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Bacteriological Monitoring in Buttermilk Bay

BUZZARDS
BAY PROJECT

BACTERIOLOGICAL MONITORING IN BUTTERMILK BAY

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&
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BBP-88-03

The Buzzards Bay Project is sponsored by The
US Environmental Protection Agency and The Massachusetts
Executive Office of Environmental Affairs

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FOREWORD

In 1984, Buzzards Bay was one of four estuaries in the country chosen to be part of the National Estuary Program. The Buzzards Bay Project was initiated in 1985 to protect water quality and the health of living resources in the bay by identifying resource management problems, investigating the causes of these problems, and recommending actions that will protect valuable resources from further environmental degradation. This multi-year project, jointly managed by United States Environmental Protection Agency and the Massachusetts Executive Office of Environmental Affairs, utilizes the efforts of local, state, and federal agencies, the academic community and local interest groups in developing a Master Plan that will ensure an acceptable and sustainable level of environmental quality for Buzzards Bay.

The Buzzards Bay Project is focusing on three priority problems: closure of shellfish beds, contamination of fish and shellfish by toxic metals and organic compounds, and high nutrient input and the potential pollutant effects. By early 1990, the Buzzards Bay Project will develop a Comprehensive Conservation and Management Plan to address the Project's overall objectives: to develop recommendations for regional water quality management that are based on sound information, to define the regulatory and management structure necessary to implement the recommendations, and to educate and involve the public in formulating and implementing these recommendations.

The Buzzards Bay Project has funded a variety of tasks that are intended to improve our understanding of the input, fate and effects of contaminants in coastal waters. The Project will identify and evaluate historic information as well as generate new data to fill information gaps. The results of these Project tasks are published in this Technical Series on Buzzards Bay.

This report represents the technical results of an investigation funded by the Buzzards Bay Project. The results and conclusions contained herein are those of the author(s). These conclusions have been reviewed by competent outside reviewers and found to be reasonable and legitimate based on the available data. The Management Committee of the Buzzards Bay Project accepts this report as technically sound and complete. The conclusions do not necessarily represent the recommendations of the Buzzards Bay Project. Final recommendations for resource management actions will be based upon the results of this and other investigations.

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

Water quality in Buttermilk Bay, southeastern Massachusetts was historically perceived as very good until March, 1984 when the entire area of the bay was closed to shellfishing. A year-long study of the bacteriological quality of the bay and all potential sources of contamination was initiated in September, 1985. Fecal coliform, the currently-accepted index of water quality, was used in the study. In nearly all cases, further differentiation of the fecal coliform group indicated that the organisms were Escherichia coli, a normal inhabitant in the intestinal tract of warm-blooded animals. Investigations centered around six possible sources of contamination: stormwater, septic systems, wildlife, marinas, freshwater inputs and point discharges.

Stormwater

Our investigations suggest that stormwater discharges are the most important factor causing the periodic reclassification of the area as unsuitable for shellfish harvesting. Maximum contamination levels in Buttermilk Bay coincide with rain events, a period in which samples are taken for the purpose of classification of the area under presently-accepted practice (sampling during "worst hydrographic conditions"). The level of fecal coliform contamination at discharge points is shown to be related to three main factors. The extent of residential development is shown to be positively related to fecal coliform levels, with highest levels observed at the western shore where housing density approximates 20 units per ha (8 units per acre). Frequency of rain events was negatively correlated with fecal coliform densities at discharge points, presumably due to a shorter period available for fecal material to accumulate on surfaces drained. In agreement with National Urban Runoff Program studies, a seasonal effect on coliform densities at discharge points was noted with minimum values observed during winter sampling. To place coliform loadings from discharge pipes in perspective, the amount of water required to dilute the discharge to 14 FC/100 ml was calculated and compared with the tidal prism (2.5 x 10^6 cu. m). Between 18%, during colder months sampled, and 440 % ,during warmer months, of the tidal prism would be required for this dilution. A survey of each surface drainage area during dry periods suggests that the source of the fecal coliform during discharge events is not sanitary wastes. Domestic dogs and wildlife are implicated as over 100 dogs inhabit areas served by drains. Use of in-situ measured fecal loadings from dog wastes indicate that the predicted volume of dog waste necessary to account for the overall geometric mean value of fecal coliform in discharged water could be accounted for by a 2-3 day accumulation.

In addition to direct discharges, storm events cause a release of fecal indicators from sediments and other protected reservoirs into the water column. The extent of this release could not be quantified, however measurements of fecal coliform from these protected reservoirs indicate that the effect may be substantial. Scavengers and waterfowl, particularly Canada geese, are strongly implicated as being the source of high fecal coliform (>1,000 FC/gram) in strand line deposits.

Septic Systems

Groundwater sampling in the Buttermilk Bay watershed presented conflicting indications regarding fecal coliform entrainment. General sampling indicated groundwater contamination at distances at least 35 m from the nearest suspected source, however a more intensive sampling scheme performed near two septic systems indicated limited mobility of fecal indicators in this area's soil. While the entrainment of bacterial indicators appears to be limited, the issue of pathogenic virus entrainment remains unresolved after the present study. A review of pertinent published studies regarding virus entrainment is presented and suggests a lateral entrainment of viruses to at least 67.05 m (220 ft) in soil types similar to the study area. It is concluded that, regarding the entrainment of pathogenic organisms in groundwater, a major public health threat, the viruses, is probably not adequately assessed with the indicator system used.

Wildlife

A waterfowl survey was conducted weekly to determine the use of Buttermilk Bay by migrating waterfowl and to determine the resulting bacteriological impact. Following techniques employed by Hussong et al. (1979), theoretical loadings were compared with actual field values. Predicted estimates generally coincided with field measurements and indicate that, except in certain areas, the use of the bay by waterfowl had fairly minimal direct impact on water quality. A long-term cumulative impact on water quality due to the fecal deposits in the beach areas, however, is indicated due to the maintenance of fecal material in a protected area. These wastes accumulate and can be released in a slow diffuse pattern, and can result in considerable local degradation of water quality. The release of these fecal indicators during certain hydrographic and meteorological events (ie. high tides and rainfall events) can expect to significantly impact the water quality, the extent of which will be determined by a number of variables to include circulation, water temperature, etc..

Marinas

Utilizing two sampling approaches, no measurable impact on the bacteriological quality of water was observed as a result of marina operation. These results should be interpreted with caution however, since the nature of the suspected wastes would necessitate extremely fortuitous circumstances in order to determine the actual impact of an overall operation. In addition, the marinas studied should be considered atypical due to inherent restrictions on boat size in one case, and the presence of pump out facilities in the other case. It is concluded that the extent of impact of marina operations will be determined by the level of convenience and cost associated with the proper handing of sanitary wastes at each facility. Studies documenting the effect of marinas are reviewed herein and indicate that in more "normal" situations, the impact of marina operations can be significantly adverse.

Freshwater Inputs

The review of historical data as well as investigations presented herein confirm that the freshwater drainage into Buttermilk Bay is a consistent source of fecal coliform. In the case of Red Brook, no point sources were located. It is concluded that two possibilities exist for the consistently higher fecal coliform densities observed. Although limited groundwater sampling failed to reveal this as an input, it is possible that septic plumes are entering the brook at undiscovered locations. In addition, investigations reviewed herein and small scale experiments suggest that the extensive marsh area near Red Brook, and possibly the marshes and bogs within the watersheds of other freshwater inputs to Buttermilk Bay are sources of "natural" fecal coliform (those fecal coliform surviving and possibly multiplying outside a warm-blooded animal host). It is certain that each of the marshes surrounding and draining into Buttermilk Bay contain a variety of wildlife species which additionally will act as a diffuse but significant source.

Point Discharges

Only one point discharge was discovered (not including stormdrains) in the present study. This consisted of a discharge pipe located at a local fish market. The location of this discharge in Cohasset Narrows probably minimizes its impact, however during certain tidal stages (incoming tide) the impact may be quite substantial and extend more into the bay.

Other Considerations

Small scale experiments verified that solar radiation is a prime determinant of fecal coliform die-off in surface layers of Buttermilk Bay. Comparison of bay water sampled at different locations suggests that in areas coincident with higher nutrient influents, the ultraviolet light penetration is attenuated which may cause an increased persistence of fecal coliform or a modification of the die-off rate in these areas. In addition to modifying the mortality rate of fecal coliform, nutrient additions may allow for maintenance and limited growth of fecal coliform and pathogens as implied by laboratory experiments. In addition to the direct utilization of effluent nutrients, laboratory investigations using water and algae collected in Buttermilk Bay suggest that algal growth, which results from nutrient inputs, may additionally supply fecal indicators, and likely pathogens, with complex nutrients, resulting in fecal indicator growth. These initial small-scale experiments collectively suggest a link between nutrient enrichment through on-site sewage disposal practices and bacteriological contamination of Buttermilk Bay which should be researched further.

INTRODUCTION

The United States Census Bureau (Carter, 1980) indicates a strong preference of people to live in coastal regions. If the present trends continue, by the year 1990, 75 percent of the population of the United States will live within 50 miles of tidal waters and the Great Lakes. This demographic shift toward coastal environments will undoubtedly result in the inability of many coastal areas to absorb the human wastes generated, and will prevent these areas from being used for many of the activities generally associated with good water quality (ie. shellfish harvesting and swimming). In southeastern Massachusetts, where unprecedented growth has occurred in the last decade, there has been a 28 % increase in the number of areas closed to shellfish harvesting between the years 1983 and 1985, and in 1984, formerly-pristine areas such as the Westport, North and South Rivers were closed due to bacterial contamination (Massachusetts Division of Marine Fisheries, 1985).

The issues involved in bacterial contamination of surface waters are complex and cover both point- and nonpoint sources of contamination. For the most part, nonpoint sources of pollution have played the major role in affecting the majority of shellfish area closures in recent years. Nonpoint pollution refers to certain categories of natural sources of wastes or wastes from activity of man which are dispersed or diffused (Furfari, 1979). While many of the issues and questions regarding point source pollution problems can be easily addressed, the nature of nonpoint source pollution (being dispersed and diffuse) has precluded many successful attempts at abatement. Paramount to controlling nonpoint source pollution is an understanding of the mechanisms by which nonpoint sources affect the nearshore marine resource in each situation. While many advances have been made in understanding nonpoint pollution, there is general agreement that many of the mechanisms resulting in coastal degradation of water quality are poorly understood. The purpose of the study described herein is to clarify the sources and mechanisms involved in the contamination of Buttermilk Bay, southeastern Massachusetts with fecal coliform, the generally-accepted indicator of water quality for purposes of shellfish harvesting and recreational contact (swimming, wading etc.).

STUDY AREA

Buttermilk Bay is a small embayment in the northern section of Buzzards Bay, southeastern Massachusetts (Figure 1.). Our study area included Little Buttermilk Bay (0.43 km^2 at mean low tide) and Buttermilk Bay proper (1.71 km^2 at mean low tide). In addition, freshwater surface inputs and their watersheds were investigated for coliform sources.

Land use within the watershed of Buttermilk Bay ranges from intense residential use (0.05 ha - 0.115 acre lots) on the

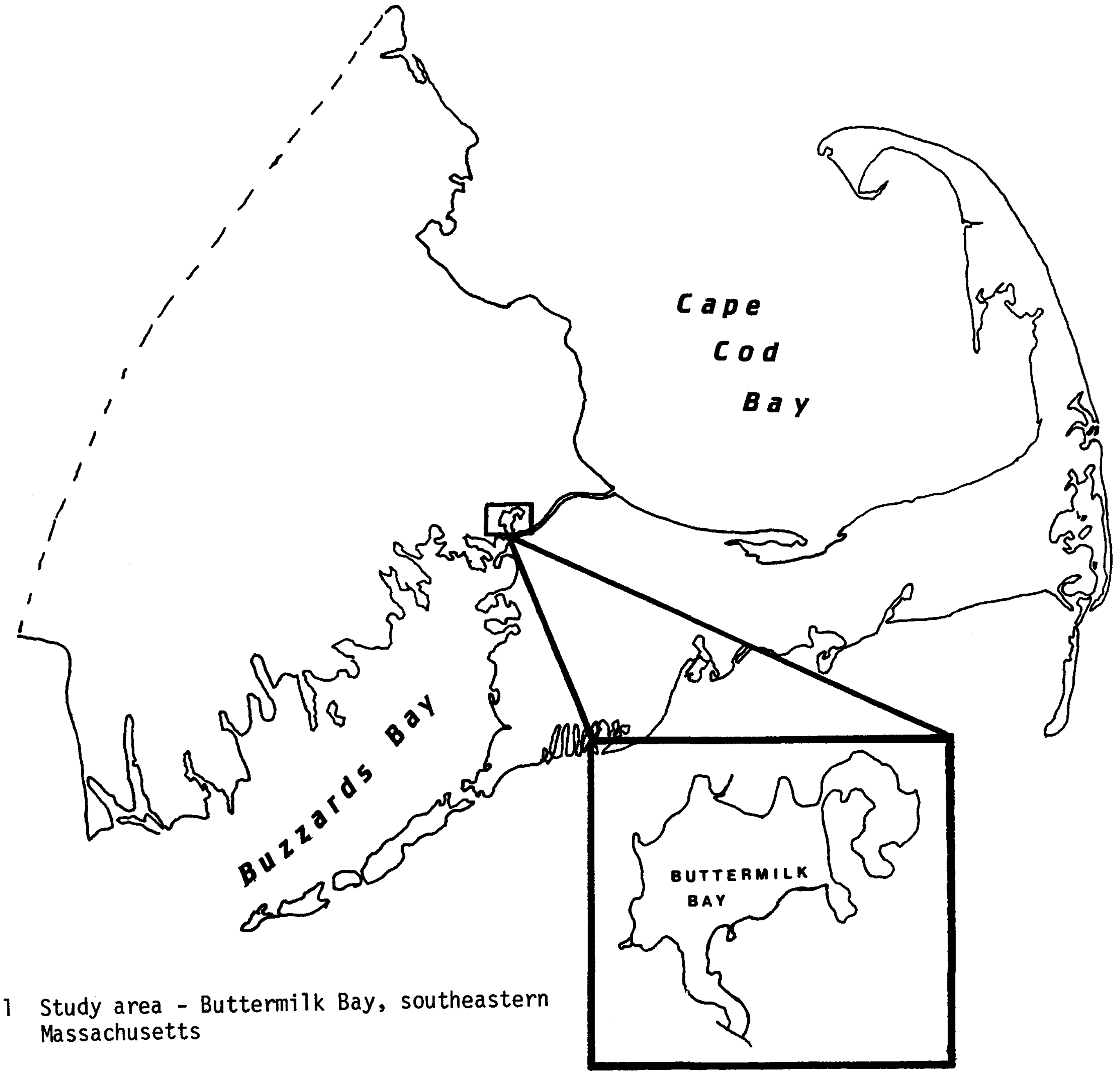


Fig. 1 Study area - Buttermilk Bay, southeastern Massachusetts

western and northern shores to lower density residential use on the eastern shore. In addition, stormwater inputs from a commercial area along Cranberry Highway (Routes 6-28) impact the bay along the southern shoreline. There are over 20 direct stormwater discharges into the bay for a combined drainage from impervious surfaces of approximately 80,620 sq. m (867,800 square feet) (Figure 2). Descriptions of all known direct discharge pipes with associated drainage areas are presented in Appendix I.

Until 1983, the area of Buttermilk Bay was perceived as having good water quality for both shellfish harvesting and other recreational uses. In October of that year, a portion of the bay near "Byron's Landing" in Wareham was reclassified as "Prohibited" under MGL Chapter 130, Section 74 A. Following a review of the existing data, the entire area of Buttermilk and Little Buttermilk Bay was closed to shellfish harvesting on March 13, 1984. Although the problem of high coliform counts was perceived as being recent to the 1984 closure, historic data indicate that high coliform and fecal coliform were evident as far back as 1973. Data collected by the Southeastern Regional Office of D.E.Q.E. indicate continued sporadic contamination problems from 1973 to date. Certain areas in the bay were opened for seasonal harvest of shellfish in October, 1986 when it was determined that the data supported this type of classification. In July, 1985 a resurvey of the area was conducted by the Southeastern Office of D.E.Q.E. and the United States Public Health Service, Food and Drug Administration. The results of this study are unavailable at this point in time.

APPROACH AND METHODOLOGY

Investigations reported herein centered around the following six possible sources of fecal coliform in the bay which serve as an outline for presentation:

1) Stormwater
2) Septic Systems
3) Wildlife (to include waterfowl)
4) Boats and Marinas
5) Freshwater Inputs
6) Point Source Discharge

In addition to source delineation, certain aspects of the ecology of the indicator organism were investigated, particularly in relation to possible links with nutrient enrichment. These later studies, although small in scale, point to the need for further study to determine possible links between eutrophication and the ecology of pathogens in embayments.

Analytical Procedures

Fecal coliform densities were determined using two methods.

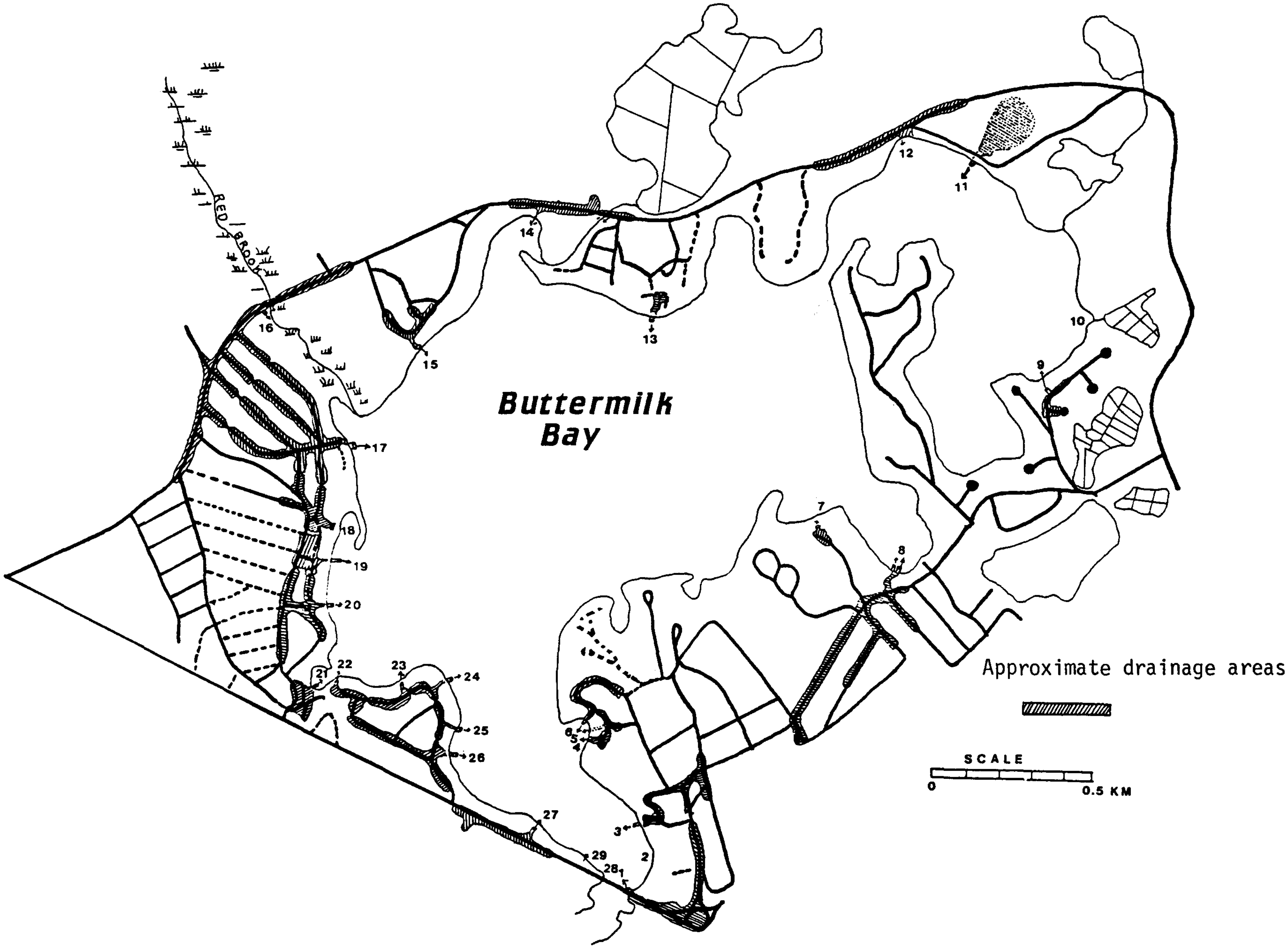


Fig. 2 Locations of stormwater discharges in Buttermilk Bay, southeastern Massachusetts with approximate drainage areas served.

The primary method used for comparability with data collected by D.E.Q.E. was the "Modified A-1" test (APHA, 1985). A 5-tube, 3, 4 or 5 dilution series (5-dilution series was used for stormwater analyses) was performed with results obtained from a standard MPN table. In addition to fecal coliform density determination, the presence of Escherichia coli was determined by adding 4-Methylumbelliferyl-beta-D-glucuronide (MUG) to the nutrient broth. E. coli produces glucuronidase, an enzyme that hydrolyzes MUG to yield a fluorogenic product. The presence of E. coli was determined by observing for fluorescence using a hand-held long-wave ultraviolet light following the determination of fecal coliform. Tests for fecal coliform using MFC Agar (Difco) were also performed for comparison with A-1 methodology as well as for the purpose of supplemental sampling where freshwater fecal coliform densities were to be determined. In addition to fecal coliform tests, in certain situations, enterococci, fecal streptococci and Clostridium perfringens densities were determined in order to evaluate their utility in determining contamination sources. Enterococci media was prepared after Levin et al. (1975) and Cabelli (personal communication). Streptococci were determined using Difco media and incubated in accordance with Standard Methods (APHA, 1985). Media and methods for the determination of Clostridium perfringens spores were performed after Bisson and Cabelli (1979).

Six stormdrains representative of various land usages were chosen for monitoring during eight storm events. Samples were taken by immersing a sterile sampling bottle in the discharge flow from the pipes at discharge points for the drains designated as Electric Ave (Code #3)., State (Code #27), Jefferson Shores (Code #26), Red Brook Drain (Code # 16), and Puritan Ave (Code #8) (APPENDIX 1). Due to the normal occurrence of a tide which submerged the drain at the discharge point, the Wychunus drain (Code #17) was sampled at the distal-most road drainage basin. A rain gauge was placed at the mouth of Red Brook and served as a indicator as to time of sampling.

During the initial two storms (5/22/86 and 7/2/86), sampling was conducted during the "first flush" period (within 30 minutes from the beginning of the rain event), and following at least 0.64 cm (0.25 inches) of precipitation. Since there was no consistent first flush effect as described by Whipple et al. (1983), it was decided to that the first flush sampling effort would be discontinued and effort would be realigned to include additional rain events (a total of eight). Subsequent sampling at discharge points on 7/21, 7/30, 8/11, 10/2, 11/5, and 12/19 was performed as soon after 0.64 cm of precipitation as possible.

For the purpose of estimating the fecal coliform loading from stormdrains, the volume of runoff entering the bay from impervious surfaces was estimated. The impervious surface area serviced by each stormdrain was first calculated by walking the area with an odometer calibrated to the nearest linear foot and measuring the width of each road section. Stormwater volume was then calculated using the formula:

$$V = A \times P(100)$$

where V = the volume of stormwater from each drain (cu. meters), A = the impervious surface serviced by each drain (sq. meters) and P = the amount of precipitation in cm. The geometric mean fecal coliform densities of the six drains combined (fecal coliform/100 ml x 10^4) were used to calculate the fecal coliform loadings for each rain event monitored.

Eleven routine sampling stations throughout the bay (Figure 3.) were chosen for monthly monitoring from September, 1985-October, 1986. Samples were taken during the mid phase of the outgoing tide with the prerequisite of having no significant rainfall during the prior 72 hrs. Samples were taken by wading or means of boat where the bottom depth was at least 1 meter. The sampling distance from the surface of the water was 30-40 cm with the exception of samples taken near the mouth of Red Brook where a stratified sampling design was used. At this station, 1 sample was taken approximately 15 cm from the surface and a second sample was taken 60-90 cm from the surface. Mid-bay sampling stations were omitted during winter months due to navigational difficulties associated with ice cover.

Groundwater samples were taken using a shallow well-point sampler with a slotted well point. Using a vacuum pump, approximately one liter of water was evacuated from the well into a sacrificial bottle. Following this procedure, a sterile bottle was connected to the device and a sample was withdrawn and analyzed.

Sediment samples were taken using two methods. For a comparison of sediment vs. overlying water vs. shellfish meat, approximately 1 m^2 of bottom was disturbed and a sample was taken within the turbid water boil. Following MPN analyses, a determination of the amount of sediment suspended per 100 mls of sample was made by filtering a well shaken sample through a weighed filter for the determination of sediment weight and subsequent translation of results into number of fecal coliform/gram of sediment. For analyses of bottom sediments near marinas sediment samples were taken using a ponar dredge . Upon bringing the sample to the surface and depositing it in a sampling tray, approximately the top 2 millimeters were scraped off with a sterile tongue depressor and placed in a solution of sterile phosphate buffered water for analyses. Determination of fecal coliform per gram of sediment was made using the method previously described.

All samples were stored in ice following collection and were analyzed within six hours of collection.

To determine the use of the bay by waterfowl, eight shore observation sites were chosen which allowed for a complete waterfowl census of the bay. Waterfowl counts were generally conducted between 0700 h and 1000 h on a weekly basis.

