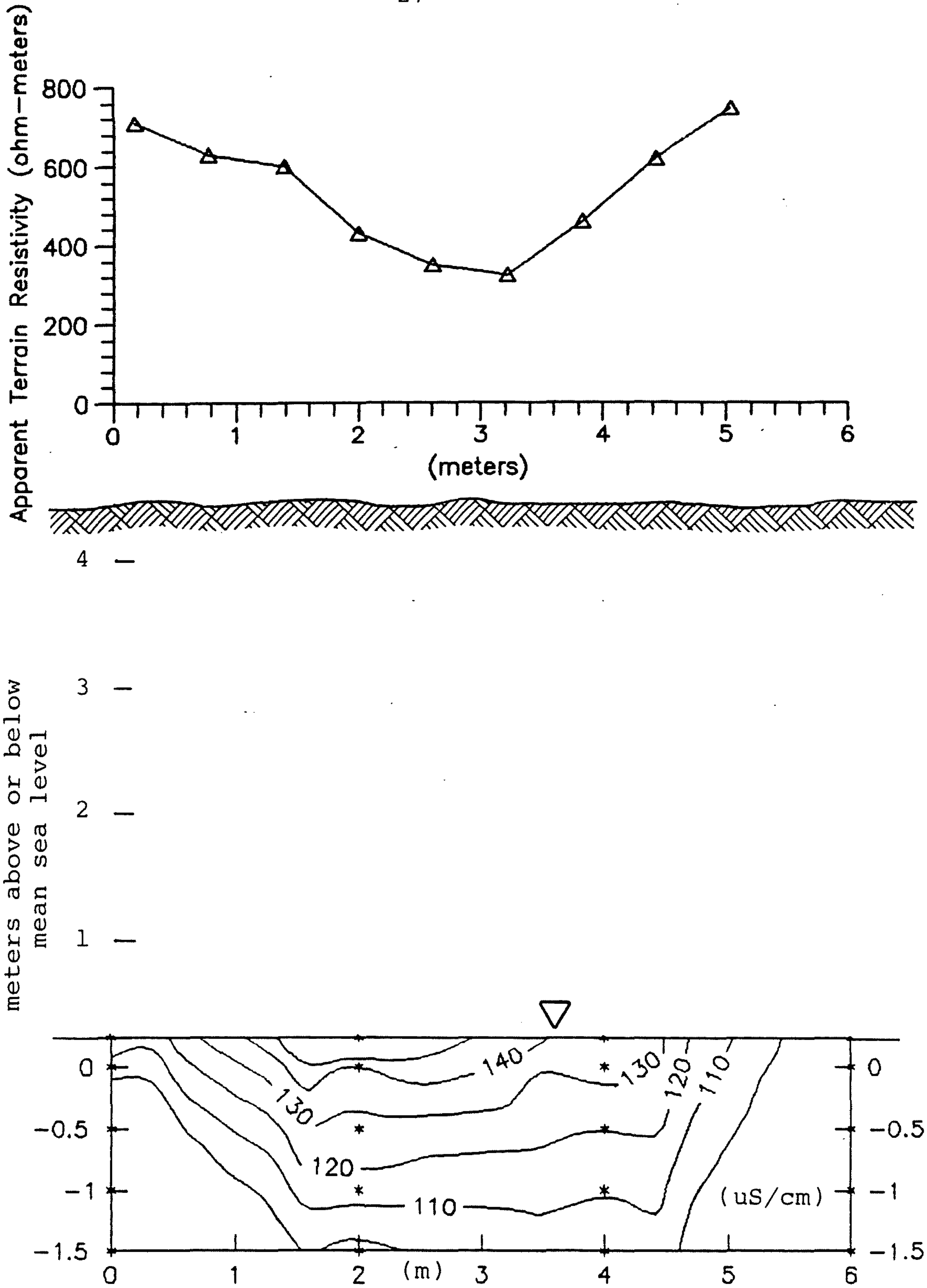


Figure 13. Apparent terrain resistivity overlying the groundwater conductance section at Site 2. Resistivity data collected 7 November, 1987. (See Fig. 6 for location.)

The relationship, at Site 2, between apparent terrain resistivity and the vertically-averaged groundwater conductance directly below each station is approximately linear (Fig. 14). A decrease in terrain resistivity of 200 ohm-meters corresponds to an increase of 15 uS/cm in groundwater specific conductance at this site.

At Site 4, space limitations forced us to locate the resistivity transect 4 meters downgradient of the conductance section (Fig. 8, Fig. B-2). (The instrument will give meaningless results if the probes are separated from each other by a large, buried object such as a cesspool.) As at Site 2, a resistivity anomaly was observed (Fig. 15). Yet because the transect was not perfectly orthogonal to the groundwater flow direction, the trough appears to be displaced about 1.5 meters to the southeast of the conductance plume core. Space limitations precluded use of the instrument entirely at Sites 1 and 3.

A second limitation of the instrument is its inability to distinguish changes in bulk terrain resistivity caused by conductive plumes of contaminated groundwater from those caused by sedimentary facies changes, changes in depth-to-groundwater, or proximity to saline groundwater. We encountered this limitation when using the instrument over the artificial beaches and filled marshes adjacent to Buttermilk Bay.

Nevertheless, in unrestricted areas where site conditions

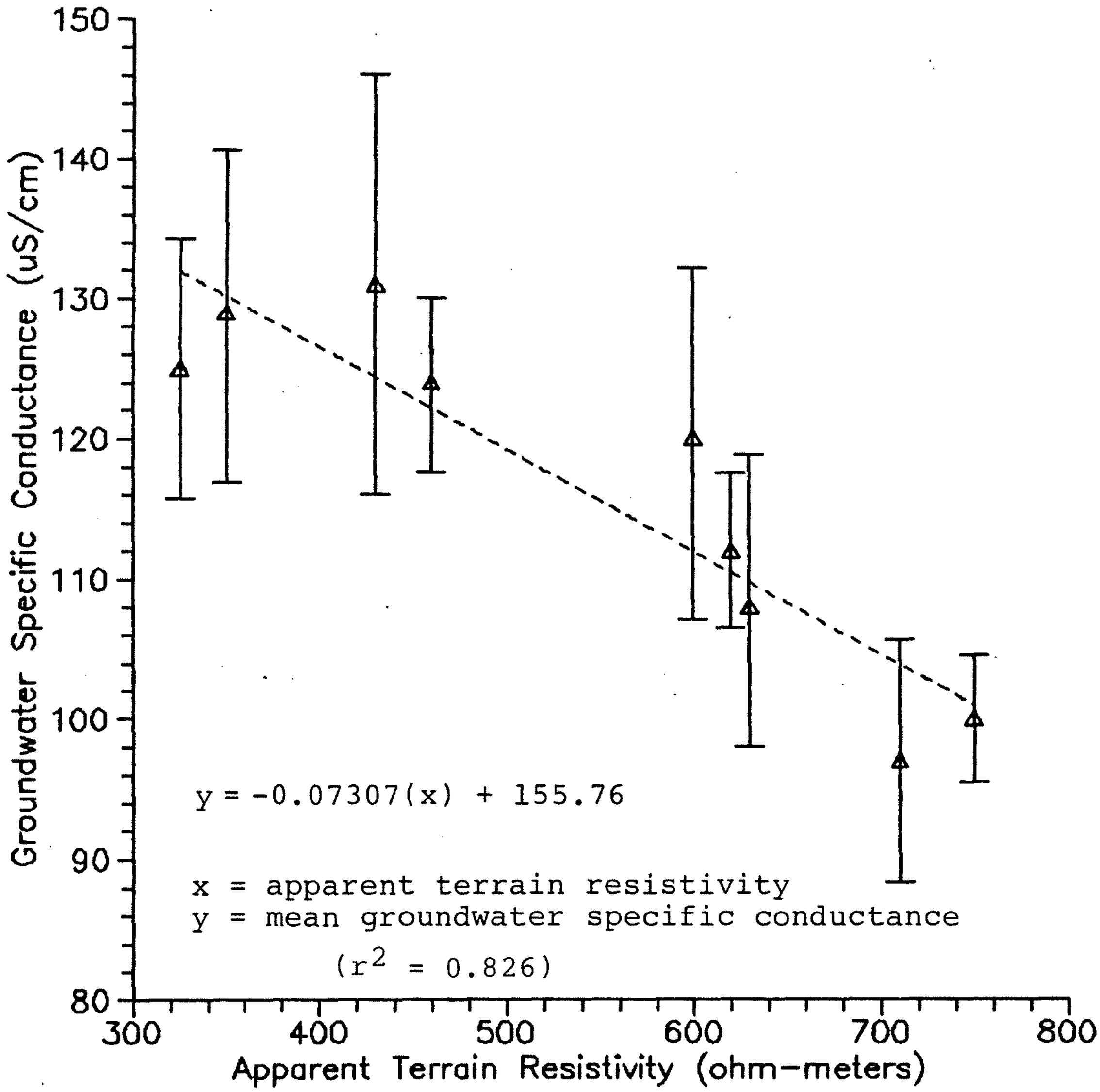


Figure 14. The relationship between apparent terrain resistivity and groundwater specific conductance in the saturated zone directly below each resistivity station, Site 2. (Mean +/- Standard Error of the Mean; all data taken from Figure 13.)

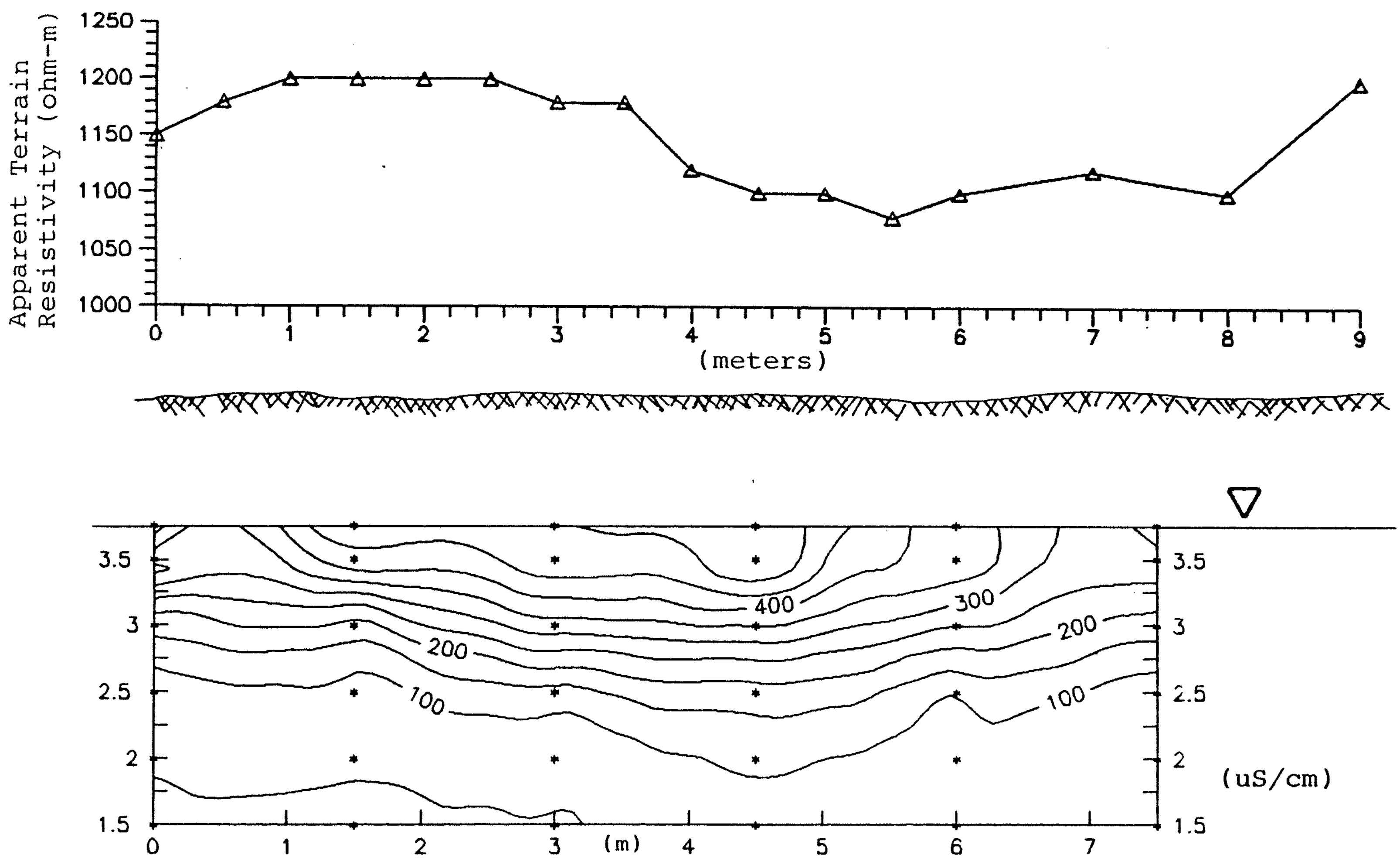


Figure 15. Apparent terrain resistivity parallel to groundwater conductance section, Site 4. Resistivity data collected 26 March, 1988. Resistivity transect is located 4 meters downgradient of conductance section (See Fig. 8 for locations).

allowed such "noise" to be filtered out of the data (i.e., where hydrogeological conditions are either relatively constant or changing in a simple manner), the instrument could be used to remotely sense small groundwater plumes with a high degree of resolution. At Site 4, for example, resistivity changes of 5% were observed between successive stations spaced only 50 centimeters apart. (The precision of the instrument is +/- 2%; see Appendix B.)

