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The Spatial and Seasonal Distribution of Coliforms in Bedford Basin

by Kenneth Freeman

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THE SPATIAL AND SEASONAL DISTRIBUTION OF COLIFORMS IN BEDFORD BASIN

BY

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INTRODUCTION

Domestic sewage discharge into coastal inlets is a situation familiar to many maritime communities. In the past, the self-cleansing ability of the recipient sea water coupled with large-scale dilution or flushing has usually been sufficient to nullify obvious environmental changes. A situation of this sort appears to have existed in both Bedford Basin and Halifax Harbour, Nova Scotia, but is subject to change. The former, which currently receives untreated waste from approximately 30,000 people, has received sewage via direct outfalls for the past 20 years and the latter for the past two centuries. The gradual increase in effluent discharge in the area, together with growing public awareness of undesirable pollution effects, has combined to direct attention to a better definition of the present condition of Bedford Basin.

Effects of sewage pollution can be deduced from nutrient levels, visual indications of eutrophication, and by the degree of coliform contamination. Nutrient levels have been determined for Bedford Basin and compared with the relatively pollution-free St. Margaret's Bay (Platt *et al*, 1970), Bedford Basin levels are higher at all times. Profuse growths of filamentous green algae, now widely accepted as *de facto* visual evidence of pollution, have been present in certain shore zones of the Basin for several years and their association with sewage-borne nutrients has been suspected. Current interest in assessing the extent of sewage pollution in Bedford Basin by more exact means stemmed from recent proposals to increase the discharge of domestic wastes into this embayment and the decision was made to employ coliform bacteria as an indicator of the present state of pollution.

Cursory surveys for coliform levels were made in 1970, including one tidal transport study done in the Narrows. This report describes the seasonal and spatial distribution of coliforms in Bedford Basin in 1971 and is based on values obtained from surveys carried out during April to September of that year.

DESCRIPTION OF BEDFORD BASIN

Bedford Basin is a body of water about 7 1/2 km long by 4 km wide with an area of 17 km^2 and having a maximum depth of 70 m. It is connected to the Atlantic by a channel 10 km in length by 400 m wide at its widest part (Figure 1). The channel is 20 m deep at its northern end, 30 m at its connection to the sea. It is subjected to semi-diurnal tides ranging from 0.6 to 2.0 m in amplitude. The Basin receives 10^4 to 10^7 m^3 day^{-1} drainage water, mainly from the Sackville River and several small creeks.

Total nitrate, inorganic phosphate and silicate maxima for 1969-70 were 637.4, 157.9 and 2,109.7 mg at m^{-2}

respectively (Platt and Irwin, MS, 1970). Minima recorded during the same study were 7.2, 9.12, and 34.7 mg-at m^{-2} for nitrates, phosphates and silicates.

Productivity expressed in mg C m^{-2} hr^{-1} varied from a high of 310.0 to a low of 7.6.

Surface temperatures ranged from 1°C to 20°C, and at 60 m from 2°C to 4°C over the same period.

Exchange of Basin water is a continuous process brought about by surface outflow and a compensatory deeper intrusion of oceanic water at the sill. Depending on its density, this intrusion displaces the deep Basin water with minimal mixing or gradually mixes with deep water through the forces of wind and tide (Platt *et al*, 1970). An estimate of 11% per day turnover of Basin water based on chlorophyll transport has been made by Platt and Conover (1971).

METHODS

Using the membrane filtration (MF) method rough estimates of total coliform densities were obtained throughout the Basin over a period of months. Preliminary surveys of the Basin were done in the spring, summer and early fall of 1970, and gave an appreciation of seasonal change in concentrations. Twenty stations were employed in the initial surveys and of these, ten were retained for the later work (Figure 1).

Subsurface samples were collected with teflon-lined Knudsen bottles and surface samples were collected by hand. No attempt was made to clean the sampling bottles between casts though prior to each survey they were thoroughly rinsed with hot water. Between surveys the Knudsen bottles were well dried. Sterile, 200 ml glass bottles were used for sample collections. Samples were taken at 0, 5, 10, 25, and 50 m, where depth permitted, except that 5 m samples were not taken from station Nos. 3-8. All survey collections were made in the early morning and were completed within 1 1/2 hours. Samples were placed in a 10°C cooler within 2 hours of collection of the first sample. No attempt was made to ascertain tidal effects on coliform densities.

Three aliquots were examined from each of the samples, one filter per aliquot, according to anticipated coliform densities. M-Endo MF broth (BBL) was employed in all plates. Techniques of analysis followed those outlined in Standard Methods For The Examination of Water and Wastewater, 13th edition, and membrane counts were done after 22 hours of incubation.

Counts were expressed as coliforms /100 ml and the medians rounded off to two significant figures. Several "sheen" colonies were picked from a random selection of plates from the April, July, and September surveys, and placed in single lactose broth at 35°C as an additional check on the bacterial biotypes being counted.

Parallel analyses using the multiple tube (MPN) method employing five tubes in each of three consecutive decimal dilutions were done on the surface and deepest sampling levels of station Nos. 2, 5 and 8. Lactose broth and brilliant green bile broth 2% (BBL) were used for the presumptive and confirmed tests respectively.