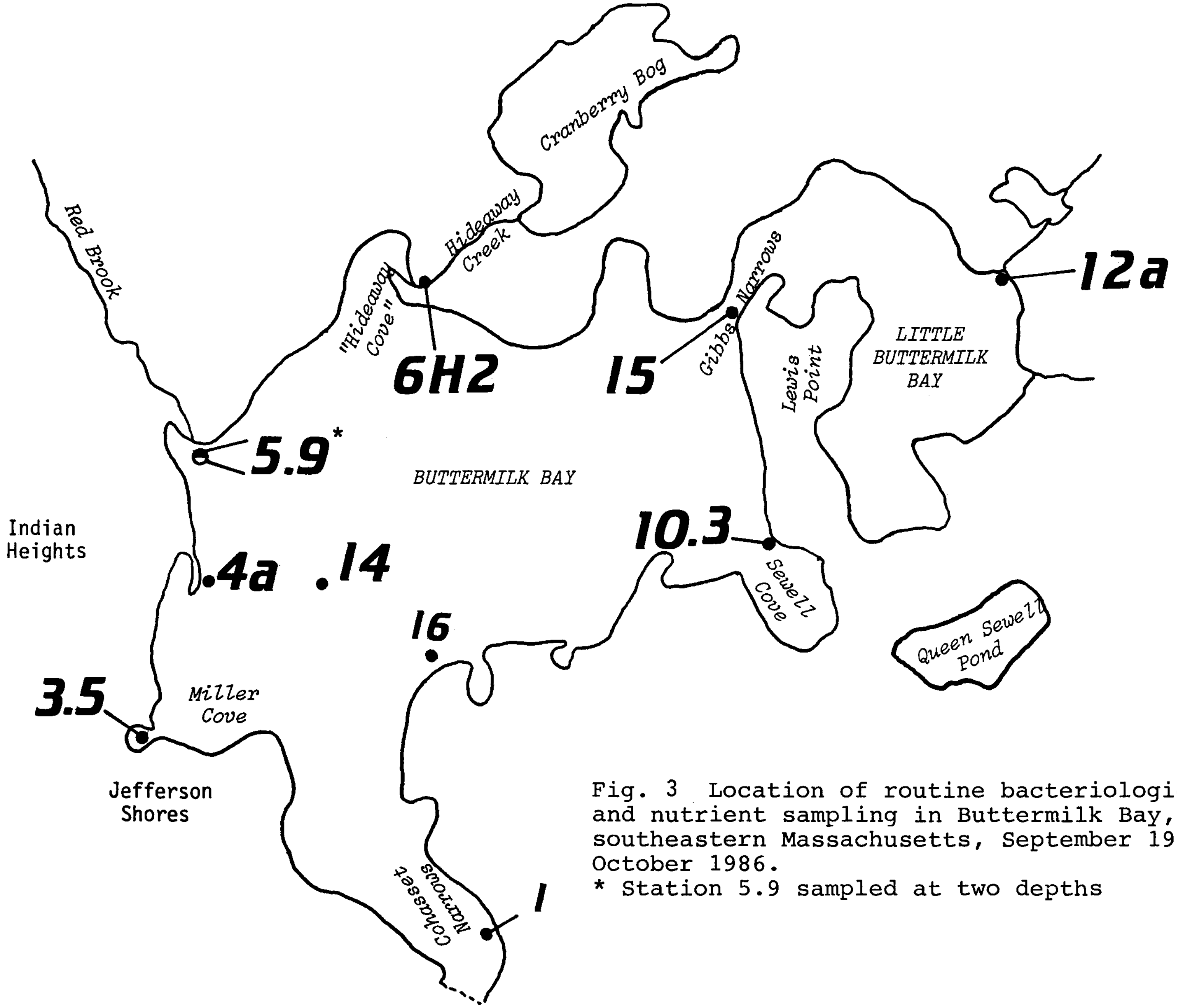


Fig. 3 Location of routine bacteriological and nutrient sampling in Buttermilk Bay, southeastern Massachusetts, September 1985-October 1986.
* Station 5.9 sampled at two depths

Waterfowl were separated into the categories of ducks, geese and swans for the purpose of estimating fecal coliform loadings.

Viability of various animal feces deposited in the area was approximated using two methods. Initially, the location of waste deposits were marked and subsampled at various intervals. One gram samples were placed in 99 mls of sterile buffered water and samples were processed using the MPN technique previously described. Fecal coliform content in organisms per gram were thus determined. In addition, during autumn, 1986, fresh goose feces was placed in the strand line in anchored nylon mesh bags (365 micron mesh) and subsampled at selected intervals.

RESULTS

STORMWATER

The presence of large numbers of bacteriological indicators and pathogenic organisms in stormwater runoff is well documented (Olivieri et al. 1977). As shown in Long Island, New York, the impact of this type of bacteriological contamination in recreational-use areas is often substantial (Koppelman and Tanenbaum 1982). In what is perhaps the most comparable portion of the National Urban Runoff Program (NURP), these investigators have concluded that, in Long Island, stormwater runoff is "generally the single most significant source of pollution, especially bacterial pollution, affecting the fresh surface waters and nearshore marine environment". Runoff to estuarine waters of Nassau County, New York has been implicated as the primary source of bacterial loading to all but one of the nine embayments.

Although the mechanisms responsible for increased fecal coliform levels in receiving waters following rain events are not fully understood, the negative affect of stormwater runoff on Buttermilk Bay is unquestionable. A summary of selected "open water" stations sampled prior to, during and following a rain event (FDA-DEQE, 1985) clearly shows increased fecal coliform levels in response to rainfall (Fig. 4). This phenomena has been observed elsewhere (Gerba and Shaiberger 1973, Hill and Grimes 1984, Schillinger and Gannon 1985, Koppelman and Tanenbaum 1982) and is the primary reason for a number of areas in Massachusetts being classified as unacceptable for shellfish harvesting (D.E.Q.E, S.E.R.O. - personal communication). Stormwater impacts on receiving waters can be classified into three main categories which are discussed separately:

1.) Impacts from direct stormwater discharges and overland runoff.

2.) Release of coliform from protected reservoirs.

3.) Surcharge of receiving waters with contaminated groundwater.

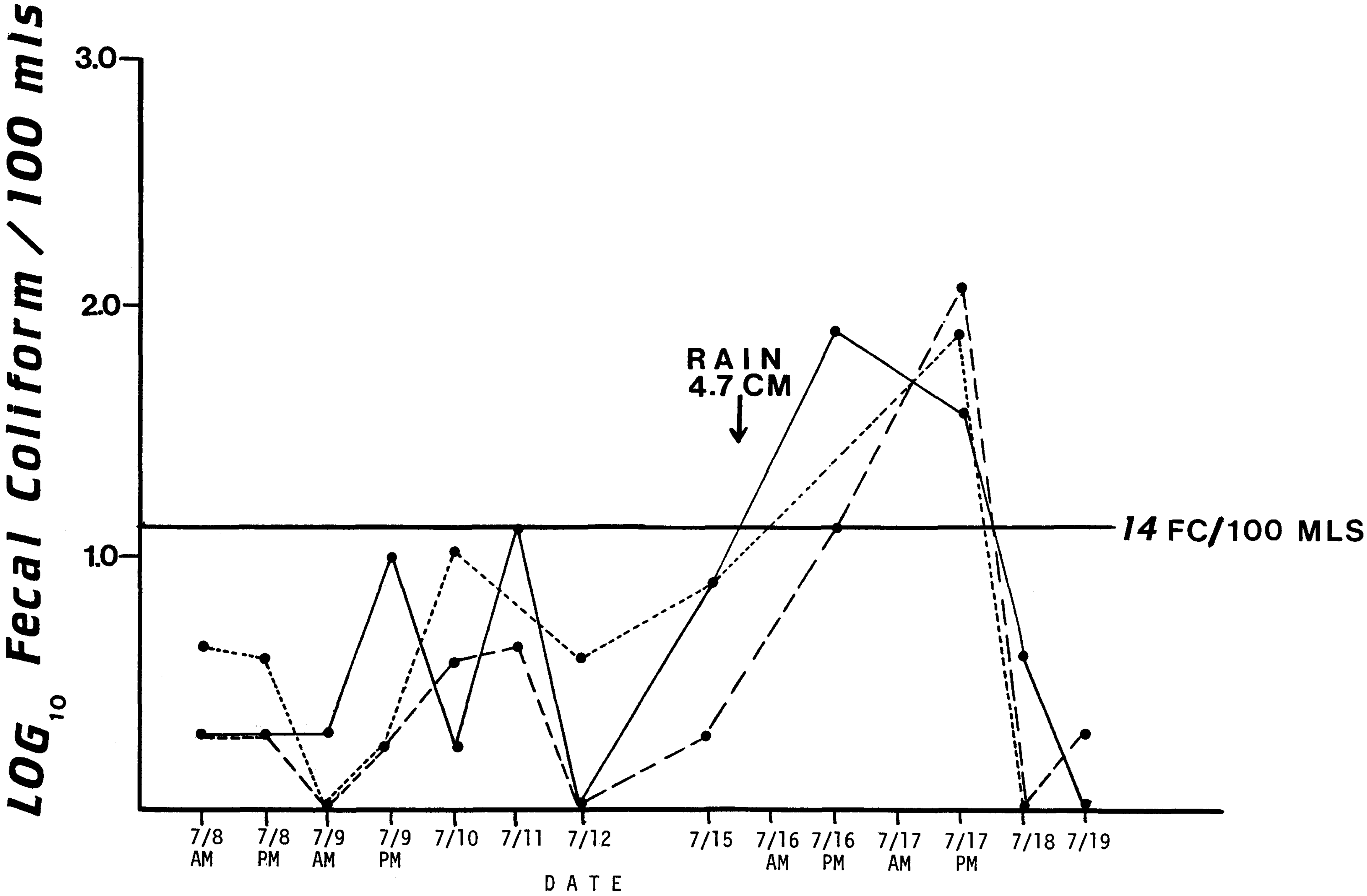


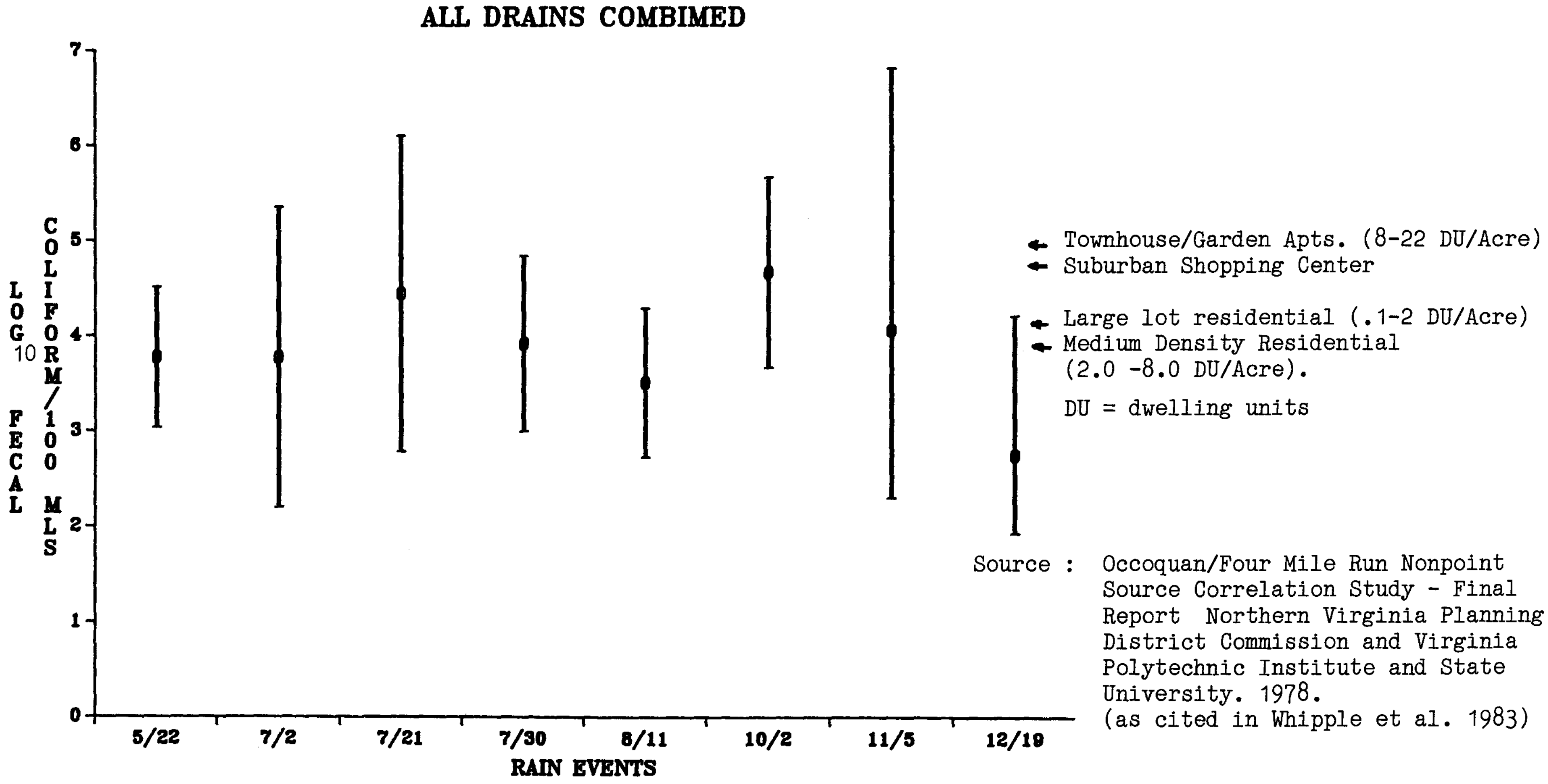
Figure 4. Fecal coliform densities observed at selected sampling stations during a joint FDA - DEQE survey of Buttermilk Bay, southeastern Massachusetts, July 1985.

Impacts from stormwater discharges and overland runoff

The area around Buttermilk Bay is serviced by at least 20 drains discharging directly into the surface waters. The impervious surfaces (primarily roadways) amount to approximately 80,620 sq. m (867,800 sq. ft). Following a 2.54 cm (one-inch) rain, approximately 2050 cu. m of stormwater is directed to the bay from man-made conduits. Using geometric mean fecal coliform densities observed during 1985 (Figure 5), volumes of water between 4.6 x 10^5 cu. m and 1.1 x 10^7 cu. m would be required to dilute the incoming stormwater runoff from impervious surfaces to a level of 14 fecal coliform/ 100 ml following a 2.54 cm rain (these values are only used as a reference). To place these coliform loading values in perspective, assuming that the tidal prism for Buttermilk Bay is 2.5 x 10^6 cu. m, the incoming stormwater entering the bay from impervious surfaces during a 2.54 cm rain event would require between 18 % and 440 % of the tidal prism for dilution to the 14 FC/ 100 ml standard. In reality, using this simplistic approach to predict the number of tidal exchange volumes necessary to dilute the incoming stormwater to acceptable level is likely invalid. Simple water-parcel transport computer models supplied by the Boston University Geology Department (APPENDIX II) indicate that the extent of penetration of contamination from drains near the mouth of Buttermilk Bay (such as the Electric Avenue Drain) and hence the ultimate passage of contamination back out of the bay, is highly dependent on the stage of tide during which the contamination is introduced.

In all instances where fecal coliform were isolated from stormwater, further differentiation using MUG indicated that the fecal coliform involved was *E. coli*. Reference throughout this section, however, is retained as "fecal coliform" for clarity in comparison with the standard used in classifying shellfish harvesting areas.

Geometric mean fecal coliform densities (all drains combined) observed in Buttermilk Bay drains (Figure 5) generally compare with values observed elsewhere (Whipple et al. 1983). While the variability of the data is considerable (Figure 6), some generalization can be made relative to coliform loading and land use. In general, fecal coliform densities observed at the "State" drain, typical of commercial-use land, were lower than those observed at drains servicing residential areas (all other drains sampled). Among the remaining drains monitored which serviced residential areas, the highest fecal coliform densities were observed at the "Wychunus" and "Red Brook" drains compared with the "Electric Ave.", "Jefferson Shores" and "Puritan Ave." Concomitantly, the areas serviced by the Wychunus and Red Brook drains are more intensively developed (ca. 20 units/ha or 8 dwelling units/ acre) compared with areas serviced by the



Source : Occoquan/Four Mile Run Nonpoint Source Correlation Study - Final Report Northern Virginia Planning District Commission and Virginia Polytechnic Institute and State University. 1978. (as cited in Whipple et al. 1983)

Figure 5. Geometric mean fecal coliform densities in stormwater entering Buttermilk Bay, southeastern Massachusetts from six selected drains. Fecal coliform were further differentiated and identified as *Escherichia coli*.

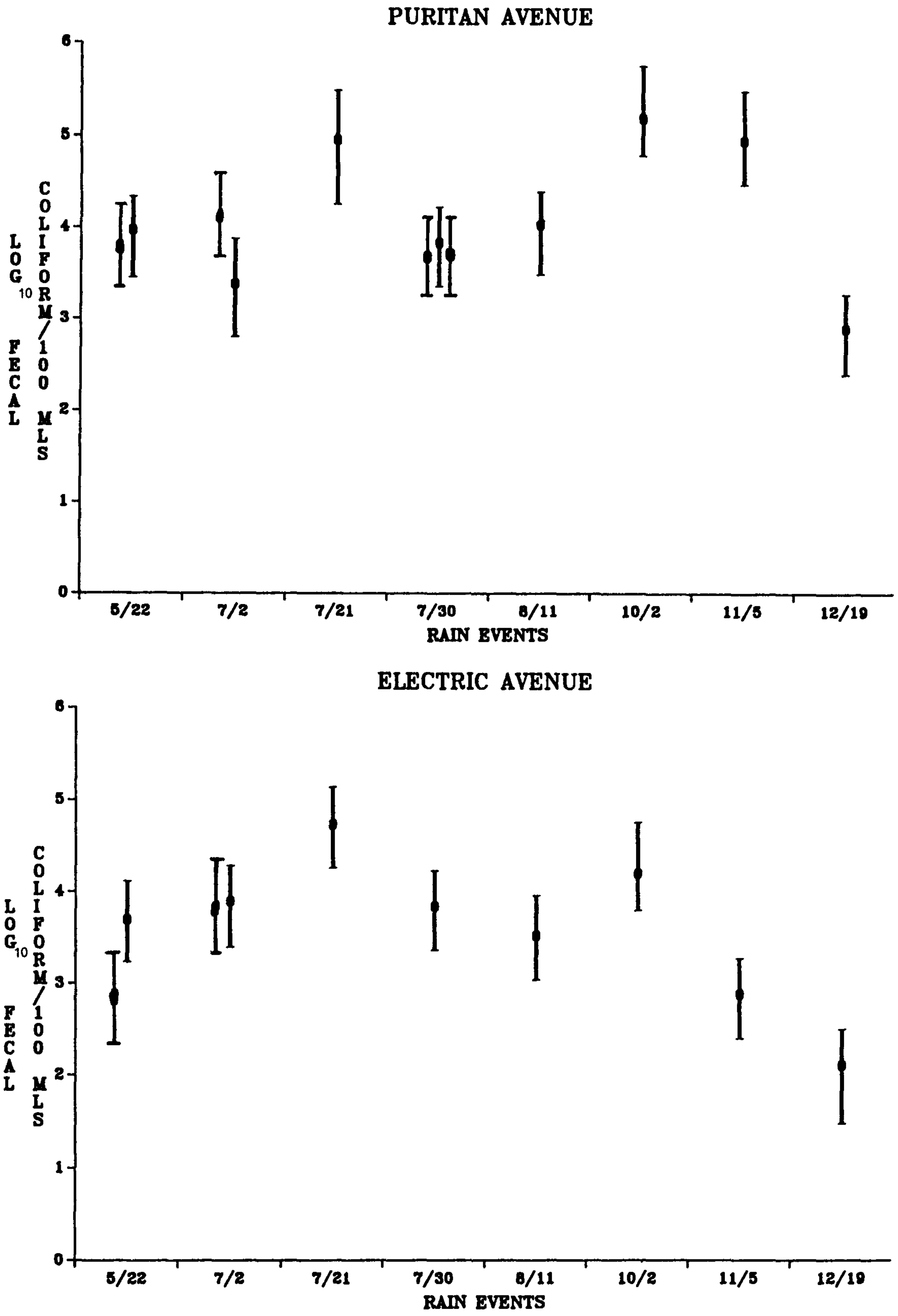
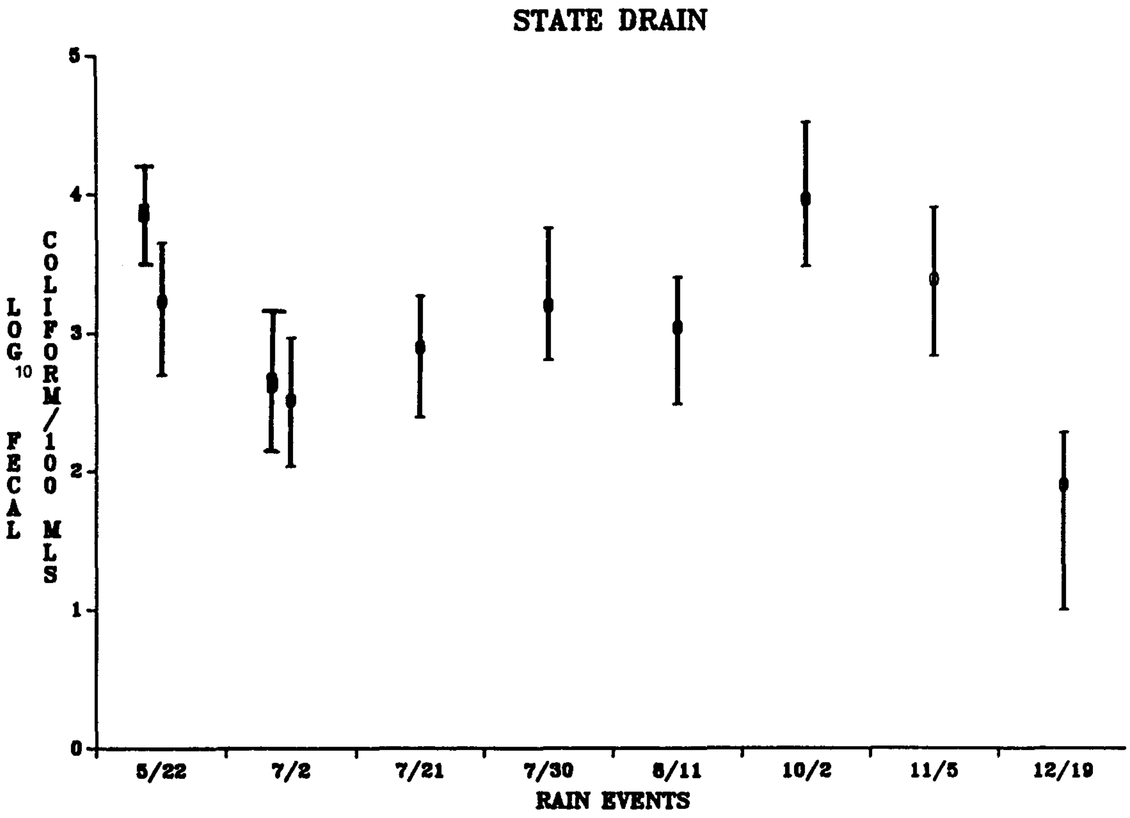


Figure 6 Fecal coliform densities observed at selected stormwater discharge points in Buttermilk Bay during 1986. All fecal coliform were further differentiated as Escherichia coli.



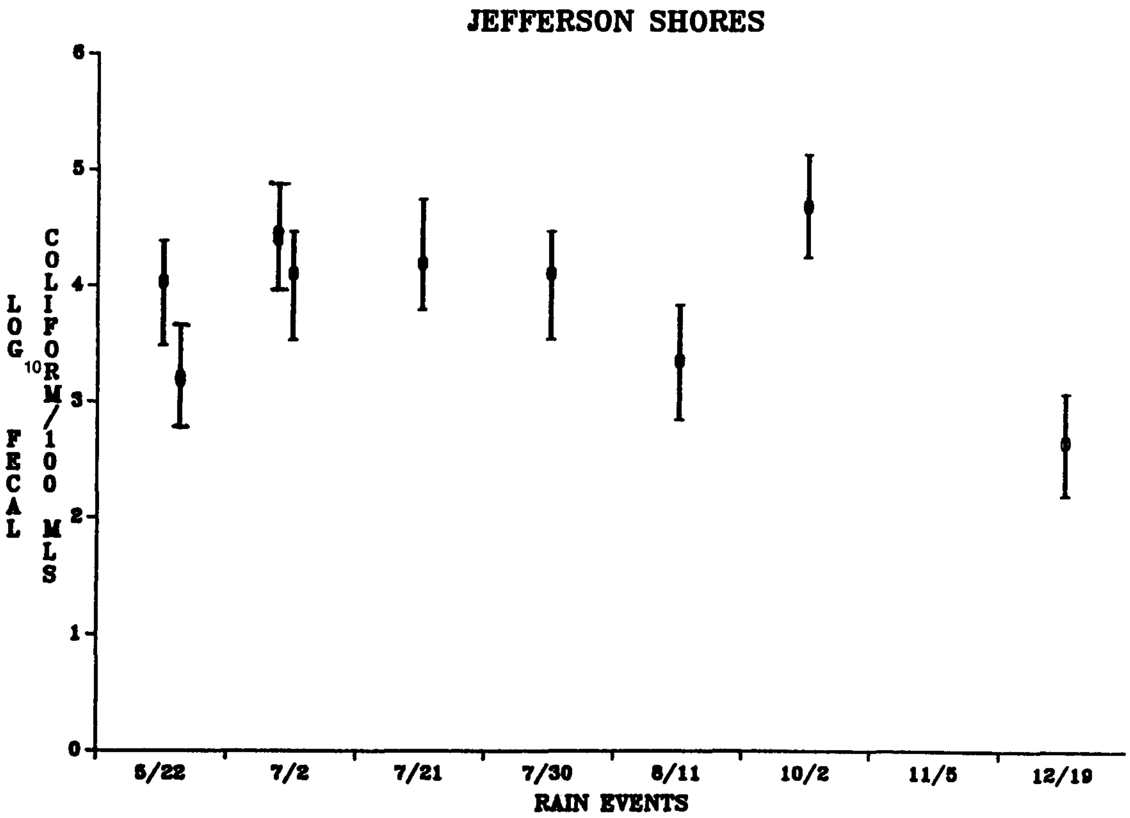
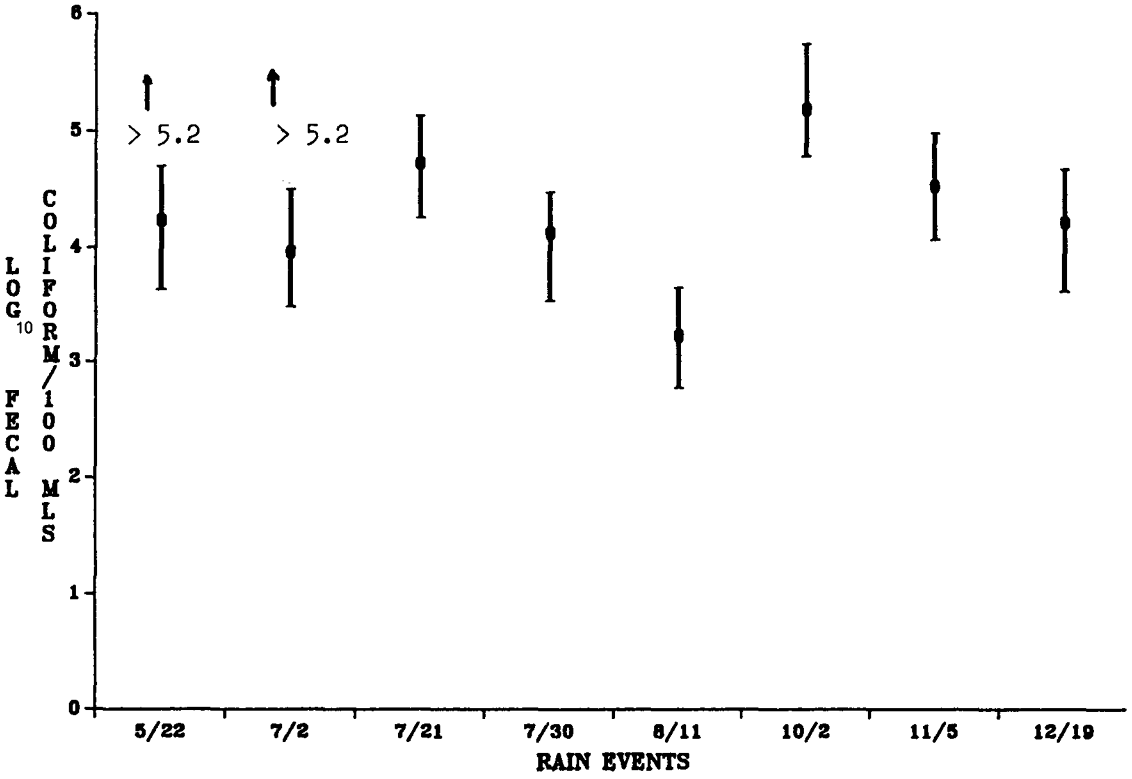