4. BACTERIA MONITORING: RESULTS

4.1 Fecal Coliform

Figure 16 displays the effluent and groundwater fecal coliform densities observed at the four sites over the monitoring period. Note that the groundwater samples were collected from the core of each plume, 1 meter downgradient of each system. Of the 23 groundwater samples, 5 contained detectable numbers of fecal coliform. All five of these samples were collected at Site 4; only one of the samples collected at this site had no detectable fecal coliform.

The overall geometric mean fecal coliform density in the effluent samples was 178,000 colonies/100 ml (Fig. 18). At the only site where groundwater fecal coliform was detected (Site 4), the overall mean density was 18 colonies/100 ml at the 1 meter well. (All fecal coliforms were found to be *E. Coli.*)

In order to obtain the means and standard errors displayed in Figures 18-22, samples with densities below the detection limits were arbitrarily assigned a density value equal to one half of the limit.

4.2 *Clostridium perfringens*

Of the 19 groundwater samples analyzed for *Clostridium*, 11 had densities equal to or above the detection limit (Fig. 17). Four of these samples were from

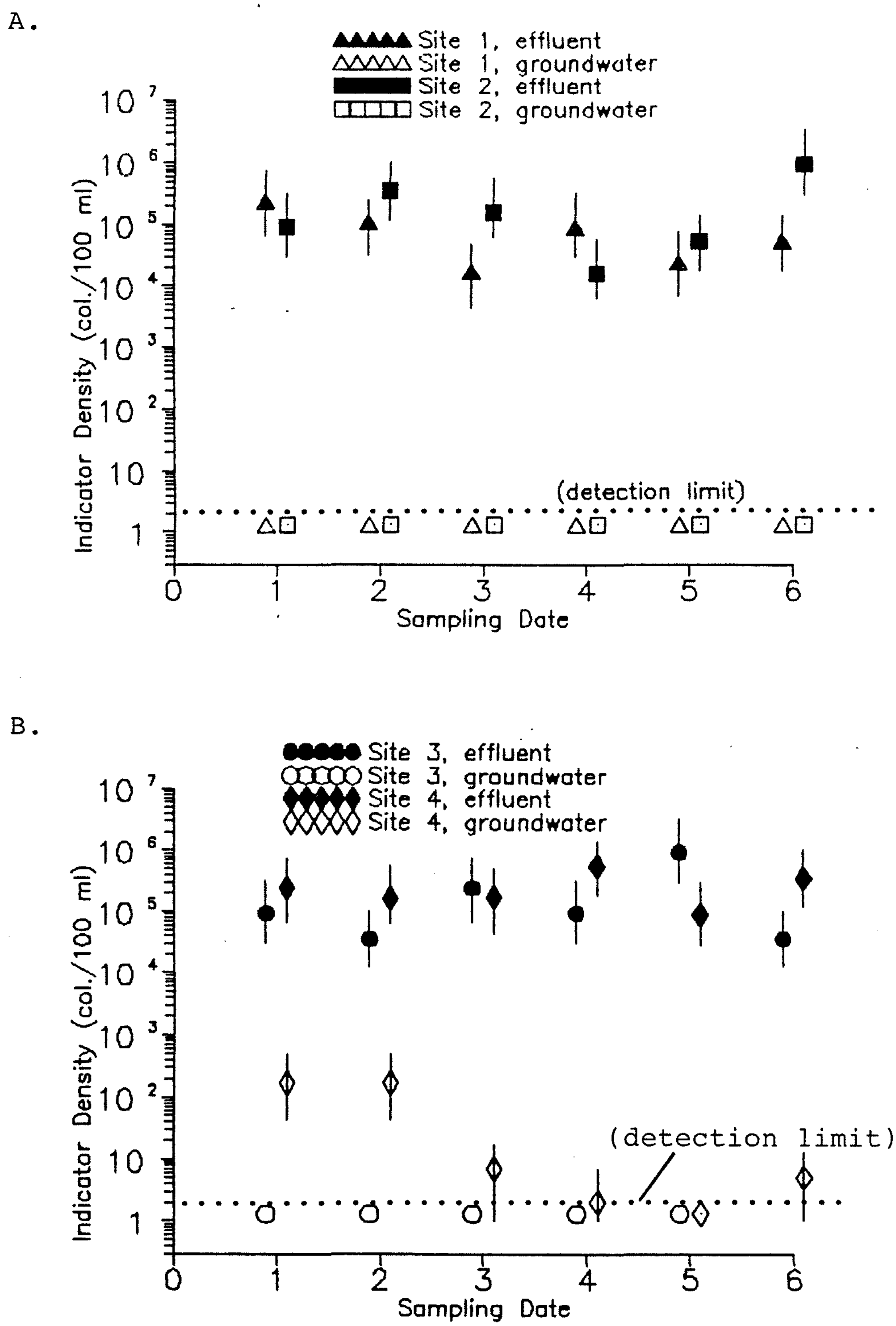


Figure 16. Effluent and groundwater fecal coliform densities on six sampling dates, Dec. 87-June 88. A: Sites 1 & 2. B: Sites 3 & 4. (All groundwater samples collected one meter downgradient of septic system. Error bar is 95% confidence interval. See Appendix C for data table.)

A.

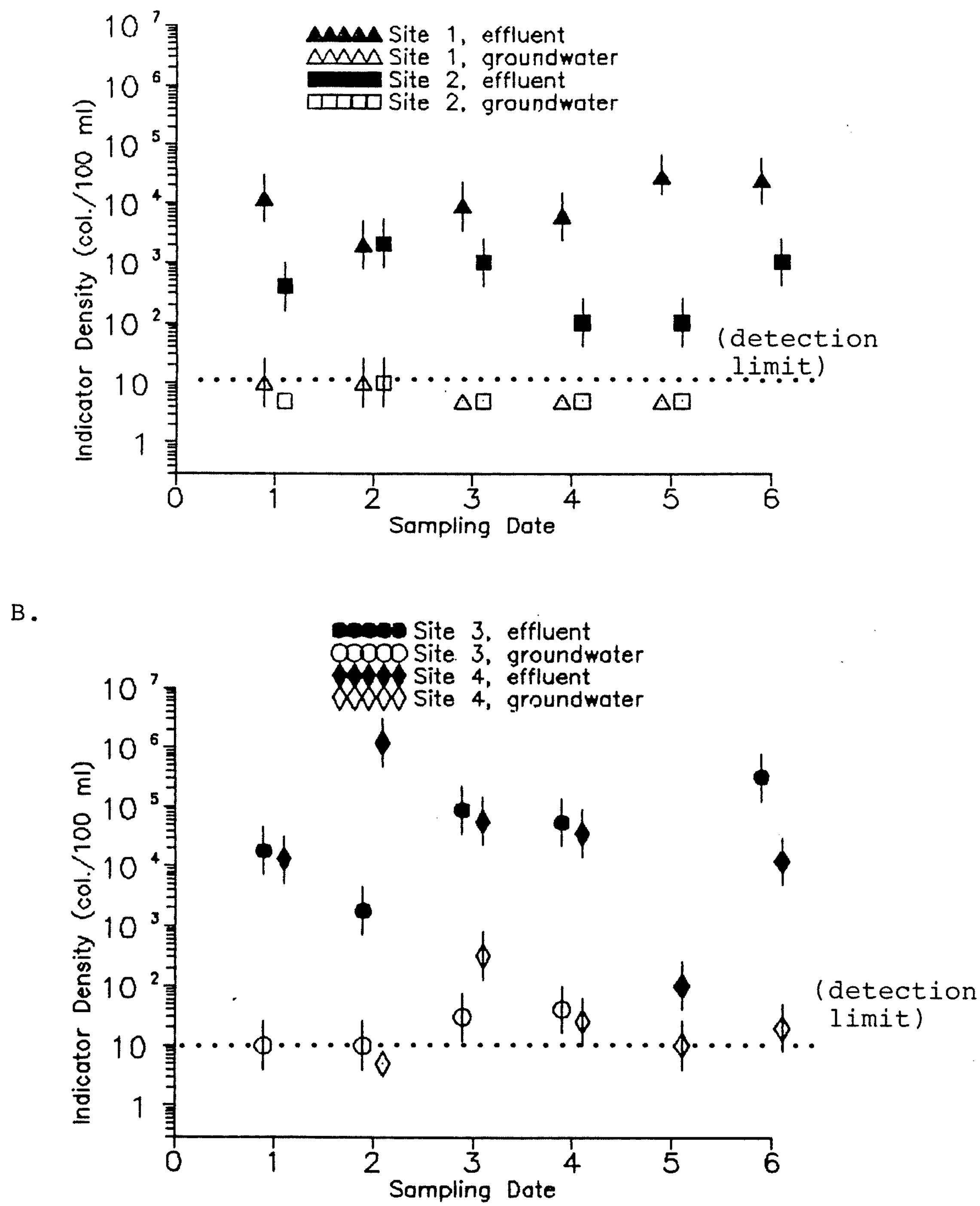


Figure 17. Effluent and groundwater Clostridium perfringens densities on six sampling dates, Dec. 87-June 88. A: Sites 1 & 2. B: Sites 3 & 4. (Groundwater samples collected one meter downgradient of system. Error bar is 95% confidence interval. Data not available for all dates, due to sample turbidity. See Appendix C for data table.)

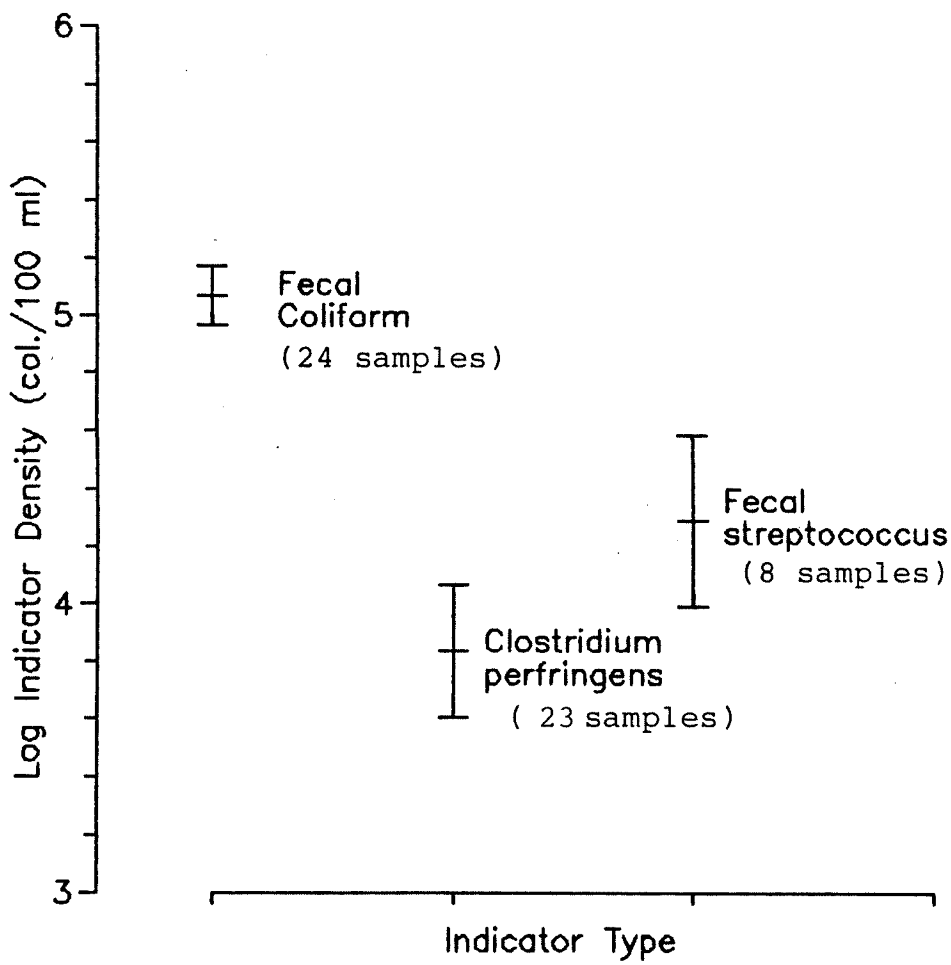


Figure 18. Mean indicator densities in the effluent samples. (Geometric mean +/- the Standard Error of the Mean.)

Site 4, four were from Site 3, two were from Site 1, and 1 was from Site 2. The overall effluent sample mean was 7,290 colonies/100 ml (Fig. 18). The means for the groundwater samples from Sites 3 and 4 were 19 and 63 colonies/100 ml, respectively. All positive samples at Sites 1 and 2 contained 10 colonies/100 ml (the detection limit).

