AN INVESTIGATION OF TWO MARINAS AS SOURCES OF POLLUTION IN BARNEGAT BAY, N.J.

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INTRODUCTION

PROBLEM STATEMENT and OBJECTIVES

1. INTRODUCTION

1.1. Marinas at Barnegat Bay

Barnegat Bay is one of New Jersey's largest back barrier estuaries, extending from the Metedeconk River to Little Egg Harbor. It is considered one of the region's most valuable natural resources, providing recreational, economic and aesthetic benefits and is an important inshore commercial and recreational fishery in New Jersey (Hillman and Kennish, 1984). In recent years, the Barnegat Bay area has been subject to an increased population growth and intense residential and commercial development. The population growth has led to a rising demand for recreational use of Barnegat Bay. Subsequently, a demand for marinas which provide access to the bay and its coastal waters has increased (Chmura and Ross, 1978; Sugihara et al., 1979; Tiedeman, 1987).

Marinas are shoreside facilities used for servicing and storing recreational and commercial boats. In addition to providing protected areas for mooring boats, marinas may also provide launch ramps, fuel pumps, boat repair services, open or enclosed dry-land boat storage, rest rooms, retail stores, groceries, bait and tackle shops, and parking facilities (Chmura and Ross, 1978; USEPA, 1985).

There are approximately 200 commercial marinas with about 12,000 boat slips in Barnegat Bay. Sixty per cent of the marinas and 68% of the slips are found in the northern reaches of Barnegat Bay (Anon., 1986). An unknown number of shoreside residences have or are building private docking facilities at Barnegat Bay.

In addition, many condominiums are developing their own marinas called dockominiums.

The construction and operation of marinas have intensified the management concerns of agencies responsible for protecting the coastal environmental resources. Marinas are thought to have adverse effects on coastal ecosystems (USEPA, 1985). Many of the activities in a marina such as wastewater disposal, fueling operations and boat maintenance can affect the water quality in the marina basin and adjacent waters. Little is known about the extent of contamination occurring within marinas through the discharge and accumulation of pollutants. Less is known about the impact of marina pollution on the water and ecosystem of the adjacent open bay.

The New Jersey Department of Environmental Protection (NJDEP) is concerned about the potentially harmful impact on Barnegat Bay caused by marinas, dockominiums, and private docking facilities. In order to respond appropriately and competently to the increasing numbers of applications for marina expansions and new marina development, the NJDEP has initiated studies to assess the impact of marinas on water quality within the marina and in the adjacent bay. This report represents NJDEP Division of Science and Research 1988 investigation of two major pollutants believed to flow from marinas and addresses the impact these pollutants may have on Barnegat Bay.

1.2. Problem Statement

1.1.1. Bacteriological Contamination Caused by Marinas

Marinas are a source of microbiological contamination for New Jersey's coastal waters because of the sanitary wastes that are discharged or leak from boats (NJDEP, 1988a; USEPA, 1985). Several studies have reported an increase in bacteria counts in water and shellfish due to the presence of boats (Udell, 1957-1963; Faust, 1982) and a positive correlation between the number of boats in a marina and the bacteria concentration in the marina's water have been reported (Faust, 1982).

Serious health hazards may develop when boat sewage is discharged into recreational or shellfish-harvesting waters (USEPA, 1985) because the discharge may introduce disease-causing viruses and bacteria in the water. Incidents of hepatitis outbreaks have been attributed to the consumption of shellfish harvested from fecally contaminated water. Gastroenteritis as well as infections of the eye, ear, nose, skin, and respiratory tract can develop from swimming or bathing in waters contaminated from boat sewage (Environmental Health Service, 1988).

Federal and state authorities have set water quality criteria to reduce and prevent illness as a result of ingesting water during recreational activities or consuming shellfish from contaminated waters. Currently, both total and fecal coliform counts are used as indicators of fecal contamination and possible health hazards. The primary contact criterion requires recreational waters not to exceed a geometric mean of 200 fecal coliforms/100 ml (PCC200) and no more than 10% of the total samples during a month should exceed 400 fecal coliforms/100ml. Waters approved for shellfish harvesting require a median count of less than 70 total coliforms/100 ml (AASH70) or less than 14 fecal coliforms/100 ml (American Public Health Association, 1981). In addition, shellfish with greater than 230 fecal coliforms/100 gm are considered unacceptable for consumption (NJDEP, 1988b).

Few data are available about the marinas of Barnegat Bay and their contribution of fecal contamination to recreational and shellfish-harvesting waters. Because of the potential health risks associated with fecal contaminated waters, an investigation of the number of coliform bacteria in the water, sediments and hard clams of marinas is needed to delineate marina-derived fecal contamination and its impact on recreational and shellfish-harvesting waters. In addition, an understanding of the hydrologic parameters and tidal currents of marina waters is needed to determine the mechanisms controlling the movement of coliform bacteria from the marinas into surrounding bay water.

1.2.2. Metal Contamination Caused by Marinas

Trace metals in the coastal aquatic environment are a concern because of their persistence in the water, sediments and biota and their toxicity to aquatic organisms and humans. Aquatic organisms in general and invertebrates in particular are known to assimilate metals acquired during feeding and concentrate the metals within their tissues (Jenne and Luoma, 1977). Metals that concentrate in the tissues of the aquatic organism can have lethal or sublethal effects not only on the organism itself but also on humans that consume the contaminated fish or shellfish.

Many sources including surface and river runoff, stormwater runoff, atmospheric deposition, dredging and dredge spoils, and marinas can contaminate aquatic ecosystems with metals (USEPA, 1985; May and McKinney, 1981; Renwick, 1981). Marinas contribute to metal levels in coastal waters through a number of processes. Metals that have settled to the sediments may be resuspended into marina waters due to boat turbulence and propellers stirring bottom sediments. Lead can be discharged into marina waters through the spillage of leaded fuel and the exhaust emissions of subsurface outboard motors. Anti-fouling paints applied to boats frequently contain copper, nickel and zinc and these metals can enter marina waters as the paints weather. In addition, the metals can be released through the weathering of brass materials on boats (USEPA, 1985).

An understanding of metal contamination originating from marinas and its impact on shellfish is needed. Quantification of the heavy metals found in hard clams collected in marinas will aid in assessing the marina contribution to heavy metal contamination.

1.3. Objectives

This investigation was a preliminary study of the impact of marina activity on the quality of surrounding waters. The following objectives were established for this study:

1. Understand the controlling mechanisms and paths of pollutants within marinas by examining the physical, hydrologic, and environmental conditions of two marinas located at Barnegat Bay.

2. Determine the relationship between fecal contamination in marinas and fecal contamination in the bay by quantifying the coliform bacteria concentrations in the water column inside and outside of two marinas over a 12-hour tidal cycle.

3. Assess the impact of bacteriological contamination originating from marinas on recreational and shellfish-harvesting water by determining whether the marina and adjacent bay waters comply with the PCC200 and the AASH70 standards.

4. Understand the movement and fate of coliform bacteria for a particular marina by determining the number of coliforms in the water, sediment, and biota of two marinas and the adjacent bay.

5. Quantify and compare weekday coliform bacteria concentrations with weekend coliform concentrations.

6. Determine the impact of heavy metal contamination derived from marinas on hard clams in Barnegat Bay. Investigate heavy metal concentrations in the hard clam, <u>Mercenaria</u> <u>mercenaria</u>, to help determine whether marina operations are

contaminating the water and biota. Assess real and potential threats to marine life and humans resulting from the presence of the metals.

SECTION 2

METHODS

2. METHODS

2.1. Marina Selection

The two marinas at Barnegat Bay selected for this study were Long Quay and Viking Village marinas. Long Quay is a semi-enclosed marina located on the mainland in Waretown, N.J. Viking Village is an open marina located on Long Beach Island at Barnegat Inlet. Neither marina has any stream or river discharging into it. Figure 1 is a map showing the marina locations in relation to Barnegat Bay. Figures 2 and 3 are maps of the marinas that illustrate their shape, size, and location.

2.2. Sample Collection

The marinas were studied on both a weekday and a Saturday to determine whether there was an increase of pollutant discharge occurring on weekends due to greater marina activity. Long Quay marina was sampled on Wednesday, July 20, 1988 and Saturday, July 30, 1988. Viking Village marina was sampled on Wednesday, August 3, 1988 and Saturday, August 6, 1988.

Water and sediment samples were collected at three sample sites for each marina. Sample site 1 was located within the marina near its fuel pumps, sample site 2 was located directly outside the marina and sample site 3 was outside the marina within the adjacent open bay. Figures 2 and 3 illustrate the location of the sample sites.

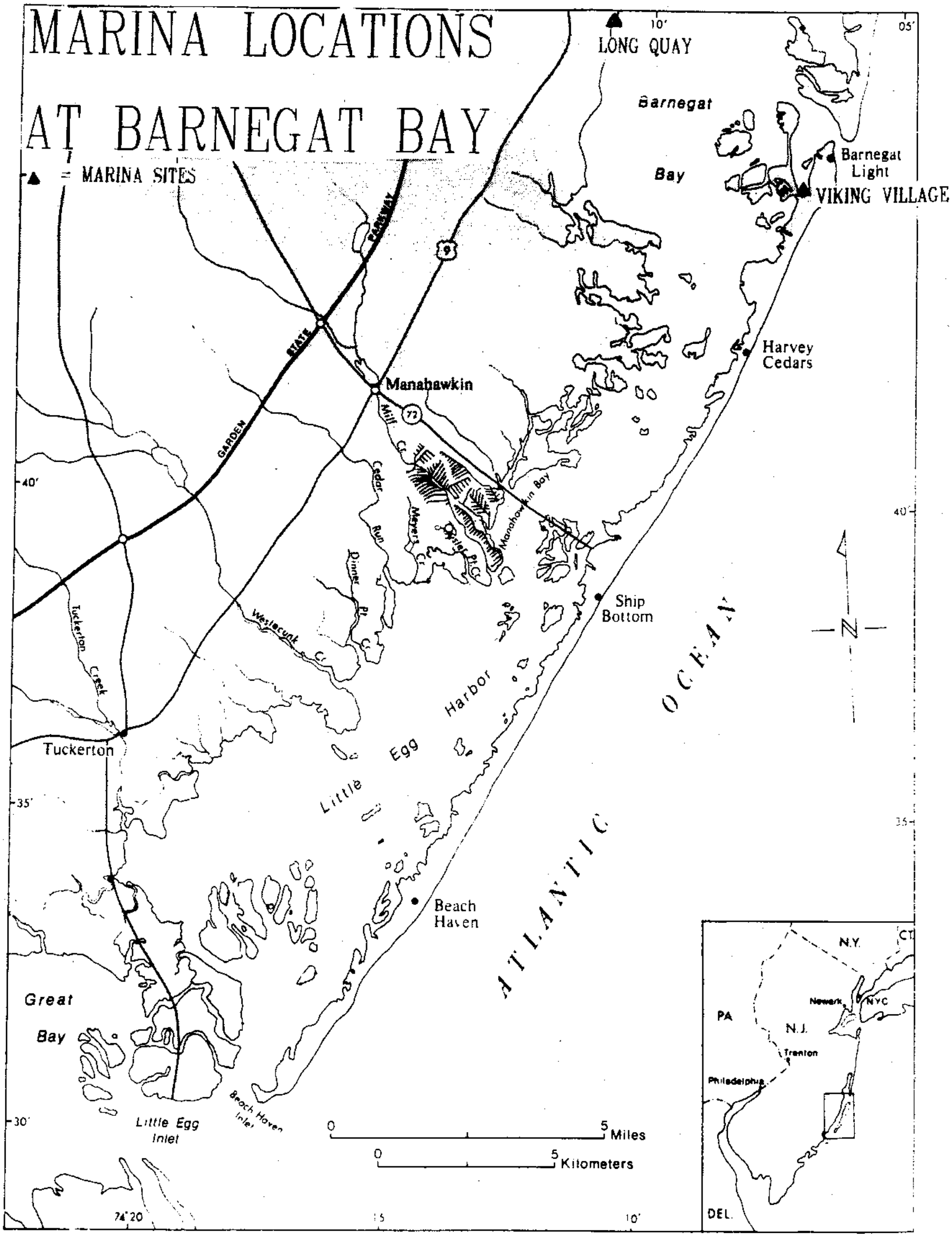

MARINA LOCATIONS
AT BARNEGAT BAY
▲ = MARINA SITES
LONG QUAY
VIKING VILLAGE
Barnegat
Bay
Barnegat
Light
Harvey
Cedars
Manahawkin
Mill C.
Cedar Run
Manahawkin Bay
Ship
Bottom
Westecunk C.
Tuckerton Creek
Tuckerton
Little Egg Harbor
Beach
Haven
ATLANTIC OCEAN
Great
Bay
Little Egg
Inlet
Beach Haven Inlet
Miles
Kilometers
GARDEN STATE PARKWAY
N.Y.
CT
PA
N.J.
Newark
NYC
Trenton
Philadelphia
DEL.