RESULTS AND DISCUSSION

Various microbiological critera are available for the detection of sewage pollution. Of the bacterial types employed, the coliform group has been the most extensively used (Clark and Kabler, 1963). There has been much controversy concerning the value of total coliforms as indicators of pollution in the sea, primarily from the viewpoint of coliform viability in this environment (Greenberg, 1956; Grabow, 1970). It is generally accepted that the presence of coliforms *per se* does not necessarily imply recent sewage contamination and many workers in sanitary bacteriology prefer to use fecal coliforms for this purpose, as these "high temperature" strains do not survive in natural waters as long as other coliform types. However, suggestions have been made (Mishra *et al*, 1968; Tennant *et al*, MS, 1964) that the elevated temperature test does not adequately differentiate between non-fecal and fecal coliforms. Although the use of total coliforms may be questionable in determining the fecal origin of pollution, it appears to be the most reasonable and convenient tool for initial assessment of the existing conditions in the estuary, partly because this involves identification of areas of redistribution from various sources. Furthermore, sewage drainage into both Halifax Harbour and Bedford Basin is sufficiently large that the contribution of coliforms from it must be substantial in relation to that from shore runoff in normal rainy periods (Figure 2).

The MF method was chosen over the more established MPN method for reasons of economy, rapidity of analysis and limited laboratory facilities. This method is now established as theoretically the more accurate of the two, and is an accepted means of coliform enumeration provided that parallel examinations are performed on some samples using the multiple tube technique. In this way, it can be determined if the bacterial biotypes being counted by the MF technique conform to the definition of the coliform group (Standard Methods For The Examination Of Water And Wastewater, 13th edition, 1971). In general, parallel coliform estimates in the present work agreed and it was therefore concluded that similar biotypes were being counted by both methods. All "sheen" colonies examined proved to be active lactose fermenters, with gas production at 35°C.

Though standard bacterial methods, particularly with regard to replication of samples and filters, were not strictly adhered to in all phases of the programme, the values derived from the detailed work of 1971 conformed to results of the previous year for subarea and level with time. Possible errors due to the use of non-sterile sampling devices were in all likelihood insignificant as there was at no time evidence of slime accumulation and they were never used for obtaining the surface samples, thus ensuring a rinsing of the interiors as the bottles descended to depth on successive casts.

Results by station and depth throughout the seasons are shown in Figures 3 to 12. The maxima of 20,000 coliforms /100 ml found at station nos. 2 and 10 are at best conservative estimates due to crowding of colonies on the membranes. The proximity of raw sewage sources made more accurate evaluations impossible under the minimal test layout employed but such accuracy was not considered necessary for the type of study done. All other stations show coliform concentrations which are at least an order of magnitude lower, with the central Basin values two orders of magnitude lower.

Mean Basin values (Figure 13) were lower in the summer than in the spring and early fall, a trend frequently attributed to seasonal freshwater runoff. That the trend in this case is due to runoff is open to question, as a comparison of the trends of both precipitation and coliform levels indicates an overall negative correlation (Table 8). This indication led to examination of results by region, in particular stations nos. 2, 9 and 10 as these would be most directly affected by landwash due to their proximity to fresh water input. The central (station nos. 5-8) and lower (station nos. 1, 3 and 4) Basin regions are too susceptible to wind and tide perturbation to provide definitive simple interpretation in terms of fresh water input. Data were examined in terms of tendencies of precipitation and coliform levels to rise or fall simultaneously or diverge, and also in terms of their monthly values with respect to their means. Both one week and two week precipitation values prior to survey dates (Table 7) were considered and the relationships determined for both time periods (Table 8).

The two methods of comparison show a consistent opposite trend between outflow and bacterial concentration at the surface of station no. 2 in the lower Basin and nos. 9 and 10 in the mouth of the Sackville River. A similar trend was noted for the 5 m depth at station no. 2 though by contrast the values in the deeper water at station no. 9 were positively related to runoff. This suggests that for station no. 9 as elsewhere, coliforms at the surface may be diluted by the runoff while coliforms at 5 m, and maybe deeper, are being moved into the upper end of the Basin by what would appear to be a physical estuarine mechanism. That is, the stronger seaward movement of the upper layer in this area may be inducing replacement below by more contaminated water. This mechanism was not detected at station no. 2.

That tide may affect coliform values in the Basin is suggested both by the lower concentrations and by the more scattered nature of seasonal results from station nos. 1, 3 and 4 as compared to the more uniform pattern from the stations in the upper portion of the Basin. Clearly, massive tide-generated water movements will influence counts at stations adjacent to major sewer outfalls depending on the relation of the stations to the position of the outfalls. Tidal effects were investigated in a preliminary way during a 13 hour survey in April 1970 in the Narrows. There was a marked increase in coliforms at all depths examined (1, 5, and 10 m) on the flood tide, but particularly at the 5 m level. Transport calculations based on current measurements and coliform values with time indicated a net import (roughly twice the export) of coliforms into the Basin over one tidal cycle. It would be possible for oceanic water, intruding over the sill at the Narrows, to take with it on the incoming tide sewage being discharged into the harbour channel. If the bulk of the incoming coliforms is well below the surface there is nothing to stop their being transported to the upper reaches of the basin provided the time required to do so does not exceed their life-span in sea water which, depending on conditions, may exceed 200 days (Greenberg, 1956).

