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FRASER RIVER ESTUARY STUDY, WATER QUALITY, SURVEY OF FECAL COLIFORMS IN 1978

by

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SUMMARY

Water quality in the Fraser River Estuary has been described in a summary report, and in a set of eleven background reports. The present report is one in a series of five technical additions, which supply information too detailed to incorporate in the background reports.

In 1978 the Province measured fecal coliform levels, at three locations in the lower Fraser River, in a short intensive program. The data were collected to help fill certain data gaps and design future monitoring programs. These data are presented here, but only a preliminary analysis has been carried out.

There was a fairly large variability in the data, as one might have expected. However, a statistical analysis, described in this report, showed that fecal coliform variations were due less to chance than to certain sampling factors. These included time of sampling, location of sampling in the river cross-section, sampling day and various combinations of these factors acting together.

PREFACE

The Fraser River Estuary Study was set up by the Federal and Provincial Governments to develop a management plan for the area.

The area under study is the Fraser River downstream from Kanaka Creek to Roberts Bank and Sturgeon Bank. The Banks are included between Point Grey and the U.S. Border. Boundary Bay and Semiahmoo Bay are also included but Burrard Inlet is not in the study area.

The study examined land use, recreation, habitat and water quality, and reports were issued on each of these subjects.

Supplementary to the initial water quality report, a more detailed analysis of the information was undertaken by members of the water quality work group. As a result, eleven background technical reports were published. The background reports are entitled as follows:

- Municipal effluents.
- Industrial effluents.
- Storm water discharges.
- Impact of landfills.
- Acute toxicity of effluents.
- Trace organic constituents in discharges.
- Toxic organic contaminants.
- Water chemistry; 1970-1978.
- Microbial water quality; 1970-1977.
- Aquatic biota and sediments.
- Boundary Bay.

Each of the background reports contains conclusions and recommendations based on the technical findings in the report. The recommendations do not necessarily reflect the policy of government agencies funding the work. Copies of these reports are available at all main branches of the public libraries in the lower mainland.

Five auxiliary reports, of which this is one, are also being published in further support of the study. These cover the following subjects:

- Site registry of storm water outfalls.
- Dry weather storm sewer discharges.
- Data report on water quality.
- Survey of fecal coliforms in 1978.
- Survey of dissolved oxygen in 1978.

Copies of these reports will be available from the Map Library, Assessment and Planning Division, Ministry of Environment, Parliament Buildings, Victoria, British Columbia, V8V 1X5.

To bring this work together the water quality work group has published a summary report. This document summarizes the background reports, analyzes their main findings and presents final recommendations. Some of the recommendations from the background reports may be omitted or modified in the summary report, due to the effect of integrating conclusions on related topics. Copies of the summary report have been placed in public libraries, and extra copies are available to interested parties from the Ministry of Environment in Victoria.

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1. INTRODUCTION

Fecal coliform levels were measured intensively at three sites in the lower Fraser River, for three days in the summer and three days in the fall of 1978. The study was carried out to fill certain data gaps and to help design future monitoring programs. The data were discussed briefly in the background report on Microbial Water Quality[1].

Our report presents a general discussion of the data, and uses statistical methods to indicate how the coliform results were affected by various sampling factors.

2. METHODS

The sampling program was run at two sites on the Main Arm and one site on the North Arm, as shown in Figure 1. The Main Arm sites were off Purfleet Point on the south end of Annacis Island, and off the north end of Steveston Island. The North Arm site was at the Oak Street Bridge. Data on the sampling sites are summarized in Table 1. A cross-section of the river at each site was sampled for three consecutive days (Sunday, Monday, Tuesday) in August and in November (or December). On each day, and at each site, duplicate samples were collected at the surface, at three locations across the river. This procedure was repeated generally every two hours, six times a day. The tide heights at each site are shown by curves in Figures 2, 3 and 4. The sampling times, shown by points on the curves, were arranged to take place on either side of a tidal cycle.

Samples were collected in 100 mL bottles, stored at river temperature in coolers and transported to the Provincial Health Laboratory within 20 hours. Incubation of each sample was timed to begin 24 hours after collection. Fecal Coliform determinations were done according to Standard Methods[2], using a three-tube dilution technique with dilution factors of 1.0, 0.1 and 0.01. Total coliform determinations were not carried out.