Figure 6 - continued


RED BROOK DRAIN

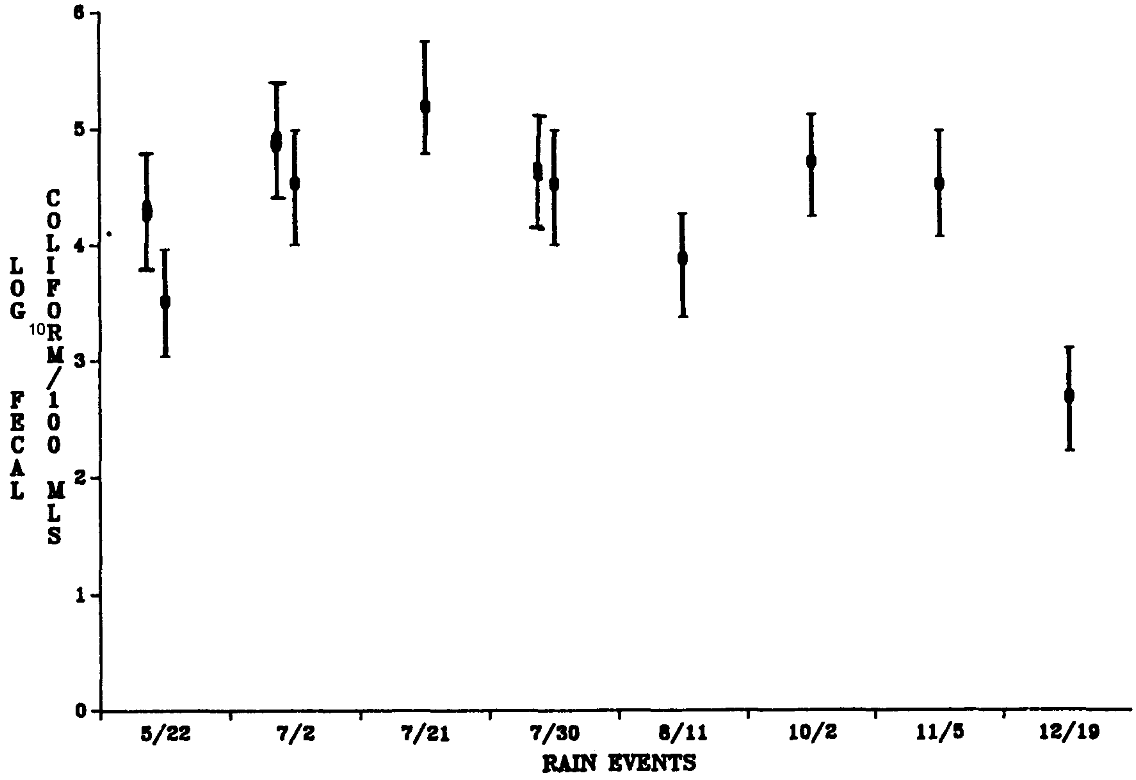

WYCHUNUS AVENUE

Figure 6 - continued

remaining "residential" drains which are less intensively developed (< 20 units/ha). These findings are supported by the Northern Virginia Planning Commission and Virginia Polytechnic Institute and State University (as reported in Whipple et al. 1983) and data summarized by the North Carolina Division of Environmental Management (1986) and suggest that the degree of residential development directly affects fecal coliform contamination within areas serviced by surface drains (Figure 6).

In addition to intensity of land use in areas serviced by a drainage system, two additional factors were identified which also affect the fecal coliform loading of surface drains. In five of the six drains sampled on August 11, 1986, coliform densities had decreased compared with the prior sampling date (July 30). Meteorological data for the prior ten days indicated that total rain in excess of 3.5 cm had fallen on three dates during this period (Figure 7). These data suggest that the time required for accumulation of fecal coliform source material (pet, rodent, bird feces etc.) was considerably less than the other dates sampled, resulting in decreased fecal coliform densities during the August 11 rain event. Converse to the situation where numerous rain events in succession prevent the excessive accumulation of source material in areas serviced by surface drains, samples collected on October 2, 1986 at all six drains sampled showed higher fecal coliform densities than during either of the two prior rain events (July 30 and August 11). An examination of meteorological data for September indicates that only one significant rainfall had occurred during the entire month (1.7 cm on September 16- Figure 7) prior to the October 2 sampling date. In addition, rainfall for the entire month of September did not exceed one inch. These data suggest that the fecal coliform densities at discharge points for surface drains will depend, in part, on the interval of time since the previous rain.

In addition to the the frequency of rain events, data collected during a December 19 rain event suggest that decreased air temperatures may serve to reduce the fecal coliform loading from surface drains. Although there were two substantial rain events within two weeks prior to sampling (1.6 cm on December 10 and 1.3 cm on December 12), we feel that the degree of attenuation on this date exceeded what would be expected from the single attenuating effect of preceding rain events. For comparison, data collected during two July rain events indicate fecal coliform densities more than one order of magnitude greater than those of December 19, this despite a greater amount of rainfall (Figure 7) on dates more approximate to those of the December 19 rain event.

Intensity of rainfall was not shown to correlate with geometric mean fecal coliform densities observed at stormdrains, however, confounding influences imparted by seasonal effects, and the frequency and proximity of previous rainfalls may preclude a definite statement regarding the effect of this factor. Fecal coliform densities during the July 21 rain event,

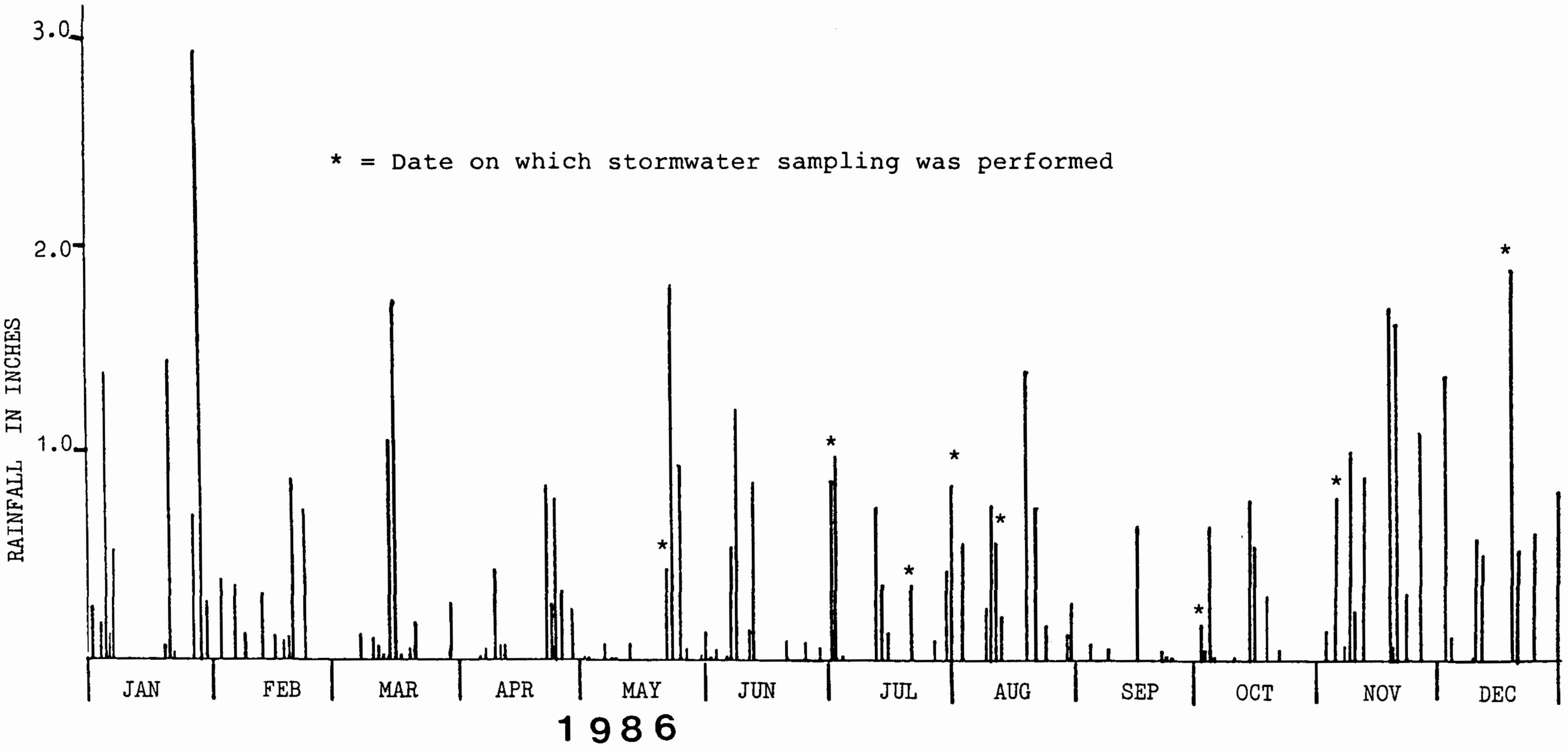


Figure 7 Summary of precipitation near the Buttermilk Bay study area Southeastern Massachusetts, as recorded (in inches) at the Cranberry Experimental Station, Wareham, Massachusetts. * indicates dates on which samples were collected at selected stormwater discharge points in the bay.

when the rainfall was 0.1 cm/h (as determined by the rain gauge at the mouth of Red Brook) were higher than those observed on May 22 and July 2 when the rate of rainfall was 0.48 and 0.69 cm/h respectively. Conversely there were other dates such as August 11 (0.1 cm/h) and December 19 (0.2 cm/h) on which lower precipitation rates resulted in lower geometric mean fecal coliform densities in discharge water.

Substantial seasonal differences in fecal coliform counts in stormdrains have been observed elsewhere (EPA 1983). NURP studies report that coliform densities in urban runoff during warmer periods of the year are approximately 20 times greater than runoff during during colder periods. As in our study, the observed seasonal differences could not be related to comparable seasonal variations in land use. Two drains chosen (Electric Ave. and Puritan) have comparable occupancy of dwellings throughout the year, yet still exhibited seasonal variation in fecal coliform densities.

Despite numerous studies nationwide under the National Urban Runoff Program and others (Olivieri et al. 1977 and Van Donsel et al. 1967), there still remain many unanswered questions regarding the actual source of fecal coliform in runoff. Although in the Buttermilk Bay area, the possibility of direct connection of sanitary waste lines with stormwater conduits can not be completely discounted, two observations strongly suggest that if sanitary waste does make its way into the collection system it is by less overt means (ie. surcharging of drainage basins by adjacent septic systems). Firstly, all storm drains were observed during peak land use periods (June - August), which were concurrently dry periods, for the presence of running water. The inspection was systematic and involved all surface drains from the distal to proximate portions of the surface drainage areas. With few exceptions, which were verified by bacteriological examination not to be due to sanitary waste, all drainage basins remained dry during dry weather. In addition, all collection pipes generally exhibited little or no flow within approximately two hours following the cessation of rain. If direct discharges of sanitary wastes were present, we would expect at least some continual flow into the collection system; this phenomena was not observed.

Comparison of fecal coliform values observed in our area with those reported by Olivieri et al. (1977) gives support to our contention that direct input of sanitary wastes via subterranean pipes would not be necessary to account for the fecal coliform values observed from discharge pipes in our study area. In this author's report of two drainage basins in which "no sewage overflows are known to be located", geometric mean densities (MPN) of 8.3×10^4 Fecal Coliform/ 100 mls ("Bush Street") and 6.9×10^3 fecal coliform/ 100 mls ("Northwood") were reported. These levels of fecal coliform contamination are quite comparable to those levels observed in our study area (Figure 5). Further, this author's summary of stormwater samples taken in a

North Carolina stormwater drainage basins indicate that, independent of sanitary wastes from sewage systems, fecal coliform contamination of rainwater can occur quite quickly after contact with the earth's surface . Fecal coliform values observed at a roof downspout (trees overhanging) approximated 740 fecal coliform/ 100 mls, and levels approximating 25,000 - 58,000 fecal coliform/ 100 mls of sample were observed from overland flow through a residential area (Betson and Buckingham 1969 as cited in Olivieri et al. 1977). Collectively, these studies suggest that although fecal coliform contamination at stormwater discharge points in Buttermilk Bay may appear substantial, these levels do not necessarily indicate the presence of direct connections between subsurface on-site systems and stormwater collection systems or the input of sanitary wastes via subsurface surcharging of drainage basins with sanitary wastes. It is still possible, however, that some septic systems installed prior to present regulations included a connecting overflow which functions only during rain events, which remained beyond our detection.

Although no in-depth studies have been performed to detail sources of fecal coliform in stormwater runoff in areas where sanitary connections are not suspected, certainly animals residing in the surface watershed are implicated. In excess of 100 dogs live within the surface watershed of Buttermilk Bay (based on July 1986 survey). In-situ investigations of the viability of dog feces in July- August 1986 indicated that at 1 week, 2 weeks and 30 days, the viabilities of dog feces deposited near the beach in overgrown areas were not significantly different. In each instance the MPN fecal coliform densities were 10^6 fecal coliform/gram of feces. Thus, the cumulative affect of just dog wastes can be quite substantial. To place the possible effect of dog wastes in perspective, an overall geometric mean fecal coliform concentration in stormwater (all dates, all drains combined) was calculated and the amount of canine fecal waste necessary to account for this value was calculated. Considering an overall geometric mean fecal coliform concentration of 7,349 FC/ 100 mls and the resulting input of fecal coliform to the bay of 1.5×10^{11} during a 2.54 cm (1 inch) rain, the amount of dog wastes necessary to account for the loading would approximate 150 kg (331 lbs.). It is conceivable that this amount of waste could be deposited by the resident dog population in 2-3 days, assuming a 454 gram/dog/day deposit from the estimated 100 dogs residing in the areas serviced by stormdrains.

The ability to predict fecal coliform loadings from domestic dogs, using these values is precluded by the complexities of the factors affecting the actual transport of viable organisms to the bay. The extent to which adjacent animal populations impact a water body are controlled by at least two factors: the probability of the wastes becoming entrained in stormwater entering the bay, and the survival characteristic of the waste following deposition. Regarding the probability that animal wastes are entrained in stormwater, the primary intermediating factor is the percent of impervious area in the drainage basin (paved surfaces) as well as the drainage characteristics of the remaining "natural" area (primarily lawn and landscaped sites of residential areas). Residential properties serviced by stormdrain systems surrounding the bay for the most part have their drainage patterns modified in such a way as to increase the probability that surface-deposited wastes will be entrained in stormwater entering the bay. These practices include landscaping which slopes from the house to the street, a sloping of driveways toward the street, and in some instances the diversion of rooftop drainage into the paved roadways. While these practices have beneficial purpose and prevent the flooding of properties, they concurrently allow for a more expedient pathway of surface-deposited wastes into the receiving waters.

Another essential element determining the impact of animal populations on adjacent water bodies is the survival characteristic of the wastes following deposit. The extended survival of fecal indicators observed in the present study and elsewhere (Temple et al. 1980, Edmonds 1976), suggests the possibility of substantial cumulative effects which must be considered in attempts to predict the fecal coliform loading from domestic dogs and other wildlife inhabiting the surface drainage basin of Buttermilk Bay (rodents, birds, rabbits etc.). The factors controlling the survival rate of indicator organisms in surface-deposited wastes are solar radiation (Bell 1976, Bell et al. 1976, Van Donsel et al. 1967), temperature (Boyd and Boyd 1962, Edmonds 1976, Van Donsel et al. 1967, Weiser and Osterud 1945) and moisture (Brown et al. 1979, Weiser and Osterud 1945). While for the most part these factors are beyond man's influence, the drainage system itself does provide a man-made environment for the protection of deposited wastes as well as possible habitat for additional wildlife such as rodents.

The effect of temperature on the survival of fecal coliforms noted by various authors may provide insight to the apparent dramatic decrease in stormwater contamination observed in December as well as decreases in stormwater loading during winter months observed elsewhere (Faust et al. 1975). While frozen ground generally decreases infiltration and would be expected to increase stormwater loading (Crane et al. 1983), field experiments conducted in the present study, as well as investigation elsewhere (Van Donsel et al. 1967, Weiser and Osterud 1945) suggests that numerous freeze-thaw cycles significantly alter the survival of surface-deposited wastes and hence would attenuate cumulative effects of waste deposit during winter months. In the present study, fecal coliform in goose feces lost viability after 4-5 days on the beach area in winter months, whereas survival exceeding 20 days was indicated in goose wastes during warmer months. Although not quantified, rapid mortality in winter months appeared also to be related to the moisture content of the fecal pellet, with moister pellets exhibiting more rapid die off during the freeze thaw cycles. This would support the conclusions of Weiser and Osterlud (1945) and Kibbey et al. (1978) who hypothesized that extracellular ice damage was the mechanism involved in mortality of E. coli at freezing temperatures.

Thus, it appears plausible that the fecal coliform levels observed at discharge points in Buttermilk Bay are the result of a resident pet and wildlife animal population, although no conclusions could be drawn regarding which of these was the major contributor. The effects of the resident animal population are emphasized by an extensive drainage system which opens considerable surface deposit area to direct discharge to the bay. This effect is further accented by land use practices necessary for the prevention of excessive flooding of residential areas. These contentions appear to be substantiated by study elsewhere under the National Urban Runoff Program and others which found that intensity of land use in a surrounding watershed has a negative impact on stormwater quality, often unrelated to actual input of human sanitary wastes. Although it is known that failing subsurface sewage disposal systems (failing to the point where septage is on top of the ground) have occurred in the past (Carl Wakefield, Wareham Board of Health - personal communication) and that these wastes may contribute sporadically to the overland or pipe discharge, in general public awareness and the nuisance aspect of odor associated with these system failures compels their immediate repair.

Release of fecal coliform from protected reservoirs

Within Buttermilk Bay both the sediments and decaying eel grass and other debris remaining after the tide ebbs (henceforth referred to as "wrack") have been determined to act as protected reservoirs and accumulators of fecal coliform. The second major category of stormwater impact to this marine system is the dislodging or elution of fecal coliform contained in these protected reservoirs, which causes their return to the water column and a compromising of the water quality in the area.

The accumulation of fecal coliform in marine sediments has been observed by many investigators (Rittenburg et al. 1958, Sayler et al. 1975, Van Donsel and Geldreich 1971, Volterra et al. 1985, Gerba and McLeod 1976, Erkenbrecher 1981, LaLiberte and Grimes 1982), and was supported by preliminary observations in our study area. Sediment-overlying water samples from selected cites in Buttermilk Bay (Table 1) taken by disrupting the sediments in a 1 sq. m and sampling in the boil suggest two conclusions. Foremost, it appears that certain areas of the bay contain sediments with the capacity to accumulate fecal indicators, and secondly, these fecal coliform can return to the water column by physically disrupting the sediments.

Qualitative observations at the time of sampling suggest that accumulation of fecal coliform in the sediments of Buttermilk Bay was related to two factors: the organic content of the sediment, and the proximity of the area to a contamination source. Samples taken at Electric Ave. (public beach), Sewell Cove and Gibbs

Narrows (in the cut) showed very little organic matter or "fluff" following disruption of the bottom; these samples concurrently showed little difference between the overlying water before disruption of the sediments and after. Samples in the Red Brook area, the area near Hideaway Creek and Station 4 contained light fluffy sediments and concurrently contained higher fecal coliform concentrations in the boil (turbid water sampled after sediment disruption). Proximity to a source as an important factor in determining the fecal coliform content of sediments as was demonstrated by the Gibbs Narrows samples of 8/29/86 and 9/11/86. Although these samples were taken at approximately the same locations, it was noted that on 9/11/86 a large flock of seagulls was feeding on exposed clams in the area during the time prior to sampling. This site had an intermediate degree of organic material in the sediment.

TABLE 1. Overlying water - suspended sediment fecal coliform densities (MPN fecal coliform/ 100 ml sample) from selected sites around the perimeter of Buttermilk Bay, southeastern Massachusetts. All fecal coliform were further differentiated and identified as *E. coli*.

Sample Date	Location	Fecal Coliform per 100 ml Overlying Water	Fecal Coliform per 100 ml Water + Sediment
3/05/86	Hideaway Creek	<2	33 *
3/05/86	Red Brook (Tidal pool)	13	350 *
3/05/86	Electric Ave.	<2	<2
3/05/86	Sewell Cove	<2	<2
3/05/86	Gibbs Narrows	<2	5
3/05/86	Station 4	11	79 *
8/29/86	Gibbs Narrows	5	2
8/29/86	Red Brook Mouth	49	79
8/29/86	Miller Cove	4	21 *
9/11/86	Gibbs Narrows	8	240 *
9/11/86	Red Brook Mouth	27	110 *
9/11/86	Miller Cove	8	2

* Sediment + water sample value outside the 95% confidence limit of the water value as defined by a standard MPN table.

The organic content of the suspending medium has been shown to be an important factor in prolonging the survival of various enteric organisms in marine (Orlob 1956, Vaccaro et al. 1950, Won and Ross 1973), freshwater (Sinclair and Alexander 1984), and terrestrial systems (Mallman and Litsky 1951, Tate 1978). Some investigators, notably Gerba and McLeod (1976), Hendricks (1970) and Hendricks and Morrison (1967) have demonstrated the ability of enteric organisms, including *E. coli*, to utilize nutrients extracted from sediments for growth. Thus is appears that, not only do sediments have the potential for protecting and accumulating fecal coliforms, but they may also support their growth in proportion to the available nutrients. This mechanism gives an added implication to the input of nutrients from on-site subsurface septic waste disposal. While this practice may not result in the actual input of enteric organisms to the bay (see section on Septic Systems), the input of nutrients from this practice which was evidenced (Valiela et al. 1987), may result in the multiplication of enteric organisms, to include pathogens, in the receiving sediments.

The accumulation of fecal coliform in sediments may result in their resuspension during rainfall events (Schillinger and Gannon 1985, Roper and Marshall 1974). Although the mechanism is unclear, mechanical disruption of the sediments at discharge points for stormwater as well as a more generalized changing of the adsorptive capacity of sediments for bacteria in response to a sudden influx of freshwater is suspected. The ability of fecal coliform to become resuspended following physical disruption has been demonstrated in our study and is supported by Grimes (1975). This may have additional implication for hydraulic clamming operations in areas where the sediments are laden with excessive fecal indicators. A single set of samples taken in October, 1968 amidst a hydraulic clamming operation in Gibbs Narrows indicated that in this case, the sediments were not accumulating fecal coliform.

In addition to sediments, deposits left with the receding tide (wrack) which were primarily dead and decaying ellgrass (Zostera marina) were examined for fecal coliform. Large deposits approximating 5-10 kg per meter of beach were common throughout the summer months. Subsampling one gram portions of eel grass by placing it in sterile buffered water and performing tests for fecal coliform (MPN) showed an extremely high degree of variability ranging from below the detectable limit to > 24,000 FC/100 gram. No obvious correlations with area were noted with the exception of very high (>1,000 FC/gram) values which were generally noted in areas where waterfowl, primarily Canada geese, had been observed in days prior to sampling. During the rain event of November 6, 1986 subsamples of approximately 2 kg were taken from six sites (concurrent with stormwater drain sampling) and placed in a sterile tray. The samples were then squeezed to extract the rainwater they had collected and the resulting sample was cultured with MPN methodology. The results are presented in Table 2.

These results suggest that in addition to serving as a protective reservoir for fecal coliform, decaying eelgrass and other matter in the wrack line serve as a diffuse source of bacteria following the percolation of rainwater through it. It is likely that during the following inundating tide, fecal coliform will be released to the bay from this source, possibly resulting in severe degradation of water quality in addition to that imparted by the existing stormdrains. Although the hypothesis has not been tested, it is likely that even under dry conditions, the inundation of contaminated wrack results in some degradation of water quality in the immediate area.

Table 2 Fecal coliform densities in rainwater extract from decaying eelgrass found at selected locations in Buttermilk Bay, southeastern Massachusetts, 1986. Numbers are expressed as fecal coliform per 100 mls of extract.

Location	Fecal coliform/ 100 ml extract
Electric Avenue Beach	13,000
Mouth of Red Brook	2,300
Approximately 30 m from mouth of Red Brook	>16,000
Hideaway Cove	>16,000
Little Buttermilk Bay at Old Head of Bay Rd.	>16,000
Puritan Avenue (near stormdrain)	16,000

Although the source of fecal coliform in dead and decaying eelgrass is not definitely known, wastes from both waterfowl and scavenging animals is strongly suspected. In conjunction with weekly bird census collection discussed later, weekly counts of animal scats on selected sections of beach indicated on an average of 2 dog scats per 100 m of shoreline and an abundance of Canada goose feces (during their presence in winter months and late summer). This fecal matter when rolled into the decaying eelgrass by water motion on the incoming tide is apparently afforded a protected site where fecal indicators can survive for extended periods and possibly multiply.

Due to the variability of the data, no attempt has been made to determine the actual fecal coliform loading from dead and decaying wrack, however it does appear that in certain situations the effect may be considerable.