4.3 Fecal Streptococcus

Samples were analyzed for this indicator from the February and March sampling runs only. No fecal streptococcus were detected in any of the eight groundwater samples collected. The overall effluent mean was 19,400 col./100 ml (Fig. 18).

5. BACTERIA MONITORING: DISCUSSION

5.1 Indicator Breakthrough to the Saturated Zone: Differences Between the Indicators

Comparisons between the indicators reveal significant differences in their initial densities and subsequent behavior in the subsurface. Overall, fecal coliforms were 16 times more abundant than *Clostridia* and 6 times more abundant than fecal streptococci in the effluent samples (Fig. 18). The observed mean fecal coliform/fecal strep and fecal coliform/*Clostridium* ratios in the effluent (5.9 and 16) are relatively close to those reported in the literature for human feces (4.3 and 8.2; Geldreich, 1977).

In the groundwater samples, by contrast, fecal coliforms occur less frequently and at lower densities than *Clostridia* under all site conditions (Fig. 19), though more frequently than fecal streptococci, which were not detected in any of the groundwater samples. The difference between the groundwater densities of fecal coliform and *Clostridium* at any given site is probably due to the superior survival characteristics of *Clostridium* spores in the subsurface (Bisson and Cabelli, 1980; Pipes, 1982). *Clostridium* is an anaerobic spore-former (Bisson and Cabelli, 1979). Its spores can persist for long periods under conditions inimical to the other two indicators, which do not form spores. The difference between the groundwater densities of fecal coliform and fecal

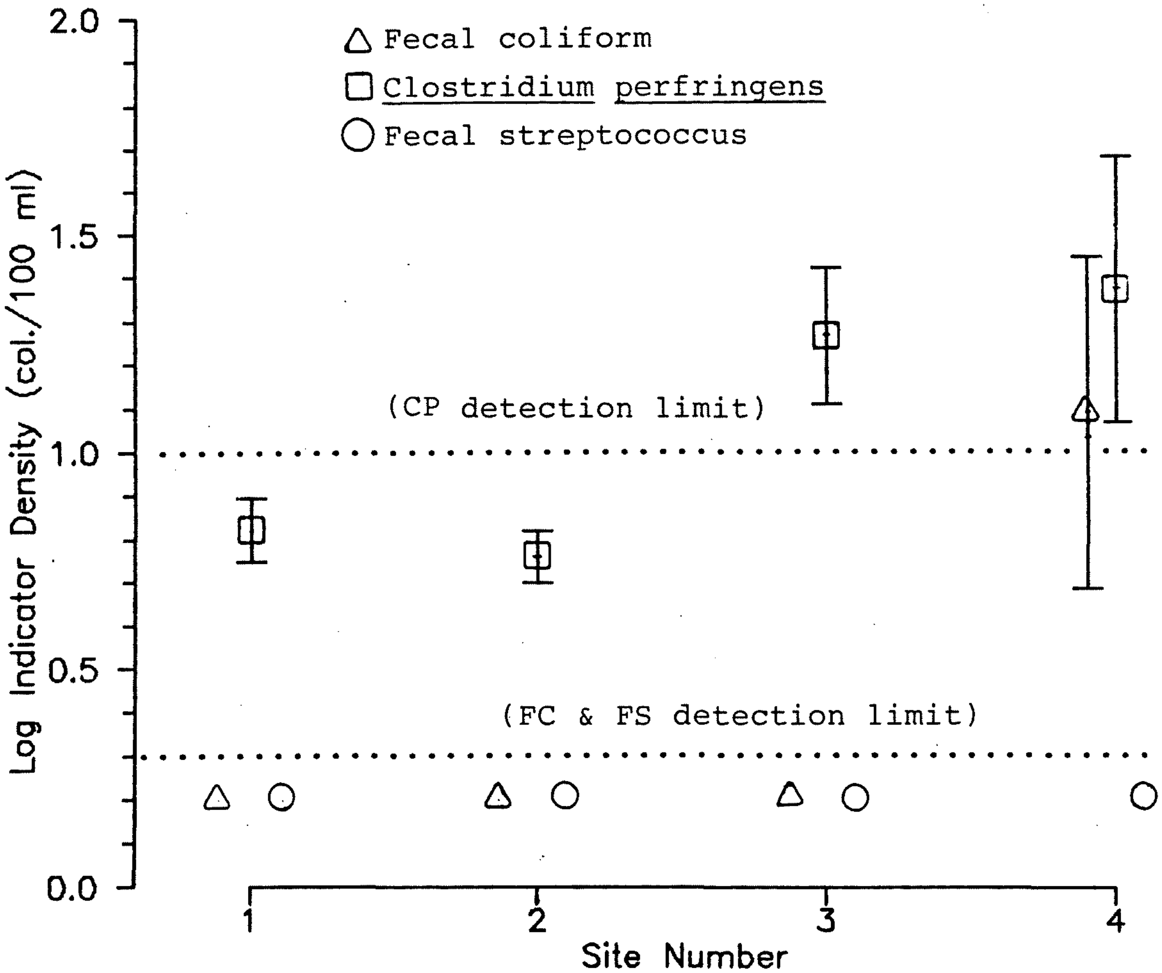


Figure 19. Mean indicator densities in groundwater samples, Sites 1-4. (Geometric mean +/- the Standard Error of the Mean.)

streptococcus is harder to explain. The absence of fecal streptococci in the groundwater samples may be due to their low effluent density, relative to fecal coliform, rather than to differences in survival and transport characteristics.

5.2 Breakthrough to the Saturated Zone: Site Factors

While the observed groundwater indicator densities depended in part upon the indicator, site and system factors were also observed to play a role. The most important site factor is probably infiltration distance (Table 1; Figures 9-12). The geometric mean log densities of both indicators vary directly with this parameter (Fig. 20).

There are probably several reasons for this behavior. High indicator densities are to be expected at Site 4, since they are released from the system under saturated flow conditions, which are generally more favorable to bacterial survival and transport than unsaturated conditions (Hagedorn et al., 1978; Hagedorn, 1984). Moreover, the formation of a microbial "mat" or filter beneath the system at Site 4 may be inhibited by the saturated conditions (Brown et al., 1979). At the remaining sites, increased infiltration distances would cause correspondingly longer residence times in the unsaturated zone--promoting indicator die-off--and increased contact between microbes and sediment particles--promoting both physical straining or filtration, and adsorption of indicators.

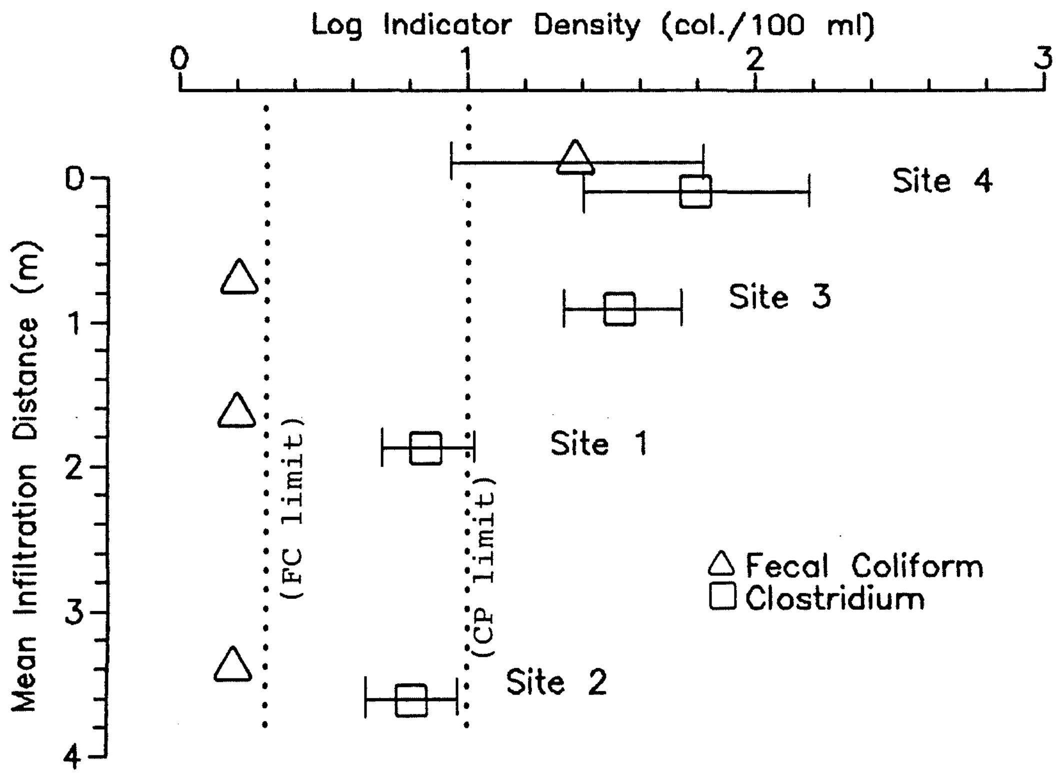


Figure 20. Corrected groundwater indicator densities versus mean infiltration distance, Sites 1-4. (Geometric mean densities +/- Standard Errors of the Means.)

Differences in effluent loading rate may also exert control on bacterial densities at the three sites where an unsaturated zone actually exists beneath the system (Sites 1, 2, and 3; Fig. 21). While groundwater fecal coliform was never detected at these sites, *Clostridia* were detected once at Site 2, twice at Site 1, and 4 times at Site 3. The relatively high mean loading rate at Site 3 (19 cm/day or 4.66 gallons/ft^2/day), combined with the small infiltration distance (0.81 m), may lead to near-saturated conditions beneath the cesspool, promoting enhanced bacterial survival and transport.

It should be noted that the groundwater indicator densities in Figs. 20, 21, and 22 have been corrected for plume dispersion. The densities shown represent strictly the effects of die-off, filtration, and adsorption to sediment particles, not the effect of dispersive mixing and dilution with ambient groundwater. The observed indicator density of each groundwater sample was divided by the mean ratio of groundwater to effluent specific conductance to obtain a corrected density. At Site 4, for example, where the mean $SC_{gw}:SC_{eff}$ value equals approximately 0.5, the corrected densities are about 2 times the observed densities.

5.3 Horizontal Transport of Indicators: Site 4

On the February sampling date, a second monitoring well was driven at Site 4, to monitor bacterial densities 2 meters downgradient of the cesspool. A total of four samples were collected from this well over a four month period. Two contained fecal coliform densities below the detection limit, and the other two were at the limit (2 colonies/100 ml). Three samples contained no detectable *Clostridia*, and one was at the detection limit (10 col./100 ml). Fecal streptococci were not detected in either of the two samples analyzed for this indicator.

Site 4 was chosen for this experiment because it represents the "worst case" site, at least with respect to infiltration distance. Little or no transport of indicators from this system would imply that septic systems are a minor source of indicators to Buttermilk Bay. The data, while limited, suggest that the log indicator density in the groundwater declines in a regular, and rapid, fashion with distance from the source (Fig. 22). Extensive horizontal transport of indicator bacteria does not appear to occur at Site 4. Therefore, septic effluent is probably a minor contributor of indicators to Buttermilk Bay, assuming that groundwater discharge is the sole route for effluent to reach the bay in this high permeability geologic setting. This deduction is consistent with a recent review of the literature (U.S. EPA, 1987), and the findings of a previous study in the Buttermilk basin (Figures A-4 and A-5). As discussed in