Based on Platt and Conover's calculation of Basin water exchange rate, the half-life of water in the Basin is approximately 5 days. With an estuarine-like system (Platt *et al*, 1970) it is therefore likely that coliforms entering the Basin at the Narrows would be detectable at depth in the north end of the estuary within their normal life span. That is, inflow from the harbour may be a significant source of pollution for the Basin. This interpretation of the data is consistent with the observed higher concentrations of coliforms in the central and upper Basin regions at the 10 m depth (Tables 5 and 6).

It is clear that the hypotheses developed from this study are not adequately tested by the sampling programme and short term intensive surveys to measure more accurately the effects of both tide and precipitation are indicated. Such surveys done in the Narrows on a seasonal basis should indicate the effect of tidal amplitude, and additional programmes following periods of heavy rainfall should reveal the effect and extent of fresh water runoff on coliform levels in the Basin. There are, in addition, other physical, biological and chemical parameters which can affect coliform concentrations in sea water. For example Bernard (1970) indicates that lower estuarine water temperatures tend to prolong coliform survival and this factor alone may directly or indirectly account for a significant part of the overall tendency for the counts in the Basin to be higher in the spring and fall than in the summer.

Following completion of the field sampling programme, construction of a sewage treatment facility serving communities around the upper end of Bedford Basin was completed and made partially operational in the late spring of 1972. The plant may be fully operational to the level of secondary treatment by 1974. Also, as an initial step in a plan to divert all Halifax sewage towards the sea, construction has begun on an interceptor line which will carry all effluent presently entering the Basin and Narrows to a discharge point just below the Narrows. It is also the aim of the City of Dartmouth to divert its domestic wastes to the sea and the intent of both cities to provide a common treatment facility near the harbour entrance. Though the diversion of outfalls now emptying into the Basin to a discharge point below the Narrows may not mean the end to pollution of the Basin by sewage, according to interpretation of the results of this study, water quality in the Basin with regard to coliform densities should improve over the years as these proposed facilities come into use.

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TABLE 1 - COLIFORM COUNTS - APRIL AND MAY 1971

		April 5			May 4		
			Median MF/100 ml			Median MF/100 ml	
Sta. No.	Depths (m)	MPN/ 100 ml	Per Depth	Per Sta.	MPN/ 100 ml	Per Depth	Per Sta.
	0		980			980	
1	5		600	600		680	770
	10		450			640	
2	0	≥2400	3,700	2,100	≥2400	20,000	4,800
	5	≥2400	1,400		≥2400	3,800	
	0		80			300	
3	10		72	60		400	300
	25		25			20	
	0		360			990	
4	10		180	180		780	780
	25		33			10	
	0	350	100		350	250	
5	10		340	47		1,000	120
	25		20			20	
	50	49	20		4	7	
	0		110			40	
6	10		300	110		300	350
	25		30			470	
	0		110			90	
7	10		190	110		790	90
	25		64			10	
	0	920	80		23	<5	
8	10		190	80		200	10
	25	79	30		33	10	
9	0		20	150		460	340
	5		240			210	
10	0		3,100	3,100		20,000	20,000

TABLE 2 - COLIFORM COUNTS - JUNE AND JULY 1971

		June 21			July 26		
			Median MF/100 ml			Median MF/100 ml	
Sta. No.	Depths (m)	MPN/ 100 ml	Per Depth	Per Sta.	MPN/ 100 ml	Per Depth	Per Sta.
1	0		250	260		1,300	930
	5		1,200			930	
	10		200			430	
2	0	≥2400	20,000	7,500	≥2400	2,100	3,300
	5	≥2400	4,600		≥2400	5,600	
3	0		20	20		1,000	210
	10		40			210	
	25		20			170	
4	0		<3	40		400	220
	10		380			220	
	25		30			160	
5	0	<2	<6	27	110	87	78
	10		30			67	
	25		70			100	
	50	49	20		33	10	
6	0		<3	20		160	40
	10		20			60	
	25		15			28	
7	0		10	10		16	32
	10		13			46	
	25		10			32	
8	0	2	<2	10	11	5	8
	10		<2			4	
	25	9	10		79	16	
9	0		370	190		350	230
	5		10			220	
10	0		1,700	1,700		1,000	1,000

TABLE 3 - COLIFORM COUNTS - AUGUST AND SEPTEMBER 1971

		August 30			September 28		
			Median MF/100 ml			Median MF/100 ml	
Sta. No.	Depths (m)	MPN/ 100 ml	Per Depth	Per Sta.	MPN/ 100 ml	Per Depth	Per Sta.
1	0		2,400	650		100	200
	5		650			500	
	10		480			170	
2	0	≥2400	20,000	6,500	≥2400	20,000	20,000
	5	1600	3,000		≥2400	20,000	
3	0		20	160		1,000	850
	10		500			850	
	25		160			27	
4	0		23	73		190	170
	10		380			200	
	25		73			30	
5	0	49	12	28	110	120	73
	10		350			220	
	25		18			50	
	50	49	38		13	12	
6	0		150	150		210	190
	10		400			230	
	25		16			28	
7	0		>270	270		170	170
	10		310			280	
	25		36			10	
8	0	1600	400	130	540	310	270
	10		130			340	
	25	33	20		17	23	
9	0		670	490		170	190
	5		>480			200	
10	0		11,000	11,000		20,000	20,000