Impacts from surcharge with contaminated groundwater

Although not specifically studied within the confines of the present study, local increases in groundwater flow velocities associated with rainfall, must be addressed as to their possible implications to bacterial contamination within the bay. Sampling groundwater at selected sites around Buttermilk Bay (Figure 8, Table 3) indicates that groundwater entering the bay does occasionally entrain fecal indicator organisms, although the sources of these organisms were not determined. Since the mortality of fecal coliform released from any source is a function of time, all factors affecting the residence time of fecal coliform in groundwater prior to the release into the surface water must be considered as important in defining the overall impact of contaminated groundwater to the bay. The increased entrainment distance of fecal indicator organisms

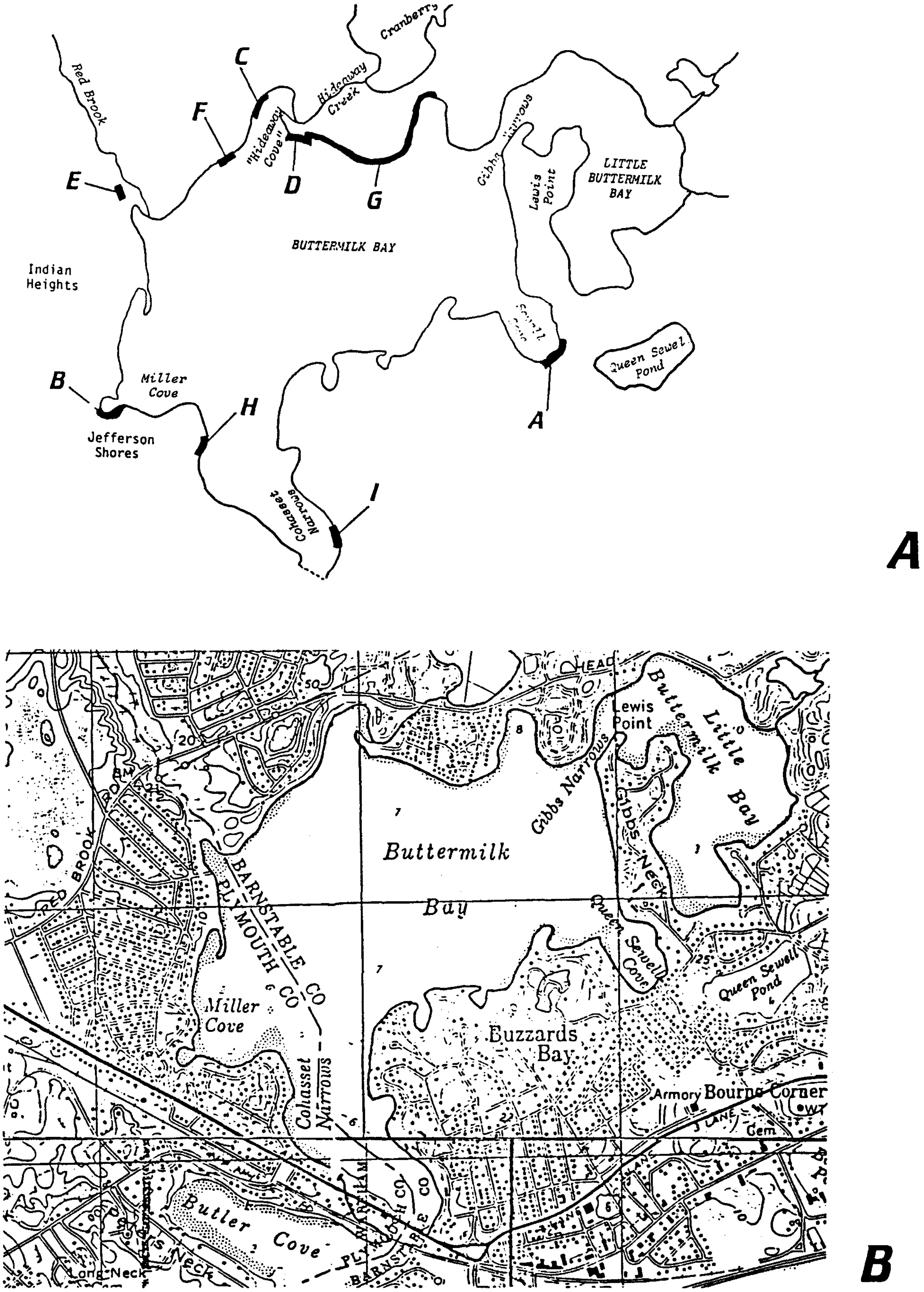


Fig. 8 A) Approximate locations of groundwater sampling stations in Buttermilk Bay, southeastern Massachusetts 1986.
B) Reference map to indicate relative development. Source: USGS, 1979.

following rainfall has been demonstrated elsewhere (Bouwer et al. 1974 and Hagerdon et al. 1978, Bitton and Gerba 1984).

The mechanism by which rainfall expedites the transport of bacterial organisms in groundwater is likely twofold. A primary consideration in bacterial entrainment, as well as virus entrainment discussed later, is the distance of travel of bacteria through an unsaturated vadose zone. Saturated conditions are generally more conducive to bacterial entrainment to groundwater (Moore and Beehier 1984). Under certain recharge or rainfall events, the areas beneath the most probable source of fecal coliform (septic systems) may approach conditions of saturated flow in some situations. If this becomes the case increased numbers of fecal coliform reaching the groundwater, coupled with increased lateral flow velocity of groundwater, could result in more enteric organisms reaching the breakout point in the bay. In addition to the passive role of moving more fecal organisms in a shorter time frame, the flooding of a subsurface system with rainwater, which would have a different ionic characteristic than septic effluent, may cause the elution or desorption of bacteria from the soil matrix as has been observed to occur with viruses (Lance et al. 1976 and Landry et al. 1979).

Thus it appears from studies elsewhere that transport of fecal coliform and other enteric organisms in groundwater is facilitated by recharge events. This phenomena may, in part, account for some of the water degradation observed in Buttermilk Bay following rain events, however results discussed later in this report (see Septic Systems) suggests that this impact is comparatively minimal.

SEPTIC SYSTEMS

Evidence that septic system effluent affects the bacteriological quality of groundwater, often for considerable distances, has been presented from a variety of studies conducted elsewhere. Studies summarized by Hagedorn (1984) indicate the entrainment of various enteric organisms for distances of 0.6-830 m (2-2723 ft) and survival times to 27 weeks. The major factor affecting the entrainment distance of enteric organisms is the soil type. Factors most important in determining the survival of enteric organisms in subsurface soil systems are defined as moisture content, moisture holding capacity, temperature, pH, organic matter and competition/antagonism from soil flora (Gerba and Bitton 1984).

In general, these investigators conclude that the greatest survival of enteric organisms in soil systems occurs in conditions of moist soils with good moisture-holding capability at low temperatures in more alkaline soils (pH above 5) that are devoid of normal flora. In addition, there is evidence that when sufficient amounts of organic matter are present, increased survival and possible regrowth can occur.

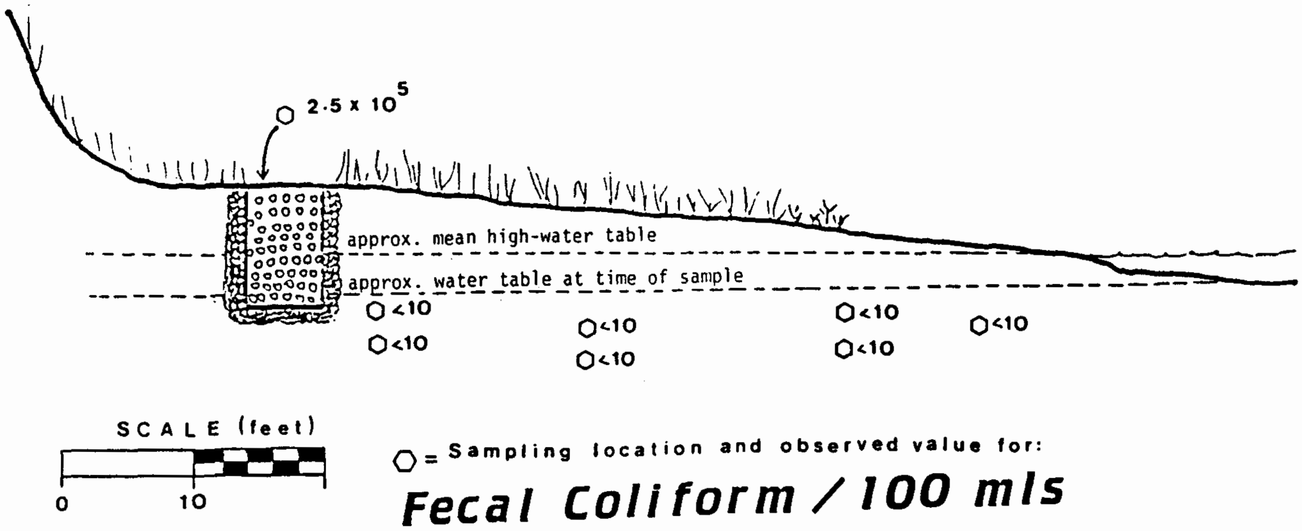
Groundwater sampling in the Buttermilk Bay watershed during 1986 presented conflicting indications regarding the entrainment of bacterial indicators in groundwater entering the bay. The sporadic occurrence of fecal indicators from selected sites around the bay (Table 3, Fig 8.) gave initial indication that organisms can be entrained in lateral flow for at least the distance from the point of discovery to the nearest septic system (ca. 35 m). In some situations, however, where septic systems were less than 5 m upgradient from the sample withdrawal point, no fecal indicators were isolated from samples taken. Further indication of very limited mobility of fecal indicators in soil came from an in-depth study of a septic system located in a periodically-saturated flow situation and a septic system located located within 70 cm of groundwater. The first septic system was chosen due to the fact that during a portion of the tidal cycle, the zone surrounding a portion of the system was saturated, and thus would be most conducive to indicator organism entrainment in groundwater. The system would be classified as "operating" even though at the time of our study it was under administrative orders for repair due to the potential for contamination of the bay. The fluid level in the second leaching element of this system was near the top of the element suggesting that aging of the system had significantly impaired its leaching ability. Nutrient analyses (Valiela et al. 1987) were used to confirm the sampling locations as being within the boundries of a septic plume.

Sampling at this first site on two dates (Table 3, Figure 9) indicates very efficient removal of fecal indicators by soil (>99.99 % removal) within 7 m of lateral flow, with further indication that the major removal takes place within 2 m. The limited entrainment of fecal indicators has been reported elsewhere utilizing various soil types. Using soils of 80%, 41% and 7.6 % sand, Brown et al. (1979) observed that, on only a few occasions were fecal indicators isolated from effluent 120 cm below septic leaching lines. Under saturated conditions, Hagedorn et al. (1978) indicated that wells 3,000 cm downgradient from a fecal coliform source did not show the entrainment of this indicator. In what is perhaps the most comparable study design to the area of Buttermilk Bay, Vaughn et al. (1983) only rarely detected coliform at lateral distances greater than 1.52 m from a leaching pool having coliform densities of 10^5 - 10^8 organisms/ 100 ml. Collectively, these studies suggest that sand, even of very low clay content is an efficient restrictor of bacterial indicator entrainment.

The second septic system investigated was located on the western shore of Buttermilk Bay and again only showed limited entrainment of indicator bacteria (Figure 10).

In light of data indicating both very limited entrainment of bacterial indicators as well as entrainment to distances of 35 m or more, we can only conclude that site specific information on a more substantial number of septic systems in the area would be

SEPTIC SYSTEM SURVEY



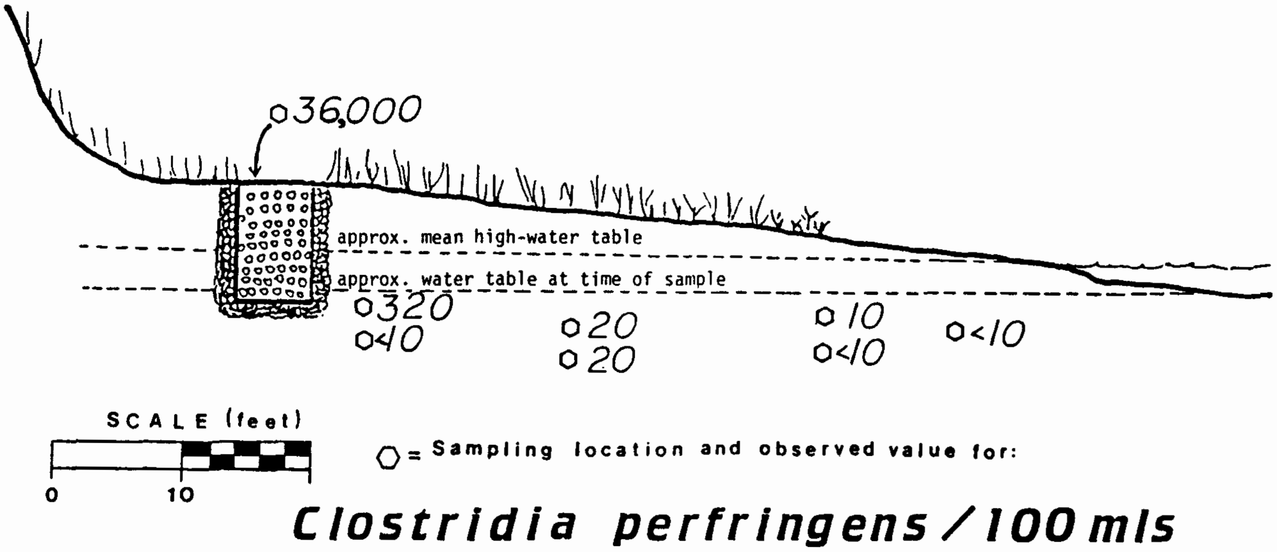
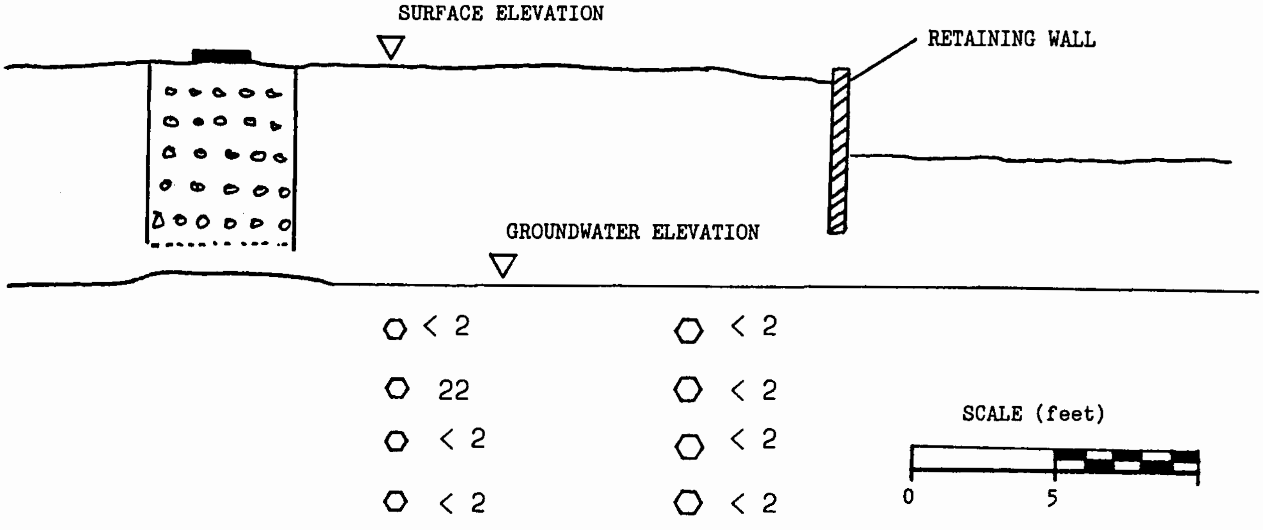
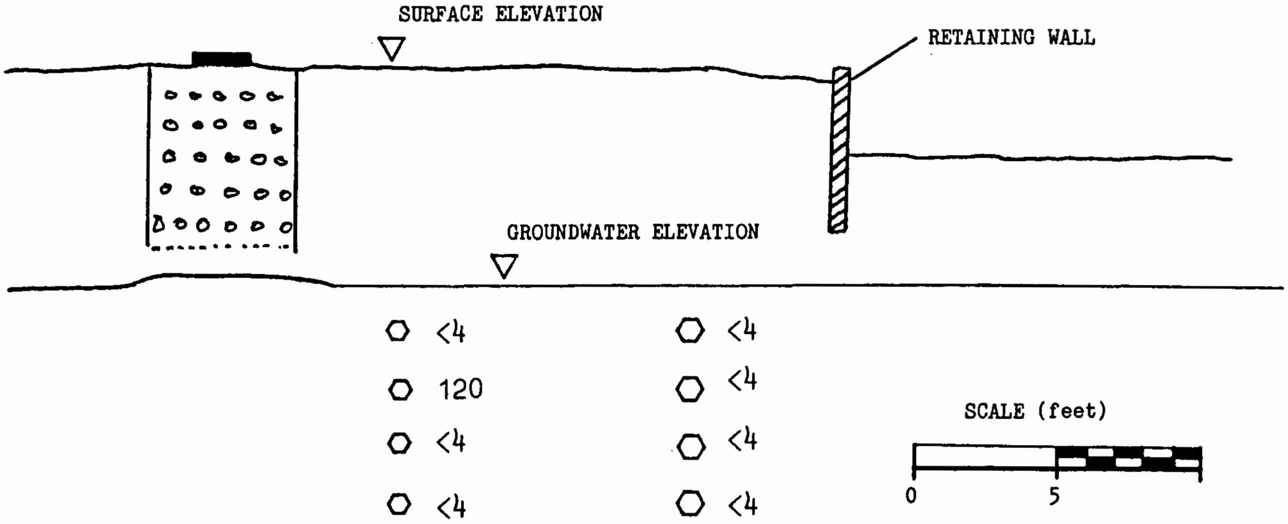


Fig. 9 - Results of groundwater sampling near a subsurface sewage leaching facility - Location F - Figure 7, September 9, 1986



⬡ = Sampling location and observed value for:

Fecal Coliform / 100 mls



⬡ = Sampling location and observed value for:

Clostridia perfringens / 100 mls

Fig. 10 - Results of groundwater sampling near a subsurface sewage leaching facility on Western shore of Buttermilk Bay in July 1986.

necessary in order to assess the overall effect that on-site subsurface sewage disposal practices have on the area as a whole. It is our general conclusion that the direct contribution of fecal bacterial indicators from subsurface systems via the groundwater route is fairly minimal. In contrast, however, the effect of on-site sewage disposal in relation to virus and nutrient contribution in groundwater, discussed later in this report, likely has the more substantial negative impact on surface water quality in the bay not suggested by the traditional fecal indicator system. Study is presently underway which will sample a larger number of septic systems, which should refine our assessment of impact from this type of source.

Table 3. Summary of groundwater analyses performed in Buttermilk Bay, southeastern Massachusetts, 1986. Samples were taken near the high-water mark using a shallow-well point sampler at a depth of approximately 1 m. All fecal coliform densities reported as number per 100 mls of sample. For Locations refer to Figure 8.

Location	Date	Sample size	High Value observed FC/100 ml	Number of positive tests	Log_{10} Mean value	Nearest suspect source
A	5/20	9	130	3	14	ca. 25 m
A	6/9	9	110	2	15	ca. 25 m
B	6/23	8	7	4	3	ca. 35 m
C	6/24	8	<10	0	0	ca. 25 m
D	6/24	3	<10	0	0	ca. 10 m
A	6/25	4	11	1	11	ca. 25 m
H	6/25	4	<10	0	0	ca. 25 m
I	6/25	4	<10	0	0	ca. 15 m
B	8/13	8	279	4	31	ca. 35 m
E	8/13	1	0	0	0	ca. 35 m
F	8/13	2	3	1	3	ca. 1 m
D	8/13	2	3	1	3	ca. 5 m
F	9/3	6	<10	0	0	ca. 1 m
G	9/22	12	0	0	0	5-50 m
B	9/	15	>160	13		ca. 35 m

WILDLIFE

The most obvious source of fecal coliform in the Buttermilk Bay system is the indigenous wildlife. Fecal coliform are present in the intestinal tract of a variety of warm-blooded animals (Geldreich et al. 1962) which inhabit the area, and have also been reported to occur in some fishes (Geldreich and Clark 1962). The implications of this source are substantial since fecal waste from wildlife often enters the system unabated by any land treatment. In general, fecal coliform loading from wildlife has two main components: direct fecal deposits resulting from use of the bay by aquatic-oriented species and fecal matter which results from terrestrial deposition, which subsequently washes into the bay with stormwater. This latter component could be expected to receive some treatment in its overland passage to the bay, however, there is evidence that some land-deposited wastes contribute to and maintain a protected reservoir of fecal coliform which acts as a diffuse source under certain hydrographic conditions (see "Release of fecal coliform from protected reservoirs").

Following techniques employed by Hussong et al. (1979), theoretical values for coliform inputs from waterfowl on a 24-hr basis were calculated based on weekly waterfowl census data collected from December, 1985 to November, 1986 (Figurell). Per capita, per diem estimates of 10^7 fecal coliform per goose, 10^9 fecal coliform per swan and 10^9 fecal coliform per duck were used based on Hussong et al.(1979) and Koppelman and Tanenbaum (1982). Estimated daily fecal coliform loadings varied from 8 X 10^7 during the month of June to a maximum of 3.1 x 10^{10} fecal coliform during January when maximum use of the bay by waterfowl was observed. To place these values in perspective, a projected resultant fecal coliform density in receiving water was calculated. To perform this calculation, certain assumptions were made to include the availability of two tidal prism volumes (2.5 x 10^6 cu. m x 2 or 5.0 x 10^6 cu. m) for dilution. Simplistically, this volume represents the dilution volume available during the 24-hr period (2 tidal cycles), which is used in conjunction with the fecal coliform load per bird per 24-hr period. Based on these calculations, at no time would the predicted fecal coliform density in a uniformly-mixed bay exceed 2 FC/100 ml.

Although the assumption of uniform mixing is inappropriate, generally our field measurements of fecal coliform densities concurrent with waterfowl usage of the area (Table 4) coincided closely with the predicted estimates for more "open water" stations (Stations 1, 16, 10.3, 15, 4a and 14). As might be expected, fecal coliform densities tended to be higher at locations which concurrently tended to concentrate waterfowl in less exchanged situations (Station 3.5,12a, 6H2 and Red Brook Stations 5.9S and 5.9B). Although some of the fecal coliform observed at these later stations may have been related to the increased presence of waterfowl, it should be noted that other effects were also responsible, as evidenced by their continued tendency to exhibit higher fecal coliform densities than open water stations during times of little or no waterfowl usage (ie. June and July).

Thus, in general, it appears that in well-exchanged, open waters of Buttermilk Bay, predictive estimates of fecal coliform loading from waterfowl approximate observed values and indicate little compromise of the water quality. However, since the distribution of waterfowl in the bay is not uniform, and since the flushing of the bay with tidal water also fails to exhibit a uniform pattern throughout the bay, local degradation of water quality due, in part, to concentration of waterfowl in sheltered shoreline areas should be expected. In contrast to the apparent

Table. 4 . Summary of fecal coliform and *Escherichia coli* densities at routine monitoring stations in Buttermilk Bay, southeastern Massachusetts, March - October 1986. For locations of stations see Figure 3. All densities expressed as number of organisms / 100 mls. Note that analyses from January to October, 1986 differentiated *E. coli* from among other fecal coliforms. *E. coli* densities are expressed parenthetically beneath the fecal coliform densities.

	STATION										
Date	1	16	10.3	15	12a	6H2	5.9S	5.9B	4a	3.5	14
09/05/85	3	<10	1	<10	ND	ND	88	13	<10	7	ND
09/25/85	10	ND	27	20	ND	ND	70	<10	<10	<10	ND
12/16/85	7	2	<2	<2	2	<2	8	4	<2	<2	<2
01/13/86	2	8	27	<2	<2	<2	<2	5	<2	11	ND
02/19/86	11	23 (18)	<2	2	2	23 (8) (Upstream of 6H2 at bog - <2 FC/100 ml)	30 (18)	8	41	19	ND
03/05/86	<2	<2	<2	<2	ND	ND	ND	ND	11	ND	ND
3/17/86	<2	<2	<2	<2	2	<2	2	2	<2	11	ND
4/15/86	<2	<2	<2	<2	<2	<2	49	<2	8 (5)	5 (2)	ND
05/08/86	<2	2	13	<2	<2	110	79	<2	8 (5)	13	ND
6/04/86	2	<2	<2	<2	180	130	22	22	<2	17	ND
6/19/86	2	5 (<2)	2	2	79	49	240	49	<2	5	<2
7/24/86	<2	<2	<2	<2	34	>2400	49	70	2	2	ND
8/27/86	<2	4	5	4	240	920 (above 6H2 at bog 1490 FC/100ml*	170	20	17	8 (5)	14
10/01/86	14	4 (2)	13 (5)	2	540	170 (above 6H2 at bog 230 FC/100ml*	240 (130)	50	7 (2)	4 (2)	2

ND= No data

* Analyses performed was a membrane filtration method and values observed were within the 95% confidence limit of the MPN technique employed on the routine sample. These data suggest that on these dates that there was no significant upstream-downstream effect.

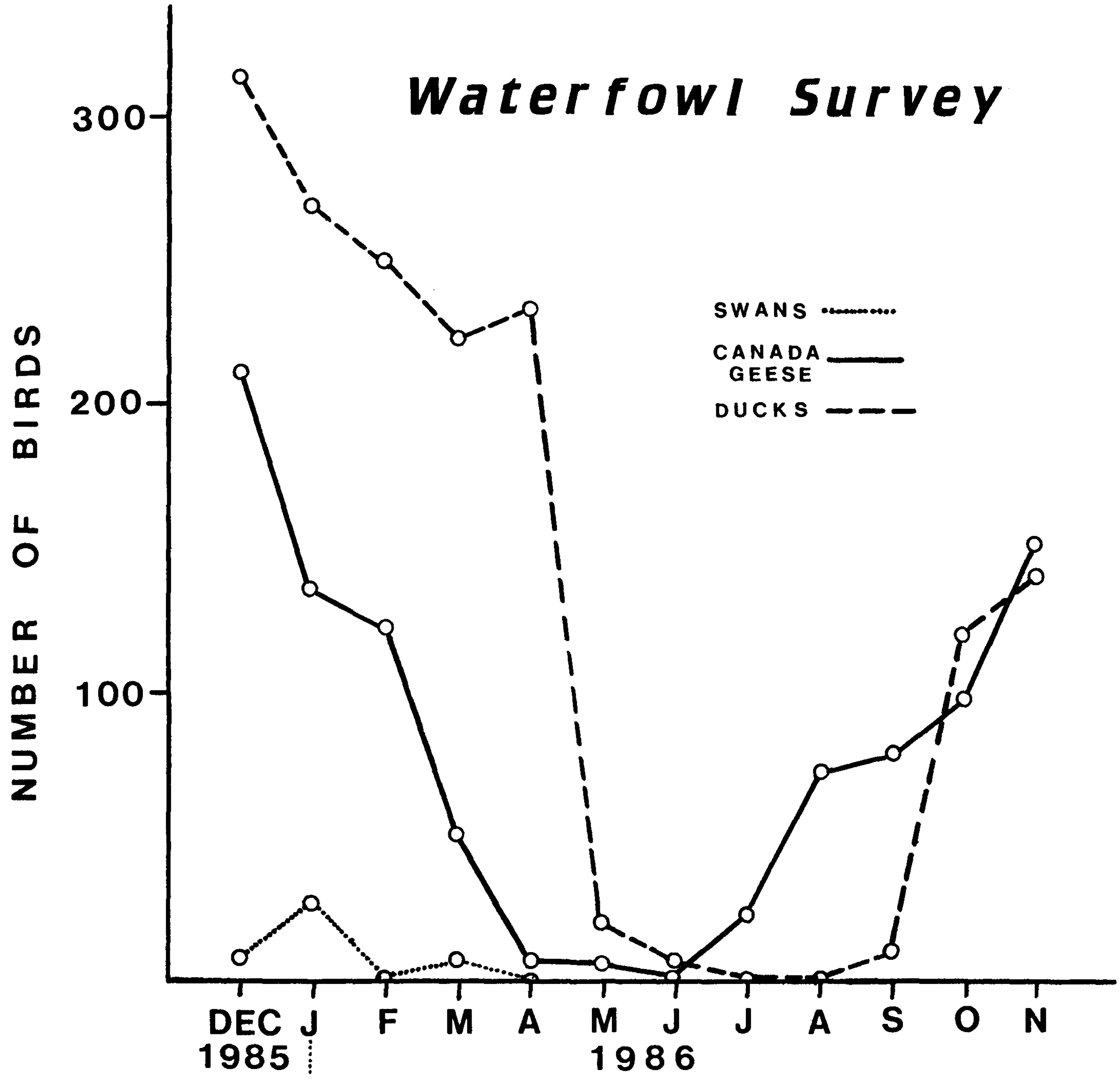


Fig. 11 Average monthly waterfowl counts in Buttermilk Bay, southeastern Massachusetts derived from weekly census data, December 1985 - November 1986.

minimal effects of fecal matter directly deposited into the bay, there is increasing evidence that the shoreline deposits provide the opportunity of fecal wastes to exhibit cumulative effects. The extent of this cumulative effect is related to the association of the wastes with protective elements such as decaying eelgrass and other debris, temperature and moisture content. The implications of fecal matter accumulation and extended survival of fecal indicators directly relates to the probability of their reintroduction to the water of the bay. Again, it appears that hydrographic conditions are the main determinant of this reintroduction. If terrestrially-deposited wastes are stranded above the high tide mark for a period exceeding the major mortality period of fecal coliform, then their reintroduction has little significance. If, however, spring tides in conjunction with rainfall cause fecal coliform dissociation in conjunction with inundation of the wastes, we would expect diffusion of the wastes from the source proportional to its volume and resultant degradation of water quality. In situ experiments to determine the viability of goose feces (See APPROACH AND METHODOLOGY) suggest that during the spring and autumn, fecal coliform maintain their viability essentially unaltered for 2- 3 weeks. During winter months a viability of 1-10 days is likely.