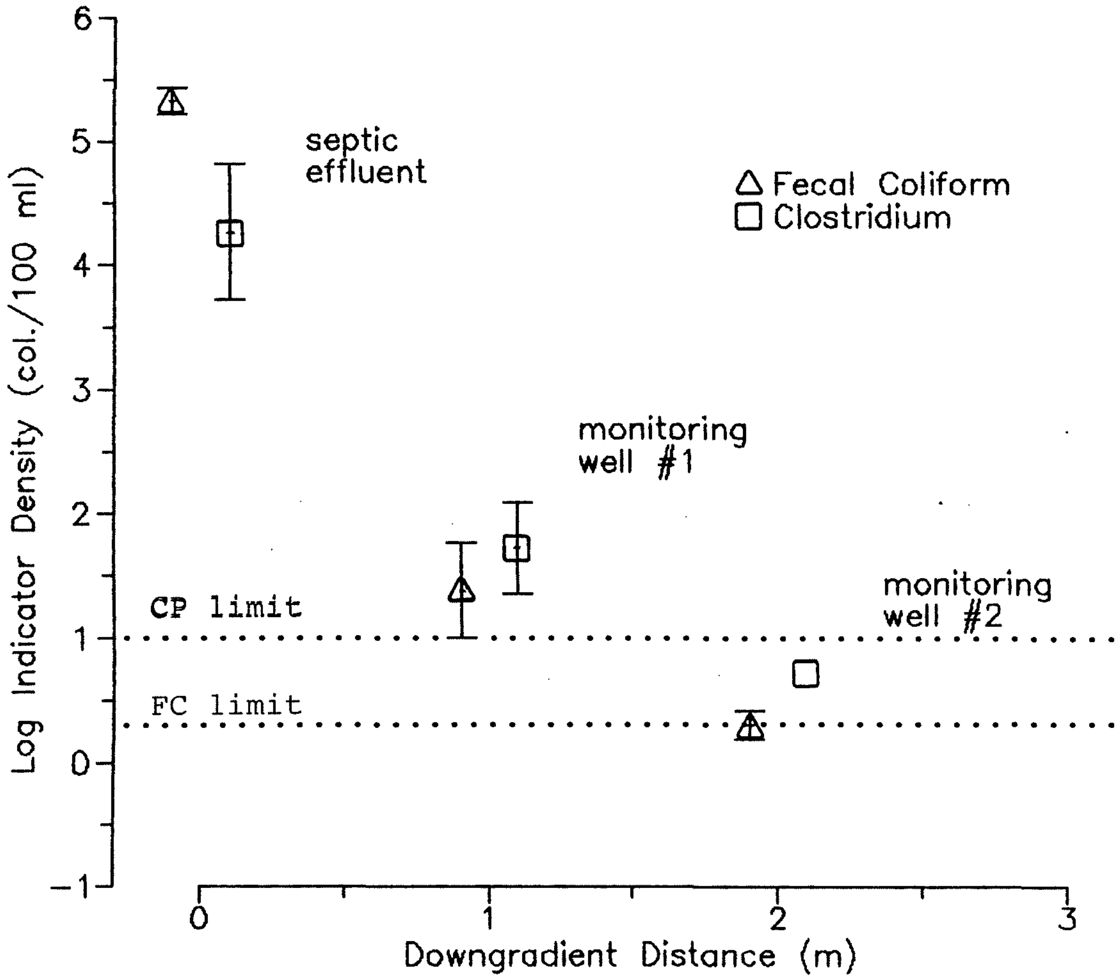


Figure 22. Corrected groundwater indicator densities at Site 4 versus downgradient sampling distance. (Geometric mean +/- Standard Error of the Mean.)

Appendix A, microbial transport is a highly variable process in the subsurface, and depends upon a variety of factors. The public health significance of these findings, and their implications for the Massachusetts Title V code will be discussed below.

5.4 Environmental and Public Health Significance

The results of this study suggest that bacterial indicators from septic systems only reach the saturated zone underlying the Buttermilk basin under "worst case" site and system conditions. Such conditions include a shallow depth to water table and a high effluent loading rate (conditions which are uncommon in most portions of the basin occupied year-round). More resistant indicators, such as *Clostridium perfringens*, break through to the saturated zone in larger numbers. The small numbers of indicators which do reach the saturated zone are apparently not transported horizontally more than a few meters from their septic source, even when directly "injected" into the saturated zone (as at Site 4). One can only conclude that septic effluent is a minor contributor to the fecal coliform load which has historically curtailed shellfishing in Buttermilk Bay.

One must *not* conclude, however, that septic systems pose no public health or environmental risk to the the bay. Such a conclusion would ignore what is now known about the limitations of bacterial indicators such as fecal coliform, especially when used to predict the microbial quality of groundwater. Data from the present study (Figs. 17 and 18) show differences in behavior between fecal coliform and two other commonly used indicators. More importantly, recent reasearch has shown major differences between the survival and transport characteristics of fecal coliform and pathogenic viruses in the subsurface (Burge and Marsh, 1978; Schaub and Sorber, 1977; Marzouk et al., 1980; Vaughn et al., 1978; Vaughn et al., 1983).

In a study with particular relevance to the Buttermilk basin, Vaughn et al. (1983) detected viruses in 18.2% of the samples collected from a well 30.5 m (100 ft) downgradient of a septic system in glacio-fluvial sediments on Long Island, New York. At a downgradient distance of 60.35 m (198 ft), 9.1% of the samples were positive. Fecal coliforms, by contrast, were only "rarely" dectected more than 1.52 meters from the absorption system. Since no plume mapping efforts were undertaken to insure that samples were collected from the plume core, these percentages probably underestimate the peak viral frequencies at these distances (30.5 and 60.35 m).

Poor correlation between fecal coliform and virus behavior is of public health concern for three reasons. First, most viruses are two orders of magnitude smaller than fecal coliforms, and therefore can only be removed by adsorption, not filtration (Canter and Knox, 1985). Second, viruses remain infective for much longer periods than bacterial indicators or pathogens, in part because they require no nutrients and must be physically inactivated by conditions such as dessication or high temperature (Gerba and Goyal, 1985). Finally, because of their mode of replication within human host cells, they can cause disease at much lower doses than bacterial pathogens (Westwood and Sattar, 1976).

In the light of these facts, the results of the present study should be interpreted cautiously. The presence of bacterial indicators immediately downgradient of septic systems under a variety of site conditions demonstrates the capacity of such systems to contaminate groundwater. The converse, however, is not necessarily true: an absence of fecal coliforms, especially in a groundwater sample, does not mean the sample is free of pathogens. Until viral studies are completed, the microbial impact of septic systems on the ground and surface water quality of the Buttermilk Basin cannot be fully assessed.

5.5 Implications for Title V

Title V is the section of the state Environmental Code which regulates the design and siting of septic systems in the Commonwealth of Massachusetts (Comm. of Mass., 1978). Three of the more critical site and system factors regulated by the code are 1) infiltration distance (a minimum of 1.2 m or 4 ft is required), 2) loading rate (Table A-4), and setback from watercourses (a minimum of 15.2 m or 50 ft is required). While the present study was not designed to test the code in a rigorous fashion, some of the results do have implications for Title V.

At first glance, the results of this study seem to confirm that Title V is providing adequate protection to ground and surface water quality. Indicator bacteria only rarely break through to the saturated zone at the two "best case sites" where infiltration distances exceed 1.2 m (4 ft), and loading rates are low. At the sites where the infiltration distances are less than 1.2 m and/or the loading rates are relatively high (greater than the Title V maximum of 14.3 cm/day (3.5 gal/ft^2/day) for sand and gravel soils), breakthrough occurs. Judging from the results at the worst case site, indicator densities drop below the detection limit (during horizontal transport) well before the watercourse setback minimum of 15.2 m (50 ft) is approached.

Yet for the reasons alluded to in Section 5.4 above, we cannot assume that protection from bacterial indicators implies protection from pathogens, espcecially viruses. Any future revision of Title V should be based on thorough field studies of viral transport under a variety of site and system conditions.

6. CONCLUSIONS AND RECOMMENDATIONS:

1. Septic systems generate discrete contamination plumes which can be detected, under proper conditions, by the VLF surface geophysical method. The plumes can also be mapped by conducting a groundwater sampling effort analagous to that used to delineate large groundwater contamination plumes (c.f. LeBlanc, 1984).

2. The groundwater immediately beneath and downgradient of septic systems in the nearshore areas of the Buttermilk Bay drainage basin is contaminated with fecal microorganisms (at least in areas where the depth to water table is less than 4 meters or 13 feet). The more resistant fecal indicator, *Clostridium perfringens*, was detected at least once at all sites. The degree of contamination was site-specific. Factors such as depth to water table and effluent loading rate play a critical role in controlling the extent of contamination.

3. Septic systems are probably not a signficant source of bacterial indicators to the bay itself. While the data are limited, densities observed 2 meters downgradient of the "worst case" site are well below the shellfish closure criterion of 14 colonies/100 ml. This finding does not preclude the possibility that septic-derived viruses are reaching the bay in large numbers.

4. Given the limitations of fecal coliform when relied upon

to predict the microbial quality of groundwater, it is critical that the existing Title V Code be maintained and strengthened. The adequacy of key provisions (regarding the minimum infiltration distance below absorption systems, minimum setback from watercourses, and loading rates for various soil/sediment types) should be tested by undertaking well-controlled viral transport studies.

APPENDIX A:

SEPTIC SYSTEMS AND THE ENVIRONMENT: AN OVERVIEW

SEPTIC SYSTEMS AND THE ENVIRONMENT: AN OVERVIEW

1. Septic Systems

1.1 Origin; present and future importance.

Septic systems have been used to dispose of domestic wastewater in the United States since the late nineteenth century (Cotteral and Norris, 1969). They derive from the marriage of two technologies: the traditional privy vault and the "water carriage" method of sewage disposal which was widely adopted in American cities during this period (Tarr and McMichael, 1973).

At present, septic systems serve one third of all U.S. households. These 22 million systems discharge approximately 3.8 trillion liters (1 trillion gallons) of effluent to the subsurface environment each year (U.S. EPA, 1986), an amount approximately equal to the long term average discharge of the Merrimack River at Concord, NH (4800 ft^3/sec). As of 1980, one quarter of all new homes constructed in this country employed some type of septic system (U.S. EPA, 1980). In recent years, "exurban" areas on the fringes of large metropolitan regions have become the fastest growing population centers in the nation (Hannifin, 1988). For example, Mashpee and Carver, two exurban towns in Massachusetts, are the two fastest growing towns in the state. Population increased 60.5% and 49.8%, respectively, in these two towns between 1980 and 1986 (Ackerman, 1988). Much of the new exurban population depends upon individual or communal septic systems for domestic wastewater disposal. In view of these trends, it is likely that septic systems will remain an important mode of wastewater disposal in the U.S. for the forseeable future (Viraraghavan, 1986).

1.2 Septic system types.

In common usage, the term "septic system" denotes a continuum of on-site sewage disposal methods. The end members of this continuum are the cesspool, and at the opposite extreme, various innovative systems whose designers have attempted to limit environmental impact. Pressure dosing and denitrification systems are examples of these innovative technologies (Otis et al. 1974; Laak, 1982; Gold and Theim, 1987). Between these end members lie the conventional sealed tank/absorption system combinations which comprise the bulk of new systems installed today. They consist of a sealed tank which receives raw sewage influent from one or more households (Fig. A-1), and some kind of "absorption system":

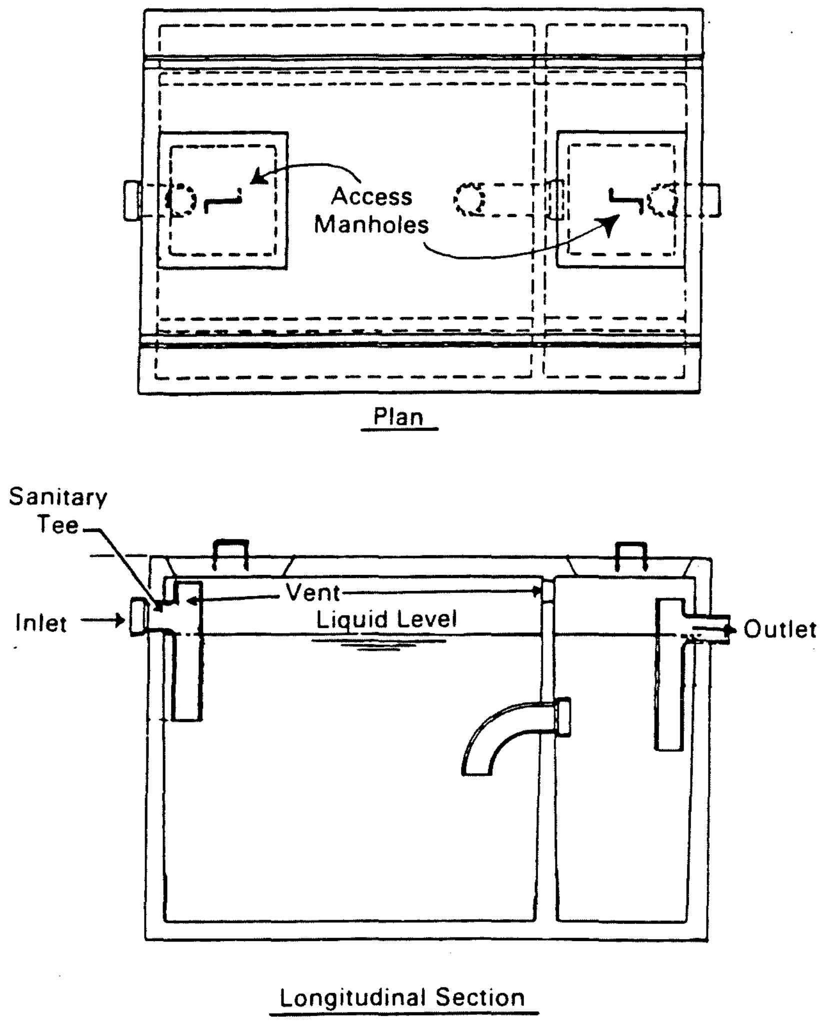


Figure A-1. Plan and section views of a typical two compartment septic tank (from the U.S. EPA, 1980).

a leaching pit, trench, or field to which liquid effluent from the tank is discharged (Figs. A-2a, b, c).