FIGURE 1.

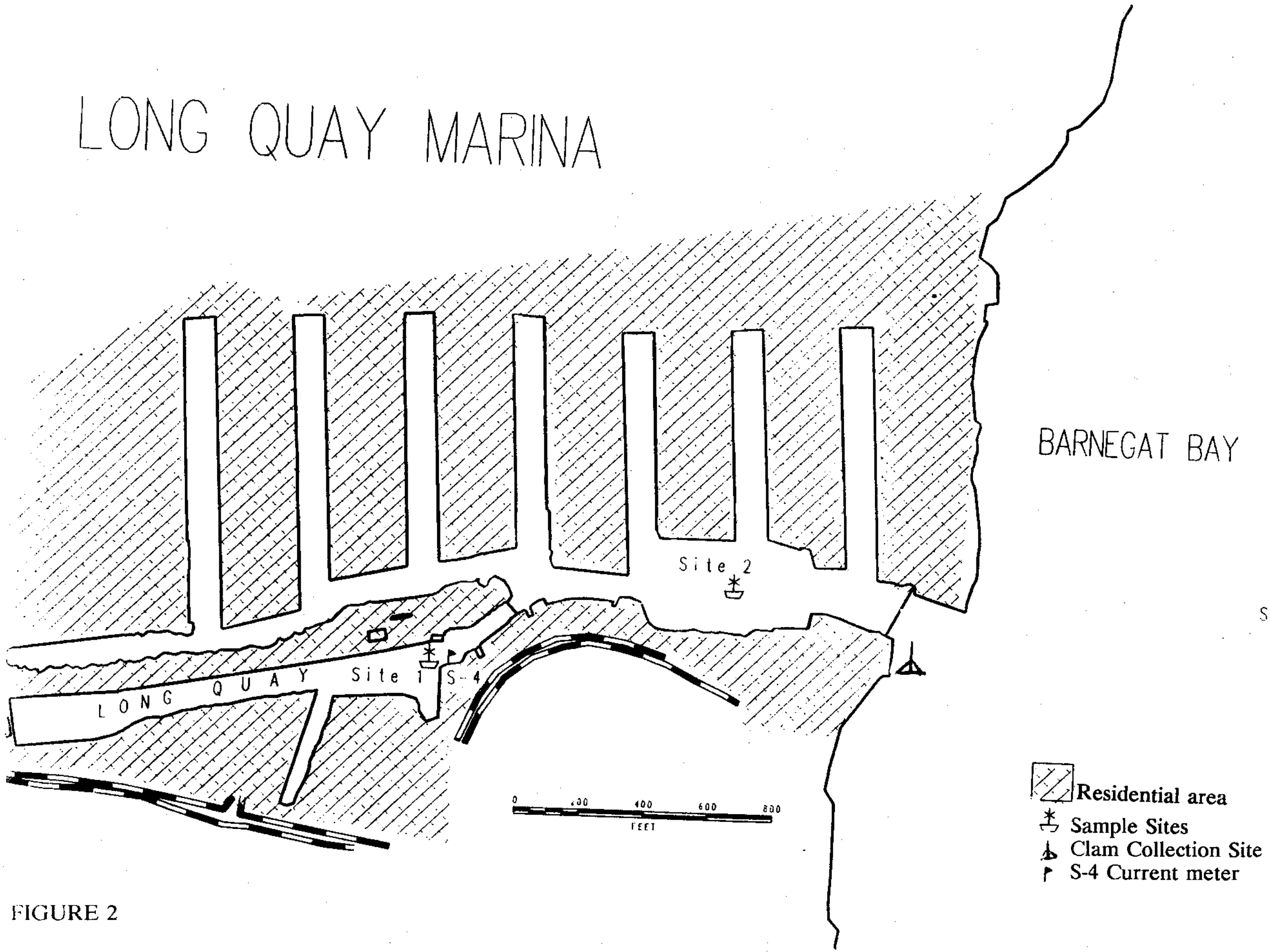

LONG QUAY MARINA
BARNEGAT BAY
Site 2
Site 1
S-4
LONG QUAY
Site
0
200
400
600
800
FEET
Residential area
Sample Sites
Clam Collection Site
S-4 Current meter

FIGURE 2

VIKING VILLAGE MARINA

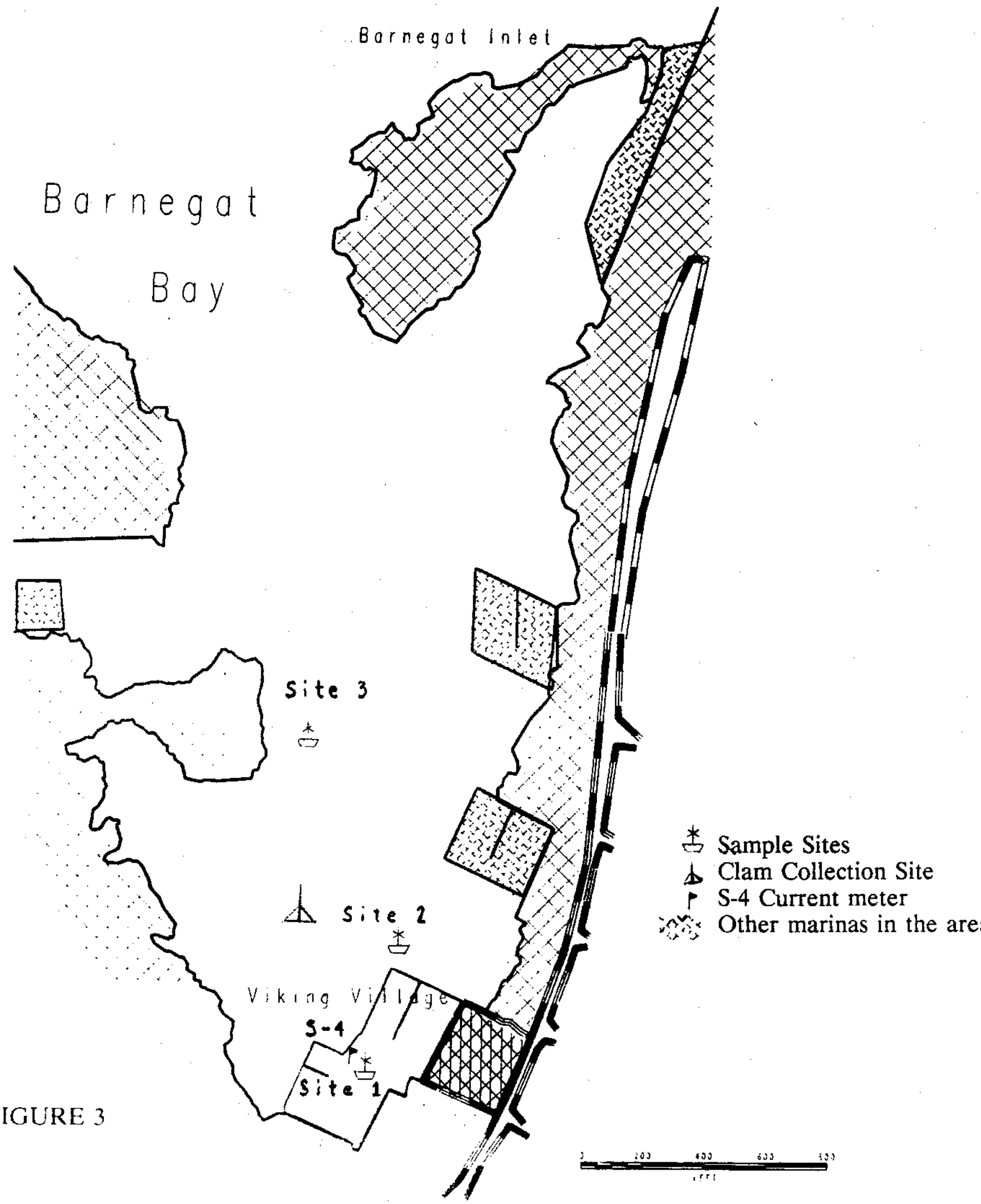


FIGURE 3

Integrated samples of the water column were taken from each marina at each of the three sample sites indicated in Figures 2 and 3. The water was collected using a Niskin water sampler, transferred into sterile bottles, and stored on ice. For each day of study a total of 5 water samples were collected at 3-hour intervals from low tide to the following low tide.

Sediment samples were also collected at each of the three sample sites of the two marinas. Ponar dredge grabs were suspended from a boat and sediments were collected and stored at 4°C in sterile jars until analysis.

Biota samples were collected at both marinas. The species Mercenaria mercenaria was selected as a test organism because it is an important and common commercial species at Barnegat Bay; a large enough organism to provide adequate tissue for lab analysis; and a sedentary filter-feeder that is susceptible to heavy metal bioaccumulation and bacteria contamination.

Shovels and clamrakes were used to collect samples of the hard clams, Mercenaria mercenaria, from mudflats directly outside of Long Quay and Viking Village marinas during the days of study. Figures 2 and 3 show the locations of the clam collection sites. As a control, hard clams were also collected from Great Bay, N.J. Great Bay is located south of Barnegat Bay and is shown in Figure 1.

Great Bay is often used by State researchers as a control area to compare its heavy metal concentrations in hard clams with metal concentrations in clams from environmentally stressed systems. Great Bay is regarded by state and federal authorities as having excellent water quality and its large beds of

Mercenaria are mostly unrestricted for shellfish harvesting (Atlantic Environmental Science, Inc., 1984; NJDEP, 1983; NJDEP, 1988b)

Following collection of the clams, all specimens were labelled, placed into plastic ziplock bags and stored on ice until analysis.

The water, sediment, and hard clam samples were carefully collected and stored to prevent bacteriological contamination of the samples. Water samples were collected and stored following the protocols suggested in Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1981).

2.3. Sample Analysis

Water, sediment and hard clam samples were analyzed for coliform bacteria. Upon collection, the samples were transported on ice to Environmental Testing Laboratories in Forked River, N.J. for bacterial analysis. The maximum transport time was less than 30 minutes. The Environmental Testing Laboratories determined the number of fecal and total coliform bacteria per 100 ml of sample using the standard coliform membrane filter procedure. All procedures used in the coliform analysis were USEPA approved and followed Standard Methods for the Examination of Water and Wastewater (1981).

The coliform counts detected in the water column were statistically evaluated using the software package Statgraphics. A linear regression analysis was performed on the data. To prevent statistical error in the analysis, the data was log-transformed and fit a normal distribution. In addition, residuals were plotted to test that the assumptions of the regression analysis were met.

Some of the clam samples from each marina were stored frozen until later analyzed for heavy metals. Five to ten clams from each marina were analyzed for zinc, cadmium, lead, nickel, manganese, copper and iron. The detection limit for each metal was 0.1 ppm. The analyses were performed using an Inductively Coupled Plasma Emission Spectrophotometer by the Department of Geological and Geophysical Sciences, Princeton University, Princeton, N.J. The viscera of each clam was removed from the shell and used for the analyses. Further details regarding the metal analysis can be obtained through Princeton University, Department of Geological and Geophysical Sciences.

2.4. Physical Measurements

On each day of study, measurements of salinity, temperature, and water depth were taken at each sample site at 3-hour intervals throughout the tidal cycle. These parameters were measured at surface, mid and bottom water depths.

Current velocity was measured and recorded at the throat of each marina on each day of sampling. Current speed and direction were measured with an S-4 continuous recording current meter at the stations shown in Figures 2 and 3. The S-4 current meter integrated one-minute current velocity measurements to produce 10-minute-interval current velocity readings throughout a tidal cycle (low tide to low tide). To best represent the average velocity in the vertical water column, the S-4 current meter was positioned at a depth equal to 0.6 of the total depth. The S-4 also measured and recorded temperature, depth and salinity at 10-minute intervals.

An ENDECO current meter was used to provide additional information on the current velocities at the throat of the marinas. The ENDECO was suspended from an anchored boat and velocity, depth, temperature, and salinity profiles were measured intermittently throughout the tidal cycle. The ENDECO current meter was also used to measure velocity, salinity, and temperature profiles outside the marina within adjacent bay waters. The tidal height was recorded hourly within the marinas on each day of the study.