The results were reported as the Most Probable Number (MPN) per 100 mL of sample. The MPN is an estimate based on certain probability formulas but it is not an actual enumeration of the coliform bacteria. It is derived from the number of tubes out of three giving a positive reaction at each dilution (a positive reaction is shown by the production of gas in the fermentation tube after suitable incubation). According to Standard Methods[2] the MPN index tends to give a higher value than the actual value, but the disparity decreases as the number of fermentation tubes used in the process increases. Work on coliform counts in samples from flowing water have showed that such data usually fit either the lognormal distribution or the negative binomial distribution, or both[3]. In these cases the MPN index, based on multiple-tube fermentations, could lead to an underestimation of mean coliform densities[3].

The measure of central tendency, or average, is usually expressed as a geometric mean or a median for coliform data. The geometric mean is a measure of central tendency for log normal distributions. The geometric mean minimizes the effects of individual extreme values but generally provides a lower estimate of coliform densities than the arithmetic mean[1].

3. RESULTS

3.1 PRESENTATION OF SAMPLING RESULTS

The coliform data, expressed as MPN/100 mL, are listed in Tables 2, 3 and 4 for each sampling site. The data, for each duplicate sample collected, are arranged according to date, hour of the day and sampling location in the river.

The data are summarized in Table 5, which shows geometric means, maximums and 90th percentiles for each set of samples.

3.2 PRESENTATION OF THE STATISTICAL ANALYSIS

A three-factor analysis of variance was carried out on the data to determine the effect of sampling variables such as day, time and distance from shore, on coliform levels at each site. The analysis was performed on the logarithms (to the base 10) of the MPN data, because it has been shown that the logarithms generally follow a normal distribution [3].

The three-factor analysis of variance, or 3-way ANOVA, enables us to assess the effect of three variables on coliform levels either singly (main effects), in pairs (two-way interactions) or all three together (three-way interaction). The results of the analysis, taken from computer printouts, are given in Tables 6, 7 and 8. Of main importance are calculated values of F and values of the significance of F, for each variable or combination of variables considered. The calculated F value is equivalent to a ratio of variances, and the value for significance of F is the probability that the evaluated F value is due to chance. If this probability is low, say below 5 percent (or 0.05), then we can assume that the F value is not due to chance This means that there is a strong probability that coliform levels are dependent on the variable, or combination of variables considered.

4. DISCUSSION

4.1 COLIFORM LEVELS

The summary of data in Table 5 shows that coliform levels were about four to eight times higher in the fall (November, December) than in the summer (August). The highest average value in the fall was at Steveston Island in November, with a geometric mean of 2 924 MPN/100 mL. In August the highest value was at Oak Street Bridge in the North Arm, with a geometric mean of 492 MPN/100 mL. The higher fall values reflect the fact that chlorination of municipal sewage is discontinued after September, at the main sewage treatment plants discharging to the river (Annacis and Lulu).

Annacis Island had the lowest average coliform levels, in both summer and fall. This may have been due to its position upstream from the other sites. Discharges of storm water and of domestic sewage from some industries could account for increases downstream from the Annacis site.

4.2 EFFECT OF SAMPLING VARIABLE

The 3-way analysis of variance was carried out on data from each site to assess the influence of sampling variables. These were sampling day, distance from shore and sampling time, referred to as day, shore and hour in Tables 6, 7 and 8. They were assumed to be significant and to affect coliform levels when the significance of F was 5 percent or less. Their significance in the six cases studied, namely summer and fall at each of the three sampling sites, is presented here.

Among the main effects, the most important was hour, which was significant in four cases out of six. It was followed by shore (three out of six) and day (two out of six). The importance of hour, or time of sampling, may be explained by the fact that samples were taken at all phases of the tidal cycle (Figures 2 to 4). Rough measurement of surface current velocity showed large variations, with some negative values indicating changes in current direction (Tables 2 to 4). Such conditions would be likely to affect sampling results, and this was demonstrated by the dependence of coliform levels on sampling time. The effect of sampling location, as measured by distance from the shore, was also fairly significant. This effect may have been due to incomplete mixing of effluent streams, containing high coliform levels, with river water. Even the day of sampling affected the results to some extent. This suggests there may have been other factors affecting results that were unaccounted for and that varied from day to day.

The joint effect of two variables is shown by the 2-way interactions. The most important of these was the shore-hour effect, which was significant in three cases out of six. This meant that in 50 percent of the cases the time of sampling, in conjunction with distance from shore, had an influence on the coliform levels measured. The joint effects of day-hour (significant in two out of six cases), and day-shore (significant in one out of six cases) were somewhat less important.

