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CLEAN WATER

EFFECT OF SEASONAL CHLORINATION OF TREATMENT PLANT EFFLUENTS ON JAMAICA BAY COLIFORM POPULATIONS

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION • U. S. DEPARTMENT OF THE INTERIOR
HUDSON-DELAWARE BASINS OFFICE, EDISON, NEW JERSEY

EFFECT OF SEASONAL CHLORINATION OF TREATMENT PLANT EFFLUENTS ON COLIFORM POPULATIONS IN JAMAICA BAY*

by

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Summary

From March through October 1968, the Federal Water Pollution Control Administration's Hudson-Delaware Basins Office conducted a study to demonstrate that post-chlorination of wastewater treatment plant effluents would significantly improve receiving water bacteriological quality. The study area was Jamaica Bay, a shallow tidal estuary located within the limits of the City of New York. Six secondary treatment plants, discharging an average of 162 mgd were involved in the study.

The eight-month investigation, separated into two phases, was designed to determine the levels of indicator organisms prior to the start-up, during, and after the cessation of chlorination of treatment plant effluents. It is important to note that these discharges, based on a daily volume, account for less than 0.5 percent of the receiving

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water volume and more than 80 percent of the fresh-water input to the Bay. This survey program was also designed to predict how long the effects of storm and combined sewer overflow discharges, which average 34 mgd, or about 17 percent of the fresh-water input to the Bay, could be detected in the Bay following a storm.

Intensive sampling of Bay waters, and examination by membrane filter techniques for total and fecal coliform were made during the non-chlorination period and for 37 days following the start-up of chlorination at the wastewater treatment plants. In the second phase of the study samples were collected prior to the cessation of chlorination on September 30 and for 17 days following this date.

Analysis of the data collected during this study showed that:

(1) In most parts of the Bay there was a significant decrease in the coliform populations following the start-up of post-chlorination of treatment plant effluents. Correspondingly, there was an increase in coliform counts in the Bay following cessation of effluent chlorination.

(2) The effects of combined and stormwater overflows in the Bay were noticeable for a period of two to three days following a storm. After this time period, coliform levels returned to their normal background levels.

It was concluded on the basis of this investigation, that post-chlorination of wastewater treatment plant effluents was an effective means for reducing receiving water coliform populations, thereby improving water quality.

Introduction

Quite frequently, the question regarding the need for chlorinating effluents being discharged to receiving waters not used for recreational purposes is raised. In an attempt to answer this question a study was undertaken to demonstrate that chlorination of wastewater treatment plant effluents, which, by volume, represented less than 0.5 percent of the receiving water volume, would significantly improve the bacteriological quality of Jamaica Bay. This estuary was an ideal site for such an investigation since more than 99 percent of the treated effluents being discharged to the Bay are chlorinated on a seasonal basis only —— May 15 to September 30.

This two-phase investigation, conducted by the staff of FWPCA's Hudson-Delaware Basins Office, Edison, New Jersey, was divided into four periods:

Phase I - Intensive Survey: March 26 - June 28, 1968

Prior to May 15, the date for start-up of chlorination at the wastewater treatment plants, the normal or background levels of indicator organisms in Jamaica Bay were determined. From this start-up date until June 28 the Bay's waters were intensively sampled so as to determine the response time of the Bay to this additional treatment as well as to determine the new levels of indicator organisms.

Phase II - Surveillance Study: September 4 - October 24, 1968

With less frequent sampling than that which occurred in Phase I, the surveillance program was designed to indicate that when chlorination at the plants was stopped the coliform levels in the Bay would respond accordingly. From September 4 to September 30, background levels of indicator organisms were determined throughout the Bay. Following the cessation of chlorination on September 30, samples of the Bay's waters were collected to determine the response time of the receiving water to this change in treatment as well as the new and higher levels of indicator organisms.

Jamaica Bay, which for this study was defined as the area inside the Marine Parkway Bridge (See Figure 1), receives the discharge from six wastewater treatment plants; however, only three, those operated by the New York City's Bureau of Pollution Control are major in magnitude. Table I outlines the type of treatment facilities discharging to the study area and the flows during this investigation. The three large New York City plants plus the small Floyd Bennett Field installation practice seasonal chlorination, while the two smaller Nassau County plants chlorinate year-round.

Table I

Study Area Treatment Plant Discharges

Installation	Treatment	Flow	Discharge Point
Floyd Bennett Field	Trickling Filter	0.3 mgd	Rockaway Inlet
26 Ward, N.Y.C.	Modified Aeration	62.2 mgd	Hendrix Creek
Jamaica Bay, N.Y.C.	Modified & Step Aeration	81.1 mgd	Grassy Bay
Rockaway, N.Y.C.	Modified Aeration	18.6 mgd	South Channel
Inwood, Nassau Co.	High-Rate Trickling Filter	1.1 mgd*	Tributary to Motts Creek
Cedarhurst, Nassau Co.	High-Rate Trickling Filter	0.8 mgd	Motts Creek