All hydraulic measurements were performed by personnel from Stevens Institute of Technology, Hoboken, N.J. in conjunction with N.J. Department of Environmental Protection, Division of Science and Research.

Aerial photographs of the marinas were digitized into NJDEP's Geographic Information System (GIS) using the ARC/INFO software package. The GIS was used to calculate the average length, width, surface area, and volume of the marinas.

SECTION 3

RESULTS AND DISCUSSION

THE PHYSICAL PARAMETERS OF THE MARINAS

3. RESULTS AND DISCUSSION - PHYSICAL PARAMETERS OF THE MARINAS

3.1. Results

3.1.1. Physical Descriptions of the Marinas

The physical parameters of each marina can be found in Table 1. Figures 2 and 3 are maps that outline each marina.

Long Quay marina is a long, narrow, semi-enclosed marina and is bordered with bulkheads that provide it with straight vertical walls. It has 130 boat slips and all boats within the marina are used for recreational purposes. The marina provides 2 launch ramps, parking facilities, one fuel pump, and two large and clean public restrooms servicing men and women.

Viking Village marina is a rectangular-shaped, open marina and is bordered by pilings and piers that act as a mooring area for the boats. It has 80 boat slips that service a mixture of recreational, commercial fishing and chartered boats. The marina offers a bait and tackle shop, parking facilities, fuel pumps and one small bathroom. The restroom is not an adequate facility for the number of people who use the marina.

3.1.2. Temperature and Salinity Profiles

Examples of the temperature data collected throughout a tidal cycle are presented in Figure 4. Table 2 presents the temperature and salinity ranges of the marinas and their adjacent bay waters on the days of study. Due to the

Table 1. Physical Parameters of the Marinas

	Long Quay	Viking Village
Surface Area(m^2)	18,419.25	13,765.78
Length (m)	488.79	171.89
Width (m)	37.68	80.09
Depth(m)	1.94	3.5
at low tide	1.91	3.29
at high tide	2.03	4.23
Volume(m^3)	35,733.35	48,180.23
Maximum velocity (m/sec)		
Flood	0.029	0.049
Ebb	0.021	0.047
Maximum flow rate (m^3/sec)		
Flood	1.32	-
Ebb	0.97	-
Tidal Range (m)	0.104	0.98
Flushing Time (days)	35-91[1]	
	10.03[2]	2.25[2]
Tidal period (hours)	12.41	12.41
Tidal Prism (m^3)	1915.602	13,490.46

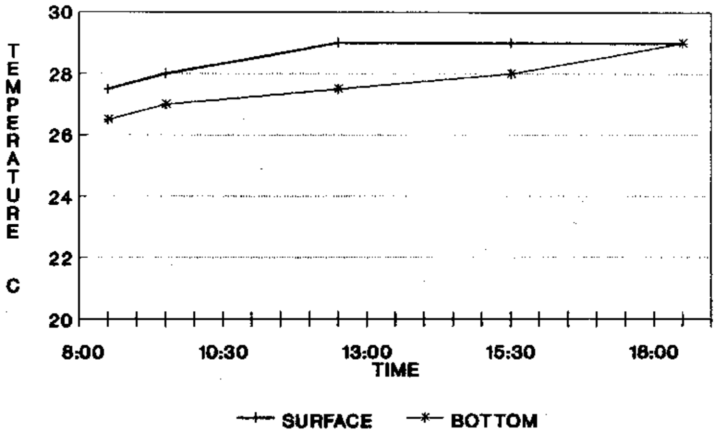
1. Calculated using Equation 2 with D = 0.1 and b = 0.5 - 0.9 (USEPA, 1985).
2. Calculated using Equation 3 (Dyer, 1973).

Table 2. Temperature and Salinity Ranges

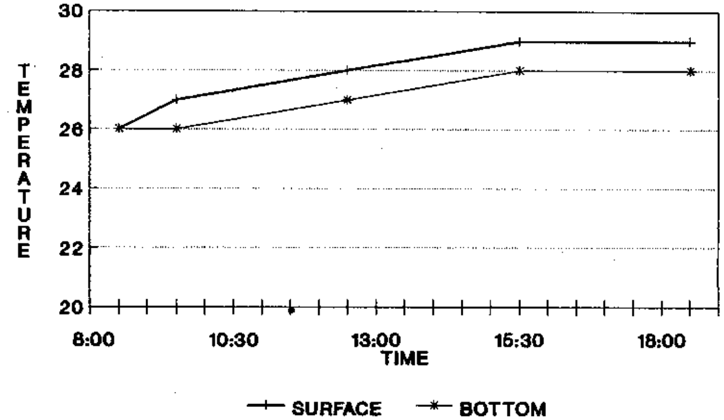
		Long Quay		Viking Village	
		Marina	Adjacent Bay	Marina	Adjacent Bay
Salinity Range (ppt)	B	26.3-27.3	26.9-27.9	28.6-30.1	28.9-30.1
	S	26.1-27	26.8-27.8	28.6-30.1	28.9-30.1
Temp. Range (^{0}C)	B	26.5-29	26-28	22-26	22-26
	S	27.5-29	26-29	24-27	25-28

1. B = Bottom waters
2. S = Surface waters

TEMPERATURE PROFILE IN THE MARINA
July 30, 1988

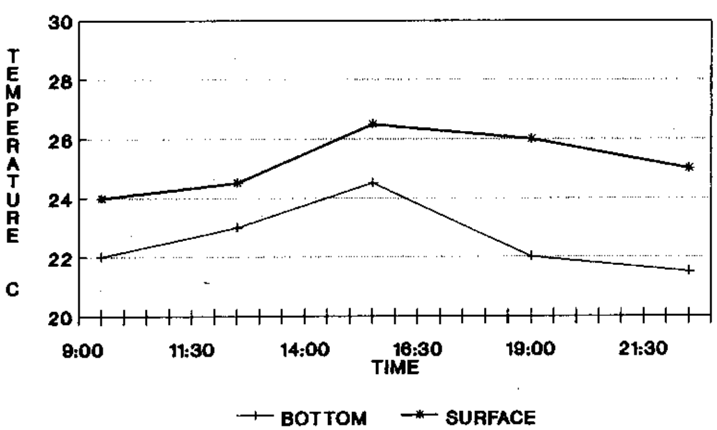


TEMPERATURE PROFILE IN THE BAY
July 30, 1988

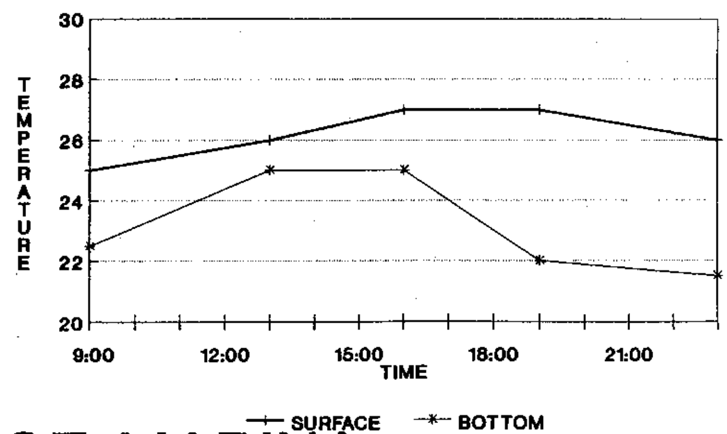


LONG QUAY MARINA

TEMPERATURE PROFILE IN THE MARINA
August 6, 1988



TEMPERATURE PROFILE IN THE BAY
August 6, 1988



VIKING VILLAGE MARINA

FIGURE 4

shallowness of Barnegat Bay, diurnal variations of the water temperature occurred in response to changes in the air temperature. Maximum water temperature occurred between 1:00 PM and 4:00 PM on each day of study.

Water temperatures at Long Quay marina were slightly higher than the temperatures in the adjacent bay waters. Thermal stratification in both the marina and the bay waters was absent with the greatest temperature difference between bottom and surface waters being 1°C. Figure 4 illustrates the temperature profiles of Long Quay marina.

Viking Village marina and its surrounding waters exhibited lower temperatures than Long Quay marina probably because of its close proximity to Barnegat Inlet which allowed direct passage of ocean waters. In addition, Viking Village marina displayed slightly lower temperatures than its adjacent bay water. The cooler waters in the marina can be attributed to the marina's greater depths. The average depth in the marina was 3.5 meters. The average depth at the bay sample site was 1.9 meters. In general, water temperature was higher in shallower waters than in deeper waters.

Thermal stratification was apparent in both the bay and the marina waters with a maximum temperature difference of 5.5°C in the bay and 4.5°C in the marina. Figure 4 illustrates the temperature profiles found at Viking Village.

Salinity ranges for the marinas are presented in Table 2. Neither of the marinas nor the adjacent bay waters showed salinity gradients within their vertical water column. In general, the marinas exhibited slightly lower salinity levels than did the bay waters; Viking Village exhibited higher salinity levels than did Long

Quay.

3.1.3. Water Exchange

The data from both current meters were used to calculate the rate of water flow in and out of Long Quay marina. The continuity equation, Equation 1 (Revell, 1969), was used to calculate Q, flow rate or discharge:

$$Q = \sum_{i=1}^{N} (Ax_i * v_i) \qquad \text{Equation 1}$$

where:

Ax_i = cross-sectional area of the ith segment at a given point in time
v_i = current velocity in that segment
N = number of segments.

The cross-sectional area (Ax) used to calculate Q was in the throat of the marina at the S-4 current meter site. Because the marina's mouth was narrow and uniform in depth with straight vertical walls, only two segments (N = 2) in the cross-section at Long Quay were used to calculate Q. The width and depth of each segment were multiplied to yield Ax_i for a particular point in time.

The recordings from the S-4 current meter represented the v_i for one segment of the total cross-section. Its current velocity readings were averaged at 20-minute time intervals and multiplied by the corresponding Ax_i. The ENDECO current meter provided current profile data within the second segment in the total cross-section. The current was measured at intervals throughout the tidal cycle and at depths equal to 0.2, 0.6 and 0.8 of the total depth. Velocity (v_i) calculated from the ENDECO was a depth average for a particular point in time.

Figure 5 plots the current velocity and rate of flow at Long Quay marina on July 30, 1988. On this date, Long Quay marina was characterized by low current velocities and flow rates. The maximum ebb and flood velocities can be found in Table 1. The data show a flood flow with a 5.4-hour duration and larger magnitude than the corresponding 7-hour ebb flow in the tidal cycle.

The rate of flow at Viking Village could not be determined because it is not a semi-enclosed marina like Long Quay. Because Viking Village is framed by pilings and piers, tidal water can enter and leave the marina from all directions except through the landlocked east and south borders. In fact, Viking Village can be considered as just one point in the larger cross-sectional area of the bay through which the tidal prism moves. Measuring the full cross-sectional area of the bay and current velocity across it was beyond the scope of this study. However, the S-4 current meter was employed to determine the current velocity in the marina. Plots of the velocity measurements are shown in Figure 6. The plots illustrate variations of current speed and direction and tidal durations at Viking Village on each day of record. Current velocity was greater than that at Long Quay. Maximum flood and ebb velocities occurred on August 6 and were 0.049 m/sec and 0.047 m/sec, respectively.

3.1.4. Flushing Time

Flushing time for a semi-enclosed marina can be estimated using simplified dilution calculations. Equation 2 (USEPA, 1985) was used to determine the flushing time of Long Quay marina.