TABLE 4 - MEDIAN MF COLIFORM COUNTS /100 ml BY STATION AND SURVEY

Survey	Sta. 1	Sta. 2	Sta. 3	Sta. 4	Sta. 5	Sta. 6	Sta. 7	Sta. 8	Sta. 9	Sta. 10	Survey Means
Apr. 5	600	2,100	60	180	47	110	110	80	150	3,100	650
May 4	770	4,800	300	780	120	350	90	10	340	20,000	2,800
June 21	260	7,500	20	40	27	20	10	10	190	1,700	980
July 26	930	3,300	210	220	78	40	32	8	230	1,000	610
Aug. 30	650	6,500	160	73	28	150	270	130	490	11,000	2,000
Sept. 28	200	20,000	850	170	73	190	170	270	190	20,000	4,200
Station Means	570	7,400	270	240	62	140	110	85	270	9,500	

TABLE 5 - MEAN COLIFORM VALUES, ALL SURVEYS

Depth	Sta. Nos. 1-4	Sta. Nos. 5-8	Sta. No. 9
Surface	4,000	110	340
x*	2,000	240	230

*(where x = next level examined, either 5 or 10 metres)

TABLE 6 - PERCENT OCCURRENCE OF EVENT, ALL SURVEYS

Event	Sta. Nos. 1-4	Sta. Nos. 5-8	Sta. No. 9
Surface value $> x$	58.3	16.7	66.7
Surface value $\equiv x$	4.2	4.2	0.0
Surface value $< x$	37.5	79.1	33.3

TABLE 7 - TOTAL PRECIPITATION IN INCHES PRIOR TO COLIFORM SURVEYS, 1971

Precipitation Duration	7 days	14 days
Survey Date		
April 5	.90	2.40
May 4	.47	.94
June 21	.00	.31
July 26	3.09	3.77
August 30	1.03	4.10
September 28	.02	.29

TABLE 8 - TWO METHODS OF COMPARING COLIFORM COUNTS AND PRECIPITATION

Coliform Data Source and Precipitation Duration	Comparison By Between Month Trend		Comparison of Direction of the Paired Monthly Values From their Respective Means	
	Same	Opposite	Same	Opposite
All stations and depths				
7 day precipitation	1	4	3	3
14 " "	2 (fig. 13)	3	2	4
Station No. 2; entire				
7 day precipitation	0	5	2	4
14 " "	1	4	1	5
Station No. 2; 0 m				
7 day precipitation	No test possible		2	4
14 " "			1	5
Station No. 2; 5 m				
7 day precipitation	2	3	3	3
14 " "	1	4	2	4
Station No. 9; entire				
7 day precipitation	3	2	4	2
14 " "	4	1	3	3
Station No. 9; 0 m				
7 day precipitation	2	3	4	2
14 " "	3	2	3	3
Station No. 9; 5 m				
7 day precipitation	4	1	4	2
14 " "	5	0	5	1

TABLE 8 - (CONTINUED)

Coliform Data Source and Precipitation Duration	Comparison by Between Month Trend		Comparison of Direction of the Paired Monthly Values From Their Respective Means	
	Same	Opposite	Same	Opposite
Station No. 10; 0 m				
7 day precipitation	1	4	3	3
14 " "	2	3	2	4
Station Nos. 1,3,& 4; 0 m				
7 day precipitation	4	1	5	1
14 " "	3	2	4	2
Station Nos. 1,3,&4; x*m				
7 day precipitation	1	4	2	4
14 " "	2	3	1	5
Station Nos. 5-8; 0 m				
7 day precipitation	4	1	4	2
14 " "	5	0	3	3
Station Nos. 5-8; 10 m				
7 day precipitation	3	2	2	4
14 " "	4	1	3	3