1.3 Effluent quality.

The sealed tank provides "primary treatment" to the sewage influent: liquid and solid fractions are separated by gravity, and the biochemical oxygen demand (BOD), total suspended solids (TSS), and dissolved organic carbon (DOC) of the the liquid fraction are lowered to some degree by bacterial action (Viraraghavan, 1976). However, primary treatment does not reduce the density of pathogenic organisms or the concentration of dissolved nitrogen and phosphorus in the liquid fraction (Viraraghavan, 1976). Table A-1 displays some of the more important chemical constituents of typical septic effluent, which can be defined as the liquid fraction of sewage which has undergone primary treatment, at its point of release to to an absorption system. Tables A-2 & 3 list the major pathogens found in human sewage, all of which are potentially present in septic effluent as well. The actual types and numbers of pathogens present depend upon the health status of the persons served by the septic system (U.S. EPA, 1987).

1.4 Absorption system performance and "failure".

The performance of an individual absorption system (including that portion of the unsaturated zone underlying the system) can be defined as its ability to remove chemical and microbial contaminants from septic effluent before that effluent infiltrates to the saturated zone, or some other point of potential human contact, use, or interest. Performance depends upon a host of factors, which can be grouped into three main categories: 1) site characteristics (geology and hydrology), 2) effluent quality (chemical and microbial), and 3) system design and operating practice (Figure A-3). In common usage, the term "failure" is applied when one of the following situations occurs (Canter and Knox, 1985; Otis and others, 1974): 1) effluent breaks out at the ground surface, or 2) effluent infiltrates to the saturated zone before an acceptable portion of the contaminant load has been removed.

The first type of failure poses an obvious public health hazard. Therefore, most sanitary codes regulating the design and siting of septic systems (such as Title V of the Massachusetts Environmental Code, Comm. of Mass., 1978) have been enacted in order to prevent it from occuring. Surface breakout is generally caused by unfavorable site geology (fine grained surficial deposits, impervious strata, shallow

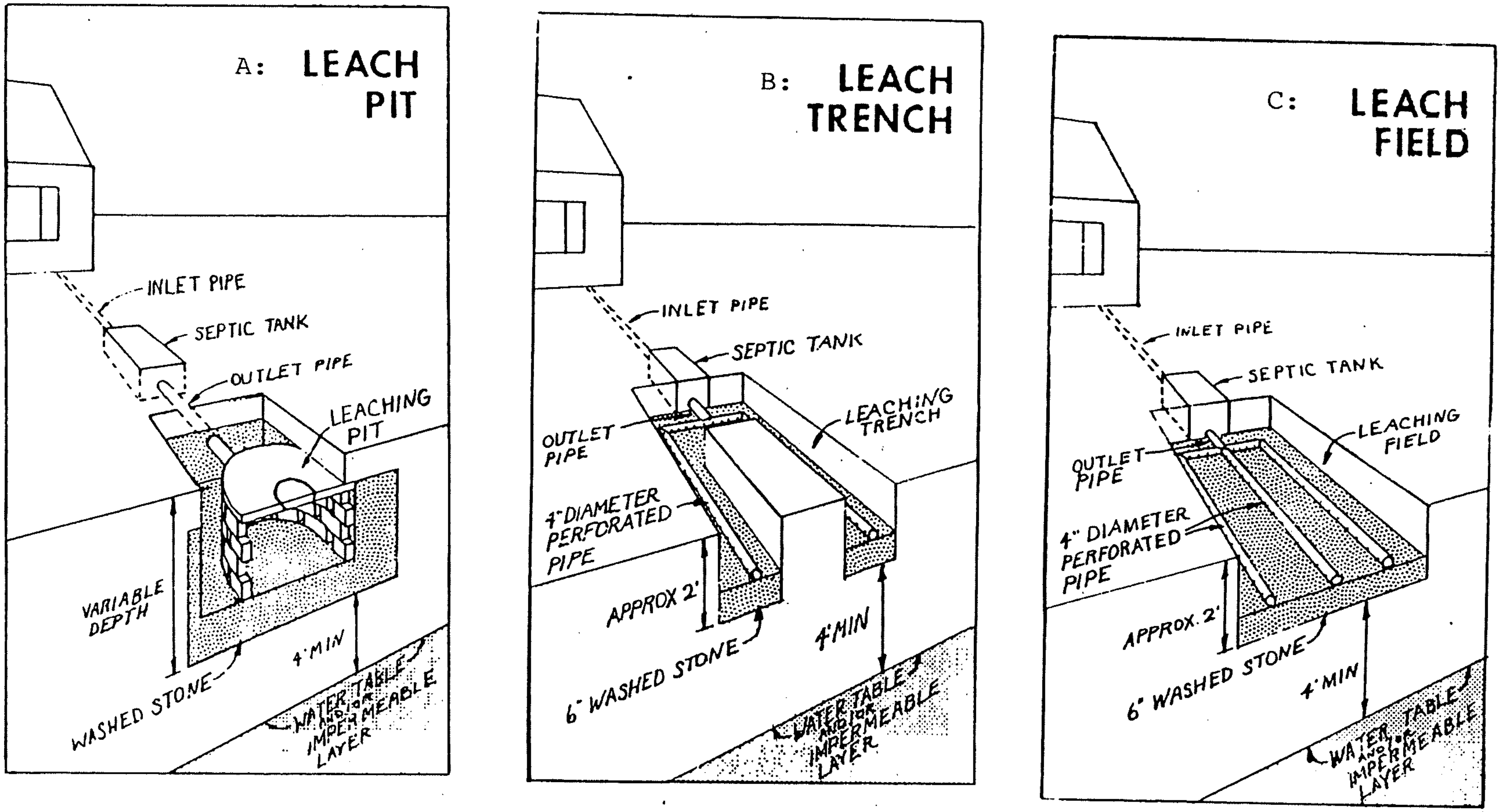


Figure A-2. Common absorption system types. A: Leach pit. B: Leach trench. C: Leach field (from the Merrimack Valley Planning Commission, 1979).

Parameter and Statistics	Results
Suspended Solids, mg/L	
Mean (# of samples)	49 (148)
95% Conf. Interval	44-54
Biochemical Oxygen Demand (Unfiltered, 5 day), mg/L	
Mean (# of samples)	138 (150)
95% Conf. Interval	129-147
Total Phosphorus, mg-P/L	
Mean (# of samples)	13 (99)
95% Conf. Interval	12-14
Orthophosphorus, mg-P/L	
Mean (# of samples)	11 (89)
95% Conf. Interval	10-12
Total Nitrogen, mg-N/L	
Mean (# of samples)	45 (99)
95% Conf. Interval	41-49
Ammonia Nitrogen, mg-N/L	
Mean (# of samples)	31 (108)
95% Conf. Interval	28-34
Nitrate Nitrogen, mg-N/L	
Mean (# of samples)	0.4 (114)
95# Conf. Interval	0.1-0.9

Table A1. Mean concentrations of selected chemical constituents in septic sytem effluent. (Data collected from seven sites between May 1972 and December 1976, cited in Canter and Knox, 1985, p.53.)

Group	Pathogen	Disease Caused
Bacteria	*Salmonella* (1700 types)	Typhoid, paratyphoid, salmonellosis
	Shigella (4 spp)	Bacillary dysentery
	Enteropathogenic *E. coli*	Gastroenteritis
	Yersinia enterocolitica	Gastroenteritis
	Campylobacter jejuni	Gastroenteritis
	Vibrio cholerae	Cholera
	Leptospira	Weil's disease
Protozoa	*Entamoeba histolytica*	Amoebic dysentery, liver abscess, colonic ulceration
	Giardia lamblia	Diarrhea, malabsorption
	Balantidium coli	Mild diarrhea, colonic ulceration
Helminths	*Ascaris lumbricoides* (roundworm)	Ascariasis
	Ancyclostoma duodenale (hookworm)	Anemia
	Necator americanus (hookworm)	Anemia
	Taenia saginata (tapeworm)	Taeniasis

Table A2. Pathogenic bacteria and parasites in sewage (from Gerba and Goyal, 1985, p. 287).

Virus	Number of Types	Diseases Caused
Enteroviruses		
Poliovirus	3	Meningitis, paralysis, fever
Echovirus	31	Meningitis, diarrhea, rash, fever, respiratory disease
Coxsackie virus A	23	Meningitis, herpanzina, fever, respiratory disease
Coxsackie virus B	6	Myocarditis, congenital heart anomalies, pleurodynia, respiratory disease, fever, rash, meningitis
New enteroviruses (Types 68-71)	4	Meningitis, encephalitis, acute hemorrhagic conjunctivitis, fever, respiratory disease
Hepatitis type A (enterovirus 72?)	1	Infectious hepatitis
Norwalk virus (calici?)	1	Diarrhea, vomiting, fever
Calicivirus	1	Gastroenteritis
Astrovirus	1	Gastroenteritis?
Enteric corona	1	Gastroenteritis?
Reovirus	3	Not clearly established
Rotavirus	2	Infantile diarrhea
Adenovirus	37	Respiratory disease, eye infections
	114 Total	

Table A3. Human enteric viruses in sewage (from Gerba and Goyal, 1985, p. 289).

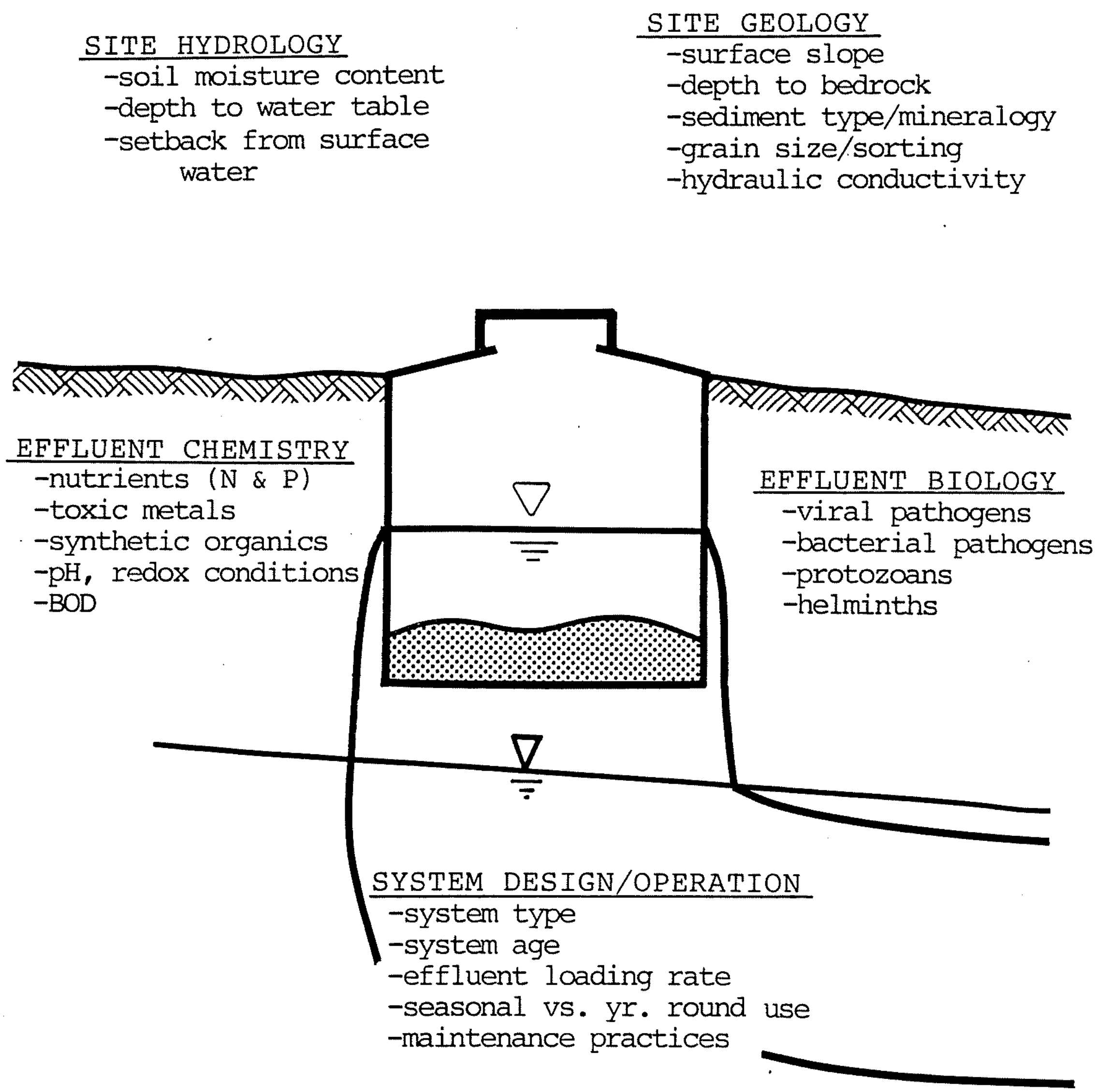


Figure A-3. Factors controlling septic system performance and environmental impact.

depth to bedrock, steep surface slopes), site hydrology (high soil moisture content, shallow depth to water table), and/or poor system design and operation leading to an excessive effluent loading rate (volume of effluent discharged per unit absorption area per unit time). Surface breakout is also promoted by infrequent pumpout (in the case of a cesspool) and increased system age, both of which reduce the absorptive capacity of the system and the underlying unsaturated zone.