LONG QUAY MARINA
TIDAL CURRENTS AND DISCHARGE
July 30, 1988

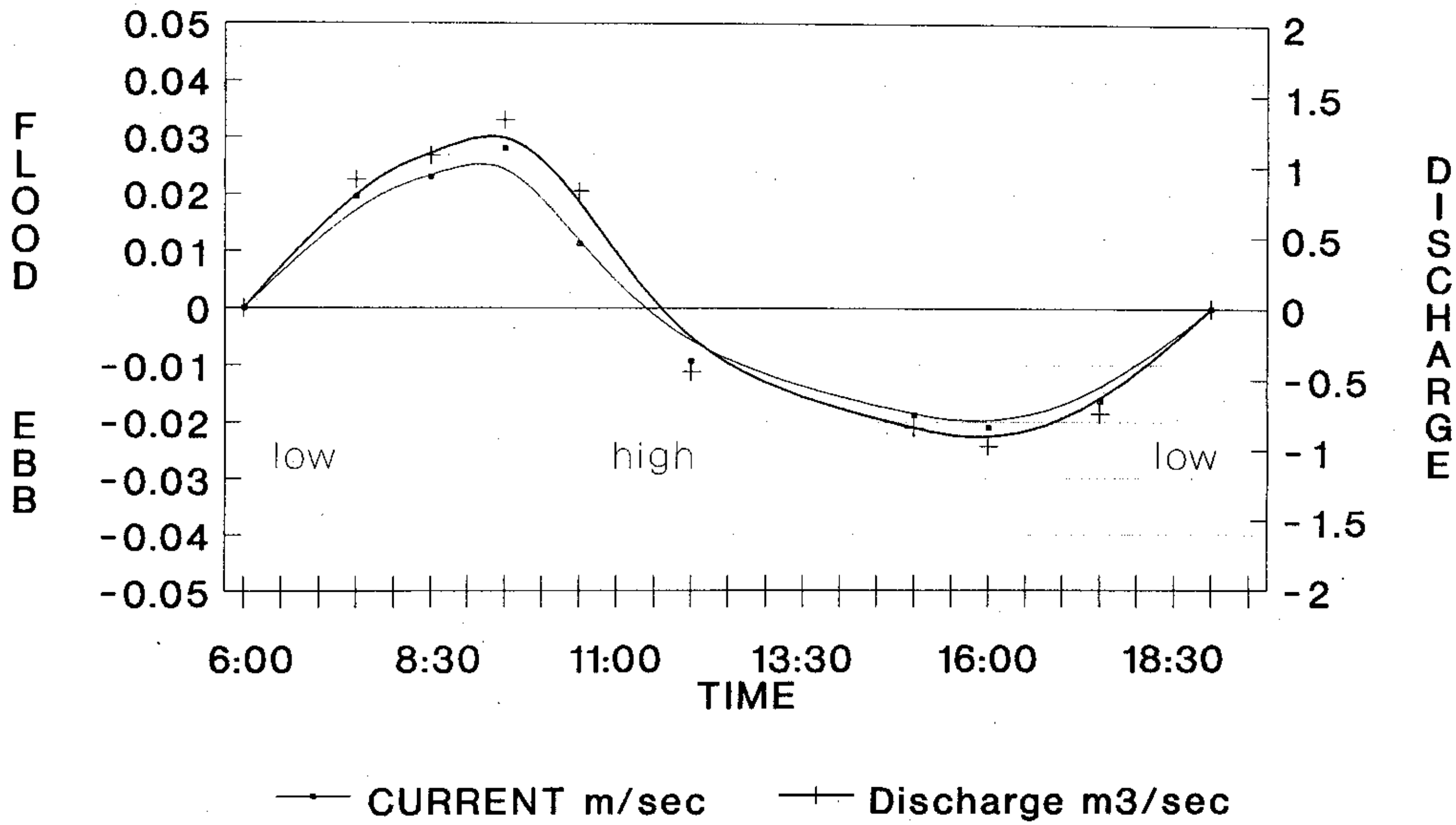
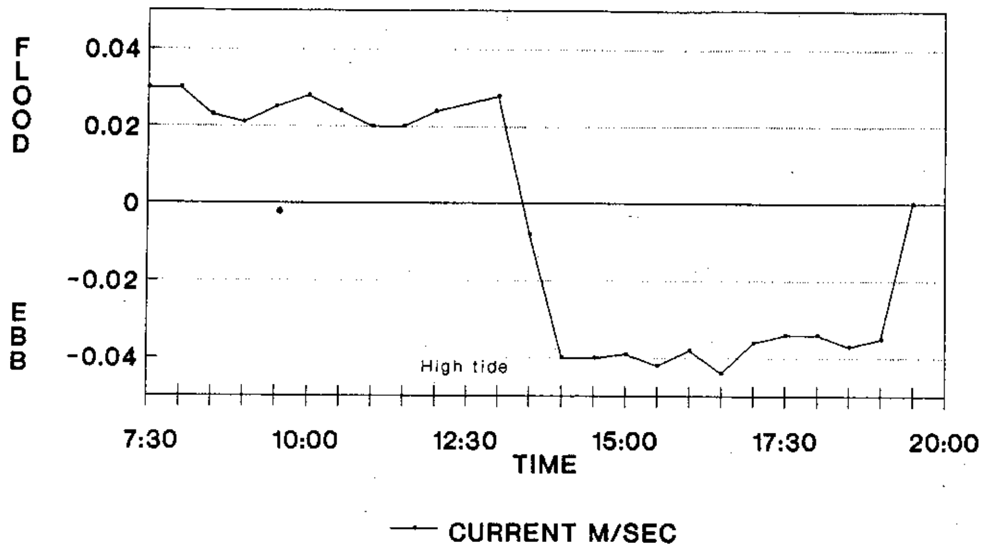


FIGURE 5

CURRENTS AT VIKING VILLAGE MARINA

August 3, 1988



August 6, 1988

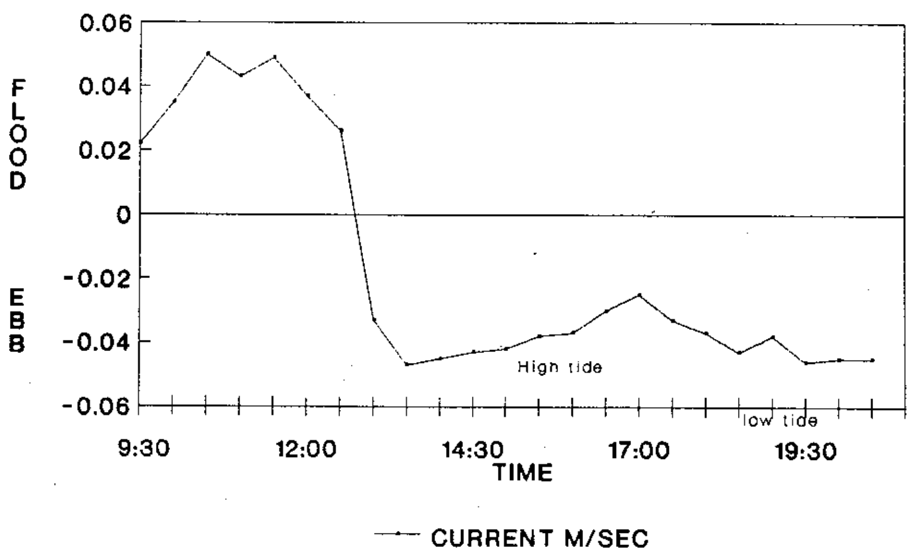


FIGURE 6

$$T_f = T_c \text{ Log } D / \text{Log} ([A L + b A R] / AH) \qquad \text{Equation 2}$$

where:

T_f = flushing time in hours
T_c = tidal period
A = surface area of marina
D = desired dilution
R = tidal range
b = return flow factor
L = average depth at low tide
H = average depth at high tide.

The parameter 'b' represents the percentage of the tidal prism (A*R) that was previously flushed from the marina on the outgoing tide and may flow back into the marina on the incoming tide. It is expressed as a decimal fraction and is estimated based upon the circulation characteristics of the marinas. For example, if ebb flow is 50% faster than flood flow, flushing should be appreciable and 'b' would be less than 0.5 (USEPA,1985). In the case of Long Quay marina, ebb flow is not 50% faster than flood, therefore b is estimated to be greater than 0.5.

The dilution factor, 'D', is dependent on the amount of flushing desired for the marina. If complete flushing is desired, a low 'D' should be selected. Figure 7 plots flushing times for Long Quay marina with various desired dilution and return flow factors. Complete flushing within Long Quay with b ranging from 0.5 to 0.9 and D = 0.1 would take 35 - 90.9 days. A higher D value of 0.5 yields flushing times ranging from 10.5 - 27.4 days.

Because Viking Village is not a semi-enclosed marina, Equation 2 could not be used to estimate flushing time. Its flushing time was estimated with the

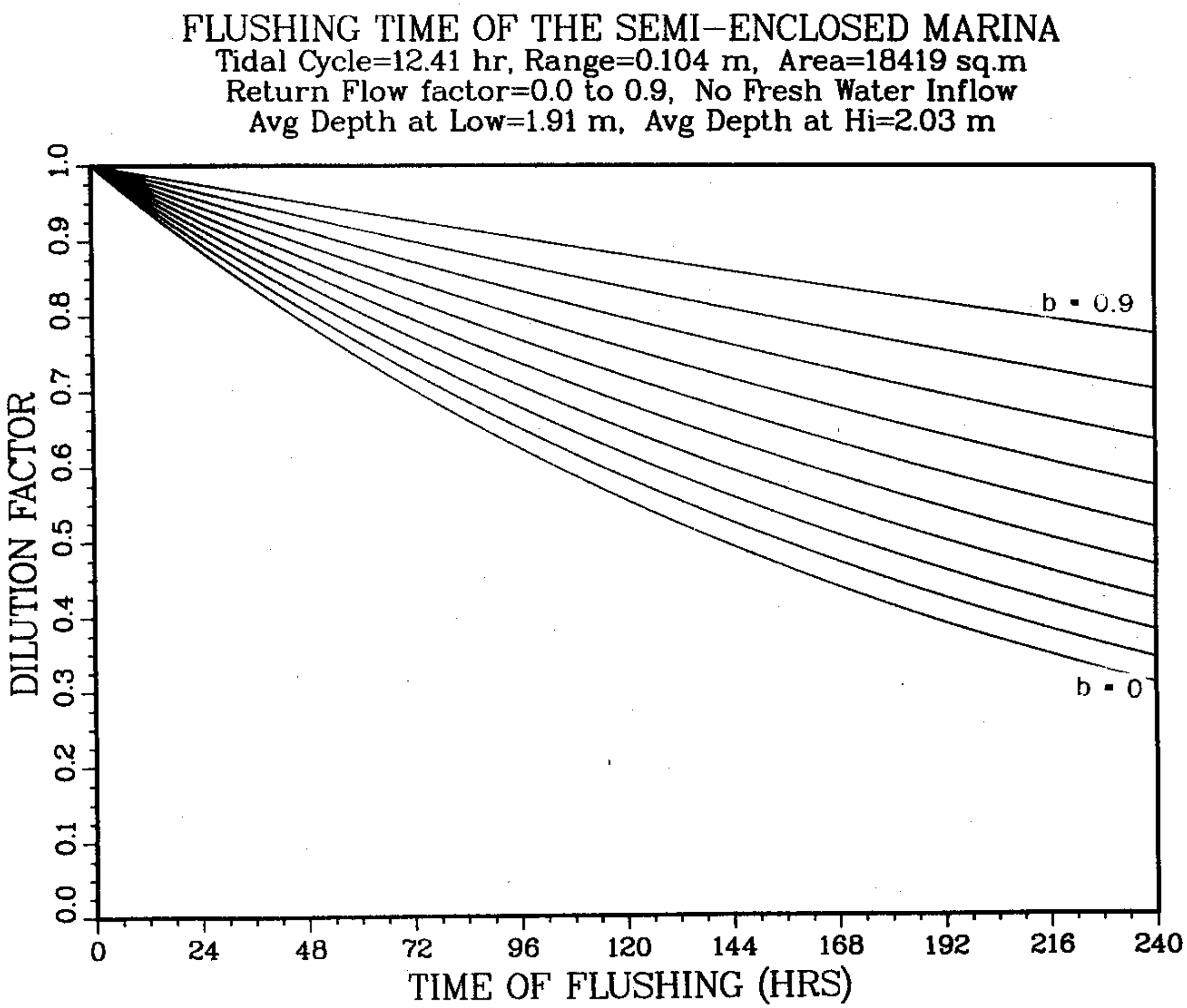

FLUSHING TIME OF THE SEMI–ENCLOSED MARINA
Tidal Cycle=12.41 hr, Range=0.104 m, Area=18419 sq.m
Return Flow factor=0.0 to 0.9, No Fresh Water Inflow
Avg Depth at Low=1.91 m, Avg Depth at Hi=2.03 m
DILUTION FACTOR
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
b = 0.9
b = 0
0
24
48
72
96
120
144
168
192
216
240
TIME OF FLUSHING (HRS)

FIGURE 7

following equation (Dyer, 1973):

$$T_f = (A\,L + A\,R) \,/\, A\,R \qquad \text{Equation 3}$$

The parameters in Equation 3 are defined as in Equation 2 with T_f equal to flushing time in tidal cycles.