The joint effect of all three variables was shown by the 3-way interaction to be important in three out of six cases. Thus the time of sampling, in conjunction with the day of sampling and the distance from shore had an effect on the resulting coliform levels.

This analysis demonstrates that the variability in coliform levels, which could seem at first glance to have been due to chance, can be attributed to various factors. However, the most important of these were time of sampling and distance from shore. Also, particular combinations of time and distance and of time, day and distance from shore can be expected to influence the coliform results.

In order to allow for the influence of all the variables, and to obtain results with a high degree of confidence, one can expect that a large number of coliform measurements would be required. Since this is usually not practical, the best that can be recommended is that sampling be replicated to allow for variables such as time, location and day of sampling. In most situations, where these variables are not taken into account, actual values will need to be treated with a fair degree of uncertainty. In a regular monitoring program the effect of time could probably be minimized by always taking samples at the same stage and height of a tidal cycle.

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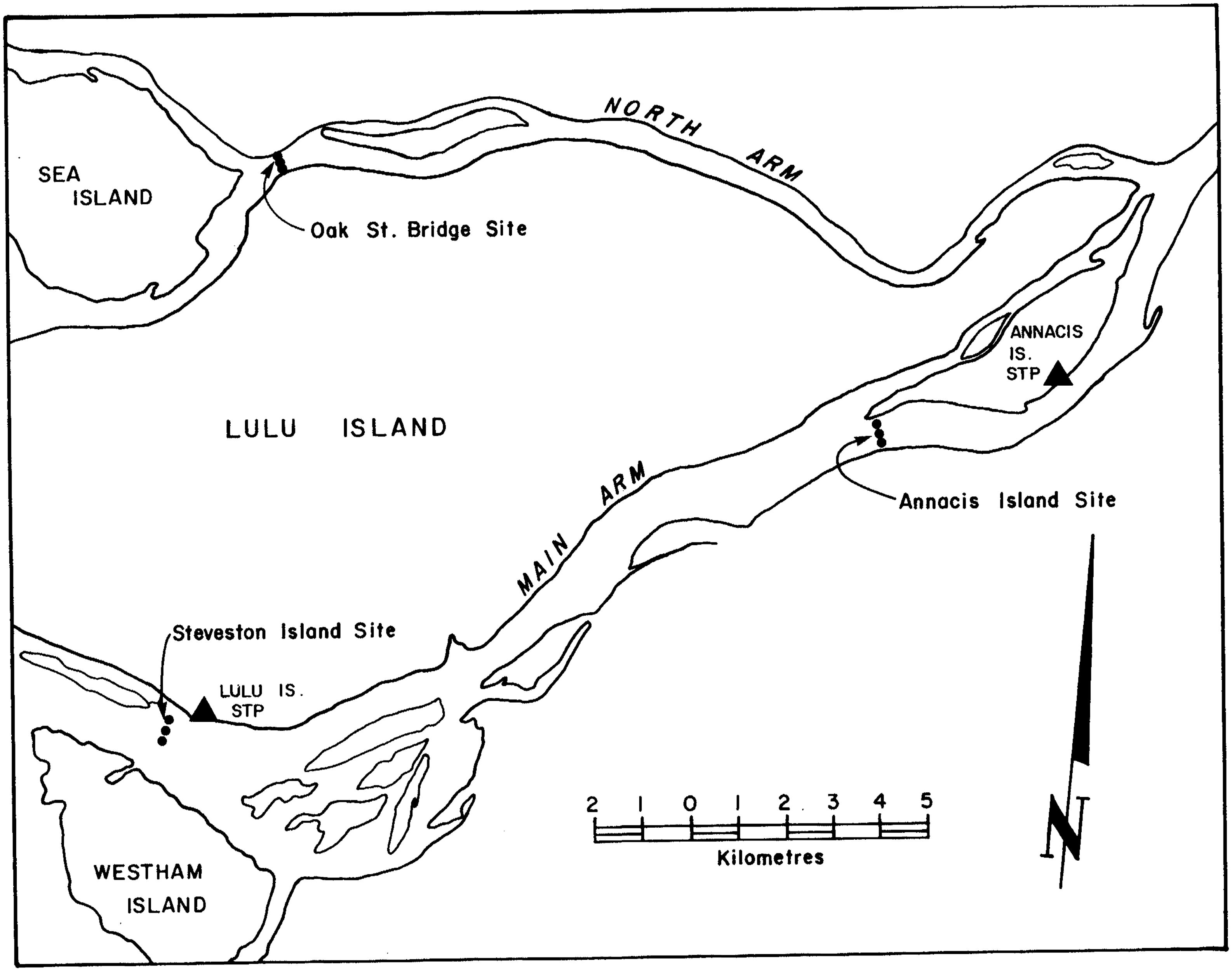