The second type of failure, onsite groundwater contamination, is more difficult to detect, and has not been a matter of public concern until recently. It is generally caused by excessive loading rates at sites with highly permeable surficial geology. Sanitary codes do little to prevent onsite groundwater contamination. In fact, the Massachusetts Title V code may actually promote it by allowing extraordinarily high loading rates (small absorption areas) in highly permeable sediments (D.W. Caldwell, personal communication; Table A-4).

2. The Environmental Impact of Septic Systems

As noted above, the term "failing septic system" has traditionally been used to describe the surface breakout of effluent at the onsite or microscale. In recent years, the term has been expanded to include systems which contaminate the adjacent groundwater (Canter and Knox, 1985; U.S. EPA, 1987). It is probably more helpful, and certainly more precise, to abandon the term entirely and refer instead to the *environmental impact* of septic systems at a range of scales. All systems, whether or not they are "failing" by the above criteria, have some effect on the groundwater flow system of which they are an integral part. Sometimes those effects are obvious on or beneath a site, and sometimes they are only evident when combined with the effects of hundreds of other septic systems at the scale of a sub-basin or larger hydrogeologic unit. In either case, the public health and environmental consequences can be important.

In the following sections, no attempt has been made to provide a comprehensive review of the literature concerning septic system impact on ground and surface water quality. Instead, the types of contamination associated with septic systems are described, and a number of studies which bear directly on the problems of the Buzzards Bay region are reviewed briefly. Recent review papers which treat various aspects of the subject are cited whenever possible.

Soil Percolation rate (min/in)	Total effluent loading rate (gpd/sq.ft.)	(cm/day)	Bottom area: sidewall area ratio
2 or less	3.5	14.3	2.5
4	2.83	11.5	2.4
6	2.37	9.7	2.3
8	1.88	7.7	2.0
10	1.55	6.3	1.8
15	1.09	4.4	1.5
20	0.83	3.4	1.5
25	0.40	1.6	0*
30	0.33	1.3	0*
over 30	UNSUITABLE		--

*No bottom area allowed in soils with percolation rates over 20 minutes/inch. Sidewall area must accomodate all effluent.

Table A-4. Maximum loading rates allowed by Title V for new septic systems in Massachusetts. The sediments underlying the Buttermilk Bay drainage basin, and the soils developed in those sediments, generally have a percolation rate less than 2 min/in. (Modified from Comm. of Mass., 1978.)

2.1 Groundwater impacts: chemical.

The most important septic-derived chemical contaminant affecting groundwater is undoubtedly dissolved inorganic nitrogen in the form of nitrate. Ammonium, the dominant nitrogen species in septic effluent (Table A1), is oxidized to nitrate in a two step, bacterially mediated process called "nitrification." Autotrophs such as *Nitrosomonas* convert NH_4 to NO_2, and others such as *Nitrobacter* oxidize NO_2 to NO_3. These bacteria require three principal compounds to support their metabolism: O_2, NH_4 (or NO_2), and CO_2 (Fenchel and Blackburn, 1979). In and below an absorption system, oxygen is usually far less available than the other two compounds. Therefore, the nitrification process is oxygen-limited in this setting. If the unsaturated zone below the system is well-aerated, and ambient groundwater is high in dissolved oxygen (common conditions in the sand and gravel aquifers of the Cape Cod region), nitrification will proceed quite rapidly upon effluent release to the subsurface.

Elevated nitrate levels in drinking water pose a public health threat. At concentrations greater than 10 mg/L (as nitrogen) nitrate can cause methemoglobinemia in human infants (World Health Organization, 1985). A link between nitrate and cancer has also been suggested, due to its association with carcinogenic nitrosamines (National Research Council, 1977).

Groundwater nitrate contamination from septic systems has been documented from the microscale to the regional scale. Childs et al. (1974) mapped the groundwater nitrate plumes associated with several individual systems in a Michigan outwash plain. In one case, nitrate-nitrogen levels greater than 10 mg/L were found in a plume core over 100 meters downgradient of its absorption system source. At the other extreme of the scale continuum, Rangone et al. (1980), Bachman (1984), Thomson and Foster (1986), and Persky (1986) have mapped septic-derived nitrate at regional scales on Long Island, the Delmarva Peninsula (Maryland), Bermuda, and Cape Cod, respectively.

Persky's report is of particular relevance to the present study, given the similar hydrogeologic and cultural setting. First, he compiled a map of groundwater nitrate concentration and population density at the regional scale (covering all of Cape Cod). Then he established a statistical relationship between median groundwater nitrate concentration and housing density, based on existing data from 18 unsewered subbasins in the region.

Nitrate showed a higher level of correlation with housing density than did any other groundwater constituent or property considered.

Other chemical contaminants in groundwater which have been attributed to septic systems include synthetic organic compounds (Viraraghavan, 1986; Noss et al., 1988), metals (Sandhu and others, 1977), and detergents (Smith and Myott, 1975). For a comprehensive review of the literature (through 1980) on septic system-derived, chemical contaminants in groundwater, see Canter and Knox (1985).

2.2 <u>Groundwater impacts: microbial</u>.

The literature presents a complex picture regarding the microbial contamination of groundwater by septic effluent. All of the pathogens listed in Tables A-2 and A-3 are of potential concern, especially the bacteria and the enteric viruses. (Protozoa and helminths are almost always filtered out quite quickly by soil particles; see Hagedorn, 1984). Though viruses cannot replicate outside of a host cell, they can survive in the subsurface environment much longer than bacteria (Gerba, 1975; U.S. EPA, 1987). They can also cause disease at much lower doses than bacteria (Westwood and Sattar, 1976).

The most direct evidence of the microbial contamination of groundwater by septic systems comes from the epidemiological literature, reviewed recently by Craun (1984). Between 1971 and 1979, septic systems were responsible for 43% of the reported outbreaks and 63% of the reported cases of illness caused by the consumption of untreated groundwater in the U.S.

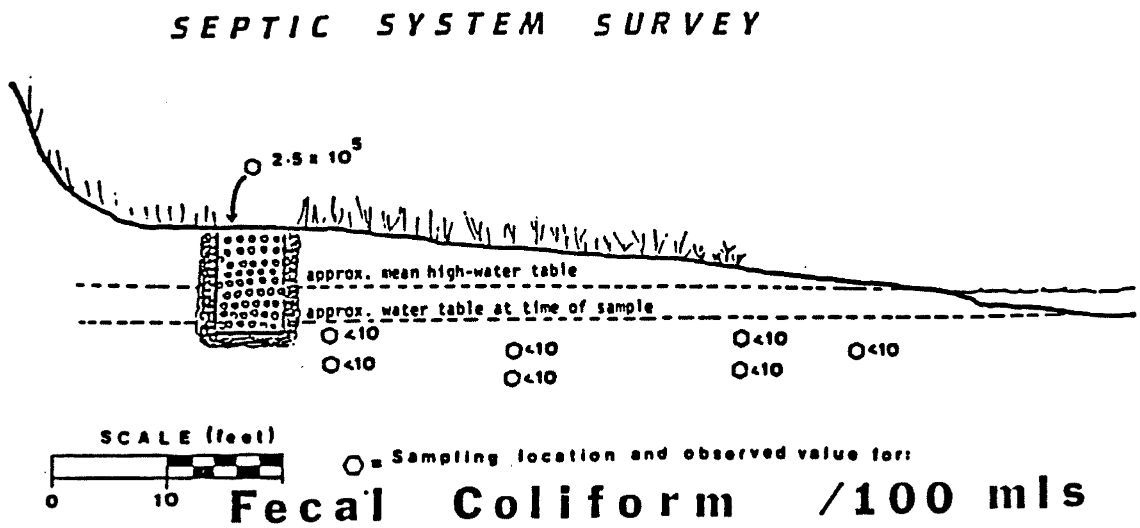
Additional evidence implicating septic systems in microbial contamination comes from the extensive literature on microbial survival and transport in the subsurface, recently reviewed by Hagedorn (1984), Gerba and Goyal (1985), Canter and Knox (1985), the U.S. EPA (1987), and Heufelder and Rask (1987). Bacterial survival is enhanced by low temperature, high soil moisture content (or saturated conditions), neutral pH, absence of predation and competition, and adequate nutrients. Viruses require no nutrients for "survival," and are inactivated by high temperatures, dessication, microbial degradation or chemical breakdown (Gerba and Goyal, 1985).

Bacterial transport is controlled partly by filtration or straining and partly by adsorption to sediment particles (Canter and Knox, 1985). Transport of viral particles, which are two orders of magnitude smaller than most bacteria, is governed mainly by adsorption. The adsorption process, in turn, depends upon the surface chemistry of both the sediment particles and the microbes in question, and the pH, ionic strength, and cation content of the groundwater or soil moisture in the unsaturated zone. Since both sediment and viral particles commonly have a net negative surface charge (at neutral pH), lowering the pH or raising the cation concentration reduces the repulsive force between the respective particles, promoting adsorption (Gerba and Goyal, 1985; Canter and Knox, 1985). Since the aqueous chemistry of the subsurface can vary greatly over time and space, as can the surface properties of the various sediment minerals and virus types, adsorption is a highly variable process (Moore et al., 1981). It is also reversible; desorption of viruses and bacteria can occur after periods of heavy rainfall (Lamka et al., 1980).

Recent field studies of bacterial and viral transport amply demonstrate this variability. Brown et al. (1979) found extremely limited movement of fecal coliform through the unsaturated zone directly below an absorption trench, in soil with an 80% sand content. Sinton (1986), by contrast, found extensive movement of fecal coliform from a leaching pit to monitoring wells arrayed in a circular pattern at a radius of 4 meters from the pit. The base of the pit was 3 meters above the water table of the alluvial sand and gravel aquifer. Geometric mean fecal coliform densities exceeded 100 colonies/100 ml in all six wells, and equaled 15,600 in one of the wells.

Vaughn et al. (1983) studied the transport of viruses and fecal coliform through Long Island glacio-fluvial sediments, similar to those of the Buttermilk basin. Over nine percent of the samples collected from a monitoring well 60 meters downgradient of a leaching pit cluster were positive for septic-derived viruses. Nearly 20% of the samples from a well 30 meters downgradient were positive. Fecal coliform, present at high (10^5-10^8/100 ml) densities in the septic effluent, "were only rarely detected beyond the 1.52 meter sample well" (Vaughn et al., 1983, p. 1477). No significant correlation was found between viral and fecal coliform occurrence in the groundwater.

Heufelder (1987) presents a "snapshot" of the indicator bacteria distribution downgradient of twp septic systems near Buttermilk Bay (Figures A-4 and A-5). At the "worst case" site (Figure A-4), where the base of the cesspool extended below the water table, no fecal coliform was detected in any of the groundwater samples. At the second site (Figure A-5),



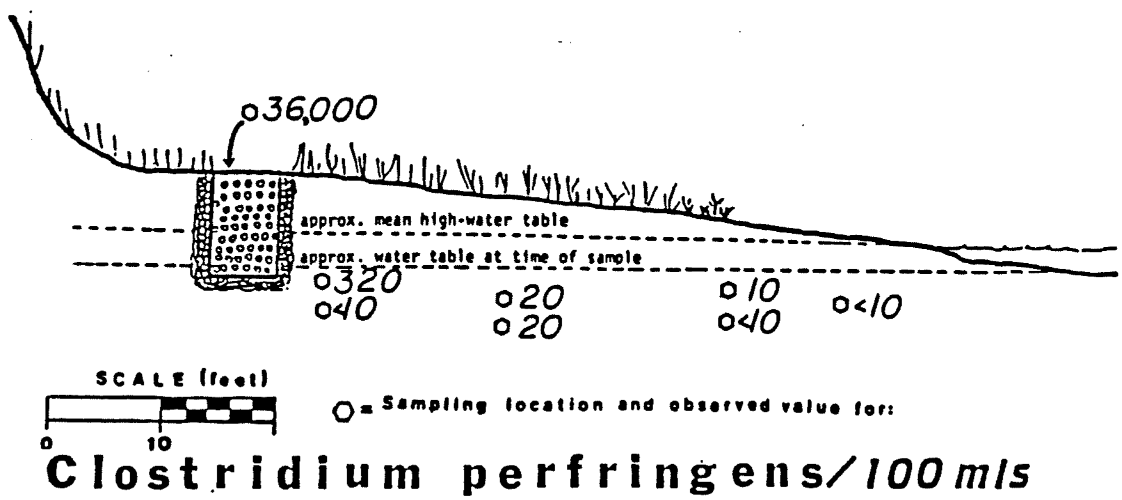
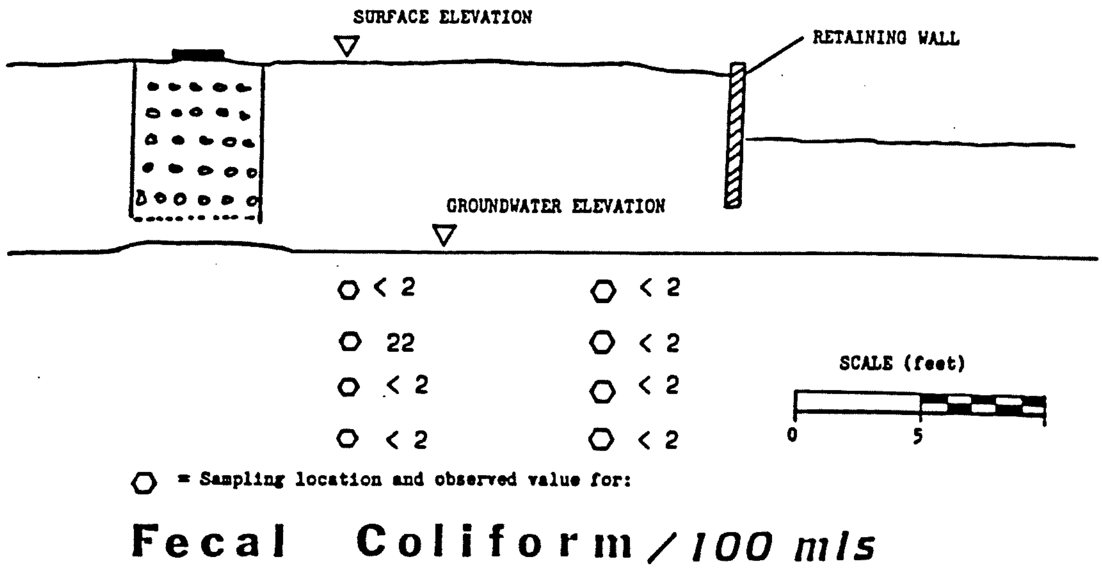


Figure A- 4. Indicator bacteria densities downgradient of a "worst case" cesspool, September 1986 (from Heufelder, 1987).