*x m = next level examined, either 5 or 10 m

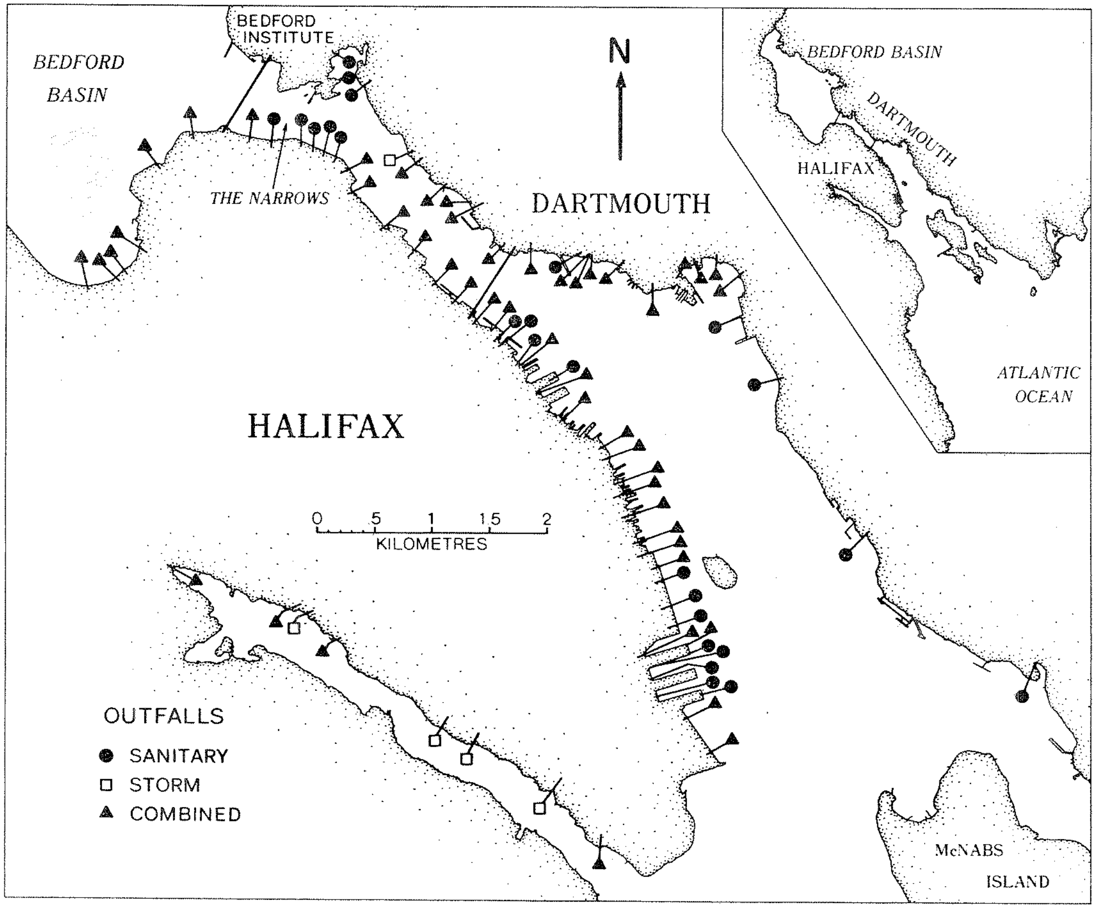

Figure 1 - Municipal storm and sewer outfalls - Halifax* and Dartmouth, N. S.

(*from the report of MacLaren Atlantic Ltd.)

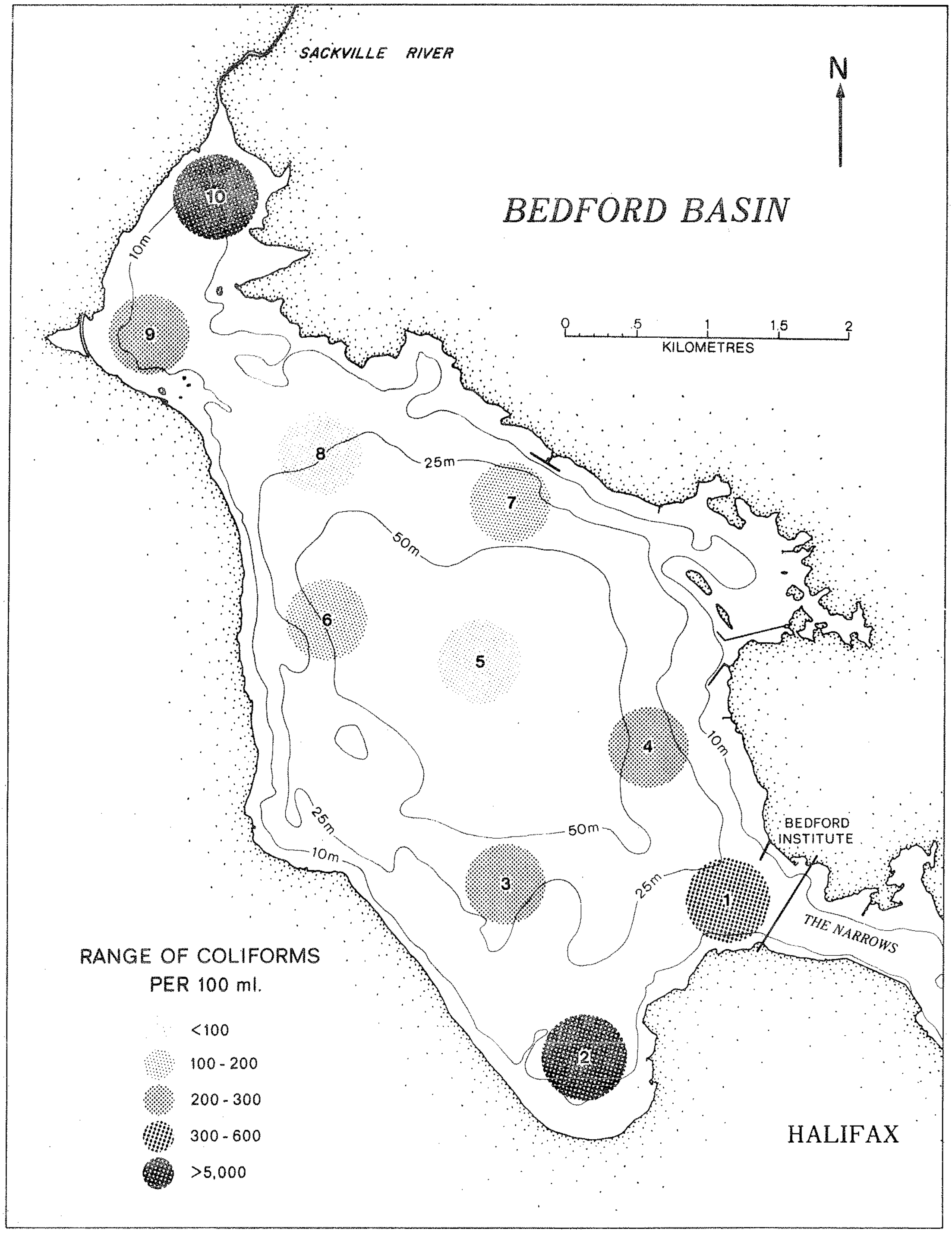

Figure 2 - Bedford Basin showing sampling locations and mean station coliform ranges from all surveys.