*Estimated, flow meter broken

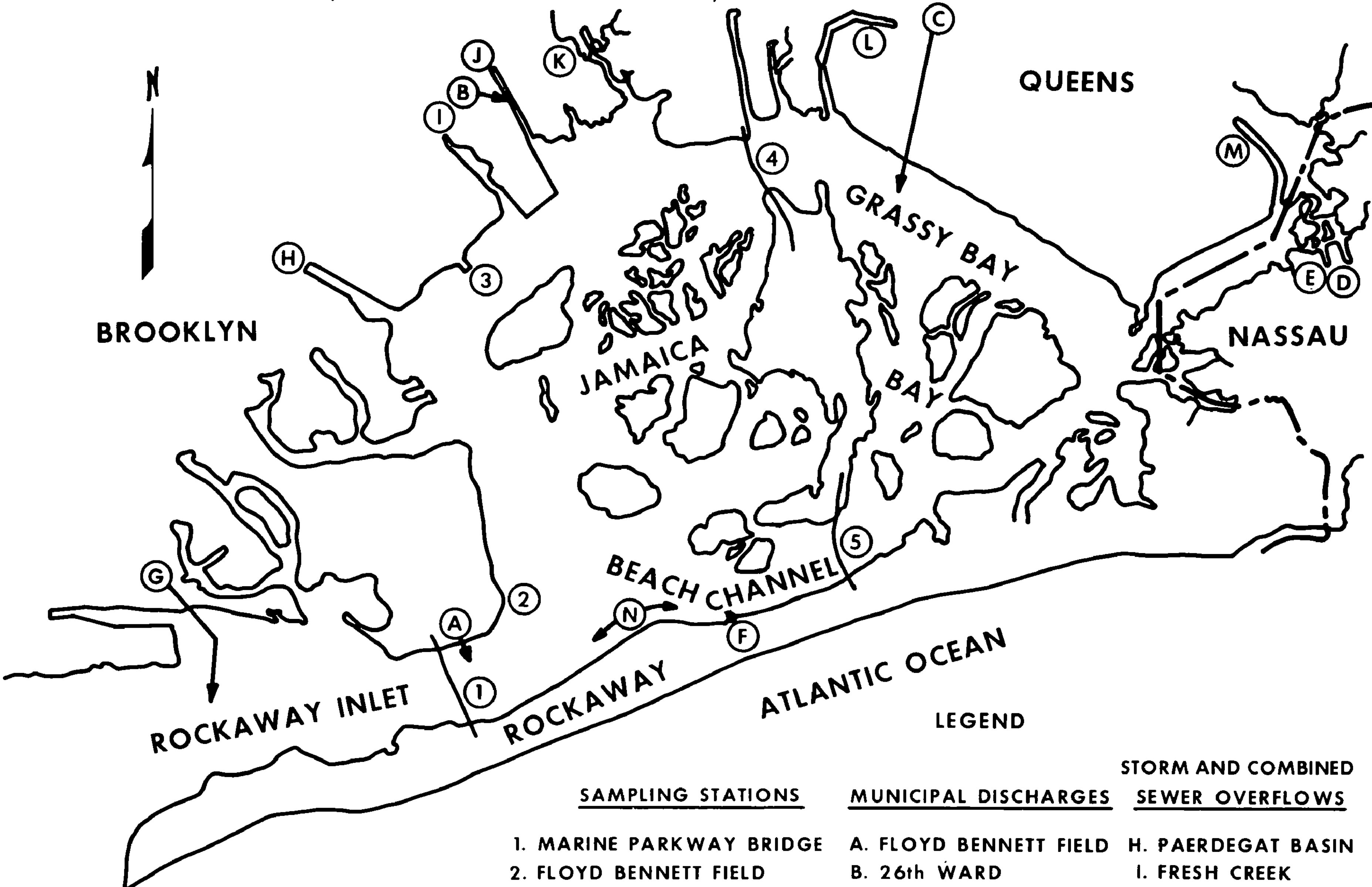
The location of these treatment facilities and their points of discharge are shown in Figure 1. Also shown in this Figure, just west of the Marine Parkway Bridge, is New York City's Coney Island Pollution Control Facility. While this plant discharged an average of 77 mgd during this study, its direct influence on Jamaica Bay was felt to be minimal since all samples were collected at low slack, or at the end of an outgoing tide.

In addition to receiving the direct discharge from treatment plants, which represents approximately 82 percent of the net fresh-water inflow to the Bay, it is estimated that the study area also receives an average daily inflow of 34 mg from storm and combined sewer discharges emanating from numerous outlets in Rockaway and six separate overflow stations along the northern border of the Bay. (See Figure 1)

Study Area Description

Jamaica Bay, measuring approximately six miles long by four miles wide is located, for all practical purposes, within the limits of the City of New York. It is bounded by two of the City's largest and most populated Boroughs - Brooklyn and Queens. (See Figure 1) Nearly 40 percent of the area of this shallow estuary, which has a mean depth of only 16 feet, consists of islands and tidal marshes located primarily in the central portion of the Bay.