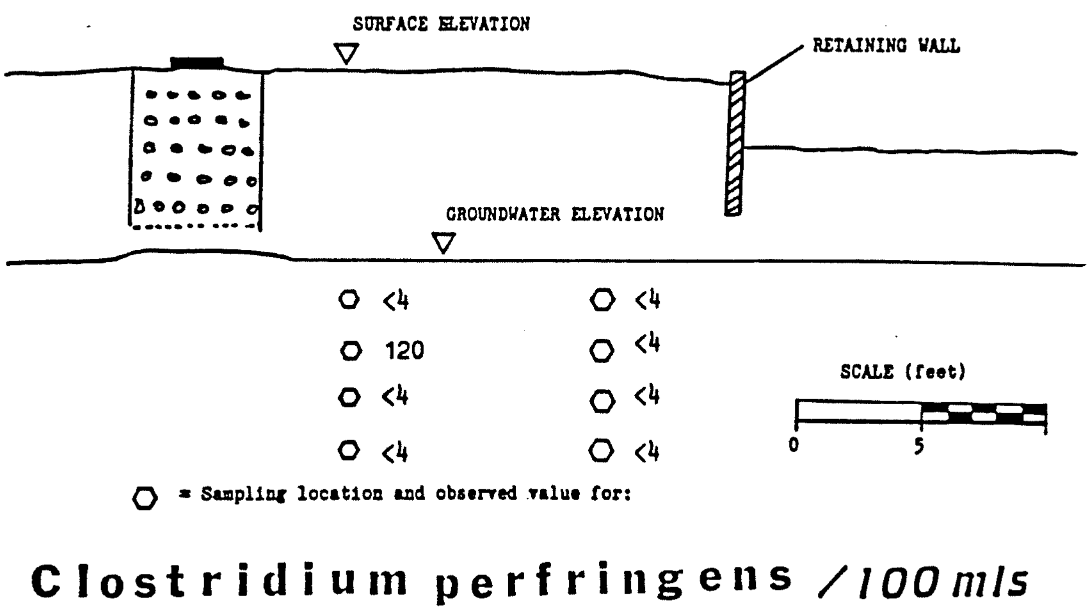


Figure A-5. Indicator bacteria densities downgradient of cesspool, July 1986 (from Heufelder, 1987).

fecal coliform was detected in one of the samples. *Clostridium*, by contrast, was found at several stations at the worst case site, up to 12 meters from the septic source (Figure A-4). At each downgradient distance, the highest densities were generally found near the water table.

Bacteria such as fecal coliform, fecal streptococcus and *Clostridium perfringens* are known as "bacterial indicators." Because pathogenic virus and bacteria assays are difficult to perform routinely, public health authorities traditionally test ground and surface waters suspected of microbial contamination for one or more indicator organisms, the occurence of which is associated with the feces of warm-blooded animals (Bisson and Cabelli, 1980; Pipes, 1982). Recent research has cast doubt on the reliability of such indicators. Specifically, the *absence* of bacterial indicators has been shown to mean little with regard to the possible presence or absence of pathogens. This is particularly true when trying to predict the occurence of viral pathogens (as opposed to pathogenic bacteria), in groundwater (as opposed to surface waters; Burge and Marsh, 1978; Gerba et al., 1979; Schaub and Sorber, 1977; Marzouk et al., 1980; Vaughn et al., 1983).

In closing this discussion, it should be noted that the U.S. EPA has recently devised a rating system to evaluate the microbial contamination potential of septic system sites (U.S. EPA, 1987). The rating system, based on an exhaustive literature review, evaluates sites with respect to the following factors: depth to water table, net recharge rate, hydraulic conductivity, temperature, [unsaturated zone] soil texture, [saturated zone] aquifer medium type, effluent loading rate, and distance to point of use. These site factors were judged to be the most critical predictors of contamination potential.

2.4 Coastal impacts: the contamination of shellfish waters.

The bacterial contamination of shellfish waters has accompanied the rapid development now occuring along many portions of the U.S. coastline (Maiolo and Tschetter, 1981; Commonwealth of Mass., 1985; Ballentine, 1985). Septic systems are commonly cited as a source of fecal bacteria to coastal waters (Jackson, 1985; Crane and Moore, 1986). Unfortunatelly, it is difficult in practice to determine the importance of septic inputs relative to other potential sources common to agricultural, urban, and completely undeveloped watersheds (Faust, 1976; Jensen et al., 1985; Heufelder, 1987, Heufelder and Rask, 1987).

One of the few studies to show conclusively the contribution of septic systems to the contamination of shellfish waters is that of Duda and Cromartie (1982) in North Carolina. They monitored fecal coliform densities in creeks draining 8 small, unsewered watersheds under both dry and rainy weather conditions. Under dry conditions, they found a strong correlation (r=.90) between the log number of septic systems in each watershed and the mean log density of fecal coliform in the creek draining the watershed. Under rainy conditions, the data showed more scatter (r=.48), presumably due to the variable effects of urban runoff on indicator densities in the creeks.

It is instructive to consider the applicability of this study to the Buttermilk basin. In describing the routes by which fecal bacteria reached the tidal creeks, Duda and Cromartie stressed the importance of local hydrogeologic factors common to the North Carolina Coastal Plain: flat topography, impermeable sediments, a shallow water table, and a highly developed surface drainage network augmented by artificial ditches. Excavated in a vain attempt to drain groundwater from low-lying areas, the ditches instead provided a direct route for fecal bacteria to reach the tidal creeks and larger estuary. Surface breakout of effluent was common near the banks of the ditches under all weather conditions. North Carolina law, at the time, required septic absorption systems to be set back only 4.6 meters from such ditches, and allowed vertical infiltration distances (depth to water table) of only 0.3 meters beneath the systems.

In every respect, conditions in the Buttermilk basin differ from the above. Hummocky, kettle-and-kame topography, highly permeable sediments, a large average depth to water table, hydrologic conditions dominated by groundwater discharge, and a poorly developed surface drainage network characterize the basin. A major purpose of the present study (Part I) is to monitor the transport of fecal indictors under these very different conditions.

2.3 Coastal impacts: eutrophication.

The primary productivity of coastal marine ecosystems is generally nitrogen-limited (Ryther and Dunstan, 1971; Goldman et al., 1973; D'Elia et al. 1986). The amount of fixed nitrogen available to the primary producers depends, in turn, upon three factors: 1) the anuual input of "new" nitrogen to the system from all sources, 2) the annual loss of nitrogen from the system, and 3) the rate at which the nitrogen in dead organic matter is remineralized within the

In the light of these considerations, it is likely that septic systems are a major source of the dissolved inorganic nitrogen load impacting coastal waters in the Buzzards Bay region. In non-agricultural areas, they are probably the dominant source. In Part II of this study, we will focus directly on this question.

* * * * * * * * *

In summary, septic systems impact the environment in a variety of ways at a range of scales. Sometimes the effects are gross and immediate, and sometimes they are subtle and longterm. Since septic systems will be prevalent in this country for the forseeable future, it is critical that we come to a better understanding of these effects.

APPENDIX B:

VERY LOW FREQUENCY TERRAIN RESISTIVITY: AN EXPLANATION

VLF TERRAIN RESISTIVITY: AN EXPLANATION

The U.S. Navy maintains a worldwide network of radio transmitters for purposes of submarine navigation. They each transmit at a fixed frequency between 15 and 25 Kiloherz, the "Very Low Frequency" portion of the radio band. The nearest transmitter to the study area is located in Cutler, Maine.

A VLF instrument such as the Geonics 16R measures the ratio of, and the phase angle between the horizontal electric and magnetic fields of the plane wave generated by such distant transmitters. The ratio of these two fields at a given point on the earth's surface is proportional to the terrain resistivity underlying that point, down to a depth of exploration known as the "skin depth." (The skin depth, for a given transmitter frequency, is proportional to the square root of the terrain resistivity.) The phase angle indicates the extent to which the earth below the instrument is homogeneous or layered. If the angle is below 45 degrees, a conductive layer overlies a resistive layer; if it is above 45 degrees, the reverse situation is indicated; if it equals 45 degrees, the terrain is vertically homogeneous.

The instrument is operated as follows. First, it is placed on the ground surface, switched to search mode and rotated until the main coil arm points directly toward the transmitter (Cutler, Maine in our case; Figure B-1). When the instrument is properly oriented, a null tone is obtained. (In our study area, the Cutler transmitter is located on a bearing of N 37 degrees E.) Second, two probes are inserted into the ground, 5 meters distant from the instrument, on a line parallel to the above bearing (Figure B-2). Finally, the terrain resistivity and phase angle readings are obtained, by adjusting graduated dials on the instrument until a null tone is obtained.

Because the phase angle data did not add significantly to our understanding of the plume geometry, it was not included in the main body of the report. At Site 2, the phase angle is relatively constant, except for a strong anomaly at a distance of 2 meters along the section (Figure B-3). It is interesting to note that this anomaly overlies the point of peak conductance in the plume. At Site 4, the phase angle anomaly is quite similar in shape to the resistivity anomaly, though it is displaced 1 meter to the left (Figure B-4).

Figure B-1. The VLF terrain resistivity instrument in operation.

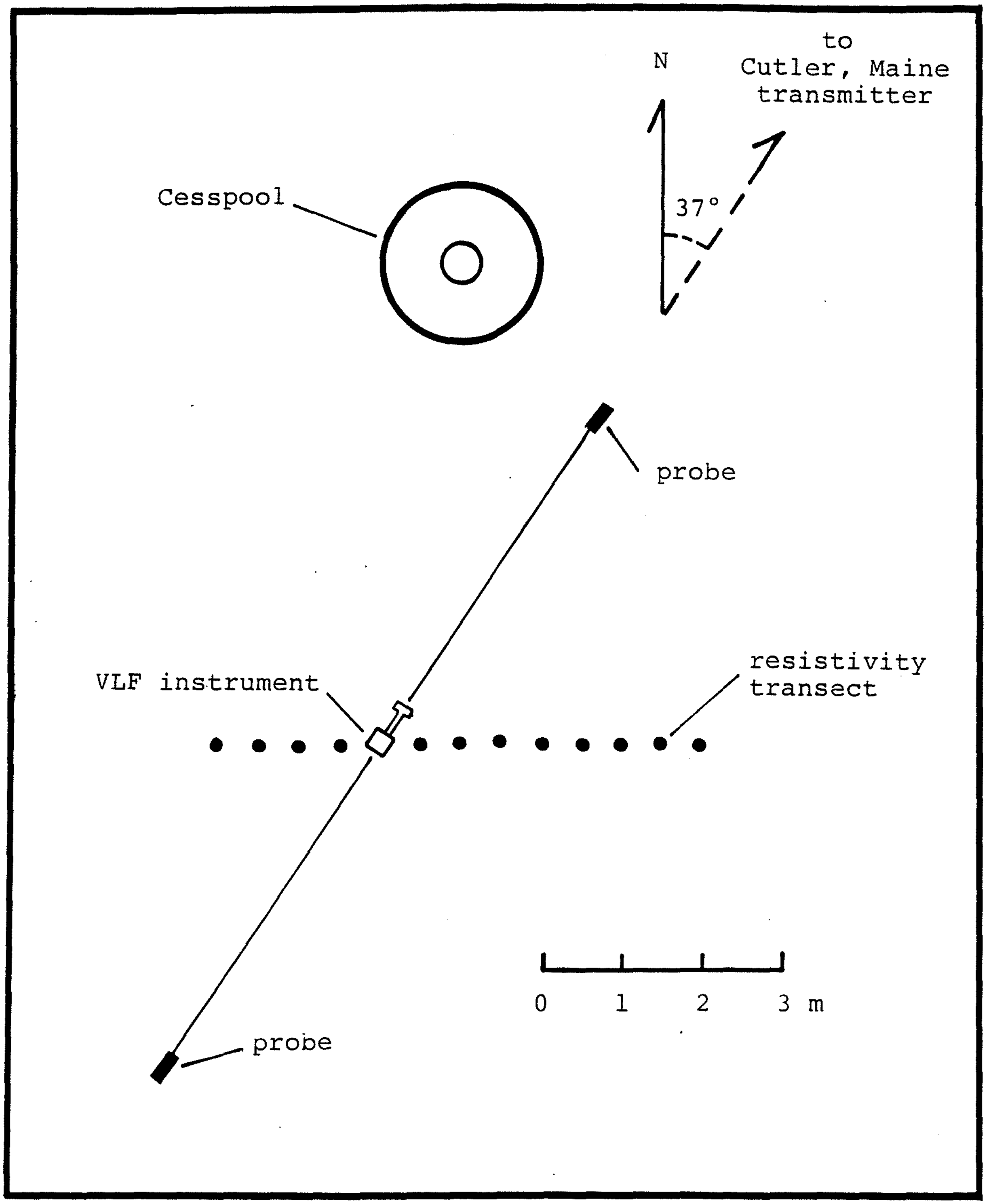


Figure B-2. VLF instrument and probe configuration for typical southeast New England site.