The flushing time calculated by Equation 3 underestimates the true flushing time because return flow is omitted from the equation (Pilson, 1985; Dyer, 1973). For example, Equation 3 calculates flushing time at Long Quay at 19.4 tidal cycles or 10.03 days, a much lower flushing time than that calculated by Equation 2. Flushing time at Viking Village was estimated at 4.35 tidal cycles or 2.25 days. These calculations suggest that the marina waters at Viking Village are more rapidly flushed than at Long Quay. This would be expected since Viking Village is not enclosed and freely mixes with the bay waters. However, knowing that Equation 3 underestimates the flushing time, it would be fair to assume it may be greater than 2.25 days.

3.2. Discussion

3.2.1. Limitations to the Hydrologic Data

It should be emphasized that the hydrological data were collected during the two week period of July 20, 1988 through August 6, 1988. In addition, the data are not synoptic. However, they are assumed to be representative of the conditions found in the two marinas during their busiest season of the year.

Flow rates and currents at the marinas may vary through many factors. Surface runoff will effect temperature, salinity and water movement within the marinas (USEPA, 1985). Freshwater input to the marinas through surface runoff was not measured in this study. However, there was no precipitation during the days of study and neglecting surface runoff should not have affected the calculations.

Wind mechanisms can play a large role in the current velocities due to the shallow depths in Barnegat Bay (Chizmadia et al., 1984). However, the objective of this study was not to determine the driving factors of the currents within the marinas but rather to measure their magnitude and relationship to the pollutant load within Barnegat Bay and the marinas. Therefore, wind mechanisms were ignored in this study but they should be considered if a detailed hydraulic study is undertaken.

3.2.2. Discussion of Hydrologic Data

Water in the marinas and the bay can move in the vertical as well as the horizontal direction within the water column. Density-driven water circulation due to temperature and salinity gradients can inhibit or promote the vertical and horizontal water movement (Carpenter, 1963; Walton et al., 1976). Previous studies at Barnegat Bay have indicated the presence of temporary temperature and salinity gradients that can induce two-layered circulation within the bay waters and inhibit mixing between the layers (Carpenter, 1963; Walton et al., 1976). A study by Makai (1979) indicated that thermal stratification was common in man-made systems at Barnegat Bay.

The effects of density differences caused by salinity and temperature gradients between surface and bottom waters and incoming tidal and marina waters can vary. Density differences between surface and bottom waters will tend to hinder interaction and exchange between the horizontal layers and entrain substances within a similar density layer (Wetzel, 1985). Water entering or leaving the marina will tend to flow into a water layer of similar density and may not readily mix with contiguous waters if density differences are reasonably large (Walton et al, 1976; Wetzel, 1983).

The rate of flow and current velocity may also affect mixing processes in stratified waters. There is evidence to suggest that lower discharge rates of a stratified waterbody may allow incoming water the time to penetrate into the stratified layers, potentially permitting better mixing and dispersion through normal circulating processes (Wetzel, 1983). In contrast, high discharge rates in stratified water may channel incoming water across or through the water mass, hindering dispersion and dilution mechanisms (Wetzel, 1983).

The above discussion can be related to the temperature and salinity profiles found at Long Quay and Viking Village marinas. The absence of a temperature and salinity gradient at Long Quay indicates a lack of stratification that could inhibit mixing and dispersion of pollutants. The slow water flow at Long Quay may also work toward better dilution of pollutants in the marina by allowing incoming water the time to freely mix with marina waters. These factors may indicate better water circulation and dilution of pollutants within the marina than would be expected from its weak current velocities and high flushing time.

Discharge rates were not calculated for Viking Village marina. However, the relatively high current speeds were indicative of appreciable water exchange. In addition, there was a large temperature difference between surface and bottom waters and cooler temperatures in the bay waters than the marina. On the basis of the temperature differences, it was possible for water entering the marina to have channelled into a water layer of similar temperature and density, specifically the warmer surface waters of the marina. This may indicate that water circulation may not be as proficient in dilution and dispersion as would be expected by the fairly rapid tidal currents.

The currents at Viking Village as depicted in Figure 6 are characterized by different tidal durations and magnitudes for each day of record. Figure 6 shows the current on August 6 strongly ebbing at the same time that the tide height was rising within the marina. There may be several reasons behind this apparent anomaly. The data represent only a small portion of the water flow through a much larger cross-section. It is not uncommon within broad bays for tidal waters to simultaneously form ebb and flood channels in different positions within the bay (Dyer, 1973). Since the direction of water flow was not recorded throughout the entire cross-sectional area, it is possible that flood flow was still dominant in the total cross section even as the in situ current meter recorded a channel of ebb flow. In addition, the structure of Viking Village allowed tidal waters to enter the marina through its west and north boundaries. The in situ current meter was positioned to record flood and ebb currents from the north and south. A flow of tidal waters entering the marina from the west would have escaped detection by the current meter and may have been the cause of the rising tidal water.

A final point to make about the data concerns the flushing times calculated for the marinas. A knowledge of the flushing time of the marinas is an essential part of understanding and calculating the behavior and fate of pollutant substances within the marinas. The USEPA (1985) has estimated that flushing times greater than 2 - 4 days are unsatisfactory and may result in the build-up of pollutants within the marina. The flushing time at Long Quay marina as calculated by Equation 2, assuming complete flushing and a return flow factor between 0.5 and 0.9, ranged from 35 to 91 days. On the basis of this flushing time, Long Quay marina appears to have insufficient tidal exchange. Limited water circulation may subsequently result in poor water quality within the marina. Flushing time at Viking Village was estimated at 2.25 days using Equation 3. However, evidence of the complex water circulation within the marina coupled with Equation 3 underestimating flushing time calls into question the validity of this estimate. The flushing time at Viking Village cannot be adequately characterized by this study and other studies are necessary to better estimate the effect of the marina's hydrologic parameters on water quality.

SECTION 4

RESULTS and DISCUSSION

BACTERIAL DATA

4. RESULTS AND DISCUSSION - BACTERIAL DATA

4.1. Results

4.1.1. Fecal Coliform Bacteria in the Water Column

The number of fecal coliforms per 100 ml of water sample throughout 2 tidal cycles at the three sampling sites is plotted in Figure 8. The geometric mean of fecal coliforms for each sampling site is listed in Table 3. The geometric mean of fecal coliform represents the average coliform count for the two days of sampling at each marina. Each sampling site had geometric means that were within the limits of the PCC200 standard.

The number of fecal coliforms at Long Quay was consistently higher within the marina and decreased as distance from the throat of the marina increased. Figure 8 illustrates that the fecal coliform levels were higher on Saturday when marina and boat activity were considered greater.

Fecal coliform counts at Viking Village were variable. Figure 8 illustrates that coliform levels were generally higher in the marina. Although the geometric mean for the two days of study indicated compliance with the PCC200, Saturday's counts of fecal coliform within Viking Village marina were above the PCC200 standard for 8 hours of the 12-hour study. While swimming did not occur within Viking Village marina during the days of study, the adjacent bay was used for recreational sports such as waterskiing and swimming. The data indicated the high count of fecal coliforms in the marina did not raise levels in the adjacent bay waters above the PCC200 standard for the days of study.

Table 3. Coliform levels in water, sediment, and hard clams

colonies/100 ml	Long Quay			Viking Village		
	M	O	B	M	O	B
Fecal coliforms in water Geometric mean	51.1	13.6	3.35	81	10	10
Total coliforms in in water Geometric mean	71.3	48.8	16.4	479	407	245
Fecal coliforms in sediments	20	-	20	900	17	11
Fecal coliforms in hard clams	783	-	137	286	-	-

M = Sample site inside marina
O = Sample site directly outside of marina
B = Sample site in adjacent bay

FECAL COLIFORM IN THE WATER COLUMN

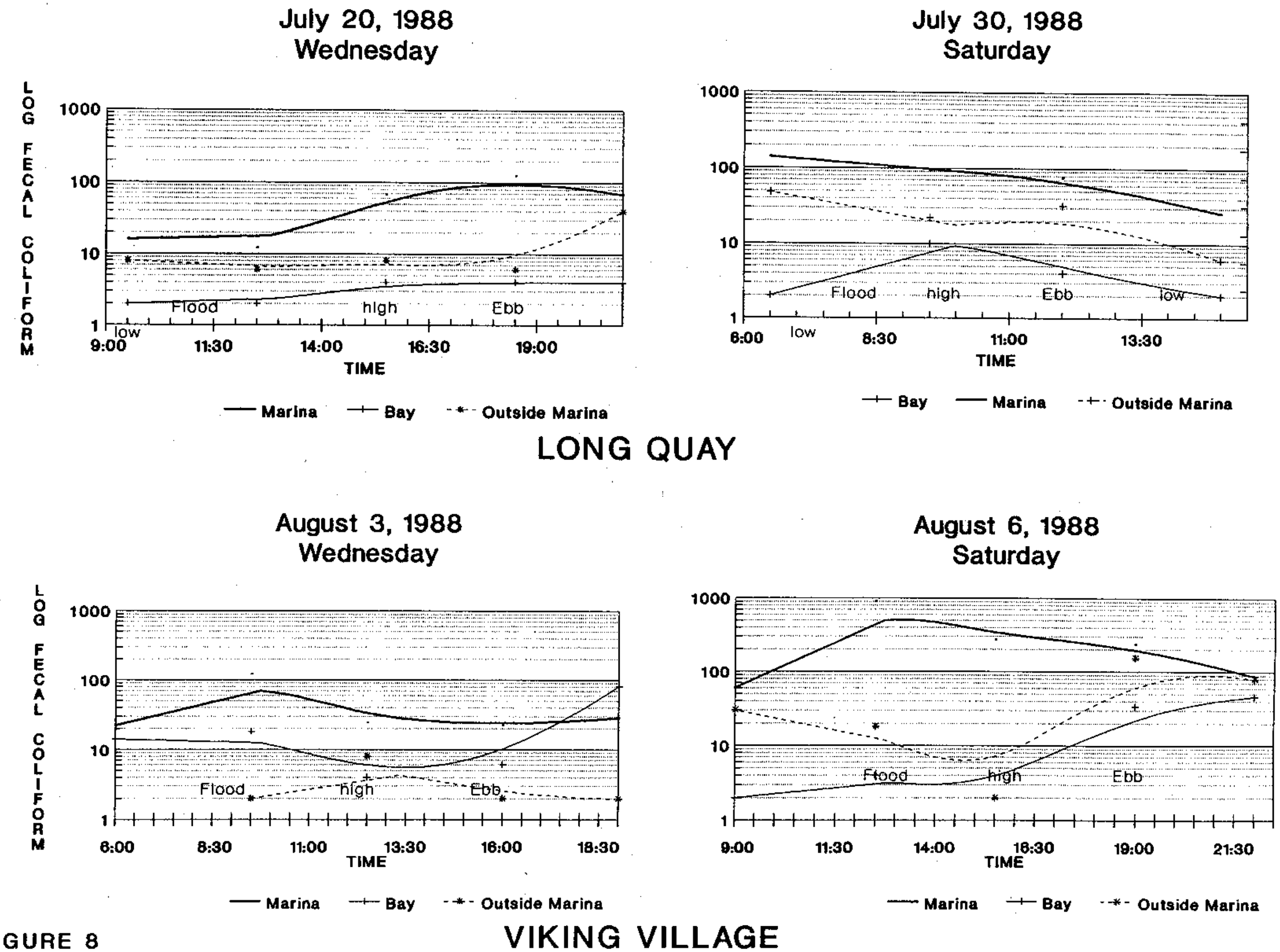


FIGURE 8

4.1.2. Total Coliform Bacteria in the Water Column

The total coliform counts throughout 2 tidal cycles at the three sampling sites of Long Quay and Viking Village marinas are illustrated in Figure 9. The geometric mean of total coliforms for each marina and every sampling site is listed in Table 3.

The geometric mean of total coliform within Long Quay marina was above the AASH70 standard. The two other sampling sites of Long Quay had geometric means below the AASH70. Figure 9 shows the number of total coliforms were greater on Saturday than on Wednesday.

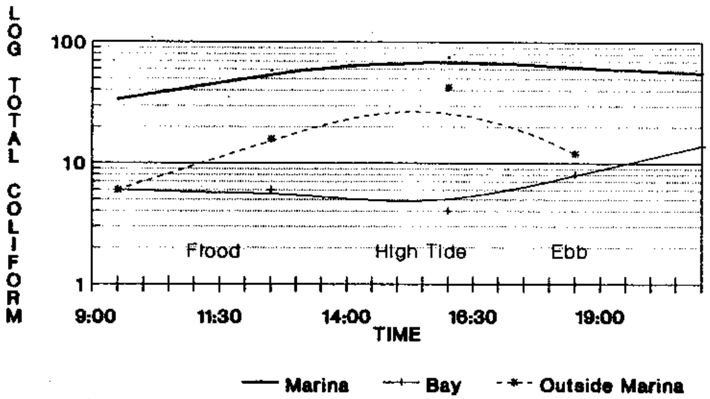
The total coliform counts at Viking Village for all three sampling sites were above the shellfish-harvesting guideline continuously throughout each day of study. While marina water generally had the highest total coliform numbers, there were occasions when the other sampling sites had higher levels.