FIGURE 1
SAMPLING STATIONS, MUNICIPAL DISCHARGES, STORM & COMBINED SEWER OVERFLOWS



LEGEND

SAMPLING STATIONS	MUNICIPAL DISCHARGES	STORM AND COMBINED SEWER OVERFLOWS
1. MARINE PARKWAY BRIDGE	A. FLOYD BENNETT FIELD	H. PAERDEGAT BASIN
2. FLOYD BENNETT FIELD	B. 26th WARD	I. FRESH CREEK
3. CANARSIE PIER, EAST END	C. JAMAICA	J. HENDRIX
4. CROSS BAY BRIDGE, NORTH	D. CEDARHURST	K. SPRING CREEK
5. CROSS BAY BRIDGE, SOUTH	E. INWOOD	L. BERGEN BASIN
	F. ROCKAWAY	M. THURSTON BASIN
	G. CONEY ISLAND	N. ROCKAWAY

Geographically enclosed, with its only outlet to the ocean being through Rockaway Inlet, Jamaica Bay has no major rivers or streams discharging into it. Major fresh-water sources include the discharge from municipal wastewater treatment plants, combined and storm sewer overflows and land runoff. These fresh-water inputs account for approximately 98 percent of the net advective flow to the Bay.

Present water resources of the Bay are restricted to boating, wildlife management, and limited fin fishing. Swimming and shellfishing are no longer permitted because of poor water quality. Many factors, excluding the problems associated with the discharge of treated domestic wastes and storm and combined sewer overflows, have contributed to the pollution problems of this estuary. Landfill and dredging operations have increased significantly over the past years, thus altering the hydrography and composition of the marshlands, which has affected water quality.

Climate in the study area is typically temperate with average monthly temperatures in the summer in the high 70's and in the winter near freezing —— 32°F. Average annual rainfall for the Jamaica Bay area is approximately 40 inches, which is distributed rather evenly throughout the year. Average monthly air and water temperatures during this investigation are shown in Table II. Pertinent precipitation data for this study are shown later in this report in Table IX.

Table II

Average Monthly Air-Water Temperatures

Month	Air (^{o}F)*	Water (^{o}F)
March	40.2	52.1
April	50.5	52.5
May	56.8	62.8
June	68.1	67.1
July	77.0	-
August	75.8	-
September	70.1	72.3
October	58.2	64.2

*Monthly average, JFK Airport, U. S. Department of Commerce

The hydrologic characteristics of the Bay are somewhat unusual even though tidal variations at Rockaway Inlet and within the Bay average five feet. The tidal prism in this estuary, or that volume of water between low and high water, represents approximately one-third of the volume of water in the Bay. In spite of this large hydraulic exchange, which occurs twice daily, it has been demonstrated that the net exchange of Bay water with the ocean is low. Thus, the Bay has a tendency to act as a storage place for pollutants discharged via municipal effluents and storm and combined sewer overflows.

Tidal current patterns within the Bay are such that the mean advective flow is through the main channels paralleling Rockaway Beach, Floyd Bennett Field, and Brooklyn. Average maximum tidal currents at Rockaway Inlet on an outgoing tide are 2.1 knots and 2.2 knots on incoming tides. Little net circulation occurs throughout the Bay because of its configuration.

Study Methodology

The problem of monitoring the changing water quality in Jamaica Bay is complicated by the tidal nature of the embayment. To eliminate as much as possible the variability in water quality caused by tidal fluctuations, all samples were collected at low water slack, which theoretically is the period of poorest water quality. Several 13-hour studies were also conducted at the five stations to determine the tidal fluctuations of indicator organisms. Chloride analyses were also run during all sampling periods to verify the tidal cycle phase.

During Phase I of the investigation the five selected stations (See Figure 1) were sampled for 35 days prior to the start-up of chlorination at the treatment plants, and for 37 days following the May 15 start-up date. During Phase II of the study, the Bay was sampled 11 days prior to the cessation of chlorination at the plants on September 30, and for 17 days following this period. Considering both phases of the program, plus the tidal cycle samplings, over 1,500 samples of Bay waters were analyzed for total and fecal coliform.

In addition to sampling Bay waters, the three major treatment plants —— 26th Ward, Jamaica, Rockaway —— were either sampled or visited at least twice per week throughout the study to determine if abnormalities in bacteriological quality in the Bay could be attributed to faulty operation at the plants.

Samples were collected from bridges or piers from a 5-foot depth, using a Kemmerer sampler. Prior to collecting the samples, the Kemmerer was agitated up and down to flush the sampling tube adequately. (1)

All bacteriological tests were performed using membrane filter techniques. Total coliform was determined as described in the 12th Edition of Standard Methods for the Examination of Water and Wastewater using Difco M-Endo broth to which 1.5 percent agar was added. Geldreich's fecal coliform procedure (2), which uses a medium consisting of an enriched lactose broth base with bile salts and rosolic acid for selectivity and an analine blue dye to indicate acid production, was used. Use of the Hudson-Delaware Basins Office mobile laboratory made possible completion of all total and fecal coliform analyses, through inoculation and placement in the appropriate incubator, within 60 minutes of sample collection.

Test Data Analysis

Analysis of the data collected during the two-phase study was aimed at defining changes in water quality in the Bay prior to and after the cessation of chlorination at the wastewater treatment plants. Other questions to be answered were: (a) Was this change in quality measureable at all sampling stations, or was it only detectable in certain areas of the Bay; (b) How long did it take the Bay to respond to the two changes in treatment? Again, was this change detectable throughout the Bay, or at only selected stations; and (c) Could some prediction be made to estimate how long the effects of storm and combined sewer overflow discharges could be detected in the Bay before the coliform levels returned to their normal background levels.