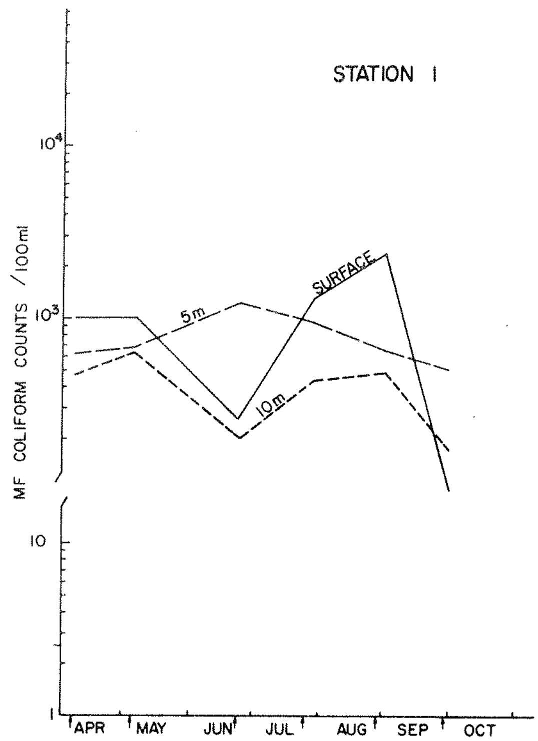

Figure 3

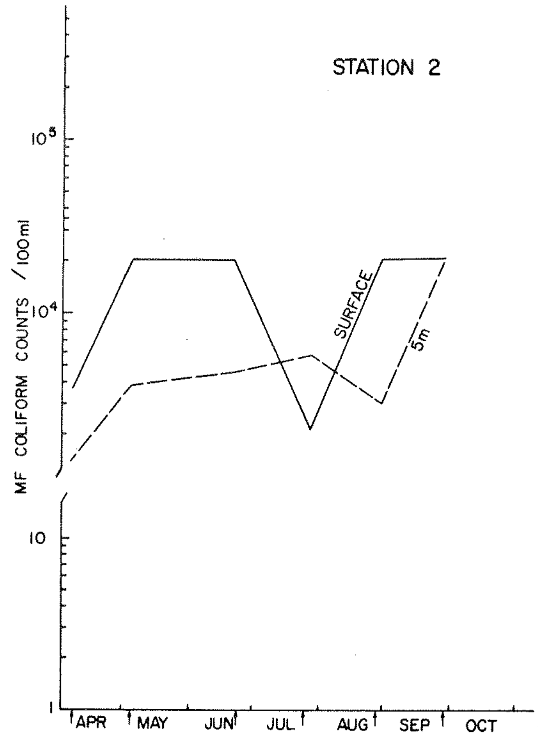

Figure 4

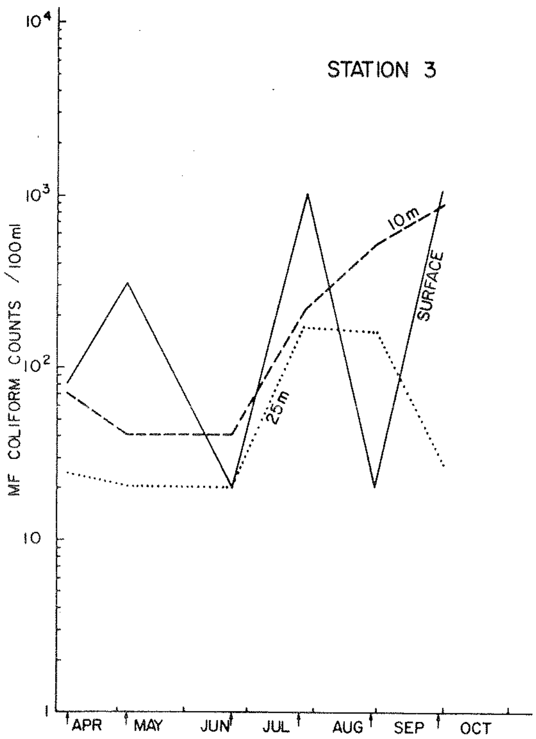

Figure 5

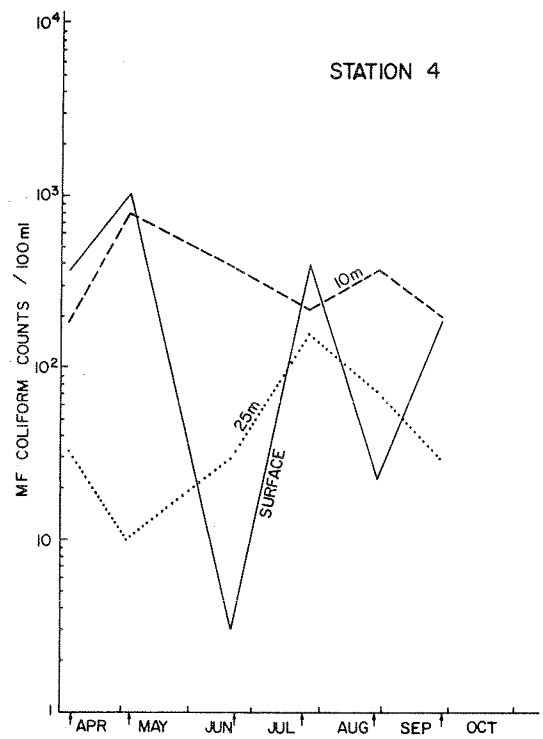

Figure 6

Figures 3-6 - Stations 1-4 showing coliform fluctuations by depth and month

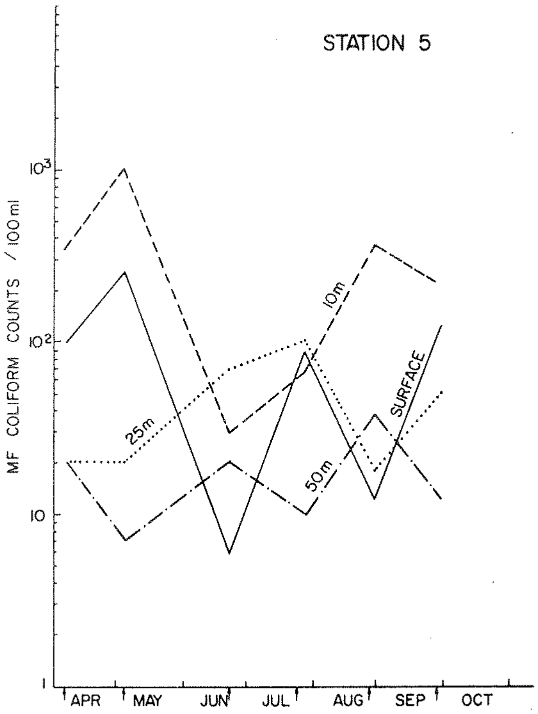