FIGURE 1. LOCATION OF SAMPLING SITES FOR COLIFORM SAMPLING, 1978

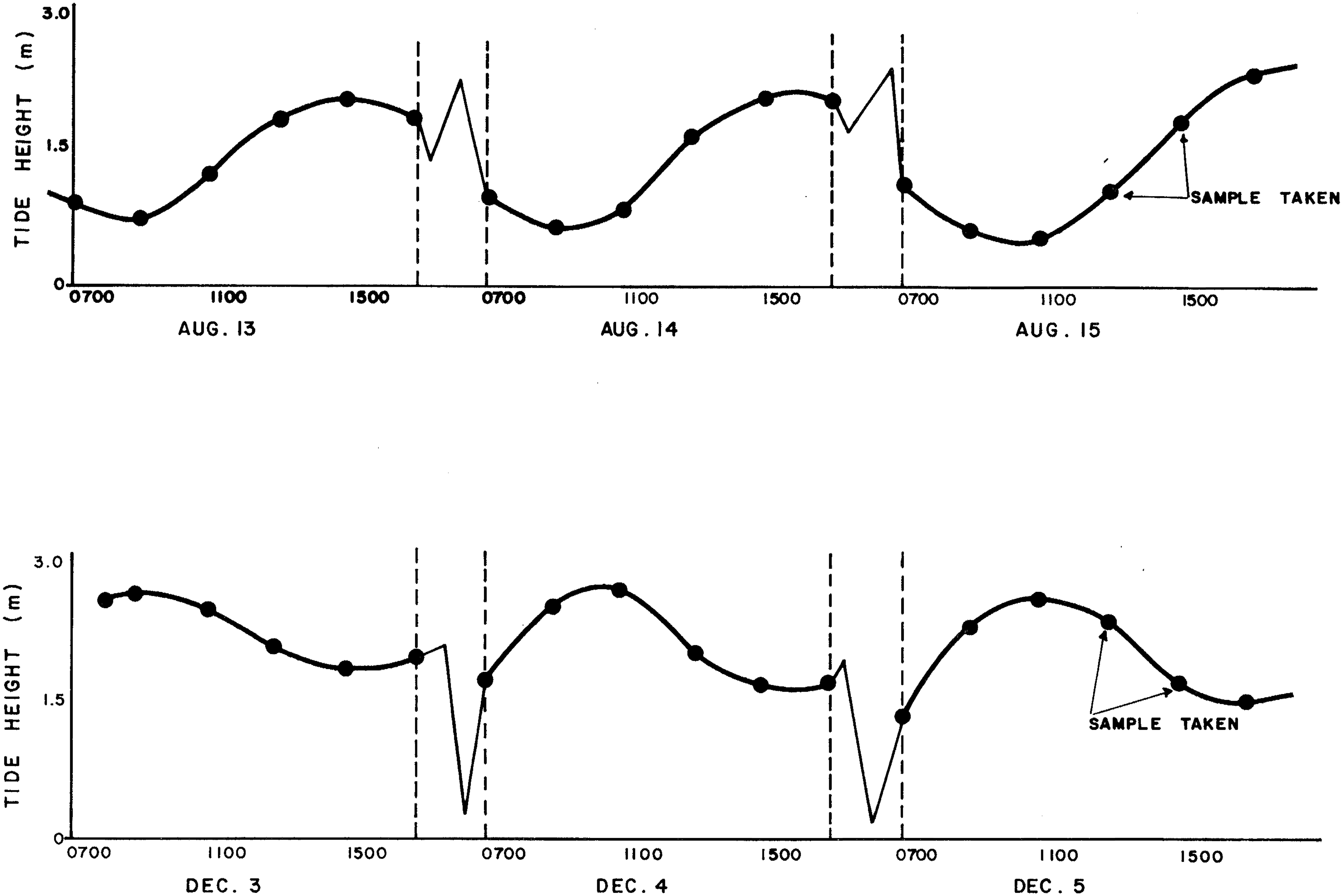

FIGURE 2 .TIDE HEIGHTS AT ANNACIS ISLAND DURING COLIFORM SAMPLING, 1978.