Due to distances between the location of the treatment plant outfalls and most of the sampling stations, it was assumed that some interval of time would elapse between the start-up of chlorination and the appearance of its effects at any one station in the Bay. Further, if coliform populations reached a steady-state condition before and after cessation of chlorination some time factor would be involved in the transition from one steady-state level to another.

Figures 2 & 3 illustrate two theoretical curve shapes which might be expected at any station in such a study. If the transport is achieved by current only, the lag time would be dependent upon distance and current

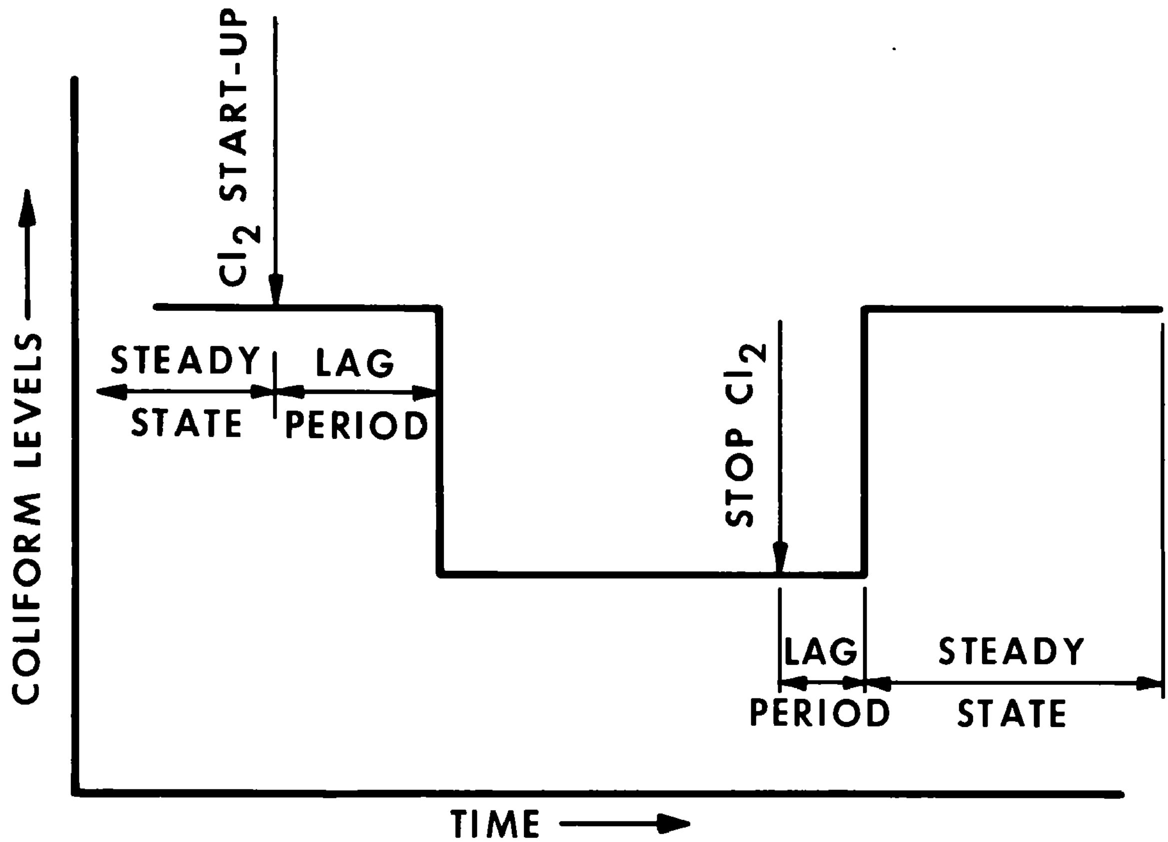


FIG. 2 THEORETICAL CURVE FOR CURRENT TRANSPORT ONLY

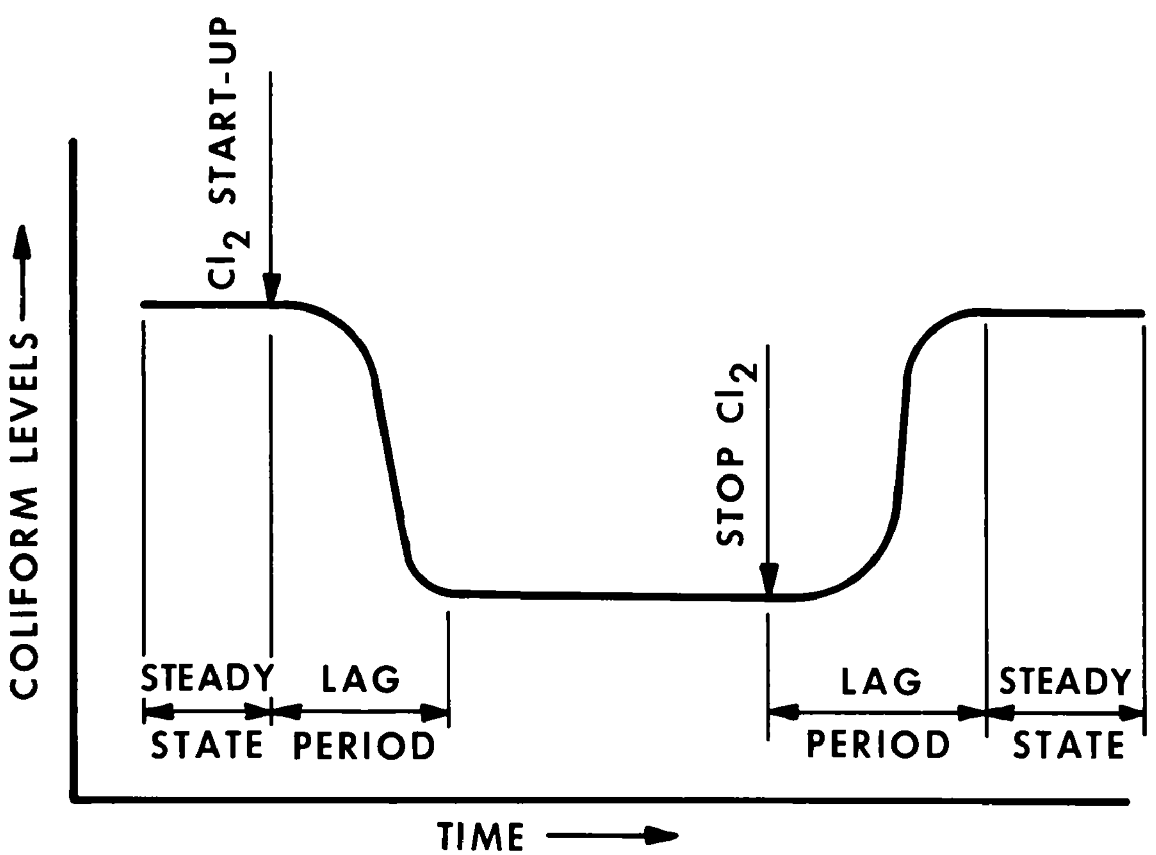


FIG. 3 THEORETICAL CURVE FOR CURRENT & DIFFUSION

velocity, and the curve would have the shape shown in Figure 2. When diffusion is an important factor in transport, the illustrating curve would have a more gradual transition from one steady-state to another as shown in Figure 3.

Defining Steady-State Conditions

A regression analysis between "days into the study" and log of the coliform counts was performed with a test of the hypothesis of a zero regression co-efficient. Because there seemed to be such a great variation in the counts due to rainfall, this effect had to be removed before analyzing the data for a steady-state condition.

Analysis of the information, adjusted for rainfall, failed to reject the hypothesis of a steady-state condition during all four time periods. A plot of the data, however, suggested that sufficient data were not available to accept the steady-state hypothesis for any time period except "before chlorination".

Even though we were unable to define a steady-state condition during all phases of the study, the question regarding whether or not there was a significant change in water quality during the four periods can still be answered. A summary of the median and geometric mean data (See Table III and IV) for all stations suggests that chlorination was effective in improving water quality at most locations. To further