Figure 7

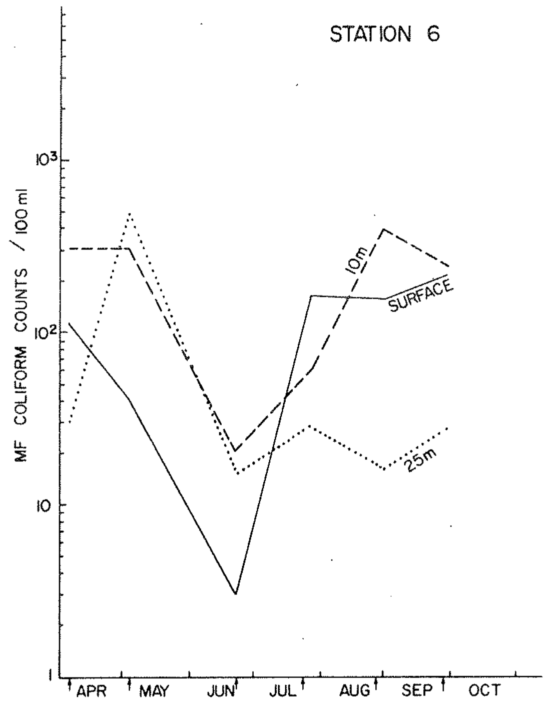

Figure 8

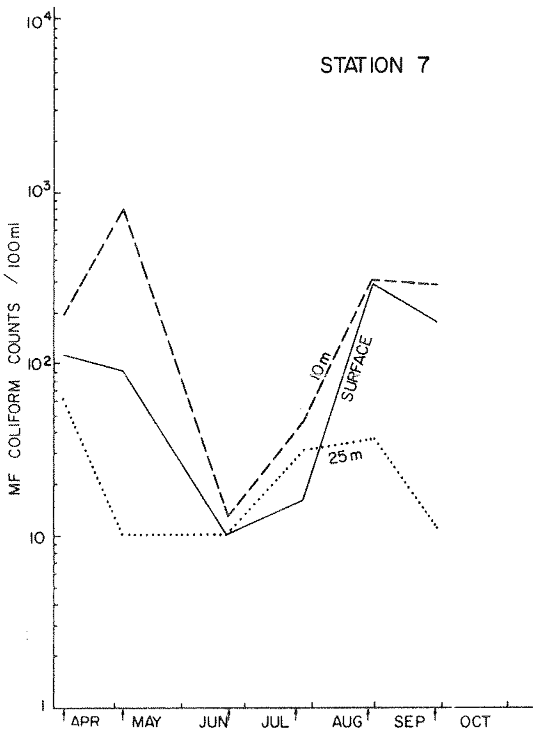

Figure 9

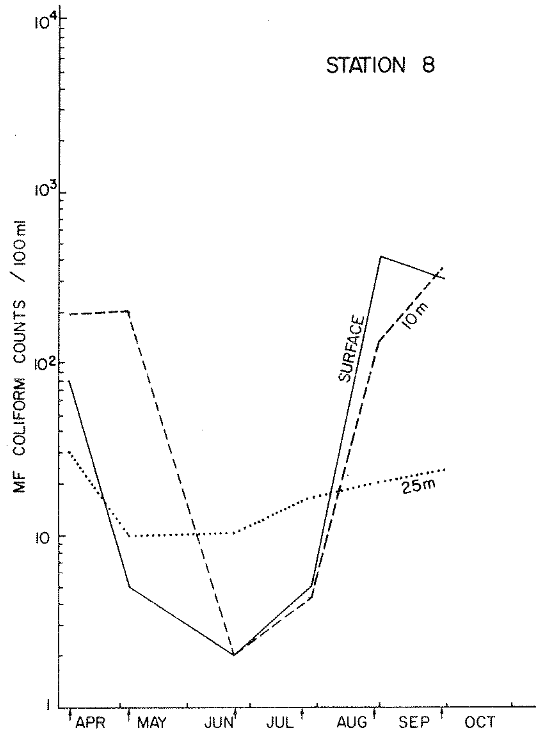

Figure 10

Figures 7-10 - Stations 5-8 showing coliform fluctuations by depth and month

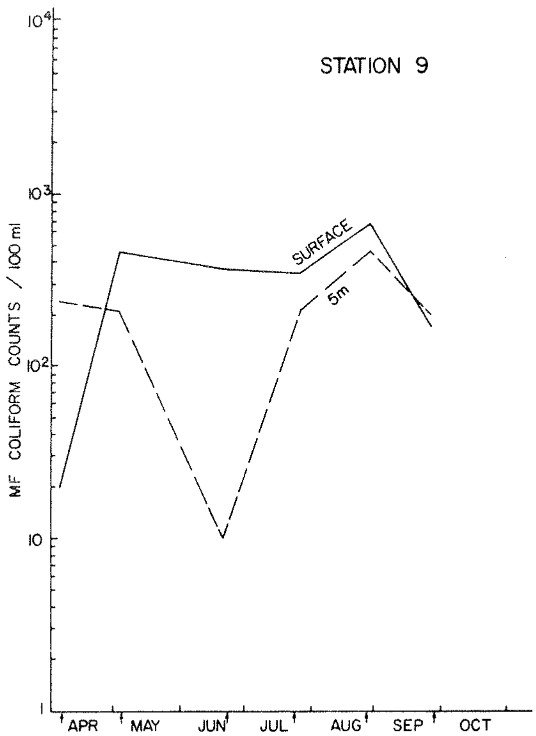