4.1.3. Regression Analysis

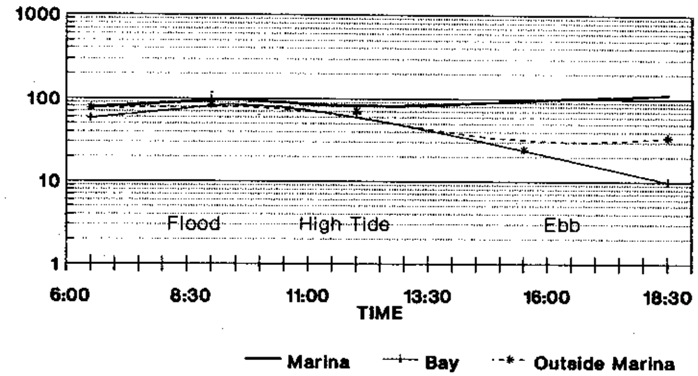
The bacterial counts of the water samples over time were log-log transformed to meet the assumption of normality for regression analysis. To compensate for the spatial and temporal variations caused by tidal waters, the number of total coliforms found at sample site 1 was plotted against the data obtained three hours later at sample site 2. In addition, data of sample site 2 were plotted against the data obtained three hours later at sample site 3. This was done to account for the travel time and progression of marina contamination

TOTAL COLIFORM IN THE WATER COLUMN

July 20,1988
Wednesday

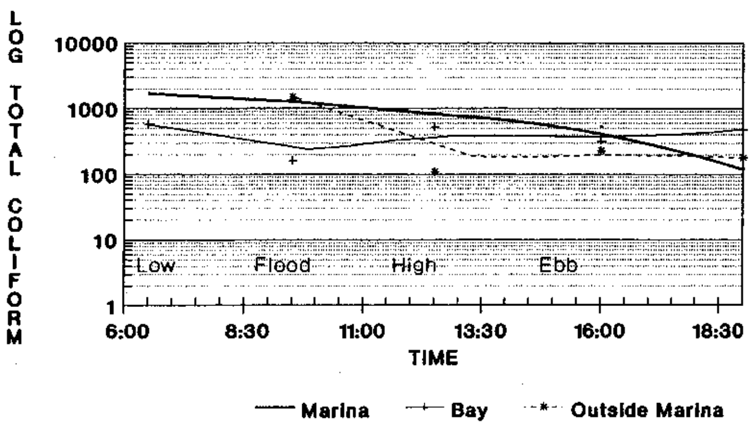


July 30, 1988
Saturday



LONG QUAY

August 3, 1988
Wednesday



August 6, 1988
Saturday

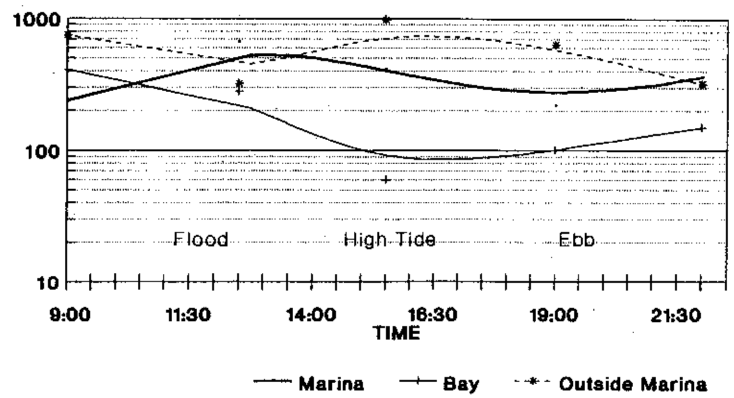


FIGURE 9

VIKING VILLAGE

as it moved through contiguous waters. The relationship between the two variables was curvilinear, fitting the general equation of $Y = a X^b$. Taking logarithms of both sides resulted in a linear relationship with the equation $\text{Log } Y = \text{Log } a + b \text{ Log } X$. Figure 10 shows the regression plot and depicts a direct correlation between the two variables with the equation of $\text{Log } Y = -0.2076 + 1.06 \text{ Log } X$. The log transformed data had a coefficient of linear correlation R equal to 0.83 and a coefficient of determination r^2 equal to 72.29. A summary of the linear regression is given in Table 4. The strength of the relationship between the two variables was tested with a calculated F-statistic of 73.034. The regression model was determined to provide a good fit to the data with $p < 0.00001$.

Residuals of the regression line were plotted and are shown in Figure 11. The residual plot indicated that the sample data met the underlying assumptions of regression analysis.

4.1.4. Fecal Coliform Bacteria in the Sediments

The number of fecal coliform bacteria in sediment samples taken from the sample sites of the marinas is listed in Table 3. The samples collected from Long Quay indicated low levels of fecal coliform within the sediment. The samples collected from Viking Village indicated relatively low levels of fecal coliform outside of the marina and a high count of 900 fecal coliforms/100 ml within the marina sediments.

Table 4. Regression Analysis - Multiplicative model: Y = aX^b

Variables-Dependent: Coliforms in the Bay Independent: Coliforms in the Marina

Parameter	Estimate	Standard Error	T Value	Prob. Level
Intercept*	-0.207551	0.0997087	-2.08157	.04664
Slope	1.05989	0.124022	8.54601	.00000

* NOTE: The Intercept is equal to Log a.

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	Prob. Level
Model	3.817418	1	3.817418	73.03433	.00000
Error	1.463527	28	.052269		
Total (Corr.)	5.280944	29			

Correlation Coefficient = 0.850216 R-squared = 72.29 percent
Stnd. Error of Est. = 0.228624

Regression of coliform levels in the bay against coliform levels in the marinas

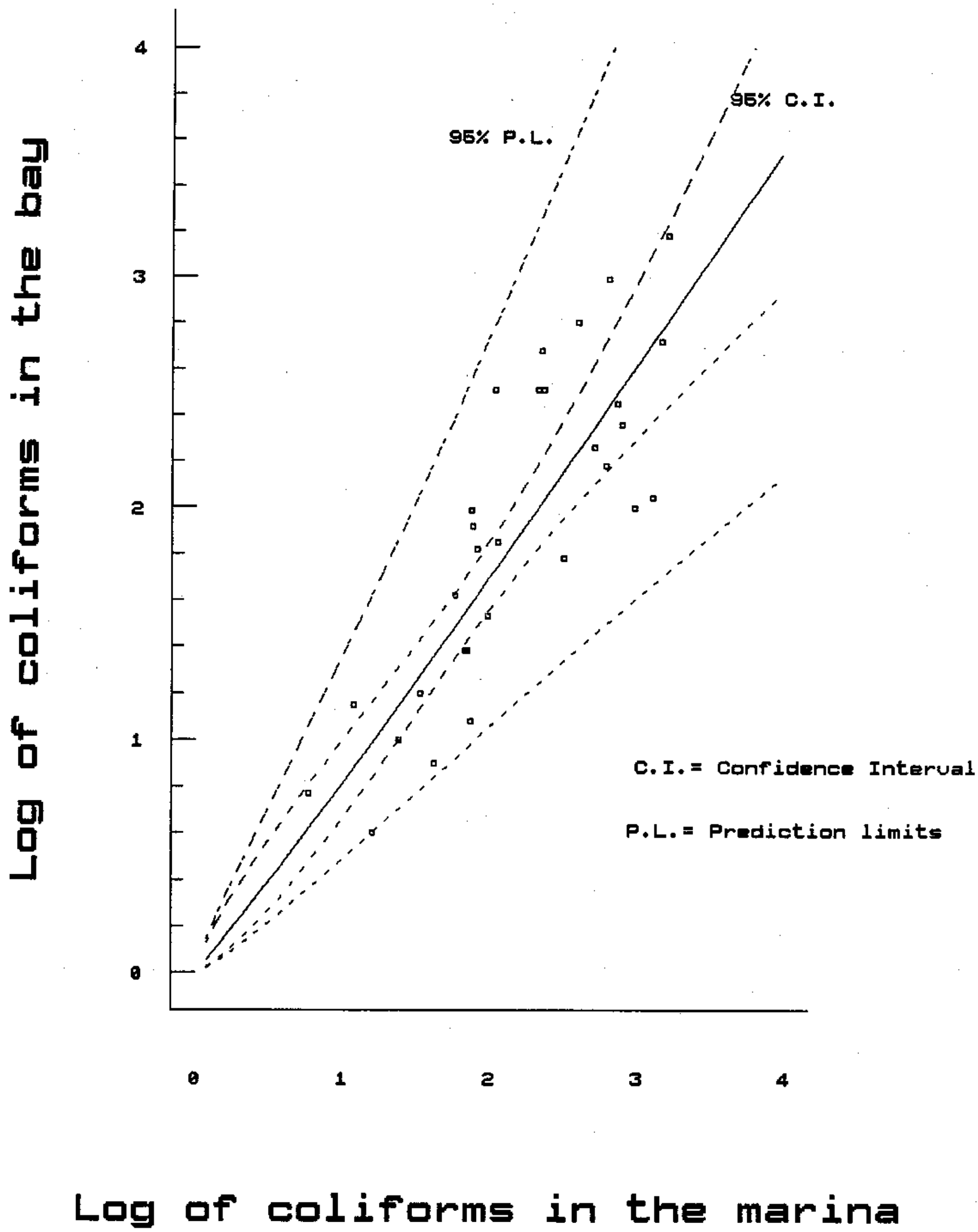


FIGURE 10

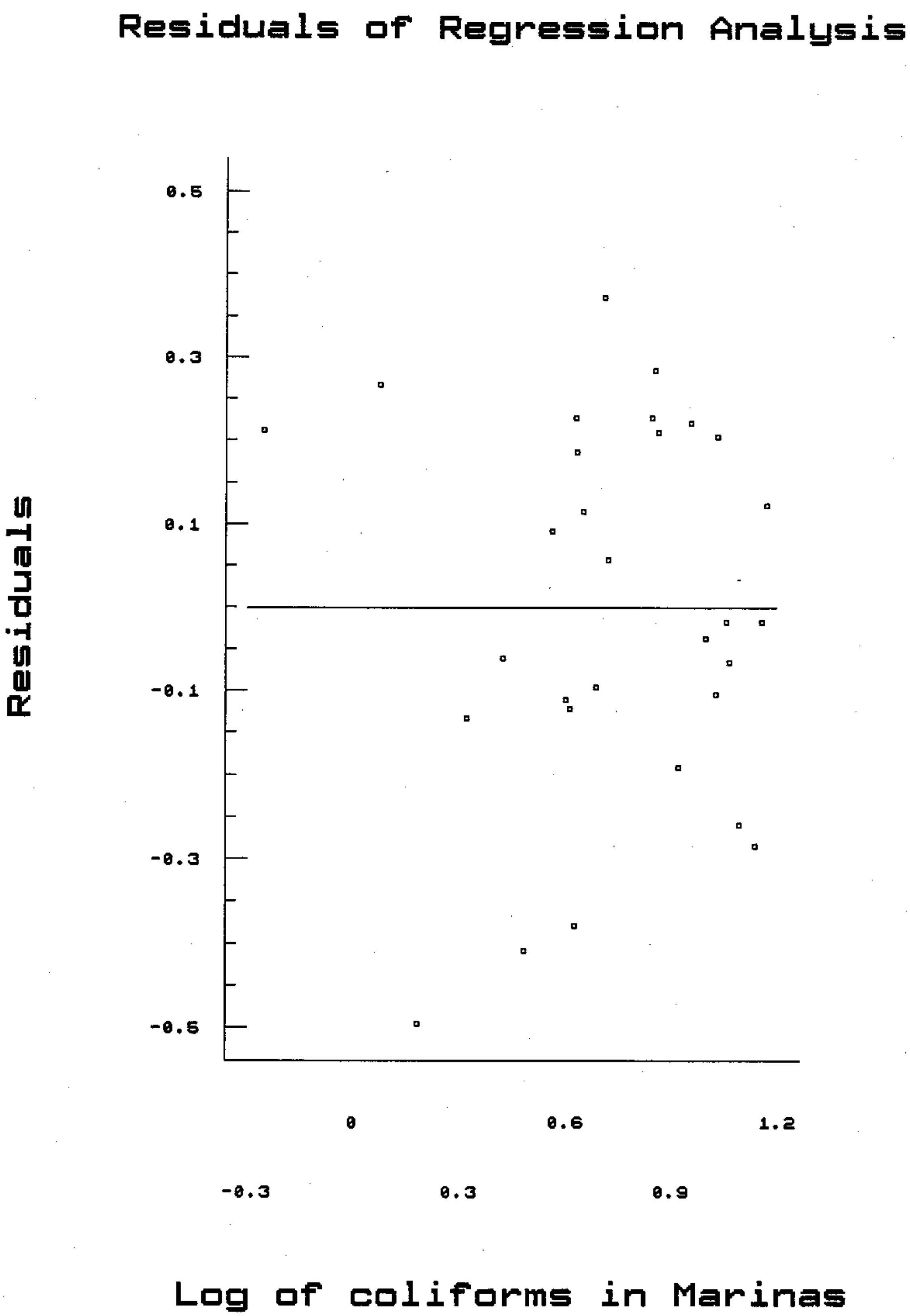

Residuals of Regression Analysis
0.5
0.3
0.1
-0.1
-0.3
-0.5
Residuals
0
0.6
1.2
-0.3
0.3
0.9
Log of coliforms in Marinas

FIGURE 11

4.1.5. Fecal Coliform Bacteria in Hard Clams

The number of fecal coliforms found in samples of the hard clam is presented in Table 3. The acceptable level of coliforms in shellfish is 230 fecal coliforms/100 gm (NJDEP, 1983). The fecal coliform number found in the hard clams collected in both marinas were above the criteria. The hard clams found in the bay adjacent to Long Quay marina had 137 fecal coliforms/100 ml and were considered safe for human consumption.