TABLE III

MEDIAN COLIFORM COUNT/100 ML

Station	PHASE I				PHASE II			
	Before Chlorination		During Chlorination Early		During Chlorination Late		After Chlorination Terminated	
	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.
East End Canarsie Pier	15500	3900	23000	3400	32000	15000	96000	18000
Cross Bay Bridge North	46000	8100	3100	4200	5800	2100	20000	4900
Cross Bay Bridge South	3300	690	80	30	40	20	5600	840
Marine Parkway Bridge	2900	560	500	170	3350	150	4100	1700
N.A.S. Floyd Bennett	2200	690	2000	360	3200	780	6800	3300

TABLE IV

GEOMETRIC MEAN COLIFORM COUNT/100 ML

Station	PHASE I				PHASE II			
	Before Chlorination		During Chlorination Early		During Chlorination Late		After Chlorination Terminated	
	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.
East End Canarsie Pier	16569	3647	18353	2414	35568	10788	76574	18875
Cross Bay Bridge North	38642	7648	3391	464	6110	1924	14563	3681
Cross Bay Bridge South	3047	712	130	36	55	22	2456	417
Marine Parkway Bridge	2257	531	606	190	507	140	3474	821
N.A.S. Floyd Bennett	1959	686	1493	467	1562	686	5274	2072

demonstrate the validity of these findings, a non-parametric analysis of variance with interaction analysis (3) was used to give an insight to the comparable question related to all four time periods.

When analyzing these data the null hypotheses established were that there was (a) no difference in water quality at each of the stations, (b) no difference in water quality during all four time periods, and (c) no significant interaction between (a) and (b), that is, all stations, during all time periods, reacted the same.

If there were no true differences in coliform counts over the four time periods, it would be expected that about the same number of observations (See Table V for total number of observations) would fall above the average median as below.

If the observed "above" and "below" distribution was greatly different then we could conclude that a true difference in fact did exist. Using a chi-square distribution, we can then calculate the probability of such a distributional occurrence.