Figure 11

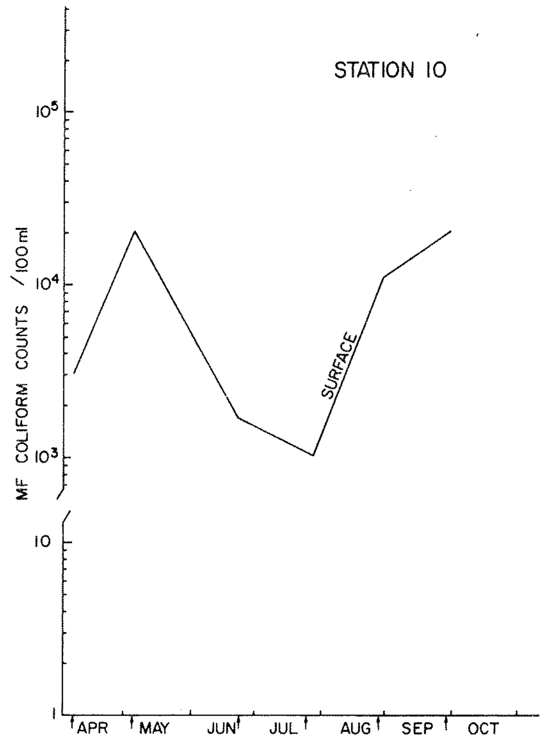

Figure 12

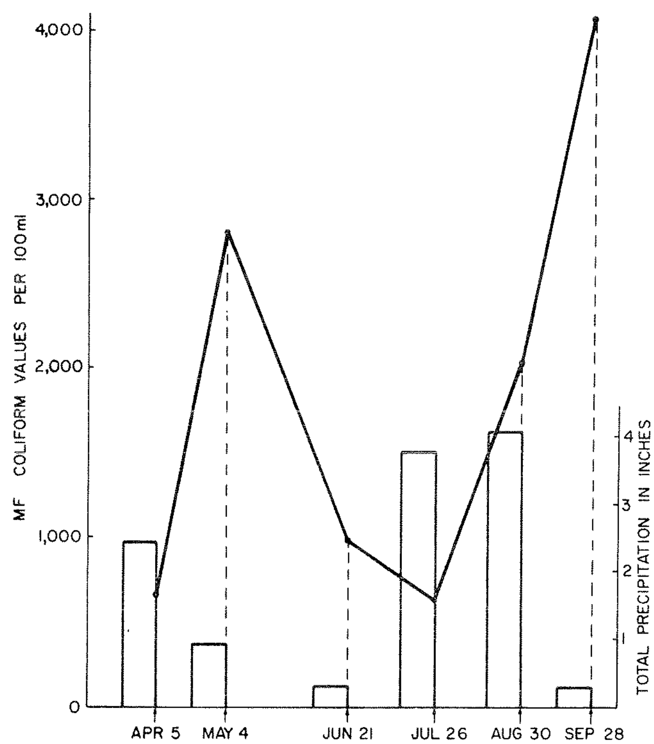

Figure 13

Figures 11-12 - Stations 9-10 showing coliform fluctuations by depth and month

Figure 13 - Mean survey coliform values (line) vs. total precipitation (bars) in two weeks prior to sampling dates.