Our investigations of fecal coliform inputs to Buttermilk Bay from wildlife, particularly waterfowl, are perhaps the most controversial aspect of the overall investigation. Due to the assumption that large concentrations of waterfowl, occupying strategic areas with respect to shellfish or recreational-use areas, can result in severe degradation of water quality, a number of municipalities have instituted bans on the artificial feeding of waterfowl. These regulations have drawn varying degrees of criticism from various groups which generally contend that the regulations are not warranted and constitute an undue measure which deprives the public of the pleasure of feeding the birds and observing them at close range, and deprives the waterfowl of an available food source to sustain them through times when food is scarce . The purpose of this portion of our investigation was to clarify the role of wildlife, primarily waterfowl, in contributing to the fecal coliform loading into Buttermilk Bay. Although it is evident from fecal coliform loading rates of various waterfowl that the potential for immediate as well as cumulative impacts on water quality exists, it was not within the scope of work or our ability to determine what percentage of the observed waterfowl were present due to artificial feeding practices. It is evident from our investigations that waterfowl concentrations do negatively impact the water quality in receiving waters. Therefore, any effort to curb the practice of artificially encouraging increased residence time of waterfowl would appear to be justified.

In addition to the controversy surrounding the feeding of waterfowl, there has been increasing concern whether the impact of waterfowl waste should have public health significance attached to it. This issue can be dissected into two basic questions which are as follows:

1) Do waterfowl harbor pathogens transmissible to humans ?

and

2) Are there currently available cost-effective methods for the determination of waterfowl vs. human wastes ?

Both of these questions have been periodically embroiled in controversy. Numerous investigators have indicated the presence of Salmonella in avian feces (Berg and Anderson 1972, Faddoul and Fellows 1966, Mitchell and Ridgwell 1971) however, other investigators (Hussong et al. 1979) have suggested that this pathogen is not ubiquitous in waterfowl. These later investigators additionally failed to isolate Shigella spp. from migratory waterfowl in Chesapeake Bay, however enteropathogenic E. coli was isolated in a limited number of waterfowl from this area. In an attempt to determine the incidence of Campylobacter jejuni in waterfowl, Hill and Grimes (1984) failed to isolate this pathogen from cecal, water and sediment samples in a flyway in Wisconsin, however the literature review presented therein indicated that this pathogen had been isolated from waterfowl elsewhere. Thus it appears that certain bacterial pathogens are carried in waterfowl, and hence the possibility of transferring the pathogen to the receiving water via the fecal route appears to exist. It should be noted that there are a number of unknowns regarding the transmittance of human pathogens via avian wastes which have not been investigated. In light of the lack of information, it appears prudent to assume that fecal wastes deposited from waterfowl do have public health significance. Since specific information does not exist to characterize these wastes, application of the presently accepted standards for fecal coliform indicators appears justified.

If it was concluded that fecal wastes from waterfowl should be considered less of a public health risk, there would still remain the question of source differentiation. With investigation by Geldreich and Kenner (1969) there has been popular use of the fecal coliform/fecal streptococcus ratio to attempt source differentiation. In general, if the ratio is greater than 4, the source is generally considered human. If the ratio is less than 0.7 then the higher fecal streptococcus values indicate an animal source. Underlying the employment of this ratio is the assumption that the sample is withdrawn at a point that would not allow differential die off the indicators. Numerous investigators have made comment regarding the differential die off of these indicators in various situations (Ostrolenk et al. 1947, Van Donsel et al. 1967, Davenport et al. 1976 and Borrego et al. 1983). In general, it is popularly believe that sources may be differentiated if sampled within 24 hours of the source.

The question of whether the fecal coliform/fecal streptococcus ratio can be used to differentiate waterfowl wastes was specifically addressed by Hussong et al. (1979). Data presented by these investigators using wild waterfowl migrating through the Chesapeake Bay area suggests that it is not possible to separate avian fecal contamination from human wastes based on this ratio. These investigators suggested that diet was the determining factor in controlling the fecal coliform/fecal streptococcus ratio. Wild feeding ducks exhibited ratios typical of human enteric flora. It thus appears that should waterfowl waste be determined to have less public health significance, the presently-accepted means for differentiation has been shown to be unreliable. Although typing of fecal streptococci for the purpose of determining more definitely the source of contamination is possible, to date, cost-effective timely methods have not been developed and incorporated into routine sampling schemes.

BOATS AND MARINAS

The effect of boating activities and marinas on the bacteriological quality of water can be segregated into two general categories, the actual input of sanitary wastes and the secondary effects of resuspension of coliform-laden sediments into the water column. Both of these effects are, by nature, extremely variable and intermittent making assessment of impacts on a study area difficult. While it is generally believed that a release of sanitary wastes in the vicinity of shellfishing or recreational waters is an unacceptable practice, circumstances can often come into play which compel a marine craft owner to disregard or occasionally violate this common sense intuition. In general it can be assumed that the actual input of sanitary wastes by marine craft into the nearshore marine environment near shellfish harvesting or recreational waters will bear direct relationship to the level of convenience or cost associated with disposing of the wastes properly. The majority of marinas do not have convenient means of disposing of sanitary wastes.

In an attempt to assess the impact of marine craft/marinas on the bacteriological quality of the water in Buttermilk Bay, two sampling designs were employed. Since fecal coliform generally survive for longer periods in sediment, and thus sediments might act to integrate water quality over an expanded time frame (as opposed to a grab sample of overlying water) sediment samples were taken at various locations in the Bourne Marina (Fig. 12). Sediment and overlying water samples failed to indicate any measurable impact on the bacteriological quality of the water or the sediments by marina operation. In addition to this study, a sampling team responding to a complaint of "feces in the water" near Fries' Marina sampled upstream of the tidal flow, various points below the boats in the marina and downstream of the tidal flow. Again, these samples failed to show any measurable impact of marina operation or marine craft discharge.

In interpreting these results it should be noted that by its nature waste disposal from marine craft would occur only intermittently and in a covert manner. Present regulations prohibit this practice in coastal waters of Massachusetts. Therefore to actually observe this practice and measure its effect would necessitate extremely fortuitous circumstances as

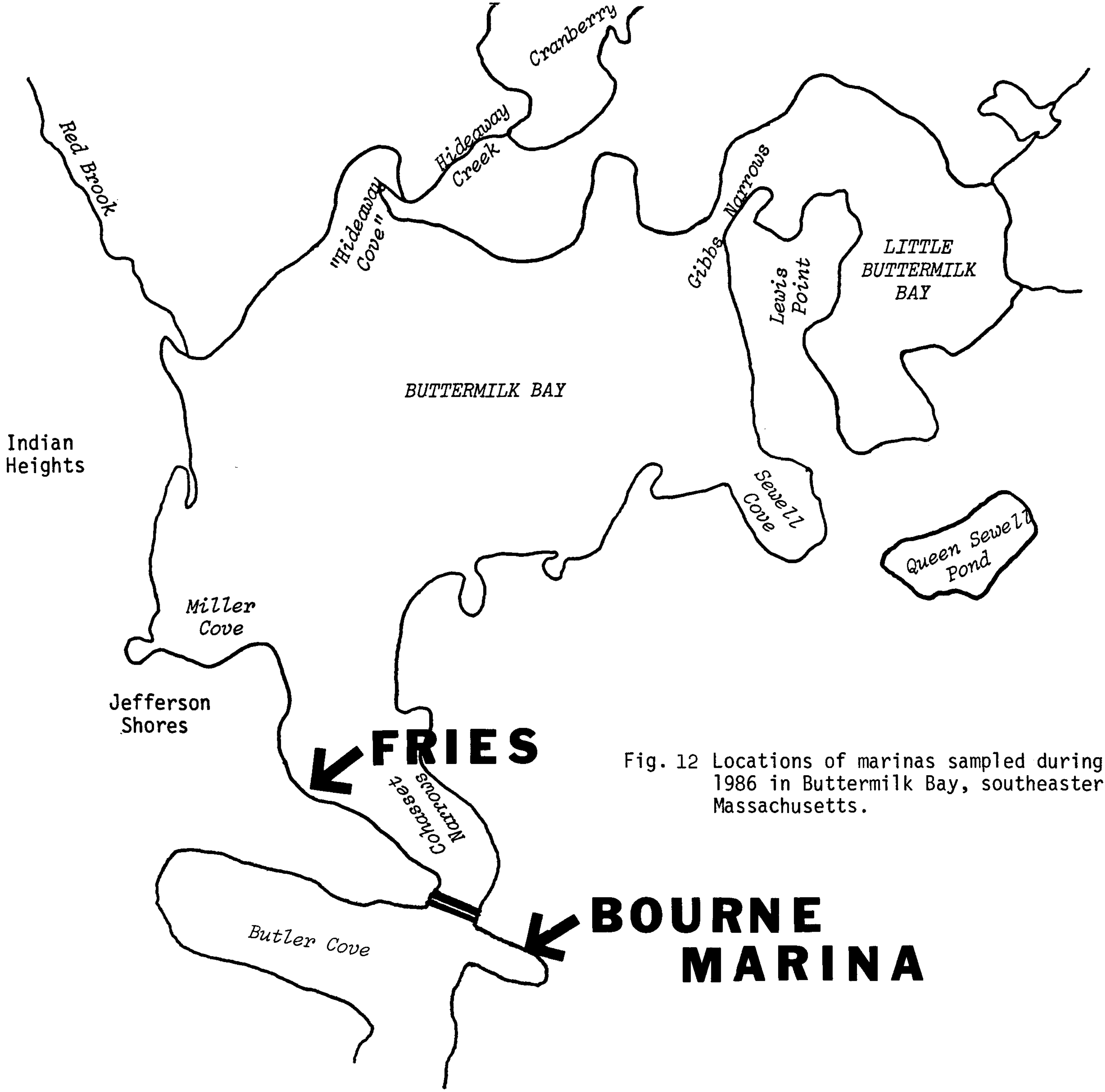


Fig. 12 Locations of marinas sampled during 1986 in Buttermilk Bay, southeastern Massachusetts.

have been reported to occur in other portions of Buzzards Bay (Beskinis - Personal communication). A second consideration to be made prior to drawing conclusions regarding marina operation from the present study is the nature of the two marinas studied. Fries' marina primarily services small day-trip boats, the size of which is restricted by the height of the Route 6 bridge restricting ocean access. The Bourne Marina is atypical due to the pump-out facilities which are not common among marinas and which would allow owners to properly dispose of sanitary wastes. It is concluded that, in general, marina operation will periodically result in the bacteriological degradation of the surrounding water in direct relationship to the inconvenience imposed by boat operators to dispose of their wastes by proper means. Other investigators, notably Faust (1978) and Garreis et al. (1979) have observed significant measurable impact due to recreational marine craft, to include increase in indicator organisms.

In relation to the impact of marine craft operation and the resulting turbulence and resuspension of coliform-laden sediments, the impact in Buttermilk Bay would appear to be minimal. Most marina operations are of an adequate depth to ensure that propeller turbulence does not cause resuspension of sediments.

FRESHWATER INPUTS

There are five significant freshwater surface inputs to Buttermilk and Little Buttermilk Bay which have continual flow throughout the year . Generally, these provide continual inputs of fecal coliform, the importance of each dependent on its relative flow.

Red Brook enters Buttermilk Bay at its eastern shore and comprises the most substantial surface freshwater input to the Bay. Its headwaters are White Island Pond in Plymouth County. The primary portion of its surface watershed is relatively undeveloped, comprised mainly of a series of cranberry bogs. A survey of the area indicated no direct discharges with the exception of runoff from Head of the Bay Road. Fecal coliform densities taken at the point where Red Brook passes under Head of the Bay Road have shown continually high (>14 FC/100 ml) values as least as early as 1973. Samples taken by regulating officials on 10/25/73 and 11/02/73 indicated densities of 280 Total Coliform/36 Fecal Coliform per 100 ml and 750 Total Coliform/36 Fecal Coliform per 100 ml sample respectively (D.E.Q.E. - data files). The sources within the watershed of this brook are evidently too diffuse for identification. A comparison of surface samples taken near the mouth of Red Brook with concurrently-taken lower strata samples (Table 4) indicates that a surface plume emanates from Red Brook on the surface, as would be expected, with the freshwater flow. Thus, the extent laterally in the bay to which the effect of Red Brook could be increasing the fecal coliform densities, will be highly dependent on the mixing and dilution characteristics encountered when entering the bay.

We believe that there are at least two factors leading to the contamination of this brook with fecal coliform. Initially a considerable wildlife population as evidenced by animal tracks and droppings probably provides a considerable fecal input which enters the brook essentially untreated. To accent the effect of animal droppings, the floodplain of this brook is periodically flooded due to tidal action, thus washing the surface load of contaminants into the brook. Several other factors likely contribute to generally-higher fecal coliform densities in Red Brook to include the protective nature of the Marsh (from destructive effect of light), the nutrient availability, and the moisture retaining characteristic of the soils. Many studies have shown that the natural fecal coliform background levels are high and extremely variable in many freshwater wetlands (Kadlec and Tilton 1979).

Two additional freshwater surface inputs, one from cranberry bogs to the north of Head of the Bay Road near Hideaway Village and one on the eastern shore of Little Buttermilk Bay entering near the end of Little Bay Lane in Bourne both have similar characteristics of fecal coliform contamination as interpreted from data of D.E.Q.E.- F.D.A.. Again, we believe that the productive watershed operates much in the same way as described for Red Brook, however, these flows are generally less substantial than Red Brook and have a more local impact. The flow in both of these streams can be restricted by artificial means to accommodate the needs of cranberry culture. In one instance, the flow of Hideaway Creek was negligible due to this practice. A restriction of flow and consequent flooding of the bogs may alter the resultant fecal coliform loading, but this effect could not be measured in the present study.

In the course of the present study, a small stream with headwaters in Goat Pasture Pond in Bourne was investigated for fecal coliform inputs. The relative seasonal changes in fecal coliform inputs generally followed similar trend as the stream in the vicinity of Hideaway Creek. No overt discharges were observed in the watershed of this stream-pond system however it was noted that this area was used as a nesting area for waterfowl which may, in part, account for the values observed.

A small stream entering Little Buttermilk Bay via a culvert under Old Head of the Bay Road was periodically measured for fecal coliform. The surface drainage area of this small stream contains a corral in which at least one horse was observed during each monthly sampling. This, in part, may explain the sporadically high coliform densities observed at the point of discharge. No other overt discharges were observed.

In summary, it was evident that all freshwater surface inputs to the Buttermilk Bay System contain fecal coliform on a continual basis. In the case of Red Brook, the volume input is substantial and may be the cause of unacceptable fecal coliform densities along the path of travel (generally along the western shore). Input from the Hideaway Creek stream enters the bay in a restricted cove with considerable sediment build up. This, coupled with a high nutrient load are likely the reasons for the consistent local degradation of water quality. In addition, a joint DEQE-FDA study during 1985 found significant increases in total and fecal coliform below the Hideaway Village development which may suggest contribution by adjacent septic systems via the groundwater. The remaining three freshwater inlets would be expected to exhibit even more localized effect due to the lower volumes of flow.

POINT DISCHARGES

Only one point discharge into Buttermilk Bay was discovered in the course of our investigations., the 10 inch diameter concrete pipe discharges from lobster holding tanks of the adjacent fish market. Samples taken from this discharge on 5 dates (Table 5) showed fecal coliform densities ranging from 172 - > 16,000 FC/100 mls. Sampling adjacent water on 15 July, 1986 indicated that within ca. 15 m in all directions from the pipe, levels were reduced from 1300 FC/100 mls at point of discharge to 13-33 FC/100 mls. It is difficult to determine whether values observed in adjacent water were totally the result of the pipe discharge. A substantial rodent population living in the adjacent rip-rap could also be a fecal coliform source.

Table 5. Fecal coliform densities of discharge water from concrete pipe adjacent to fish market.

Date	Fecal Coliform/100 ml sample
6/9/86	172
6/11/86	> 16,000
7/8/86	> 1,600
7/15/86	1300
7/17/86	240

FURTHER CONSIDERATIONS

In the process of interpreting fecal coliform data and estimating fecal coliform loading from various sources, it became apparent that small scale experiments were necessary to verify the applicability of published studies in reference to mortality rates of indicator organisms. An intimate knowledge of all factors affecting mortality of fecal coliforms is paramount to determining the significance of organism density measured in the field. The purpose of this portion of our study was to determine, in a preliminary way, whether factors existed in Buttermilk Bay which would invalidate comparison with other studies (Rittenberg et al.1958, Borrego et al. 1983, Gerba et al. 1977, Bellair et al. 1977 and others).

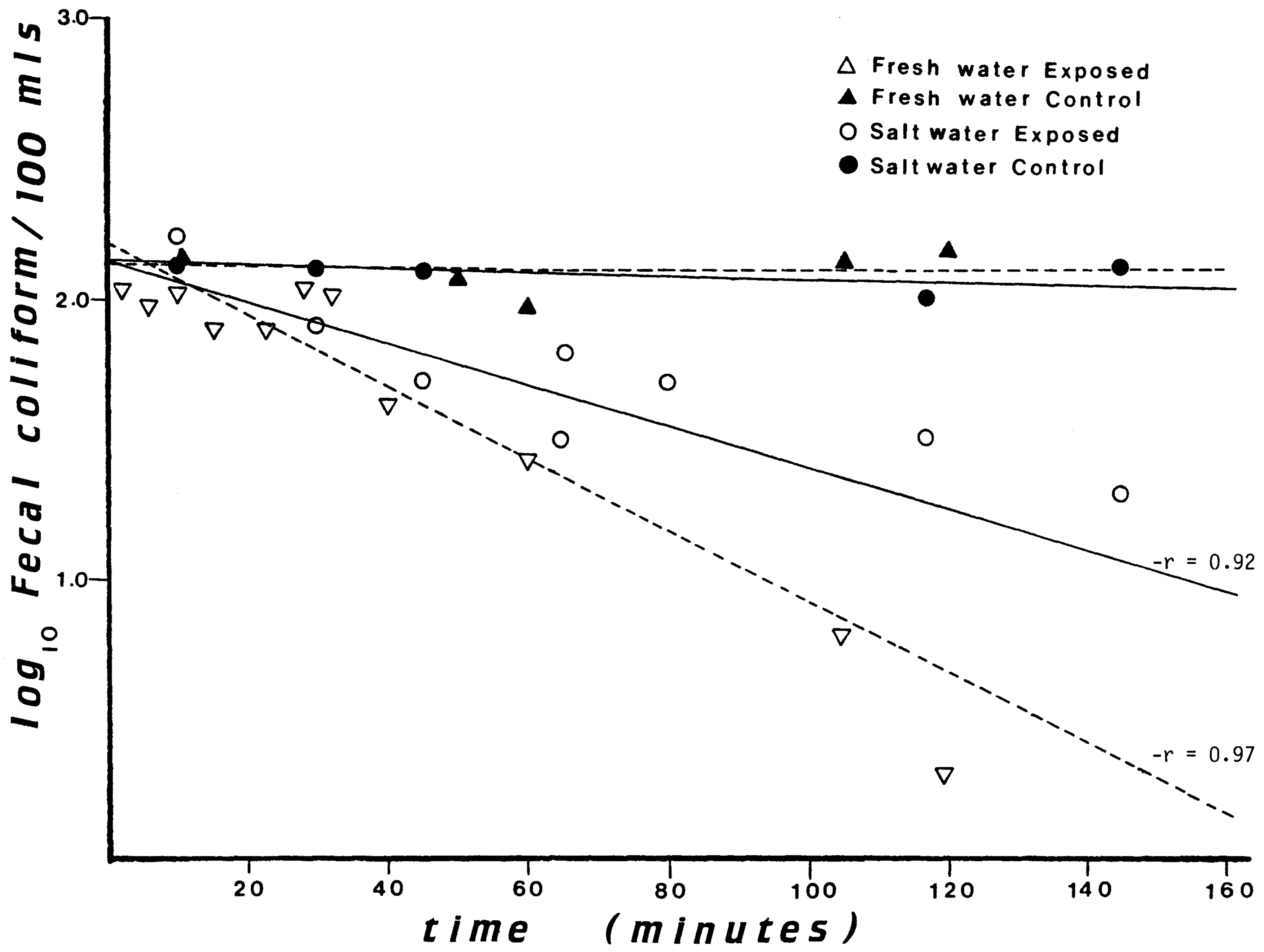


Figure 13 Fecal coliform die-off with time in freshwater and saltwater samples immersed in 1-2 mm. of water in Buttermilk Bay, July 17, 1986.

Upon entering an estuary or receiving water, coliform bacteria are influenced by a number of factors which tend to limit population growth and induce mortality. A typical mortality curve for Escherichia coli, indicates up to 90% mortality in 3-5 days (Mitchell 1968, Canale et al. 1973). A number of factors, summarized below, have shown to act in a regulatory manner to coliform in marine environments:

1) Solar Radiation (light)

2) Temperature

3) State of association with sediments

4) Availability of nutrients

While certain aspects of these factors have been previously discussed and will not be reviewed here, what follows is a summary of small scale experiments designed to explore very site-specific possibilities regarding the ecology and hence mortality factors of fecal coliform in Buttermilk Bay. In addition, pertinent literature is presented regarding the effect of temperature on fecal coliform survival in order to fill in gaps of understanding regarding season effects on fecal coliform growth.

The effect of solar radiation

Perhaps the most influential factor exhibiting adverse effect on coliform organisms is solar radiation. Kapuscinski and Mitchell (1983) relating their in vitro mortality rates for a pure culture of E. coli exposed to sunlight (T90 < 4.9 h) with those of Foxworthy and Keeling (1969) (T90 < 5.5 h) suggested that solar radiation is the principal determinant of microbial mortality in seawater. While some reviews have minimized the effect of solar radiation (Hendricks 1978) or neglected it altogether (Mitchell 1968), other authors (Fujioka et al. 1981, Bellair et al. 1977 and Gameson and Saxon 1967) have indicated substantial bactericidal effects of sunlight penetrating to depths of 4m. Kapuscinski and Mitchell (1983) reviewing studies of Webb and Baker (1979) and others indicated that wavelengths of solar radiation shown to induce the highest mortality of E. coli are reduced by only 10 fold at ca. 2 m in enriched seawater. Preliminary experiments in our study area conducted during sunny days with both fresh and salt water show close agreement with work of Fujioka et al. (1981), and indicate a substantial bactericidal effect of sunlight for fecal coliform (Figure 13). These data strongly implicate sunlight as a major factor in the decay of fecal coliform populations in openwater areas of Buttermilk Bay. This contention is supported by Chamberlain and Mitchell (1978) who provided convincing argument based on work of other authors (notably Gameson and Gould 1975 and Foxworthy and Kneeling 1969) that the variability in coliform decay rates in seawater can be primarily attributed to the variability of surface light intensity and other factors influencing the depth profile of light intensity and bacterial concentration.

Preliminary investigation at selected sites in Buttermilk Bay indicate that at certain locations, notably Hideaway Creek and Red Brook, where fecal coliform densities are generally at unacceptable levels for shellfish harvesting, the ultraviolet light penetration is attenuated in comparison to open-water stations (Figure 14). Although the reason for this attenuation is not known, it is correlated with a comparatively higher nutrient content (Valiela et al. 1987). In addition to nutrients, natural products of plant decomposition (tannins etc.) or extracellular products of algae may be providing the ultraviolet light absorbing compounds. Excretion of such compounds from marine algae has been reported (Craigie and McLachlan 1964). These data initially suggest that nutrient addition may alter the ultraviolet absorbing characteristic of receiving water in certain situations which may result in an attenuation of the fecal indicator mortality. This may explain in part, the generally higher fecal coliform densities at these two sites.

Our initial experiments suggest that, in areas of high nutrient input, the ultraviolet light absorbance characteristic of the receiving water is modified to allow greater survival of indicator organisms, and likely pathogens as well. This adds to the implication of nutrient inputs from septic systems in affecting the overall microbiological quality of the receiving water.

The effect of temperature

While it is generally believed that there is increased survival of fecal coliform at lower temperatures and conversely that mortality increases with temperature (Vasconcelos and Swartz 1976) work by other investigators, notably Hendrichs (1972) and Won and Ross (1973) suggests that this relationship is highly dependent on ambient nutrient levels. Hendricks (1972) observed that below a sewage effluent, maximum growth of enteric bacteria was observed at 30 C. Won and Ross (1973) observed that mortality rate decreased at 22 C depending on the concentration of nutrient to include extract from autoclaved feces. Vaccaro et al. (1950) found that nutrient addition extended the survival time of *E. coli* threefold at higher temperatures compared with raw water. It thus appears that nutrient rich water may exert a second attenuating effect on the mortality of fecal coliform by providing the nutrients for cell maintenance and growth. We are unsure at what temperature nutrient enrichment has no effect on fecal coliform growth, however Shaw et al. (1971) has suggested that the minimal temperature for growth in glucose minimal medium was between 7.5 and 7.8 C.