Table VI shows the above median frequency matrix and Table VII the below median frequency matrix from which the chi-square values and their degrees of freedom shown in Table VIII were calculated. With the chi-square analysis, if there was no true difference between the expected and observed values, then the hypotheses would be correct. However, the observed conditions differed so greatly from the expected or hypothesized

TABLE V

NUMBER OF OBSERVATIONS

Station	PHASE I				PHASE II			
	Before Chlorination		During Chlorination Early		During Chlorination Late		After Chlorination Terminated	
	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.
East End Canarsie Pier	34	33	37	37	11	10	17	17
Cross Bay Bridge North	35	34	36	37	11	11	17	17
Cross Bay Bridge South	35	34	37	37	10	10	17	17
Marine Parkway Bridge	35	34	37	37	10	10	17	17
N.A.S. Floyd Bennett	34	32	37	37	11	11	17	17

TABLE VI

"ABOVE" MEDIAN FREQUENCY MATRIX

Station	PHASE I				PHASE II			
	Before Chlorination		During Chlorination Early		During Chlorination Late		After Chlorination Terminated	
	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.
East End Canarsie Pier	32	28	33	29	11	10	17	17
Cross Bay Bridge North	32	32	14	11	8	10	13	14
Cross Bay Bridge South	12	12	2	2	0	1	12	7
Marine Parkway Bridge	9	11	9	7	1	1	8	10
N.A.S. Floyd Bennett	8	12	14	14	2	5	11	13

TABLE VII

"BELOW" MEDIAN FREQUENCY MATRIX

	PHASE I				PHASE II			
	Before Chlorination		After Chlorination Early		During Chlorination Late		After Chlorination Terminated	
	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.
East End Canarsie Pier	2	5	4	8	0	0	0	0
Cross Bay Bridge North	3	2	22	26	3	1	4	3
Cross Bay Bridge South	23	22	35	35	10	9	5	10
Marine Parkway Bridge	26	23	28	30	9	9	9	7
N.A.S. Floyd Bennett	26	20	23	23	9	6	6	4

TABLE VIII

CHI SQUARES AND SIGNIFICANCE

	Chi Aquares		Degrees of Freedom		Probability of a Larger Value of χ^2	
	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.
Total	197.9309	175.7797	19	19	<.005	<.005
Locations	140.0893	111.2452	4	4	<.005	<.005
Times	27.3048	38.1497	3	3	<.005	<.005
Interaction	30.5367	26.3848	12	12	<.005	<.005

that the final probability as calculated by the chi-square was less than 0.005. (See Table VIII) Thus, we reject the null hypotheses and conclude that:

(a) there is a significant difference in the coliform concentrations of the Bay water at the various sampling locations.

(b) there is a significant difference in the coliform concentrations of the Bay water during all four time periods.

(c) there is a significant interaction between the sampling locations and the time periods. This is to say that the change in coliform concentrations of the Bay water over time is not the same for all sampling locations.

Because of this significant interaction term, it is necessary to investigate the change in coliform conditions for each sampling location. This can be best accomplished by referring back to Table III. Note that Cross Bay Bridge North, Cross Bay Bridge South and Marine Parkway Bridge locations indicate lower median coliform concentrations for the two "during chlorination" time periods than the "before chlorination" and "after chlorination" time periods. This fact tends to support the original hypothesis of a reduction in coliform counts due to chlorination of effluents. However, the stations located at the east end of Canarsie Pier and the Naval Air Station at Floyd Bennett imply a steady increase of coliform counts over the four time periods, which does not support the above mentioned hypothesis.

A possible explanation for the steady increase in coliforms at these two stations could be due to increases in water temperature, coupled with the present problem of the lack of adequate chlorination facilities at the 26th Ward treatment plant, which is located near Canarsie pier. Floyd Bennett samples would have been adversely influenced because of the tidal current patterns and by the fact that all samples were collected at low slack, thus placing the "26th Ward effluent" in the vicinity of this station during sampling.

Since we were unable to define steady-state conditions during all segments of the study, it is statistically impossible to state the length of time required for the Bay to reach a new equilibrium after either the start-up or cessation of chlorination. A cursory review of the plotted data, however, suggests that a response time ranging from 24-48 hours, depending upon the particular station and its location to the proximity of effluent sources, is likely. This response time agrees with previous studies (4) conducted in 1963 by this laboratory in Raritan Bay. Depending upon the location of the station and the proximity to the outfall, response time in Raritan Bay ranged from 6 to 50 hours.

Storm and Combined Sewer Overflow Effects

FWPCA studies in Jamaica Bay have indicated that the average daily discharge from storm and combined sewer overflows, (See Figure 1 for locations) based on a storm occurring at a frequency of about once every three days, amounts to approximately 34 mg. This volume represents approximately 17 percent of the daily fresh-water input to the Bay. It is also noted that a one inch rain storm which occurred five times during this particular investigation, results in the discharge of approximately 250 mg of combined sewage to Jamaica Bay.

An attempt to relate rainfall and coliform data collected during this study failed to establish a consistent statistical relationship except for the "after chlorination" time period for all stations except Cross Bay Bridge South. It is suspected that because of the frequency of rainfall during this study, which averaged once very three to four days, insufficient data were collected to establish this relationship.