4.2. Discussion

4.2.1. Regression Analysis

The regression analysis performed in this study clearly indicated that the number of coliforms in the water column of the bay was directly related to the number of coliforms and thereby fecal contamination, in neighboring marinas. The r^2 value indicated that 27% of the total variation on the observed data could not be explained by the regression model.

Some of the variance found in the model can be attributed to sources other than the marinas contributing to the coliform numbers found within the bay. In addition to marinas, land and river runoff, stormwater runoff and wildlife may discharge fecal contamination into Barnegat Bay (NJDEP, 1988a). However, there was no precipitation during or immediately prior to the days of study. Therefore, stormwater runoff could not have contributed to the coliform numbers on the days of study. Also, treated sewage is not a source of fecal contamination at Barnegat Bay because all municipal wastewater from the area is discharged into the ocean through long ocean outfalls (Environmental Health Service, 1988).

In addition to the different sources of fecal contamination, a mixture of environmental conditions effecting the die-off rate, regrowth, and survivability of the coliform organism could have caused variance in the regression model. Environmental factors such as salinity, pH, turbidity, availability of bacterial nutrients, temperature, sunlight exposure, dissolved oxygen and sedimentation can influence coliform numbers (Churchland and Kan, 1982). Salinity has been determined to have a strong inhibitory effect on fecal coliforms (Churchland and Kan, 1982). Temperatures below the body temperature of the bacteria's host will decrease the coliform's survivability (Brock and Madigan, 1988). In addition, the ability of fecal coliforms to survive in seawater was found to increase with the presence of suspended solids (Gerba and McLeod, 1976) and that survivability was dependent on the deposition potential of the suspended solids (Milne et al., 1986). Finally, the diurnal variations of the fecal and total coliforms in the water noted on each day of sampling may have occurred in response to the tidal cycles and non-uniform input of fecal contamination on the days of study.

Despite all of the above factors and the fact that the two marinas studied had very different environmental, hydrologic, and physical characteristics, the model was a good enough fit to make preliminary predictions of the two marinas' contribution of fecal contamination into neighboring waters. Each marina discharged fecal contamination into the bay and the degree of contamination was in accordance with the characteristics of that marina. The low current velocities and high flushing time observed at Long Quay assisted in maintaining low coliform numbers in the adjacent bay waters. The more rapid current velocities of Viking Village allowed a greater number of coliform bacteria derived from the marina to be discharged into the adjacent bay water.

4.2.2. Bacteriological Quality of Recreational Waters

It is of interest to note that during the period of study, fecal coliform levels in the adjacent bay of both marinas remained below the acceptable recreational water quality standard. In fact, the fecal coliform counts found within the marina water column of Long Quay remained below the PCC200 standard. Fecal coliform numbers were also low in the sediment sample collected from Long Quay's marina basin. This evidence suggests that either fecal contamination at Long Quay was low due to adequate public restroom facilities at the marina or the environmental, physical, and hydrological conditions of the marina induced sufficiently high die-off and low sedimentation rates to prevent elevated coliform numbers. The water quality within the marina and the low discharge rates at Long Quay collaborated to maintain good recreational water quality within the adjacent bay.

There was evidence from this study that indicated boat sewage can degrade water quality within a marina. Fecal coliform counts at Viking Village marina exceeded the PCC200 standard on Saturday when the marina and its facilities received high use. The sediment sample collected from Viking Village marina contained a high count of 900 fecal coliforms/100 ml. The bacterial water quality within the marina as suggested by both the water and sediment data, was not adequate to meet standards for recreational activity during the time of high marina use. A probable cause of the high bacteria numbers was the lack of adequate public restroom facilities at Viking Village. Marina users were more apt to use the facilities on their boats rather than the marina's facilities. Also, the commercial fishing and chartered vessels within the marina may be a larger source of fecal contamination than the recreational boats found at Long Quay marina. The fishing vessels may also contribute nutrients and suspended solids into marina waters providing conditions more conducive to the survival and sedimentation of the bacteria.

While the fecal coliform levels in the waters of the bay surrounding Viking Village did not exceed the PCC200 standard on the days of study, the fecal coliform numbers were elevated. Figure 8 indicates that as tidal waters of Viking Village were ebbing out of the marina, fecal coliform numbers in the adjacent waters were increasing. The elevated fecal coliform numbers in the adjacent bay water may have been caused by the high current velocities found at Viking Village in conjunction with the thermal stratification that may have inhibited dilution processes.

Elevated bacterial counts in the bay as a result of the fecal contamination from Viking Village can cause the bay water to exceed recreational water quality criteria if additional fecal contamination enters the water. NJDEP has maintained a monitoring program in this bay area for the years of 1986 and 1987. The bay area of Viking Village was monitored for fecal contamination every Monday from the month of May through the month of September. The area was found to exceed the PCC200 standard 27.6% of the time in 1986 and 22.2% of the time in 1987 (NJDEP, 1988a). This data, combined with the high coliform counts found in the marina in this study, the uncertainty concerning flushing and its ability to dilute the fecal contamination, and the high number of marinas in the area, all suggest that recreational activities in this area may be a health hazard especially during times of high marina use.

It would not be valid to assume these data fit all marinas at Barnegat Bay. However, the study does indicate that recreational activities occurring within certain marinas, particularly those without adequate restroom facilities, may present health hazards. Each marina has its own environmental, hydrologic, and physical characteristics that will affect the survivability of coliform and pathogenic bacteria and thereby the health hazard of recreational activities. The marinas at Barnegat Bay that provide recreational activities such as swimming and sailing lessons and the people who participate in the activities should be aware of the potential for poor water quality in marinas due to the discharge of boat sewage. While there are no monitoring requirements for marinas, it is advisable that the marinas that provide services that allow primary contact recreation should monitor their waters in the summer for bacterial contamination during times of high boat activity in the marina. In addition, recreational activities at marinas that do not provide adequate and sanitary restroom facilities for the public should be prohibited.

4.2.3. Bacteriological Quality of Shellfish-harvesting Waters

Shellfish-growing waters may fall under the following four classifications:

1. Approved Area for the harvest of shellfish.
2. Prohibited Area where waters are condemned for the harvest of shellfish.
3. Seasonal Area where waters are condemned for the harvest of shellfish except during specific times of the year.
4. Special Restricted Area where waters are condemned for the harvest of shellfish except for the harvesting of shellfish to be further processed. (NJDEP, 1988b)

Many state shellfish authorities believe the Approved Area criteria for shellfish-harvesting waters (AASH70) does not provide sufficient guidance to protect against human disease-causing agents introduced into waters through boat sewage (USEPA, 1985; USFDA, 1972). The AASH70 standard was based on bacterial studies of municipal wastes and the pathogen-to-coliform ratio in municipal sewage. There is a much higher proportion of pathogens in fresh fecal material discharged into marinas than there is in municipal sewage (USEPA, 1985). Therefore, the health effects of fresh fecal material introduced into waters are more pronounced than the effects of the diluted and treated discharge of municipal sewage (USEPA,1985; USFDA, 1972). In consideration of this, the U.S. Food and Drug Administration's Division of Shellfish Sanitation promulgated National Policy Guidelines for use by State shellfish officials (USFDA, 1972). A concentration above 2 total coliforms/100 ml in marinas, the equivalent of 70 total coliforms/100 ml found in municipal wastes, is considered an unacceptable level of fecal contamination for shellfish-harvesting waters.

The FDA's National Policy recommends all marinas, boatyards, and mooring areas be closed for shellfish harvesting during boat season. The NJDEP, in acknowledgement of the more health threatening conditions posed by the discharge of boat sewage, prohibits shellfish harvesting from all marinas and man-made lagoons throughout the year (NJDEP, 1988b).

This study provides data which support the FDA and NJDEP decision to close marinas for shellfish harvesting. Total coliform numbers detected in both of the marinas' water column were above the FDA's recommended guideline and the AASH70 standard. In addition, clams collected in the marinas had higher levels of fecal coliform than is considered safe for human consumption.

The bay waters immediately neighboring Long Quay are classified as a Special Restricted Area. Bay waters further east are classified as a Seasonal Area with shellfish harvesting approved only during the period of November 1 through April 30 of each year. This study indicated that total coliform numbers in this area were below the AASH70, but above the FDA's guideline of 2 total coliform/100 ml. Because this area of the bay is restricted for shellfish harvesting, the coliform numbers do not pose any health threats.

The bay waters immediately neighboring Viking Village are classified as a Special Restricted Area. Less then 1000 yards from the marina, the water is classified as an Approved Area for shellfish harvesting. Viking Village marina had total coliform numbers in the marina's adjacent bay waters that were well above the AASH70 standard and the FDA's shellfish harvesting guideline. This evidence, coupled with the NJDEP's monitoring program that found the area above 200 fecal coliforms/100 ml over 20% of the time in the years 1986 and 1987 (NJDEP, 1988a), indicates that this area is not adequately classified as a shellfish-harvesting area.

The classification of shellfish waters should be based on an understanding of the bacterial water quality of the area and its potential to have unacceptable levels of bacterial contamination. In New Jersey, shellfish-harvesting areas are not classified on the basis of neighboring marinas and their potential to degrade the water. Seasonal Areas and Special Restricted Areas are classified on the basis of population size and extent of development on land adjacent to the shellfish-growing areas. Many bay waters that are neighboring marinas at Barnegat Bay are classified as an Approved Area for shellfish harvesting (NJDEP, 1988b).

Shellfish harvesting areas adjacent to marinas should be classified as Seasonal Areas or Special Restricted Areas, dependent on the zone of marina impact, based on the following:

1. There is a heightened human health threat from consuming shellfish

contaminated from boat-derived sewage.

2. Evidence from this study indicates that bacteria from marinas can survive and be transported into adjacent bay waters and shellfish-growing areas.
3. The water adjacent to Long Quay and Viking Village marinas had bacterial levels above the FDA's recommended guideline of 2 total coliforms/100 ml for boat-derived sewage.
4. The bay water adjacent to Viking Village marina had bacterial levels above the AASH70 and less than 1000 yards away from the marina was an Approved Area.

SECTION 5

RESULTS and DISCUSSION

METAL CONCENTRATIONS

5. RESULTS AND DISCUSSION - METAL CONCENTRATIONS

5.1. Results

5.1.1. Metal Concentrations in the Hard Clams

Metal concentrations found in the hard clams collected at Viking Village and Long Quay marinas and Great Bay are presented in Table 5. For comparison, the average heavy metal concentrations found in hard clams collected throughout New Jersey and alert levels established by NJDEP are also listed in Table 5. Alert levels have been set only for the more toxic metals and the average metal concentrations found in the hard clams at each collection site were below the alert level criteria.