The effect of state of association with sediments

Many investigators have indicated that bacterial survival is enhanced by association with sediments, however the mechanism for

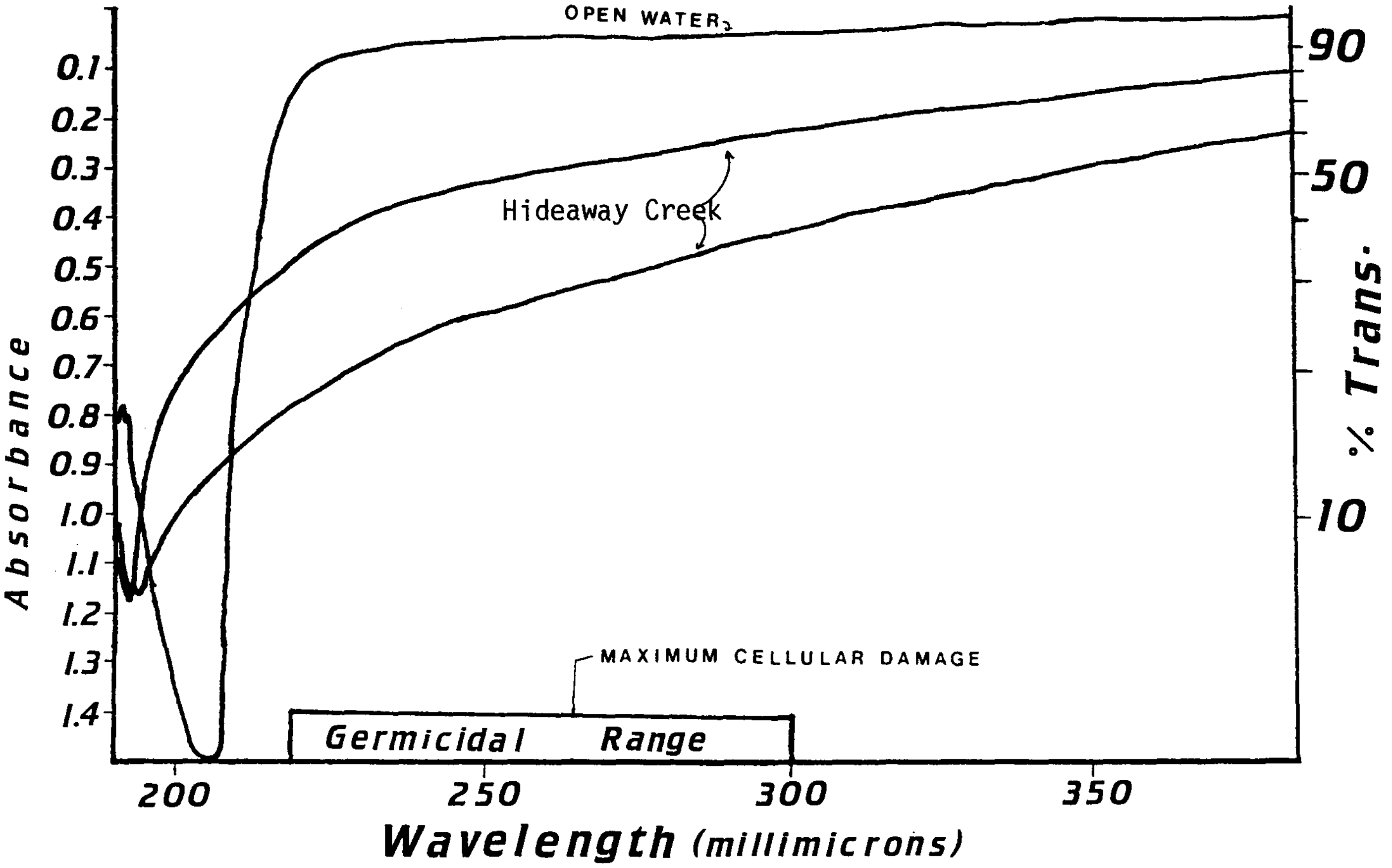


Figure 14 - Companian of ultraviolet light absorption among selected stations in Buttermilk Bay. Open water stations were represented by station 1, 3.5, 14, 16, 10.3 and Station 15. (Figure 3) Hideaway Creek was sampled at Station GH2.

this protection is not fully understood (See "release of coliform from protected reservoirs"). An experiment conducted on August 11, 1986 in which contaminated water samples were buried beneath approximately 1-2mm of sediment in plastic bags confirms that at least one of the protective mechanisms of sediment is the screening of light (Figure 15). Samples concurrently placed beneath 1-2 mm of water experienced complete fecal coliform die off within 2 h, whereas samples buried in the sediment experienced significantly less die off over the same time period. Variables such as dissolved oxygen and temperature remained constant over the 2 h period.

In addition to protection from antagonistic factors such as light , sediments can apparently offer a media for growth depending upon the nutrient availability. Hendricks and Morrison (1967) found that *E. coli.* growth was supported at 16 C on extract from bottom sediment. Gerba and McLeod (1976) observed growth in fecal coliform from sediments in areas receiving sewage effluents as well as areas free from such inputs.

There are two major implications of these findings to the Buttermilk Bay system. If, as noted by Schillinger and Gannon (1985), a significant portion (16-47 %) of bacteria in stormwater runoff become associated with sediment, the nutrient level of the receiving sediments becomes an important factor in estimating the significance of this portion of the stormwater bacterial loading. For instance, if stormwater pipes are located as to discharge in an area receiving substantial nutrients through the groundwater, increased bacterial survival and perhaps growth of settled bacteria increases the significance of the stormwater discharge by prolonging its negative impact. In addition to stormwater, all other sources such as waterfowl feces, groundwater inputs etc. from which fecal coliform settle out into the sediments may also utilize nutrients in sediments and hence have their effect prolonged.

Availability of nutrients

Numerous studies have thus far been reviewed suggesting that fecal coliform can utilize nutrients in the water column and the sediments. These studies will not be reviewed here. Although the origin of the nutrients has not been documented, the possibilities include natural decomposition, septic system wastes via groundwater, nutrients from fecal wastes deposited directly in the water and stormwater runoff. What began as an incidental experiment in conjunction with study of nutrient enrichment and algal succession (Costa - Boston University Marine Program) gives initial indication of an additional source of nutrients for fecal coliform, that of algal products. As part of an experimental design to examine algal growth in response to nutrient gradients, acetate strips were left in the bay at various locations in respect to a nutrient source (Red Brook) to assess algal growth. Concurrent with the collection of the strips for chlorophyll analyses, 10 cm x 1 cm strips were removed and placed in sterile

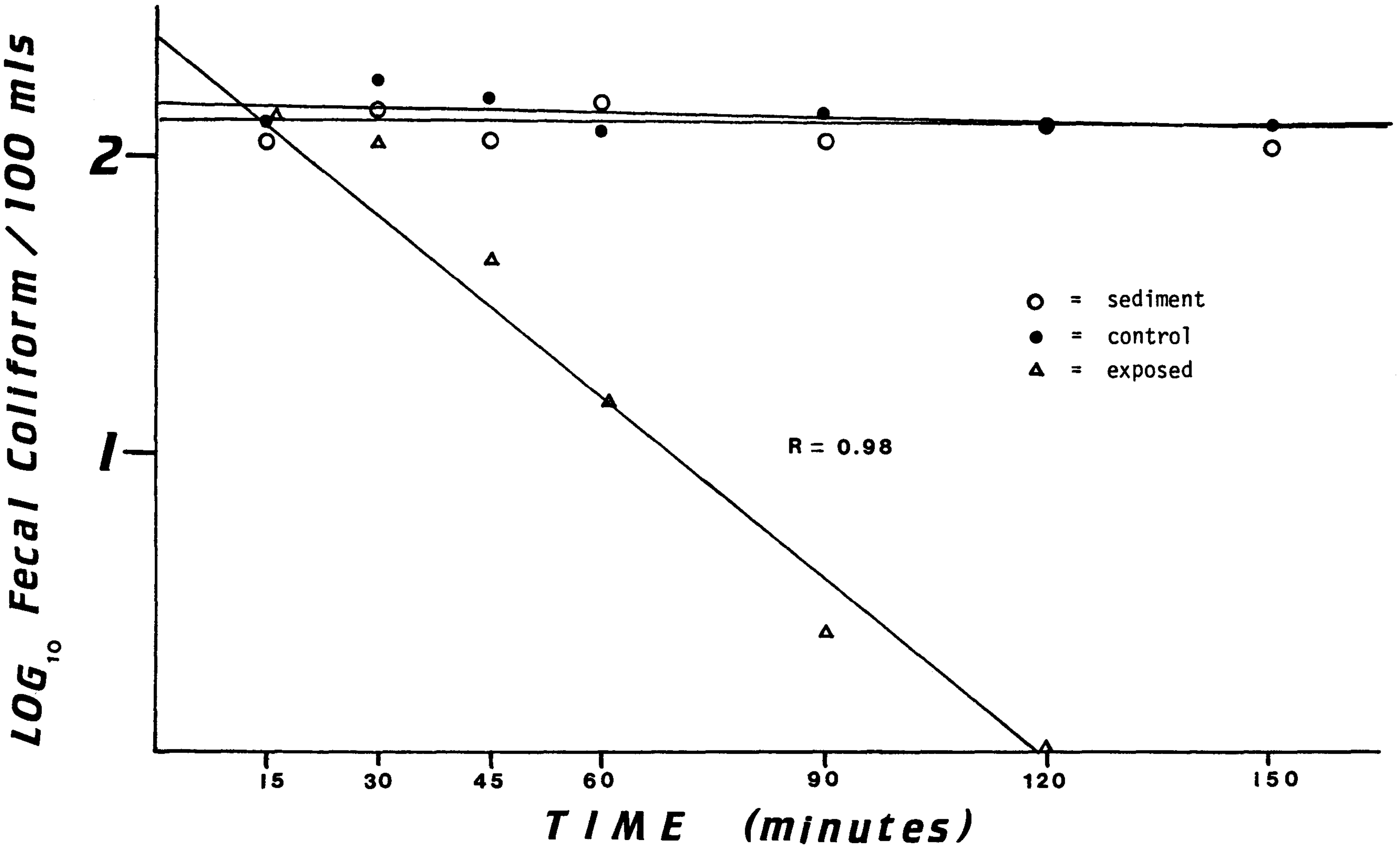


Figure 15 - Fecal coliform die-off with time in samples buried to a depth of 1-2 mm of sediment compared with samples immersed in 1-2 mm of water in Buttermilk Bay, August 11, 1986.

phosphate buffered water. Concurrent water samples were also taken. The samples were taken to the lab and processed using MPN methodology previously described. The samples were then stored at 20 C under subdued natural light (laboratory ambient light). After 7 days, the density of fecal coliform was again measured in all samples. The results (Figure 16) showed that those samples containing the acetate strips with algae growth experienced 1-3 log 10 increases in population of fecal coliform, while those water samples taken from the same areas without the algal strip cultures experienced at least 90 % mortality. These data suggest that the algae were providing nutrients capable of supporting growth of fecal coliform. The excretion of organic compounds by various species of marine and freshwater algae has been reported (Hellebust 1965, Larsson and Hagstrom 1982,McFeters et al. 1978, Nalewajko et al. 1980). These later investigators reported that the doubling time for Pseudomonas fluorescens was reduced from 2-19 days to 2 hours in mixed culture with Chlorella sp. This algal genus was also the subject of study by McFeters et al. (1978) who observed that the supernatant from cultures supported growth of fecal coliform. In general it appears plausible from our investigations as well as published studies that at least some species of marine algae produce extracellular products which can support growth of fecal coliform.

The implications of this "secondary" effect of nutrient enrichment in Buttermilk Bay are uncertain. It appears plausible that in certain situations where water exchange is limited and nutrients concentrate in amounts that support algal growth, fecal coliform may derive nutrients capable of maintenance and possibly growth. Collectively, these issues of the implications of nutrient enrichment and its effect on the bacteriological quality of the receiving water warrant further research.

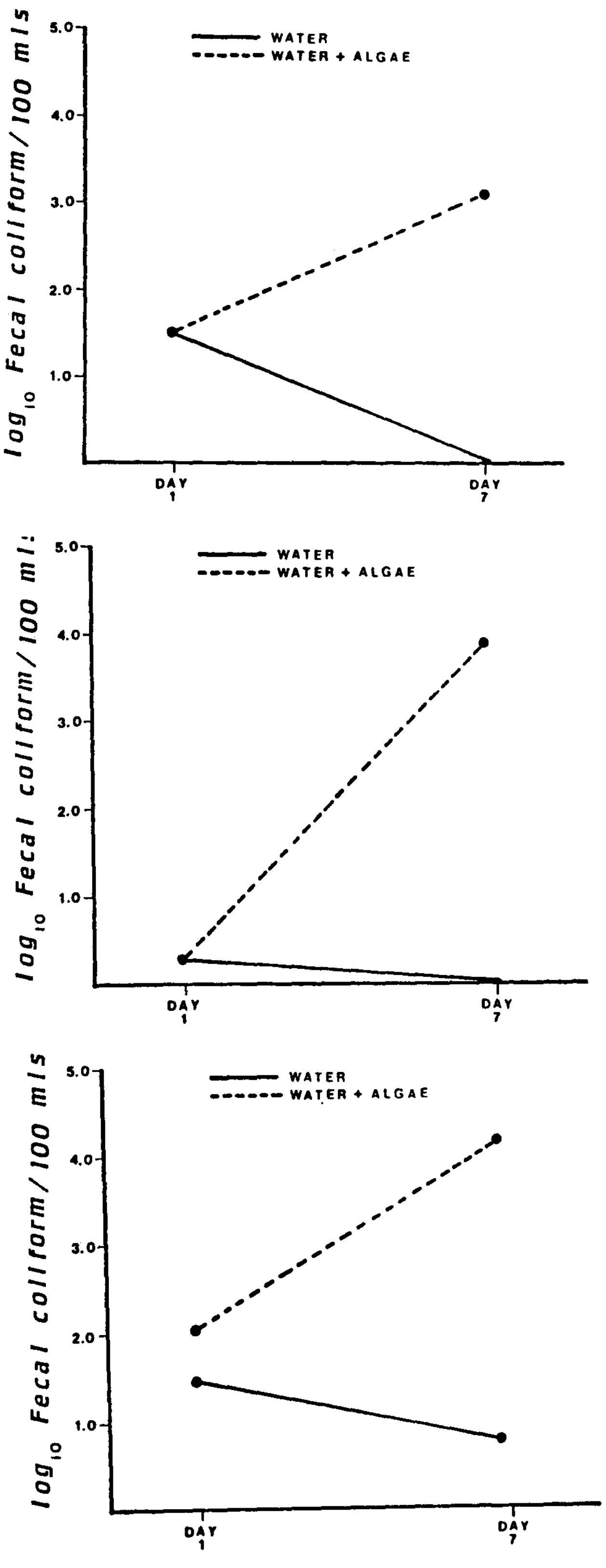


Figure 16 - Growth of fecal coliform in the presence of indiginenous algae at 20°C under laboratory conditions.

USE OF ALTERNATE BACTERIAL INDICATORS TO EVALUATE SOURCES AND DEGREE OF BACTERIAL CONTAMINATION

Almost since the acceptance of the total and fecal coliform standard, researchers and health officials have searched for alternate indicator organisms for the classification of recreational waters which would more accurately reflect the public health risks. The problems associated with the development of an indicator organism system fall into two categories:

1) Cost effective methods for analysis must be developed,

and

2) It must be demonstrated that under "average conditions" the organism(s) is(are) consistently correlated with the occurrence of human pathogenic organisms which produce an observable effect (ie. waterbourne disease outbreak).

The search for alternative indicator organisms for recreational waters basically stems from the fact that it is not possible to analyze water for the myriad of pathogens which could be present. In addition, methods for direct measurement of some pathogens, notably the viruses, have not been developed.

With the exception of the enterococci, which has gained some acceptance as an indicator of public health risk in contact recreational waters, other bacteria, although not incorporated into a defined indicator organism scheme, have found use as diagnostic tools in evaluating contamination sources. In the course of the present study, certain alternate bacterial indicators were investigated to assess their utility in determining contamination sources. Among those indicators chosen was Escherichia coli (a subset of the fecal coliform group), Clostridium perfringens, fecal streptococcus , and a subgroup of the fecal streptococcus group which includes strains of Streptococcus faecalis and Streptococcus faecium called the enterococci. The following summarizes this author's experience with each of these alternate indicator organisms, with an analysis of how each organism's density patterns related to the presently-employed standard for the evaluation of shellfish harvesting areas, the fecal coliform group. For regression analyses, data were first $\log_{10}$ -transformed.

In general, all of the indicators investigated have been shown in various situations to have sanitary significance. The difficulties in applying results from one study area to another however, are numerous since the variability in characteristics of each study site are often substantial. Generally, the shallow closed embayment served by subsurface sewage systems has not been widely studied. Thus, it is questionable whether data collected in the majority of published studies relating to sewage outfalls in more open, exchanged areas is applicable to our study area in

Buttermilk Bay. At minimum, however, it can be stated that alternate indicators are useful tools in the whole arsenal of public health officials which, if interpreted in light of specific situations, can possibly serve to delineate contamination sources.

Escherichia coli

One of the most useful alternate indicator organisms investigated was *Escherichia coli*. This subset of the fecal coliform group is generally considered more fecal specific, since the fecal coliform system includes the genus *Klebsiella*, an organism which is not fecal specific. Although *Klebsiella* is infrequently present in human feces, a substantial number of extra-enteral sources have been noted (Seidel et al. 1977, Dufour and Cabelli 1976). In addition to the the existence of extra-enteral sources, it should be noted that there is no epidemiological link implicating the transmission of *Klebsiella* infections via the waterbourne route, further negating its use as a bacteriological standard for recreational water. The persistence of use of the fecal coliform system in spite of the shortcomings of one of its components appears to be the result of historical misconceptions (Cabelli et al. 1983) and lack of definitive investigations relative to alternative indicator systems.

The usefulness of fecal coliform differentiation in our study area was diagnostic. Since there is indication from published studies that *Klebsiella sp.* can multiply outside of a warm-blooded hosts, it was beneficial to rule out extra-enteral sources of a non-fecal specific "fecal coliform" (*Klebsiella*) such as decomposing marsh situations which are common in the Buttermilk Bay watershed.

In all but seven cases during monitoring at routine sampling stations, fecal coliform in samples were comprised entirely of *Escherichia coli* (Table 4). This accounts for the high degree of correlation between fecal coliform and *E.coli* densities (r= 0.98) in routine samples (Fig. 17). In addition, all fecal coliform observed in stormwater samples were further differentiated as *E. coli*.

Although, as stated, *E. coli* is considered more fecal specific, our investigations and published studies reviewed elsewhere herein, do suggest the possibility of extra-enteral sources of *E. coli*. If this is the case, the usefulness of differentiating members of the fecal coliform system is reduced to determining whether *Klebsiella* is a component of the fecal coliform densities being observed. In the event that *Klebsiella* is the major component in any situation, this information may redirect effort away from investigations of human sources, which are often quite expensive and time-intensive. In the event that *E. coli* is the major component of the fecal coliform densities observed, the indication is less definitive and leaves the

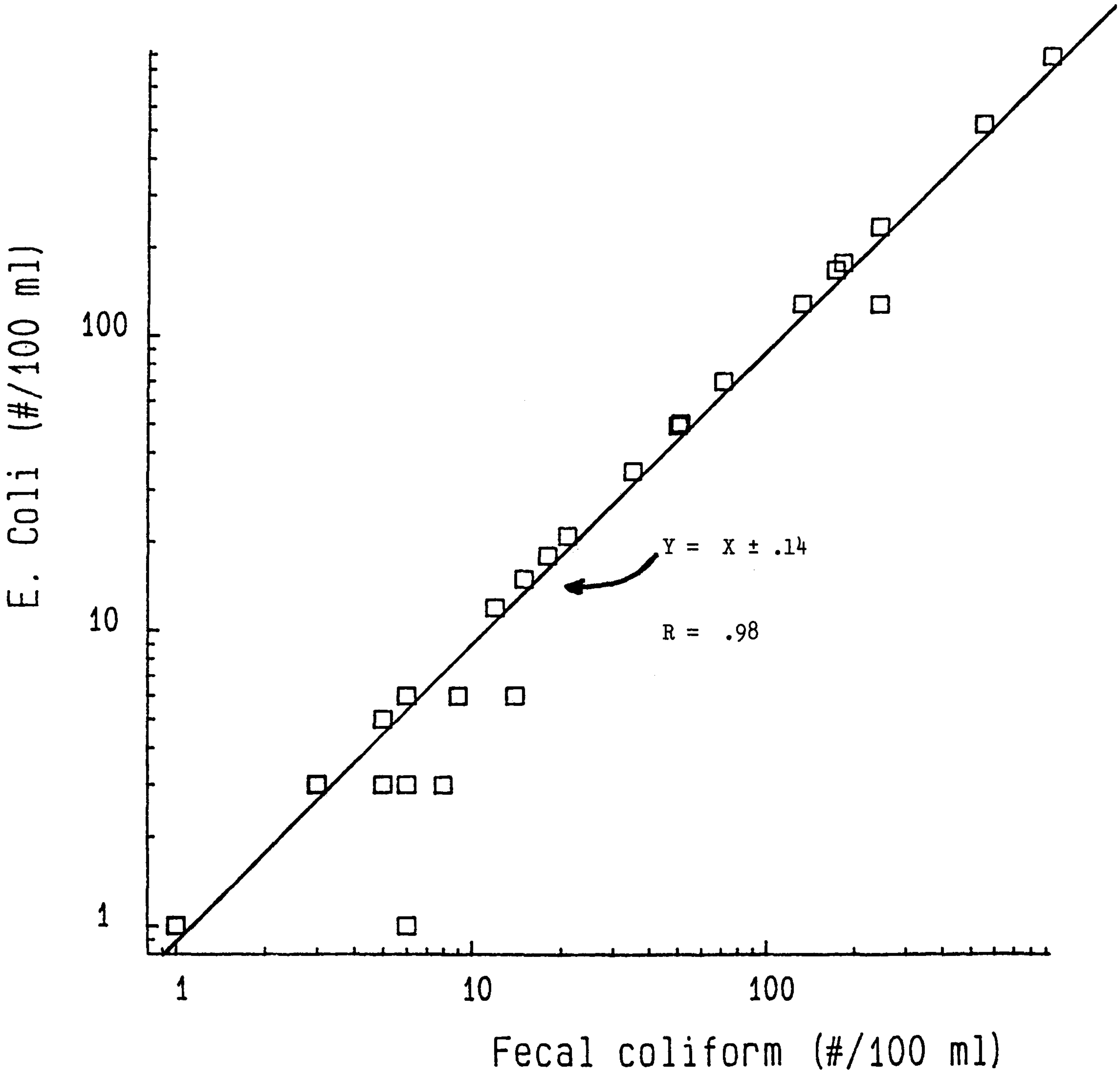


Figure 17 - Relationship between fecal coliform and E. coli densities in samples collected at routine sampling stations in Buttermilk Bay during 1986. Data were $\log_{10}$ transformed.

possibility of either contamination of sanitary significance or significant contribution by extra-enteral sources.

Clostridium perfringens

Despite the fact that *Clostridium perfringens* is consistently associated with human wastes (Akama and Otani 1970, Haenal 1970 and Drasar et al. 1975 as cited in Cabelli 1980), it is presently not incorporated into a definite fecal indicator system. Although densities of this organism were generally low at routine sampling stations in the present study (Table 6), some general patterns did emerge. With the exception of one sampling date, *Clostridium perfringens* showed highest densities at Station 6H2 near the Hideaway Village development. This may suggest the input from septic system leachate in the area, since it has been shown elsewhere herein (See SEPTIC SYSTEMS) that *C. perfringens* is found in septic system leachate in densities exceeding 10^3. The poor correlation between this indicator and fecal coliform (r=.099) is somewhat expected (Figure 18). The culture technique used in this study enumerates the spore of this organism, which is resistive to adverse environmental conditions. It is thus a conservative tracer which would indicate a contamination source long after the fecal coliform experienced die off.

In addition to station 6H2, the occurrence of *C. perfringens* was consistent at the mouth of Red Brook (Station 5.9) and in the inner portion of Miller Cove (Station 3.5). While the occurrence of *C. perfringens* at Miller Cove may again indicate contamination from groundwater sources (ie. septic systems), since 50% of the groundwater samples taken in this area on 6/23/86 were positive for *C. perfringens*, there is no direct evidence for this source from groundwater samples taken at the mouth of Red Brook.

Another possible source of this indicator could be waterfowl and pet fecal material deposited near or at the shoreline. A survey of the wrack on July 25 at ten selected sites around the bay indicated *C. perfringens* at densities ranging from <10 organisms/gram of wrack (observed at one station) to over 600 organisms/gram. There was no correlation between *C. perfringens* and fecal coliform densities in the wrack at this time. The occurrence at 9 of the ten stations sampled however, suggests that the organism may be somewhat ubiquitous in the strand or wrack material, with waterfowl and domestic animals as the likely source. Geldreich (1977) for instance reported that dog waste contained 2.51 x 10^8 *C. perfringens* per gram of feces.

Thus it appears that there are two sources of *C perfringens* entering the bay, surface deposit by pets and waterfowl, and groundwater inputs from septic systems. While the groundwater observations may point to areas of septic effluent inputs, the lack of correlation with the currently-used standard (fecal coliform) brings into question the role of this source in the classification of the bay for shellfish harvesting.

Table. 6 . Summary of *Clostridium* *perfringens* densities at routine monitoring stations in Buttermilk Bay, southeastern Massachusetts, March - October 1986. For locations of stations see Figure 3. All densities expressed as number of organisms/100 mls.