Table IV provides pertinent rainfall information regarding frequency and intensity. A plot of the coliform counts versus "days into the study" overlayed with a plot of rainfall suggests that one or two days, depending upon the location of the stations in relation to the overflow points, are necessary for a decline in the increased counts following a rain storm. Figures 4 and 5 illustrate these observations. It is important to point out, however, that to accurately define this figure down to the nearest hour, duration of rainfall, intensity, runoff co-efficients, as well as time of the day the storm occurred would have to be known in order to properly estimate recovery time of the Bay waters.

TABLE IX

RAINFALL PATTERNS DURING INVESTIGATION[1]

Month	Number of Days Sampled	Total Monthly Precip.	Greatest Day Precip.	Greatest Day Date	No. Days Rainfall 0.50 or more	No. Days Rainfall 1.0 or more	No. Calendar Days with Rainfall[2]
March	3	4.90	1.93	12	3	2	12
April	23	1.97	1.19	24	2	1	6
May	25	5.34	2.88	29	3	1	12
June	21	4.16	1.81	12	2	2	11
July	0	2.58	1.80	24	2	1	5
August	0	2.78	0.79	7	2	0	10
September	12	2.54	1.56	11	2	1	6
October	16	1.85	0.71	7	1	0	5

[1] Data reported from JFK Airport, U. S. Dept. of Commerce

[2] 0.10 inch or more

FIGURE 4
PHASE I : 3/26 TO 6/28/68
COLIFORM COUNTS vs RAINFALL
CROSS BAY BRIDGE SOUTH