Of the metals investigated, cadmium, manganese, zinc and iron appeared in concentrations not considered acute or sublethal for aquatic organisms. The manganese and high iron concentrations in the hard clams can be attributed to the natural concentrations found in the water of the area. Cadmium was not detected in the hard clams.

The data indicate that lead, nickel, and copper concentrations were significantly greater at Viking Village marina than the metal concentrations detected in the clams of Great Bay and the statewide average concentrations. Lead, and nickel concentrations at Long Quay marina were greater than Great Bay's concentrations. The copper concentration, found at Long Quay, while considered high, is comparable with the level of copper found in the clams of Great Bay and the statewide average.

Table 5. Metal concentrations in the hard clam

	LONG QUAY (PPM)	VIKING VILLAGE (PPM)	GREAT BAY (CONTROL) (PPM)	STATE AVERAGE[1] (PPM)	ACTION LEVEL[2] (PPM)
ZINC	173	177	128	48.81	1000
sd	18	5	7		
CADMIUM	0.0	0.0	0.0	0.06	2.0
sd	0	0	0		
LEAD	2.3	4.5	0	2.53	5.0
sd	1.7	1.0	0		
NICKEL	23.0	13.4	4.9	2.59	NE
sd	4.1	2.5	1.6		
IRON	130	151	187	39.3	NE
sd	10	2	7		
MANGAN.	8	8	6	46	NE
sd	3	1	2		
COPPER	9.5	21.5	9.7	10	NE
sd	0.3	0.3	1.4		

sd = standard deviation
NE = none established

1. Data provided by N.J. Department of Health in a Memorandum from HFR-214 to HFF-217.
2. Alert levels provided by NJDEP, Division of Science and Research.

5.2.2. Estimated Metal Concentrations in the Water Column

Estimates of the concentrations of zinc, copper, lead and nickel present in the water column were calculated using Equation 4 (USEPA, 1979).

$$C_w = C_o / BCF \qquad \text{Equation 4}$$

The bioconcentration factors (BCF) for zinc, copper, lead, and nickel were determined by the USEPA (1979) and are defined as the ratio of the concentration of the metal in the aquatic organism (C_o in ppm) divided by the concentration of the metal in the water (C_w in ppm). Table 6 lists the BCFs for marine invertebrates and the calculated concentrations for each metal in the water column.

5.2. Discussion

5.2.1. Cadmium

Cadmium was not detected in any hard clams collected in this study. This suggests that the marinas are not a source of cadmium contamination and that generally cadmium contamination is not a problem in the area of study.

5.2.2. Manganese

Manganese levels detected in the hard clams collected from the marinas were comparable to the concentrations detected in the clams of Great Bay. In addition, the concentrations were well below the statewide average.

Table 6. Estimated Metal Concentrations in the Water Column

	BCF	Concentration in the Water (ppb)	
		Long Quay	Viking Village
Nickel	259	89	52
Zinc	100,000	2	2
Copper	1670	6	13
Lead	200	12	23

BCF = Bioconcentration factor for marine invertebrates.
BCF provided by USEPA, 1979.

Manganese detected in the clams were probably a result of natural ambient manganese concentrations.

5.2.3. Iron

It is generally known that many locations in N.J. are rich in iron. The concentration of iron found in the clams ranged from 130 ppm to 187 ppm and are indicative of the large quantities of iron naturally found in the water column. Iron is considered non-toxic and an essential nutrient. The high levels of iron detected may have beneficial effects due to the ability of iron compounds to scavenge more toxic metals such as copper, lead, and zinc from the water (USEPA, 1979). Therefore, high iron concentrations may assist in the reduction of any heavy metal contamination in the water of Barnegat Bay.

5.2.4. Nickel, copper, zinc and lead

Copper, nickel, zinc and lead were grouped together because they were the four metals most likely to be released into the water column through marina activity. Copper, zinc and nickel are common ingredients of anti-fouling paints used on boats and are also components of brass. Corrosion of brass materials on boats and the weathering of boat paint can contaminate the marina waters with copper, zinc, and nickel. Lead can enter the water through spillage of leaded fuels and exhaust emissions of outboard motors (USEPA, 1985).

Each of these metals were detected at elevated concentrations within the hard clams collected at the marinas. The concentrations of copper, nickel and lead estimated in the water column were at a level that could cause sublethal impacts on aquatic organisms. The fact that copper, nickel and lead were detected at high levels reinforces the belief that marinas exacerbate metal contamination in the water.

Nickel- Nickel is relatively non-toxic to humans, however aquatic organisms may be damaged at concentrations greater than 30 ppb in the water column. Research has indicated that 30 ppb of nickel can effect the reproduction of Daphnia (Biesinger and Christenson, 1972) and larvae of M. mercenaria can be killed by 310 ppb (Calabrese and Nelson, 1974). The concentration of nickel found in the clams of Viking Village and Long Quay were 3 to 4 times greater than Great Bay's hard clams and ranged from 13.4 ppm to 23.0 ppm. The estimated nickel concentration in the water column ranged from 52 ppb to 89 ppb. This evidence suggests that nickel may be having sublethal effects on the aquatic organisms within this area.

Nickel is a mobile metal that can remain solubilized in water and resist sedimentation (USEPA, 1979). The mobility of nickel makes it difficult to pinpoint the true source of contamination for the hard clams at Long Quay and Viking Village. While marinas may be a source of nickel contamination for Barnegat Bay, the extent of contamination contributed by marinas is uncertain.

Zinc- Zinc is considered non-toxic to humans and higher zinc concentrations are tolerated by aquatic organisms. However, bioassays have shown that 70 ppb in water can impair Daphnia reproduction and 140 ppb can induce abnormal development in oyster embryos (Biesinger and Christenson, 1972).

The highest zinc concentrations were detected in the hard clams collected from the marina mudflats. However, they were comparable with the zinc levels detected in the clams of Great Bay. Zinc concentrations for all of the hard clams collected were below the NJDEP alert level of 1000 ppm. The estimated zinc concentration in both marinas' water column was 2 ppb. Zinc appears to be at concentrations well below that which could cause sublethal effects on aquatic organisms. The sources of the zinc concentration are unknown but are probably the result of local geophysical characteristics.

Copper- Copper is considered an essential nutrient for humans, however excess copper can cause liver degeneration, hemolysis, anemia, and jaundice (Weis, 1980). Copper in aquatic environments can adversely effect aquatic organisms. Research has shown that as little as 5 ppb can retard the activity of copepods, 10 ppb can effect Daphnia reproduction (Reeve et al., 1977) and 19 ppb can adversely effect oyster juveniles (Mandelli, 1975). It is of interest to note that studies have indicated that the effects of copper in some species tested can be counteracted by the presence of zinc and iron (Braek et al., 1976).

The clams collected outside of Viking Village marina had a high average copper concentration of 21.5 ppm, more than twice the level of copper found in clams of Long Quay, Great Bay and the statewide average. The concentration of copper in the water was estimated at 6 ppb for Long Quay and 13 ppb for Viking Village. The copper concentrations of Long Quay and Viking Village in particular have the potential to cause sublethal effects on the aquatic organisms in the vicinity.

However, the interaction of copper with zinc may be reducing the adverse impacts.

Viking Village marina is probably a source of copper contamination for the neighboring bay waters since the marina harbors many large fishing vessels that are weathered and whose paint are cracked and peeling. However, there is no evidence from this study than can conclusively pinpoint Viking Village as the source of the elevated copper found in the clams of that vicinity.

Lead- Lead is toxic to humans and exerts its effects on the nervous system, kidney and hematopoietic system (Weis, 1980). Dietary levels as low as 5 to 50 ppm can produce behavioral changes in humans and increase human susceptibility to infectious disease (Reiter et al., 1975). Lead can also adversely effect aquatic ecosystems. Bioassays have indicated that concentrations as little as 0.5 ppb can kill the ciliate, Vorticella and 19 ppb increases the mortality in snails (Weis, 1980). Thirty ppb in the water column has impaired reproduction in Daphnia (Biesinger and Christenson, 1972) and 5 ppm has decreased the hatching success of shrimp eggs (Saliba and Kryz, 1976).

There was no lead detected in the clams at Great Bay. Lead was detected in the clams of Long Quay at 2.3 ppm with a standard deviation of +/- 1.7 ppm and Viking Village at 4.5 ppm with a standard deviation of +/- 1.0 ppm. The standard deviation of lead found in the clams of Viking Village indicates that some of the collected clams had lead concentrations greater than the 5.0 ppm alert level. The level of lead found in the hard clams of Viking Village had the potential of adversely effecting humans who consumed the shellfish. In addition, the lead concentrations in the water of Long Quay and Viking Village as indicated in Table 6 may be having sublethal effects on marine organisms.

The high lead concentrations detected in the clams may have resulted from several sources of contamination. Because lead in aquatic systems is believed to be removed from the water column to the bed sediments in close proximity to its origin (USEPA, 1979; McNurney et al., 1977), lead contamination in the shellfish beds of the marinas may be ascribed to a nearby source. The shellbeds at Viking Village were located close to the shore line. Therefore, marinas as well as surface runoff and stormwater runoff are probably all sources of the lead contamination. The level of contamination found in Viking Village warrants further investigation of the source of lead contamination.

SECTION 6

CONCLUSIONS

6. CONCLUSIONS

1. Long Quay marina had relatively slow tidal currents and water flows. Flushing time was estimated to be long and potentially inadequate for maintaining good water quality within the marina. There was no evidence of a salinity gradient and only a slight temperature gradient was observed during the time of study. A lack of stratification in conjunction with a low rate of discharge suggests that water entering the marina may be free to mix and dilute the entire water column. This may help to offset the effects of a long flushing time.

2. Viking Village had relatively fast currents that did not follow a discernible pattern and were indicative of appreciable water exchange. Thermal stratification was evident on each day of study. Flushing time was estimated at 2.25 days. The equation used in calculating the flushing time oversimplified the complex currents within the marina and therefore can not be considered to predict the flushing time accurately.

3. A short flushing time is considered by the USEPA as an important marina characteristic that helps maintain good water quality. The USEPA (1985) has estimated that flushing times greater than 2 - 4 days are unsatisfactory and may result in the build-up of pollutants. However, Long Quay marina, despite its longer flushing time, had better bacteriological water quality and lower metal concentrations in its hard clams than did Viking Village. In addition, the rapid currents at Viking

Village not only did not keep the marina's water unpolluted, but also contributed to a greater degradation of the adjacent bay water. Therefore, flushing time should not be the only factor considered when estimating the behavior and fate of marina-derived pollutants.

4. The water quality of the bay was directly affected by the fecal contamination in the marinas as measured by the coliform densities. The flushing processes and environmental conditions of the marinas will effect the flux of bacteria out of the marinas and into the bay.

5. The number of fecal and total coliform bacteria was consistently greater in the marina waters than in the bay waters and lower on Wednesday than on Saturday, when marina activity was higher. Water quality in Viking Village marina was not acceptable for recreational purposes on Saturday. There is evidence that the poor water quality of Viking Village adversely affected the adjacent bay water. In consideration of these findings, it may be concluded that recreational activities occurring within some marinas may be hazardous to the health of humans on days of high boat use. The acceptability of marina waters for recreational purposes needs to be studied further. It is recommended that marinas that provide primary contact recreation should monitor their water for possible high bacteria counts due to the discharge of boat sewage during periods of high marina activity.

6. To help maintain good water quality, marinas should be required to provide adequate and clean restrooms that encourage the public to use the marina facilities instead of the facilities on their boats.

7. The data indicate that shellfish-harvesting areas can be adversely affected by bacteriological contamination from marinas. Marinas should continue to be prohibited for shellfish harvesting. To further protect against the health hazard of consuming shellfish contaminated with boat-derived sewage, areas adjacent to marinas should be monitored to determine the extent of contamination contributed by marinas. In addition, these areas should be restricted for shellfish harvesting and classified as Seasonal Areas or Special Restricted Areas.

8. Marinas are possible sources of copper, zinc, lead and nickel contamination for aquatic ecosystems. These metals were detected at elevated levels within the clams collected at Long Quay and Viking Village. Lead was detected at concentrations that may be hazardous to humans. Copper, nickel, and lead were detected at levels that indicate concentrations in the water column may be adversely effecting marine organisms. There was not enough evidence from this study to indicate that marinas were the source of the elevated metal concentrations. Other potential sources of contamination include surface runoff, stormwater runoff, atmospheric deposition, dredging and dredge spoils.

9. Further research is needed to provide definitive evidence that marinas are a source of metal contamination.

SECTION 7

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