	STATION										
Date	1	16	10.3	15	12a	6H2	5.9S	5.9B	4a	3.5	14
3/17/86	<10	<10	<10	<10	20	40	10	<10	<10	40	ND
4/15/86	<3	<3	<3	<3	7	10	7	7	<3	3	ND
05/08/86	6	6	<3	<3	<3	30	6	10	13	33	ND
6/19/86	<3	<3	3	<3	3	3	3	6	<3	<3	ND
7/24/86	<3	<3	<3	<3	<3	63	<3	<3	<3	<3	ND
8/27/86	<10	<10	<10	<10	<10	129 12 (upstream of 6H2 at bog)	18	9	<3	<3	ND
10/01/86	<10	10	<10	<10	<10	<10	<10	<10	<10	<10	10

ND= No data

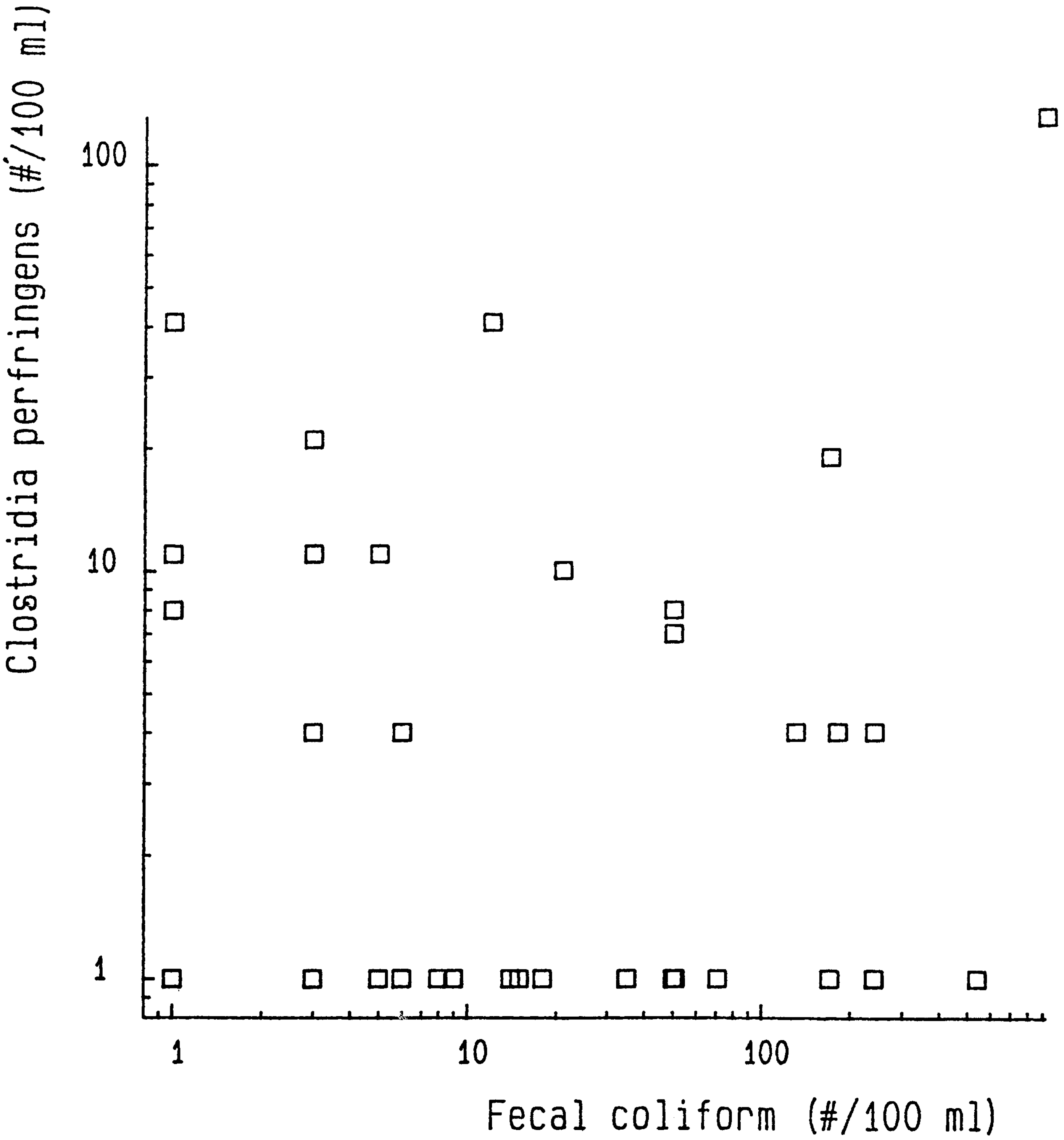


Figure 18 - Relationship between fecal coliform and Clostridia perfringens densities in samples collected at routine sampling stations in Buttermilk Bay during 1986. Data were $\log_{10}$ transformed. R = .10.

Table. 7. Summary of fecal streptococci densities at routine monitoring stations in Buttermilk Bay, southeastern Massachusetts, March - October 1986. For locations of stations see Figure 3. All densities expressed as number of organisms /100 mls.

	STATION									
Date	1	16	10.3	15	12a	6H2	5.9S	5.9B	4a	3.5
3/17/86	<10	<10	<10	<10	20	10	10	10	<10	<10
4/15/86	<3	<3	<3	<3	270	27	40	3	3	<3
6/19/86	<10	<10	<10	<10	240	120	20	30	<10	<10
7/24/86	<10	<10	<10	<10	200	TNTC	30	290	<10	<10
8/27/86	<10	10	20	10	540	600	300	60	10	30
10/01/86	<10	<10	10	<10	60	950	310	10	<10	<10

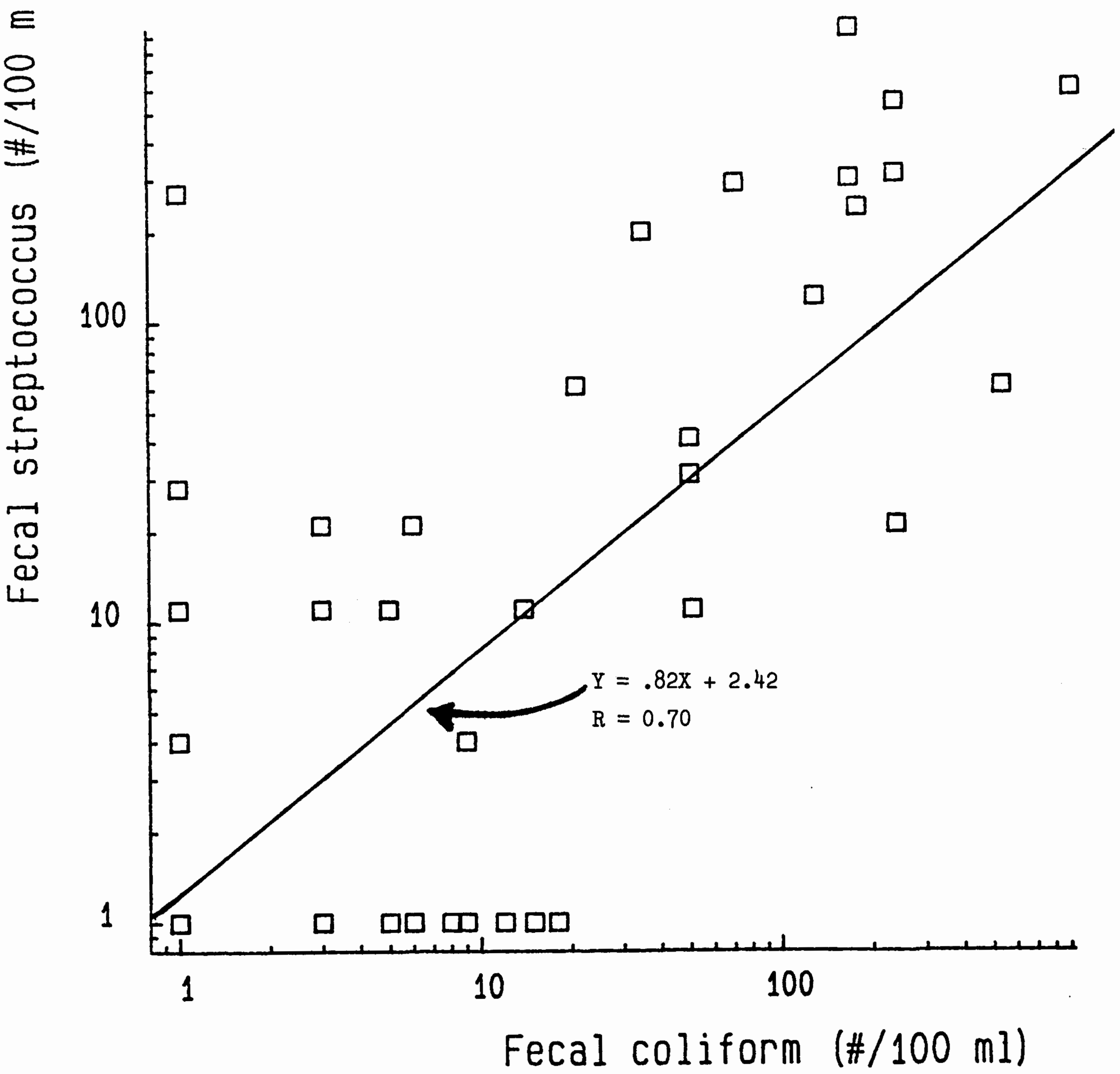


Figure 19 - Relationship between fecal coliform and fecal streptococci densities in samples collected at routine sampling stations in Buttermilk Bay during 1986. Data were $\log_{10}$ transformed.

FECAL STREPTOCOCCUS

Within the context of recreational waters, the fecal streptococcus group is generally used in a diagnostic manner to determine sources of fecal contamination. A discussion of the use of the fecal coliform/fecal streptococcus ratio is presented elsewhere (see WILDLIFE section). This indicator group generally contains members with limited sanitary significance which has restricted its use as a fecal indicator (Geldreich and Kenner 1969). In our study area, their occurrence was most consistent at points of surface freshwater inputs (Stations 12a,6H2, and 5.9- Table 7). Their significance could not be determined due to studies questioning the utility of the fecal coliform/fecal streptococcus ratio, however there was some correlation between these two indicator groups (r= .70 - Figure 19). Other studies being conducted in Buzzards Bay (Larry Gil, DEQE, Div. Water Pollution Control - personal communication) suggested that a high percentage of colonies growing on the K-F Strep media were false positives as determined by confirmatory tests for fecal streptococcus.

ENTEROCOCCUS

The use of this fecal indicator group has received much attention in recent years as an indicator of risk in using recreational waters, particularly for contact purposes. Cabelli (1983) reports a high correlation between enterococci densities and gastrointestinal disorders among bathers at New York Beaches. As a result of that author's findings, some states have adopted this standard for use at bathing beaches.

During the present study, the occurrence of enterococci paralleled that of streptococcus as expected since it is a subset of this group (Table 8).

Two main problems arise when attempting to interpret our enterococci data. Firstly, study by Cabelli (1983) was performed in relation to situations receiving large point discharges. Since these situations typically are in more open, exchanged areas, the numerous factors present in a closed shallow embayment receiving smaller point and non-point discharges, such as Buttermilk Bay, have not been addressed. In addition to the question of applicability, some difficulty was experienced counting the colonies due to the growth of atypical colonies on the media used. This was particularly true for areas where there were bordering wetlands. In general it was observed that enterococci showed little correlation with the fecal indicator group (r= .46 - Figure 20). Due to the lack of epidemiological data from comparable sites, the sanitary significance of enterococci densities observed could not be determined.

Table. 8 . Summary of enterococci densities at routine monitoring stations in Buttermilk Bay, southeastern Massachusetts, March - October 1986. For locations of stations see Figure 3. All enterococci densities expressed as number of organisms / 100 mls.

STATION

Date	1	16	10.3	15	12a	6H2	5.9S	5.9B	4a	3.5	14
3/17/86	<10	<10	36	20	<10	<10	82	10	20	<10	ND
4/15/86	<3	37	<3	7	3	<3	53	<3	3	7	ND
6/19/86	<10	<10	<10	<10	70	30	<10	10	<10	<10	<2
7/24/86	30	<10	10	<10	50	TNTC	<10	40	20	20	ND
8/27/86	70	<10	160	30	550	280	80	110	10	30	ND
10/01/86	<10	<10	20	<10	30	140	310	500	120	10	<10

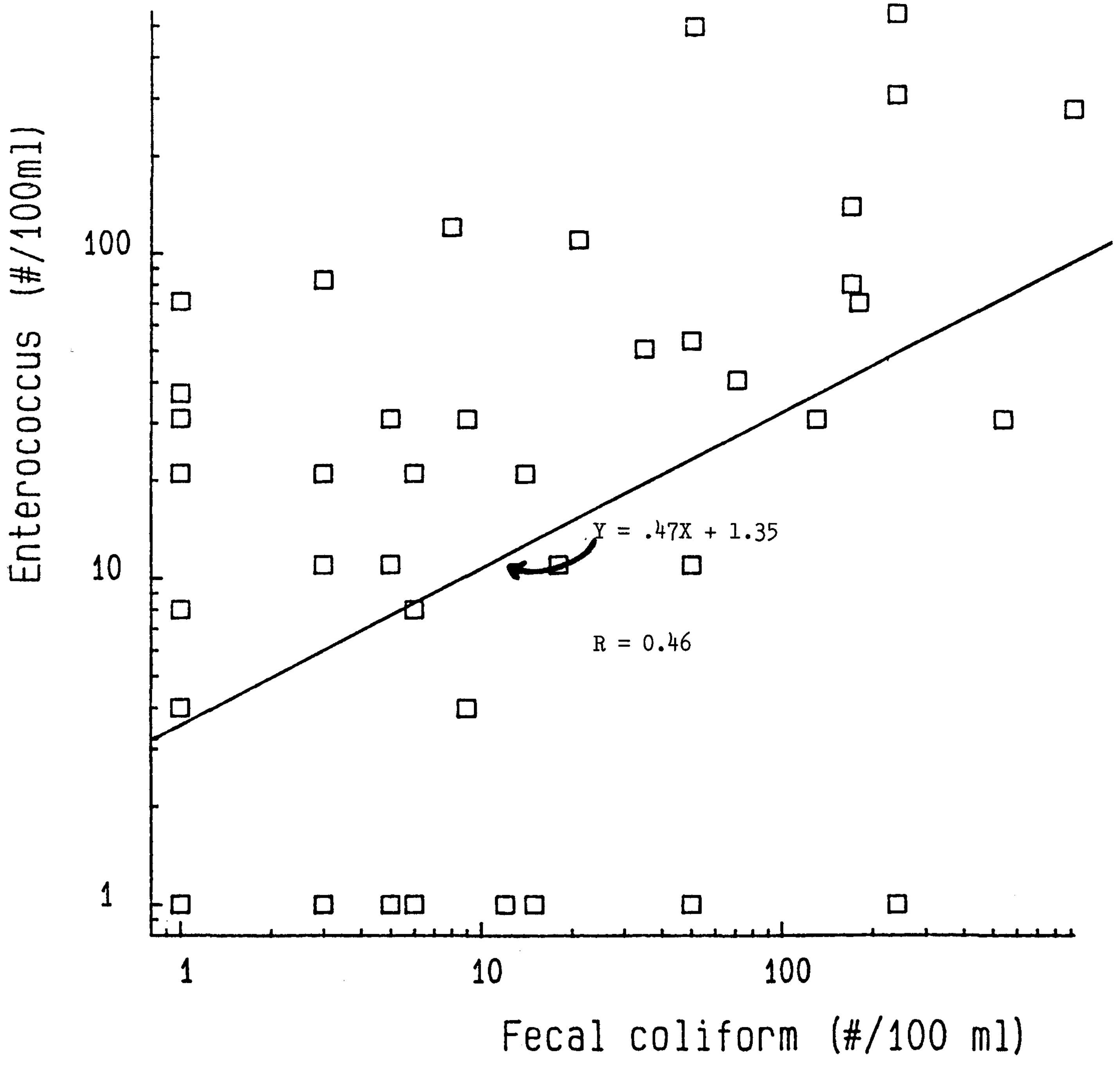


Figure 20 - Relationship between fecal coliform and enterococci densities in samples collected at routine sampling stations in Buttermilk Bay during 1986. Data were $\log_{10}$ transformed.

VIRUSES - A LITERATURE REVIEW OF PERTINENT ISSUES

While the issue of fecal coliform presence in Buttermilk Bay has been addressed in the course of the present study, it should be understood that the presence of an additional biological component of domestic sewage, the viruses, also has public health implications. Due to the constraints of the present study, the impact from viruses entering Buttermilk Bay could not be evaluated directly, however, what follows is a comprehensive review of published studies relating to virus entrainment in groundwater and persistence in the nearshore environment, with comment on the applicability of these studies' results to our area.

More than 110 different viruses are known to be excreted in human feces (Goyal 1984). While the number of viruses shed from individuals varies greatly depending on the infection status of the host, 10^6 to 10^7 virus particles per gram of feces has been reported by this author as an average. A review of the literature leaves little doubt that human pathogens, notably enteric viruses are neither inactivated nor removed in conventional wastewater treatment systems (Dubois et al 1979). Since on-site subsurface sewage disposal units receive no chemical treatment, with the possible exception of limited disinfection as a result of residual chemicals from laundry and cleaning wastes, it is imperative to ensure that system location practices allow for adequate means of pathogen removal by means of filtration, adsorption and retaining the waste until pathogenic organisms lose their ability to enter routes where they will allow exposure to a human host in an infective state. In order to ensure this, a sound understanding of the process and factors involved in pathogen travel and survival in groundwater as well as the persistence in the marine environment is essential. What follows is a discussion of these factors from the published literature regarding viruses.

At the outset, it should be understood that, to date, there have been no comprehensive studies documenting the impact of bacteria or virus originating in on-site subsurface septic facilities on adjacent surface waters. With few exceptions, therefore, much of the inferences made herein relative to on-site systems originate from data collected in association with alternate land disposal techniques such as rapid or slow sand filtration beds, septic lagoons or irrigation practices. Since collectively these alternatives as well as the on-site alternative have as their basic component waste application into soils, an extrapolation of data gathered with respect to pathogen entrainment and survival from alternate methodology into on-site application situations appears justified.

With respect to the threat of compromising water quality of adjacent surface waters with on-site septic system practices, the issue can be broken down into three basic questions which will serve as the outline for the following discussion and literature summary.

(1) Do viral pathogens have the ability to become entrained in groundwater which recharges surface water?

(2) Can these pathogens survive for extended periods in groundwater?

(3) Can viral pathogens remain viable for extended periods in the marine environment ?

A number of obstacles immediately present themselves when trying to answer these basic questions, particularly in reference to viral pathogens. In 1983, Vaughn and Landry (1983) indicated that the field of environmental virology was in its "embryonic" state. To draw upon this same analogy, it can be stated that due to technical problems associated with various aspects of virus culture and monitoring the field to this date remains in its infancy.

Although there is no epidemiological evidence linking on-site subsurface disposal practices with disease outbreaks from adjacent recreational water usage, the evidence of water-related disease outbreaks involving consumed water (see Gerba et al 1985 for a review of the literature relating to waterbourne gastroenteritis and hepatitis) is considerable. Thus, investigation into the disease-transmission possibilities involving recreational usage of water receiving septic leachate, particularly in areas where edible products such as shellfish are harvested appear quite warranted. Within the confines of a properly operating on-site subsurface system, groundwater entrainment is the only vector by which pathogens migrate from the disposal site.

Groundwater recharge enters adjacent surface waters by one of two modes. In most situations, recharge enters the surface water laterally at some point beneath the surface of the water. At this point, biological contaminants entrained in groundwater must "survive" the passage through the sediment-water interface or survive containment in those sediments. It is the lack of understanding of the processes in this sediment-water interface which calls into question the validity of applying information collected in most published groundwater microbiology studies toward resulting surface water pollution. Simply stated, extended entrainment/survival of pathogens in groundwater may have reduced implication to surface water pollution if the pathogens are unable to "survive" the passage into the surface water. For this purpose, the later portion of this report summarizes the available data on the survival of certain pathogens in marine sediments.

A second mode by which biological contamination in groundwater can reach surface waters is commonly referred to as seepage or "breakout". In this situation, hydrographic conditions such as an ebbing tide, rain or snowmelt recharge etc. increase the hydraulic head or gradient to the point where groundwater seeps or breaks through the surface of the soil adjacent to the body of water and completes its path to the surface water by way of an overland route. During these situations, biological contaminants entrained must survive a different, typically more variable set of environmental conditions, during its overland passage to be considered a possible threat to the public health. For this purpose, additional environmental factors and their effect on the survival of various pathogens is also reviewed.

ENTRAINMENT OF VIRUSES IN GROUNDWATER

In their review of recent literature Keswick and Gerba (1980) reported that various studies indicated that viruses could be entrained in groundwater to distances up to 408 m from their point of application. It should be noted, however, that reports of lateral entrainment of viruses in excess of 70 m are rare in the literature. The majority of investigations relative to virus entrainment and survival in groundwater have been in regard to land application of domestic wastes and have indicated limited mobility of viruses in soils. Duboise et al (1976) in laboratory studies using soil columns indicated that viruses migrated at least 10 cm. In Eustis fine sand, Bitton et al (1984) noted that virus migration following sludge application was less than 33 cm. McConnell et al (1984) reported that, applying seeded river water at an application rate of 0.2m/h through soils containing higher than 98% sand, reovirus were noted to be retained within a distance of 1.22 m. Gerba and Lance (1978) applying primary sewage effluent to soil columns of loamy sand soil indicated that only on one occasion were viruses detected at the 250 cm. depth. Laboratory experiments of Dubois et al (1974) using sandy forest soil indicated a 98.6% removal of Polio I and 99.6% removal of T 7 Virus within 19.5 cm. of sandy forest soil. In other laboratory experiments Wang et al (1981) comparing 4 soil types and using Polio I and Echo I viruses found that with the exception of Rubicon Sand, in which there was a penetration of at least 87 cm., other soils tested removed at least 98% of the viruses within 67 cm. While laboratory experiments of Lance and Gerba (1984) indicated virus movement of 160 cm. under saturated conditions, this author noted considerably less entrainment distances (40 cm) when unsaturated conditions were tested.

In apparent contrast to these studies, field investigations indicate a more extensive entrainment of viruses. Mack et al (1972) isolated Poliovirus Type 2 from a 30.5 m-deep well located 91.5 m from the edge of a wastewater drain field. Wellings et al.(1975) describing the penetration and entrainment of viruses following application of secondary sewage to a cypress dome indicated from a single isolation of virus that lateral entrainment was 38 m from the source at a depth movement to 3 m. Vaughn et al (1983) in what is likely the most pertinent investigation to our study area of Buttermilk Bay, investigating leachate from septic tanks in a shallow sandy soil aquifer observed virus to be entrained to aquifer depths of 18 m and lateral movement to a distance of 67.05 m. This author, citing additional work by himself and coauthors also noted lateral entrainment 45.7 m downgradient from recharge basins receiving effluent following tertiary treatment. Further work cited by these authors reported a single isolation of coxsackievirus from an observation well 402 m downgradient from a sanitary landfill. Using a tracer virus (coliphage f2), Schaub and Sorber (1977) have demonstrated lateral entrainment of virus to 182.8 m at a site used for rapid infiltration of wastewater.

Not all field studies indicate extensive lateral movement of viruses. Brown et al (1979) concluded from studies using coliphage that 120 cm. was adequate to minimize the possibility of groundwater contamination. Gilbert et al (1976) observed that when secondary sewage effluent was applied to sandy-loam soil 99.99% of the viruses were removed within 9 m of passage.

There are many possible reasons for the variability noted in the previously cited studies regarding the mobility of virus within the soil column. Foremost, it should be understood that the field of environmental virology, to include sampling methodology and isolation techniques has undergone significant changes in the past two decades. Thus, there are significant differences in the detectability limits in many of the studies reviewed. Perhaps more important, however, in accounting for the variability in entrainment values are differences among the studies in the many variables affecting the movement of viruses in groundwater. Keswick and Gerba (1980) in reviewing those factors affecting the entrainment and survival of viruses in groundwater have listed numerous specific factors under three broad categories of hydrogeological, biological and meteorological. While each of the specific factors affecting virus retention in soil are discussed under separate headings in the following discussion, the reader should realize that no one factor can be singled out as the most influencing factor in survival or entrainment of viruses in groundwater. In a given situation, it is likely that many factors operate in complex concert to cause an observed level of entrainment or survival. In addition, it should be understood that soil systems are dynamic systems in which many influencing factors undergo periodic changes which in turn alter survival and entrainment characteristics of pathogens.

Factors Affecting the Survival and Entrainment of Viruses in Groundwater

Temperature

Similar to what has been reported for bacterial indicators, temperature has been reported to exert a primary influence on the persistence of viruses in groundwater. A review of investigations in this area (Duboise et al. 1979) generally indicates an inverse relationship between virus survival and soil temperature. Dubois et al. (1976) found that survival at 4 C was greatly prolonged over 20 C. During investigation of sludge amended soil, Tierney et al. (1977) found maximum survival (at least 96 days) during winter compared with survival of only 11 days during summer months. Under winter conditions Damgaard-Larsen et al. (1977) observed the survival of coxsackievirus to persist for 23 weeks. Yates et al. (1985) found that poliovirus underwent a 1-log reduction in titer in 3-5 days at 26 C as opposed to 28.8 days at "lower" temperatures. Hurst et al. (1980 b) concluded that temperature was one of the most important factors affecting virus survival in soil systems.

Moisture Content of Soil

Numerous studies summarized by Vaughn and Landry (1983) strongly support the role of soil moisture in virus survival. These studies generally suggest that losses in soil moisture result in higher inactivation rates for viruses and suggest that on-site subsurface sewage disposal systems situated where drying cycles could be achieved will exhibit the more optimal virus inactivation as opposed to systems situated where soils underlying the leaching facility retains adequate moisture on a continuing basis (such as near or in the saturated zone).

Distance to Groundwater

The likelihood that viral pathogens will be entrained in groundwater and carried significant distances from the site of deposition is directly related to the underlying conditions which facilitate the travel of the virus to the groundwater table. The two factors integrally involved in this process are distance and time. If the velocity of an effluent is kept constant, the probability that a virus particle will reach the groundwater table is negatively correlated with the depth of the vadose zone. In close conjunction with the soil depth, however, the rate of recharge is clearly shown to positively affect the penetration of viruses into the vadose zone (Wang et al. 1981 and Vaughn et al. 1981). In short, higher recharge rates generally cause further movement of viruses toward the groundwater table, and in some cases the virus may reach the saturated zone. Thus a lower recharge rate in some situations may determine whether viruses become entrained in groundwater or get retained in the vadose zone.

pH

Due to the electrochemical nature of virus particles, the pH of both the sewage effluent and the soil microenvironment strongly influence the adsorption of virus. Although an in-depth discussion of the electrochemical double layer (ECDL) of viruses and the various reactions of this layer is outside the scope of this paper, it is sufficient to say that, in general, lower pH ranges tended to increase adsorption of viruses in studies reviewed. Goyal and Gerba (1979) using nine different soils concluded that soil pH was the single most important factor influencing virus adsorption to soil. Burge and Enkiri (1978) noted an increased adsorption of a bacteriophage at decreased pH. Schaub and Sagik (1975) additionally observed increased adsorption at lower pH using 2 Encephalomyocarditis viruses. Conducting a study using 34 minerals and soils, however, Moore et al (1981) did not demonstrate significant correlation of polio virus type 2 with pH alone.

Since each virus has a specific surface charge characteristic and since the pH and ionic strength of the aqueous environment has a key role in determining the overall strength of the charge (and hence its mobility in soil), it is likely virus type (discussed later) is an important factor in determining the effect pH has on virus entrainment. In addition to this two factor interaction, Sobsey et al (1980) indicated that soil type can also modify the correlation of pH and virus adsorption. In general, however, it does appear that lower pH environments do enhance adsorption. This author additionally reported that, even in soils with low adsorptive capability (i.e. sands) an enhancement of the limited ability can be achieved by lowering the pH.