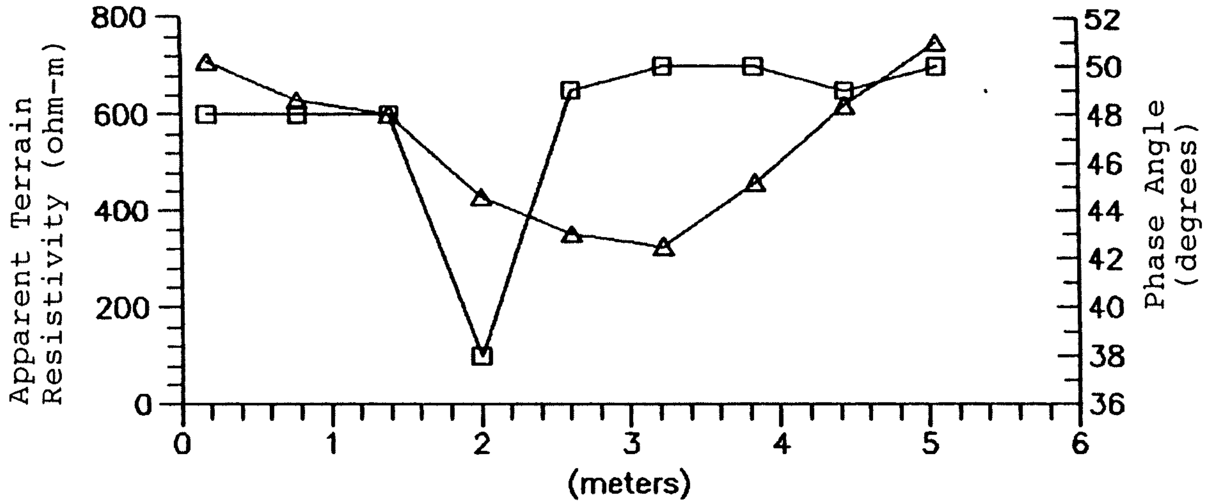


Figure B-3. Apparent terrain resistivity and phase angle overlying the conductance section at Site 2.

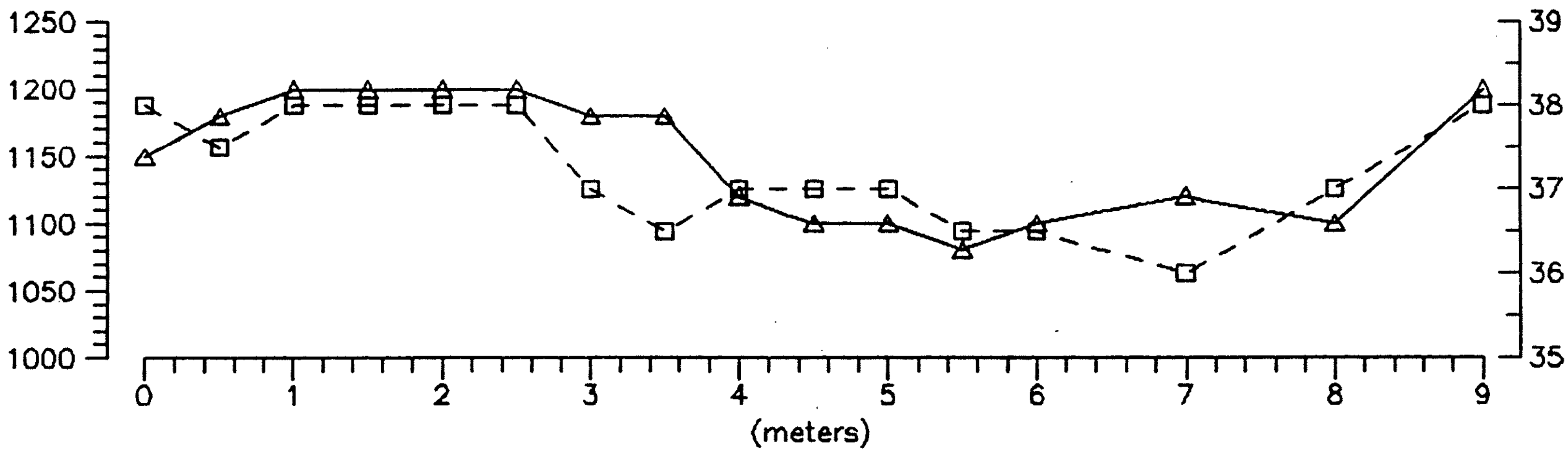


Figure B-4. Apparent terrain resistivity and phase angle parallel to section at Site 4.

APPENDIX C:

INDICATOR BACTERIA DATABASE

A NOTE CONCERNING UNITS

Microscale Database: Indicator Bacteria

SITE	TYPE	DATE	FC LOG	FC UPLIM	FC LOLIM	CLS LOG	CLS UPLIM	CLS LOLIM	STP LOG
1	S	10-Dec-87	5.38	5.88	4.83	4.08	4.48	3.68	n.a.
1	S	21-Jan-88	5.04	5.40	4.49	3.30	3.70	2.90	n.a.
1	S	25-Feb-88	4.23	4.69	3.63	3.95	4.35	3.54	5.51
1	S	29-Mar-88	4.96	5.51	4.48	3.78	4.18	3.38	4.15
1	S	10-May-88	4.38	4.88	3.83	4.45	4.85	3.15	n.a.
1	S	28-Jun-88	4.73	5.15	4.26	4.38	4.78	3.98	n.a.
1	G	10-Dec-87	<0.30	<0.30	<0.30	1.00	1.40	0.60	n.a.
1	G	21-Jan-88	<0.30	<0.30	<0.30	1.00	1.40	0.60	n.a.
1	G	25-Feb-88	<0.30	<0.30	<0.30	<1.00	<1.00	<1.00	<0.30
1	G	29-Mar-88	<0.30	<0.30	<0.30	<1.00	<1.00	<1.00	<0.30
1	G	10-May-88	<0.30	<0.30	<0.30	<1.00	<1.00	<1.00	n.a.
1	G	28-Jun-88	<0.30	<0.30	<0.30	n.a.	n.a.	n.a.	n.a.
2	S	10-Dec-87	4.96	5.51	4.48	2.60	3.00	2.20	n.a.
2	S	21-Jan-88	5.54	6.00	5.08	3.32	3.72	2.92	n.a.
2	S	25-Feb-88	5.20	5.76	4.81	3.00	3.40	2.60	4.28
2	S	29-Mar-88	4.20	4.76	3.81	2.00	2.40	1.60	2.70
2	S	10-May-88	4.73	5.15	4.26	2.00	2.40	1.60	n.a.
2	S	28-Jun-88	5.96	6.51	5.48	3.00	3.40	2.60	n.a.
2	G	10-Dec-87	<0.30	<0.30	<0.30	<1.00	<1.00	<1.00	n.a.
2	G	21-Jan-88	<0.30	<0.30	<0.30	1.00	1.40	0.60	n.a.
2	G	25-Feb-88	<0.30	<0.30	<0.30	<1.00	<1.00	<1.00	<0.30
2	G	29-Mar-88	<0.30	<0.30	<0.30	<1.00	<1.00	<1.00	<0.30
2	G	10-May-88	<0.30	<0.30	<0.30	<1.00	<1.00	<1.00	n.a.
2	G	28-Jun-88	<0.30	<0.30	<0.30	n.a.	n.a.	n.a.	n.a.
3	S	10-Dec-87	4.96	5.51	4.48	4.26	4.66	3.86	n.a.
3	S	21-Jan-88	4.54	5.00	4.08	3.26	3.66	2.86	n.a.
3	S	28-Feb-88	5.38	5.88	4.83	4.95	5.35	4.55	4.60
3	S	29-Mar-88	4.96	5.51	4.48	4.75	5.15	4.35	4.84
3	S	10-May-88	5.96	6.51	5.48	n.a.	n.a.	n.a.	n.a.
3	S	28-Jun-88	4.54	5.00	4.08	5.51	5.91	5.10	n.a.
3	G	10-Dec-87	<0.30	<0.30	<0.30	1.00	1.40	0.60	n.a.
3	G	21-Jan-88	<0.30	<0.30	<0.30	1.00	1.40	0.60	n.a.
3	G	25-Feb-88	<0.30	<0.30	<0.30	1.48	1.88	1.08	<0.30
3	G	29-Mar-88	<0.30	<0.30	<0.30	1.60	2.00	1.20	<0.30
3	G	10-May-88	<0.30	<0.30	<0.30	n.a.	n.a.	n.a.	n.a.
3	G	28-Jun-88	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
4	S	10-Dec-87	5.38	5.88	4.83	4.11	4.51	3.71	n.a.
4	S	21-Jan-88	5.20	5.76	4.81	6.08	6.48	5.68	n.a.
4	S	25-Feb-88	5.23	5.69	4.63	4.76	5.16	4.36	3.60
4	S	29-Mar-88	5.73	6.15	5.26	4.56	4.96	4.16	4.62
4	S	10-May-88	4.94	5.34	4.56	2.00	2.40	1.60	n.a.
4	S	28-Jun-88	5.54	6.00	5.08	4.08	4.48	3.68	n.a.
4	G1	10-Dec-87	2.2	2.69	1.63	n.a.	n.a.	n.a.	n.a.
4	G1	21-Jan-88	2.2	2.69	1.63	<1.00	<1.00	<1.00	n.a.
4	G1	25-Feb-88	0.8	1.23	0.00	2.51	2.91	2.11	<0.30
4	G1	29-Mar-88	0.3	0.85	0.30	1.40	1.80	1.00	<0.30
4	G1	10-May-88	<0.3	<0.30	<0.30	1.00	1.40	0.60	n.a.
4	G1	28-Jun-88	0.7	1.11	0.00	1.28	1.68	0.90	n.a.
4	G2	25-Feb-88	0.3	0.85	0.00	1.00	1.40	0.60	<0.30
4	G2	29-Mar-88	<0.3	<0.30	<0.30	0.30	0.85	0.00	<0.30
4	G2	10-May-88	<0.3	<0.30	<0.30	1.00	1.40	0.60	n.a.
4	G2	28-Jun-88	0.3	0.85	0.00	n.a.	n.a.	n.a.	n.a.

Table C-1. Indicator bacteria database, Sites 1-4.

BACTERIA DATA TABLE: EXPLANATION

S = septic effluent
G = groundwater, 1 meter downgradient of system
G1 = groundwater, 1 m downgradient of system, Site 4
G2 = groundwater, 2 m downgradient of system, Site 4
FC LOG = the logarithm of the fecal coliform density
CLS LOG = The logarithm of the Clostridium density
STP LOG = the logarithm of the fecal strep density
UPLIM and LOLIM define the 95% confidence intervals
All bacteria figures are in log colonies/100 ml
n.a. = sample data not available. (In many cases, sample turbidity prevented *Clostridium* enumeration.)

A NOTE CONCERNING UNITS:

In accordance with standard scientific practice, the metric (SI) system is used in this report. Where appropriate, English equivalents are given in parentheses.

Those who prefer the English system of units may wish to refer to the following relationships:

1 centimeter = 0.394 inches
1 meter = 3.281 feet
1 kilometer = 0.621 miles

1 m^2 = 10.76 ft^2
1 hectare = 2.471 acres

1 m^3 = 1000 liters
1 liter = 0.264 gallons (U.S.)

Microsiemens/centimeter (μS/cm) are units of specific conductance currently accepted by the U.S. Geological Survey. They are equivalent to micromhos/centimeter (μmhos/cm) units.

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