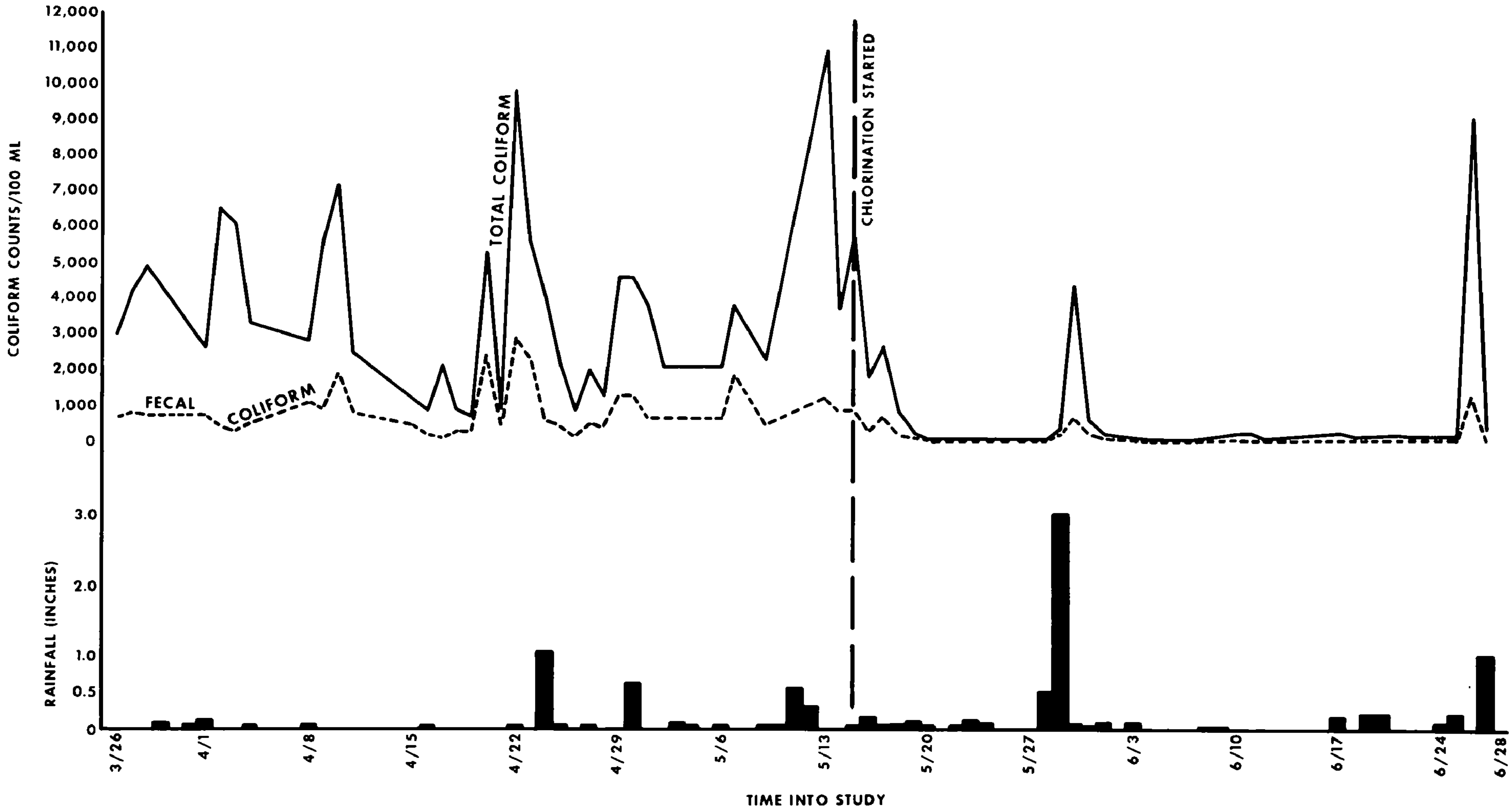
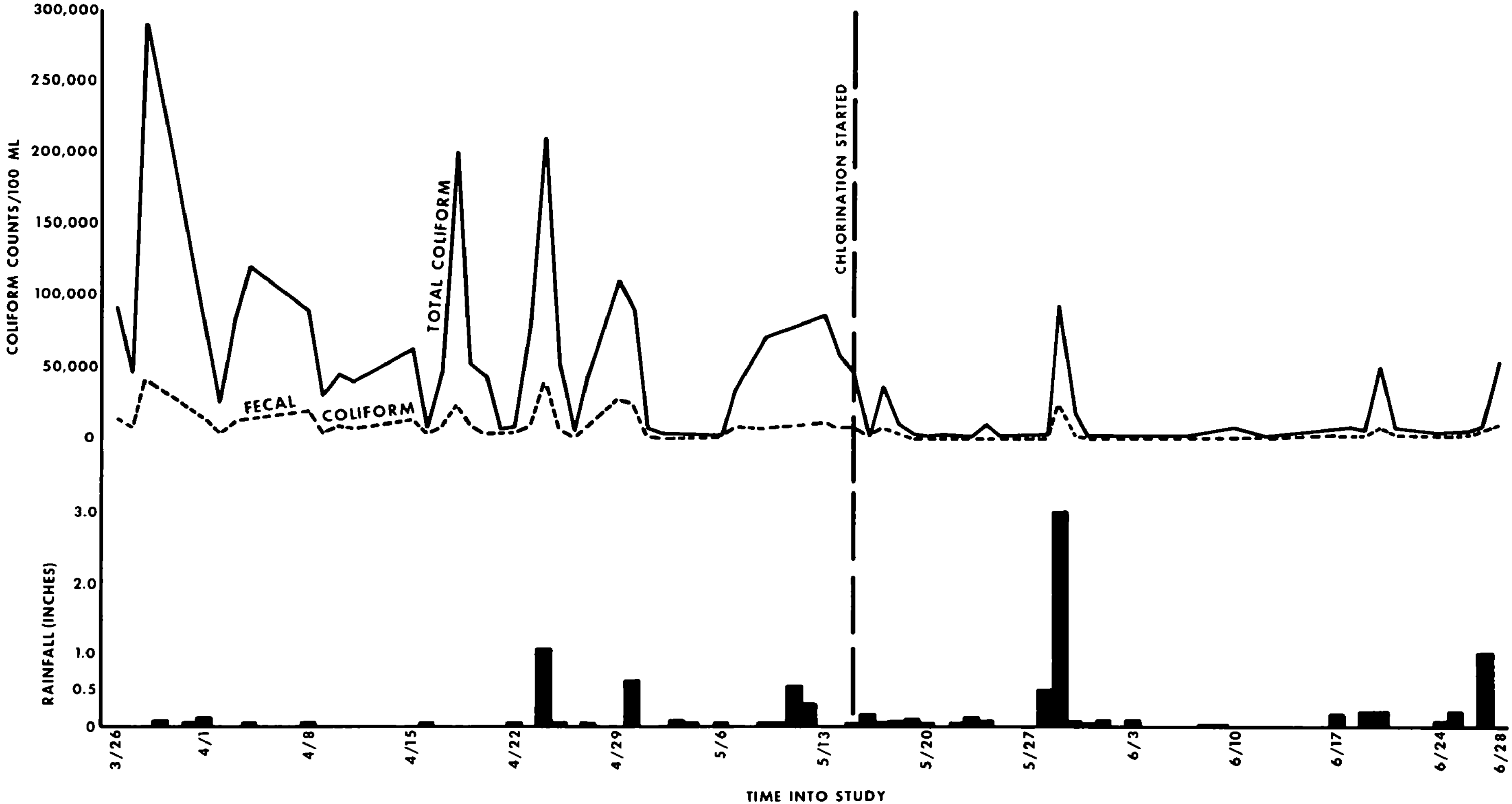


FIGURE 5

PHASE I : 3/26 TO 6/28/68

COLIFORM COUNTS vs RAINFALL

CROSS BAY BRIDGE NORTH



Conclusions

Analysis of the bacteriological data collected in Jamaica Bay during this eight-month long effluent chlorination study, which involved six secondary treatment plants discharging more than 160 mgd, has shown that:

(a) there was a significant decrease in the coliform populations present in most parts of the Bay following the start-up of post-chlorination of effluents at the treatment plants.

(b) there was a significant increase in coliform populations at most Bay stations following the cessation of post-chlorination.

(c) the estimated response time of most of the Bay stations to this change in treatment at the plants —— start-up and cessation of chlorination —— ranged from 24 to 48 hours.

(d) the effect of the discharge of storm and combined sewer overflows can be detected in most of the Bay for two to three days following a storm.

(e) post-chlorination of wastewater treatment plant effluents, even when the daily volume of these discharges represent less than 0.5 percent of the volume of the receiving water, is an effective means for improving the bacteriological quality of the receiving water.

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