Type of Soil

The majority studies reviewed dealing with adsorptive capacity of soils indicate soil type is extremely important in governing the mobility of viruses in applied effluent. In general, one of the key characteristics of soil determining its adsorptive capacity is the clay content. Sandy and organic soils are poor adsorbers of virus (hence would allow for more extensive entrainment), whereas clay soils are good adsorbers (Keswick and Gerba 1980). This condition is supported in study by Sobsey et al (1980), Schaub and Sagik (1975) and others. Conversely, however, Schaub and Sorber (1977) demonstrated extensive migration (ca. 183 m) of viruses in "silty, sandy gravel".

Two additional factors reported by Vaughn and Landry (1984) that are closely related to overall clay content are cation exchange capacity (CEC) and specific surface area (SSA). In general, these two factors are positively correlated with clay content. Burge and Enkiri (1978) specifically mentioned these factors noting that adsorption of a bacteriophage increased as these two factors increased. Findings of Funderburg et al (1981) using this same bacteriophage as well as poliovirus 1 and reovirus 3 correspond well with findings of Burge and Enkiri (1978). While correlation with these specific soil characteristics (CEC and SSA) and adsorption was not observed by Goyal and Gerba (1979) these authors do concur that soil type is a major factor affecting adsorption of viruses, reporting that clay in soil enhances adsorption.

In addition to clay components, insoluble organic components in soil have been shown to affect adsorption. Natural soil organic matter has been shown to be a weak adsorber of viruses (Moore et al 1981). Studies conducted using septic sludge, however, seems to indicate the ability of this organic matter to retain viruses in upper soil layers (Bitton et al. 1984 and Damgaard-Larson et al.(1977). Pancorbo (1981) reported that viruses had more affinity toward aerobically digested sludge than anaerobically digested sludge.

Dissolved Solids

Many studies have been published relating to the various affects of dissolved solids on virus adsorption to soils. As mentioned previously, those materials affecting the pH of the system can have appreciable affect by modifying the overall surface charge of the virus particle (see pH), and hence its mobility in groundwater. In addition, there are some indications in the literature, notably study of Schaub and Sagik (1975) and Carlson et al (1968) that the metallic cation concentration positively correlated with virus adsorption. The later authors noted that divalent cations affected virus adsorption more positively than equal molar strength solutions of monovalent cations. In subsequent study Bitton et al (1975) determined that trivalent aluminum cations were more effective in enhancing adsorption than divalent ions. Lefler and Kott (1974) found differential adsorptive enhancement abilities of soil columns dependent on the concentration of the divalent calcium cation.

Studies by both Schaub and Sagik (1975), Moore et al.(1981) and Scheuerman et al (1979) suggest that dissolved organic material negatively affects virus adsorption. In an experiment designed to separate out the affects of the water-soluble organics from the insoluble components in "muck" soil, the later authors concluded that the "Humic substances" within the muck soil interfered with the adsorptive capacity. Lo and Sproul (1977) using dissolved proteinaceous organic materials found that not only did the substances compete for adsorption sites on silicate minerals, but caused viruses to desorb and become mobile in the soil column. It was apparently this type of interaction that Sobsey et al (1980) observed when he found nutrient broth to be the most effective treatment to elute viruses. These findings stand in apparent conflict with other studies by Gerba and Lance (1978) who found that organics present in primary on secondary effluent did not affect virus adsorption and Goyal and Gerba (1979) who found no consistent pattern of affect relative to % organic matter in applied effluent. In addition to the prior mentioned surfactants have been shown to diminish the adsorptive capacity of soils (Dizer et al. 1984).

It thus appears that in general an increase in total dissolved solids enhances virus adsorption with the possible exception of high molecular weight organic fractions which may compete for binding sites in some situations. Di and tri-valent comprehensive review of literature in regard to this aspect was presented by Melnick and Gerba (1980).

Solar Radiation

The negative effect of solar radiation in surface waters has been noted by a number of investigators (Bitton et al. 1979, Kapuscinski and Mitchell 1983). A number of factors govern the photinactivation process to include association with sediments, depth in the water column, and presence of blue-green algae (Bitton et al. 1979). Although this author suggested that light inactivation was less important at depths exceeding 6 inches, Kapuscinski and Mitchell (1983) have suggested that light wavelengths exceeding 370 nm can cause mortality and that these wavelengths can penetrate to depths of 5 m and experience only a 10-fold reduction in intensity.

GENERAL SUMMARY AND CONCLUSIONS

The causes for the bacteriological contamination of Buttermilk Bay can be separated into two categories: continual inputs and inputs related to storm or rain events. It is the later category which plays the major role in the classification of Buttermilk Bay for shellfishing purposes and to a great extent has determined the public's perception of water quality in the bay in general. The primary sources of fecal coliform during rain events are discharge pipes serving an extensive drainage area in the surface watershed of the bay. The degree of contamination from any one pipe is related to the intensity of land use within its service area, periodicity of rain events and season of year. In general the drain servicing the most intensively used land during summer months in which rain events are infrequent will exhibit the highest contamination levels during rain events. Although the sources of fecal coliform in discharges could not be positively identified, a large pet and wildlife population in the area is implicated. Comparison of this study's values with nationwide observations under the National Urban Runoff Program suggests that fecal coliform values observed at discharges are not necessarily caused by direct sanitary waste input to the discharge systems. An intensive survey of the areas serviced by all surface drains failed to disclose any cross connections with the drainage system.

In addition to stormwater discharges, the release of coliform from protected reservoirs, such as the strand line and sediments, also contributes to the increased fecal coliform levels during rain events. Although the fecal coliform loading from these factors could not be determined, data presented do indicate the effect may, in certain situations, be substantial.

During periods of little precipitation, water quality in the bay is generally good with the exceptions of areas around constant inputs. These constant inputs include freshwater streams as well as one intermittent point discharge. Regarding the freshwater inputs, historic comparisons showing high fecal coliform values as far back as 1973 in the case of Red Brook suggest that encroaching development is not entirely responsible for values observed just prior to and during the recent shellfish closures. Point sources within this watershed and the four remaining were not located, suggesting fecal coliform of a diffuse source, possibly natural in origin. Nutrient levels as well as protective characteristics of the drainage basins suggest the possibility that indicator organisms are subject to significant modification to its mortality rate. The single point source discharge located near a local fish market can be expected to impact the immediate area, the extent of which will be determined by the local mixing conditions.

The effect of waterfowl use on the bacteriological quality of water was found to have two components. Direct fecal deposit into the bay was shown to have minimal effect in most situations, while beach deposition was shown to have the potential for significant cumulative effects.

The total effect of septic systems on the bacteriological quality of Buttermilk Bay could not assessed, but three main possibilities for impact were suggested. Initially, there is some indication that fecal coliform can be entrained in groundwater near the bay to distances of approximately 35 m. In addition to bacteria, an extensive review of published studies indicates that viral pathogens are entrained to greater distances in groundwater. Using published studies which are most applicable to our study area, it is possible that viral pathogens can be entrained for lateral distances of at least 67 m, even in situations where the subsurface septic system of origin is properly located in accordance with present regulation. The variety of variables involved in predicting virus movement in groundwater, however, precludes using this value as a definitive guideline.

Small scale laboratory and in-situ experiments suggest the possibility that nutrient inputs, some of which can be traced to septic systems, affect the bacteriological quality of the water additionally by altering the mortality rates of organisms in the receiving waters. Two major mechanisms are suggested to include an altering of the ultraviolet light penetration of the water and providing nutrients for maintenance and possibly growth of indicator organisms and pathogens.

APPENDIX I

DESCRIPTION OF DISCHARGES ENTERING BUTTERMILK BAY

APPENDIX 1

Descriptions of Discharges into Buttermilk Bay

Preliminary notes: All drains have been observed during dry conditions. With the exception of locations referenced as # 10 (Marsh Stream), # 11 (Groundwater recharge at Old Head of Bay), # 17 (Wychunus St. Drain),# 21 (Inner Miller's Cove) and # 29 (Lobster tank and drains from fish market), all drains exhibited no flow. Flow observed at # 17 and # 19 are considered to be from tidally influenced groundwater. Additionally, with the exception of those aforementioned drains, flow at the other stormdrains ceases within approximately 2 hours following rain events.

The following is a summary of the drains and discharges located in Buttermilk Bay. Impervious surface drainage area was estimated based on drainage area walks using a Rolotape and calculating area.

Reference Code: # 1

Location: East side of Cohasset Narrows draining highway.
Description: 45.7 cm (18 inch) diameter steel pipe discharging above high water line.
Approximate Impervious-Surface Drainage Area in Sq.M.: 8,046 (86,570 Sq.Ft.)
Characteristics of Drainage Basin: Commercial (Craft Shop, Diner, Restaurant and Gas Station)

Reference Code: # 2

Location: Electric Avenue Boat Ramp.
Description: Boat ramp with bermed paved surface to direct drainage.
Approximate Impervious-Surface Drainage Area in Sq.M.: 2091 (22,500 Sq.Ft.)
Characteristics of Drainage Basin: Residential, Boat ramp and some beach parking.

Reference Code: # 3

Location: Public Beach near Electric Ave.
Description: Corrugated Pipe with discharge below high water line.
Approximate Impervious-Surface Drainage Area in Sq.M.: 5980 (64,340 Sq.Ft.)
Characteristics of Drainage Basin: Residential, Beach Parking, light commercial. Bermed to direct drainage.

Reference Code: # 4

Location: Brom Dutcher Rd.
Description: Open Ditch emptying at edge of bay above high water line.

Approximate Impervious-Surface Drainage Area in Sq.M.: 325 (3500 Sq.Ft.) plus approximately 372 Sq.M. (4,000 Sq.Ft.) semi-pervious roadbed.
Characteristics of Drainage Basin: Residential

Reference Code: # 5

Location: Brom Dutcher Rd.
Description: Pipe corrugated-galvanized -installed 1986.
Approximate Impervious-Surface Drainage Area in Sq.M.: 325 (3,500 Sq.Ft.)
Characteristics of Drainage Basin: Residential

Reference Code: # 6

Location: Vanderdonk Rd.
Description: Concrete Pipe with approximately 6.1 M of vegetative buffer between discharge point and waterline.
Approximate Impervious-Surface Drainage Area in Sq.M.: 1905 (20,500 Sq.Ft.)
Characteristics of Drainage Basin: Residential with the majority of road bermed to direct drainage.

Reference Code: # 7

Location: End of Quamhasset Rd.
Description: Small Collection Basin with Pipe and at least 30.5 M vegetated buffer between discharge and bay.
Approximate Impervious-Surface Drainage Area in Sq.M.: 465 (5,000 Sq.Ft.)
Characteristics of Drainage Basin: Residential

Reference Code: # 8

Location: Puritan Rd. near Quamhasset Rd.
Description: Two Corrugated Pipes discharging above high water mark, but not accessible at high tide.
Approximate Impervious-Surface Drainage Area in Sq.M.: 9812 (105,572 Sq.Ft.)
Measured value was multiplied by 1.1 to estimate paved driveways
Characteristics of Drainage Basin: Residential. Much of surface is bermed to direct drainage. Basins located on Puritan Ave south of Erin Lane may be leaching basins alone.

Reference Code: # 9

Location: Little Bay Lane
Description: Collection basin with discharge pipe into Spartina patens (short chordgrass) marsh. Approximately 22.9 M of buffer exists between discharge point and bay.
Approximate Impervious-Surface Drainage Area in Sq.M.: 2788 (30,000 Sq.Ft.)
Characteristics of Drainage Basin: Residential. Bermed surfaces to direct drainage.

Reference Code: # 10

Location: End of Little Bay Lane
Description: Termed "Marsh Stream" by D.E.Q.E.. Has Clapper Valve and drains an old bog and marsh.
Approximate Impervious-Surface Drainage Area in Sq.M. N/A
Characteristics of Drainage Basin: Marsh with stormdrain entering in at Puritan Rd.

Reference Code: # 11

Location: Old Head of Bay Rd.
Description: Stream resulting from groundwater recharge. Culvert under Rd. discharges into bay at high water mark.
Approximate Impervious-Surface Drainage Area in Sq.M. N/A
Characteristics of Drainage Basin: Private Property, farmlike. Two horses kept on property.

Reference Code: # 12

Location: Corner of Old Head of Bay and Head of Bay Rd.
Description: Pipe not located (although a discharge pipe direction can be seen in the adjacent drain). May be just a road-cut discharge.
Approximate Impervious-Surface Drainage Area in Sq.M.: 4294 (46,200 Sq.Ft.)
Characteristics of Drainage Basin: Not bermed, steep slope. Residential area. Very pervious surface both sides of road.

Reference Code: # 13

Location: In Hideaway Village
Description: Concrete Pipe emerging from rip rap
Approximate Impervious-Surface Drainage Area in Sq.M. Not Determined but less than 93 (1,000 Sq.Ft.) impervious.
Characteristics of Drainage Basin: Intensely developed residential.

Reference Code: # 14

Location: Near the stream behind hideaway village.
Description: Road berm into Hideaway Village Stream. Road bermed on one side only.
Approximate Impervious-Surface Drainage Area in Sq.M.: 1626 (17,500 Sq.Ft.)
Characteristics of Drainage Basin: Residential and agricultural. Cranberry Bog stream which passes under Head of the Bay Road. Thus drainage is primarily from bog.

Reference Code: # 15

Location: Bayhead Shores
Description: Corrugated Pipe discharging above the high water mark.
Approximate Impervious-Surface Drainage Area in Sq.M.: 1413

(15,200 Sq.Ft.)
Characteristics of Drainage Basin: Residential

Reference Code: # 16

Location: Red Brook at Head of Bay Rd.
Description: Included here are two discharges, one concrete pipe discharging above the water line on the west side of the creek, and a bermed discharge on the east side.
Approximate Impervious-Surface Drainage Area in Sq.M.
West side pipe - 8,643 (93,000 Sq.Ft.)
East side cut - 3,764 (40,500 Sq.Ft.)
Characteristics of Drainage Basin: primarily residential with the exception of the north side of Head of the Bay Rd. which is an undeveloped parcel of privately-owned and municipally-owned land.

Reference Code: # 17

Location: Wychunus Ave in Wareham, Mouth of Red Brook
Description: Corrugated pipe discharging below the high water mark.
Approximate Impervious-Surface Drainage Area in Sq.M.: 10,855 (116,800 Sq.Ft.)
Characteristics of Drainage Basin: Residential, lot sizes approximately 465 Sq.M. (5,000 Sq.Ft)- primarily year-round residences.

Reference Code: # 18

Location: Town Landing in Wareham
Description: 16 ft x 1 ft. grate receiving runoff from road. Located on beach.
Approximate Impervious-Surface Drainage Area in Sq.M.: 1631 (17,650 Sq.Ft.)
Characteristics of Drainage Basin: residential. Lots approximately 465 Sq.M. (5,000 Sq. Ft.). Mix of seasonal and year-round homes (mostly year-round).

Reference Code: # 19

Location: Between 55 and 51 Cleveland Way, Wareham.
Description: 38.1 cm (15 in) diameter corrugated pipe discharging below the high water mark.
Approximate Impervious-Surface Drainage Area in Sq.M.: 1631 (17,550 Sq.Ft.)
Characteristics of Drainage Basin: Residential with approximately 465 Sq.M. (5,000 Sq.Ft) lots. High percentage of seasonal cottages. The drained area is split about evenly between paved surface and semi-pervious hardpan. This drain has been observed after rains and appears to stop draining prior to other drains.

Reference Code: # 20

Location: The end of Chippewa Drive, Wareham
Description: 38.1 cm (15 in) diameter corrugated pipe discharging

generally below the sand surface, below the high water mark.
Approximate Impervious-Surface Drainage Area in Sq.M.: 2035 (21,900 Sq.Ft.)
Characteristics of Drainage Basin: Residential with approximately 465 Sq.M. (5000 Sq.Ft.) lots. Higher percentage of seasonal cottages in the drainage basin. 725 Sq.M. (7800 Sq. Ft.) of basin is composed of semipervious hardpan.

Reference Code: # 21

Location: Discharge into inner Miller's Cove
Description: Corrugated pipe discharging below high water mark.
Approximate Impervious-Surface Drainage Area in Sq.M.: 279 (3,000 Sq.Ft.)
Characteristics of Drainage Basin: Residential

Reference Code: # 22

Location: Between two end houses on Jefferson Road.
Description: 25.4 cm (10 in) diameter cement pipe with approximately 4.6 M of grass buffer between point of discharge and bay.
Approximate Impervious-Surface Drainage Area in Sq.M.: 1115 (12,000 Sq.Ft.)
Characteristics of Drainage Basin: Residential

Reference Code: # 23

Location: Between # 61 and # 63 Jefferson Rd.
Description: 15.2 cm (6 in) pipe discharging above high water mark.
Approximate Impervious-Surface Drainage Area in Sq.M.: 537 (5775 Sq.Ft.)
Characteristics of Drainage Basin: Residential

Reference Code: # 24

Location: Beside # 37 Jefferson Rd.
Description: 30.5 cm (12 in) concrete pipe discharging below the high water mark.
Approximate Impervious-Surface Drainage Area in Sq.M.: 1004 (10,800 Sq.Ft.)
Characteristics of Drainage Basin: Residential. 372-744 Sq.M. lots (4,000-8,000 Sq.Ft.) lots.

Reference Code: # 25

Location: Near # 23 Jefferson Rd.
Description: Corrugated 25.4 cm (10 in) pipe discharging below the high water mark.
Approximate Impervious-Surface Drainage Area in Sq.M.: 1338 (14,400 Sq.Ft.)
Characteristics of Drainage Basin: Residential, 465-1208 Sq.M.

(5,000-13,000 Sq. Ft. lots. Primarily year-round.

Reference Code: # 26

Location: Between # 15 and # 17
Description: Two corrugated 25.4 cm (10 in) diameter pipes discharging below the high water mark.
Approximate Impervious-Surface Drainage Area in Sq.M.: 3399 (36,575 Sq.Ft.)
Characteristics of Drainage Basin: Residential. 372-744 Sq.M. (4,000-8,000 Sq. Ft.lots, primarily year-round residences.

Reference Code: # 27

Location: On Route 28 By Boatyard
Description: 45.7 cm (18 in) concrete pipe draining highway. Discharge at high water mark.
Approximate Impervious-Surface Drainage Area in Sq.M.: 7026 (75,600 Sq.Ft.)
Characteristics of Drainage Basin: Commercial (Professional Building, Restaurant, Boatyard, Realty, Hotel)

Reference Code: # 28

Location: By Captain Harris Fish Market
Description: 30.5 cm (12 in) steel pipe draining highway. Discharges below high water mark.
Approximate Impervious-Surface Drainage Area in Sq.M.:4740 (51,000 Sq.Ft.)
Characteristics of Drainage Basin: Commercial (Fish Market, Liquor Store, Antique Shop, Bait and Tackle). Highway.

Reference Code: # 29

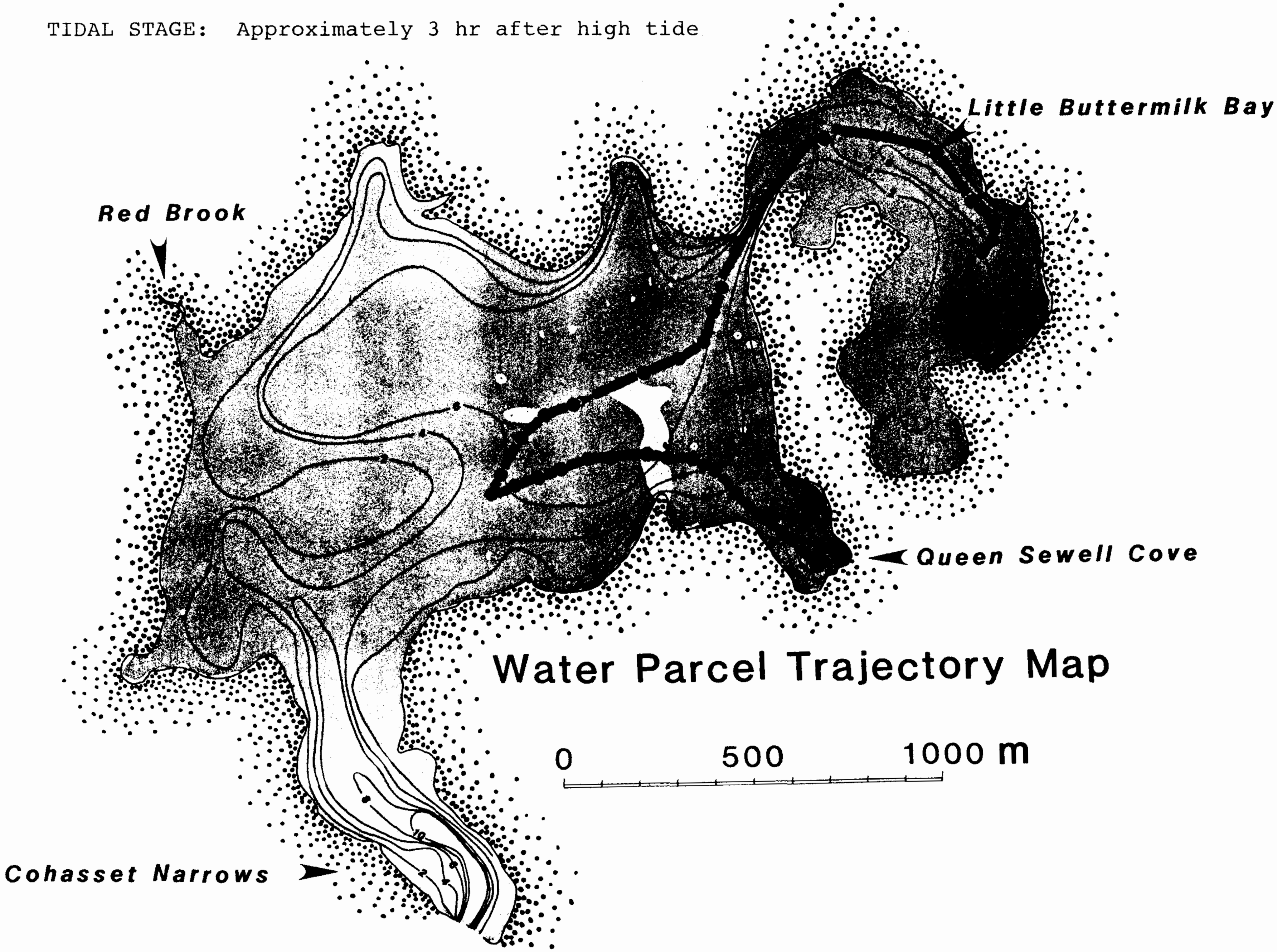
Location: By Captain Harris Fish Market
Description: 25.4 cm (10 in) concrete pipe
Approximate Impervious-Surface Drainage Area in Sq.M. N/A - apparently ties in to lobster tank and floor drains.
Characteristics of Drainage Basin: see above

APPENDIX II

PARTICLE TRAJECTORY MODEL REPRESENTATION FOR SIMULATING THE FATE OF BACTERIOLOGICAL CONTAMINANTS ENTERING DISCHARGE POINTS IN BUTTERMILK BAY

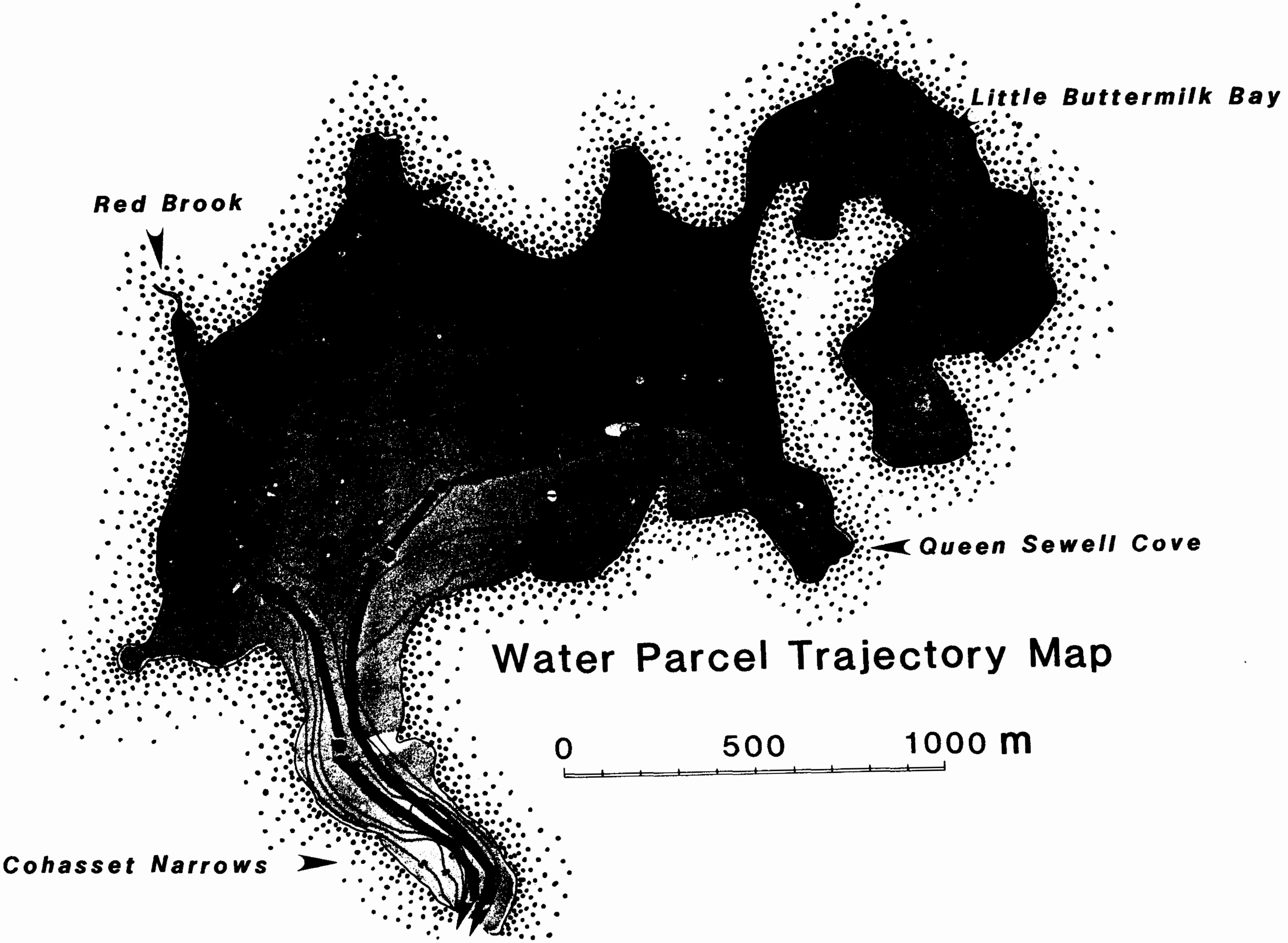
Note: These particle trajectories are based on entry at the specified tidal stages and were obtained using TEA, a finite element computer model developed by the Massachusetts Institute of Technology, Energy Laboratory. They have been provided compliments of Craig Fish, Boston University Geology Department.

TIDAL STAGE: Approximately 3 hr after high tide



Water Parcel Trajectory Map

TIDAL STAGE: beginning of outgoing tide



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