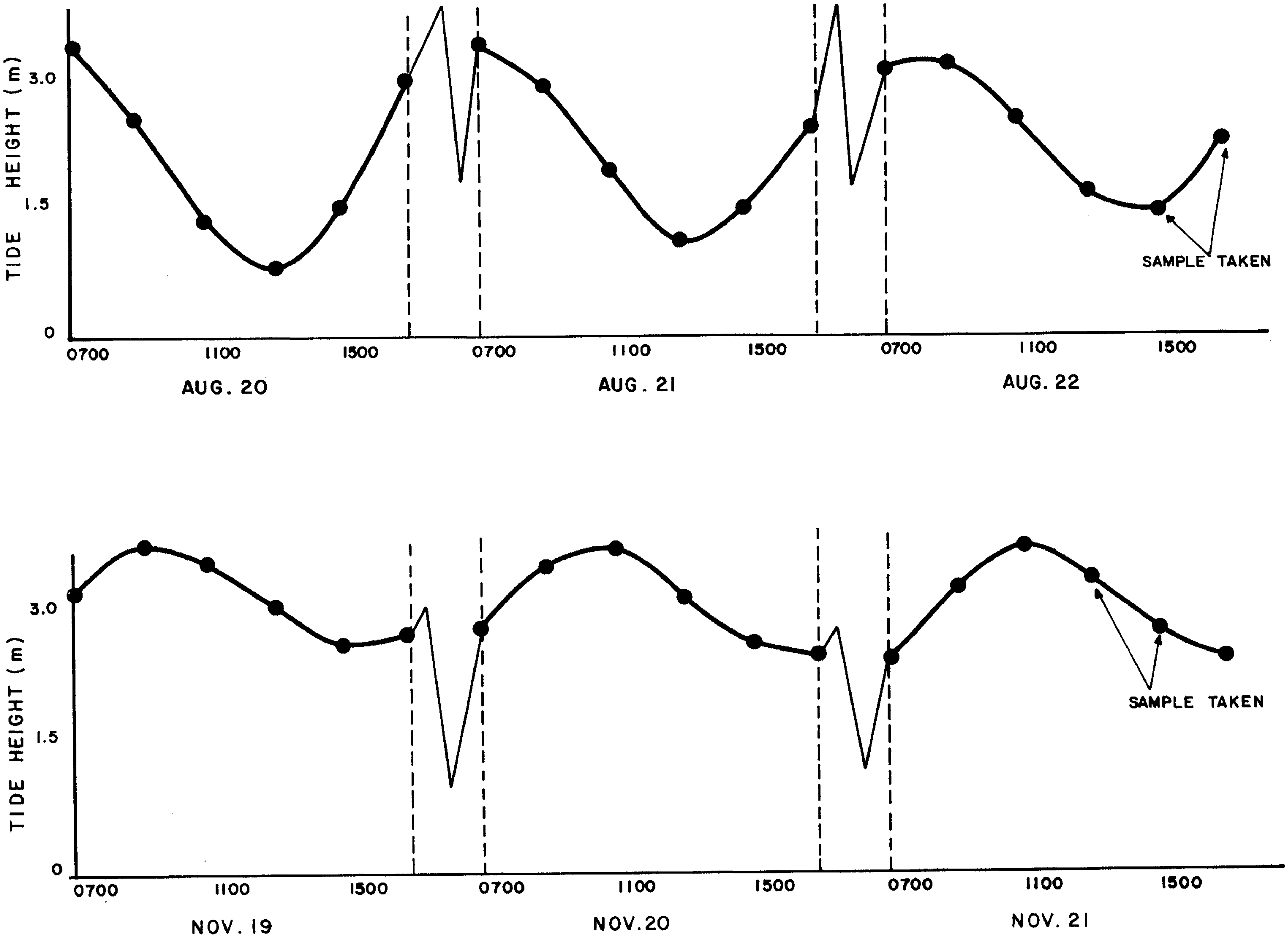

FIGURE 3 . TIDE HEIGHTS AT STEVESTON ISLAND DURING COLIFORM SAMPLING, 1978.

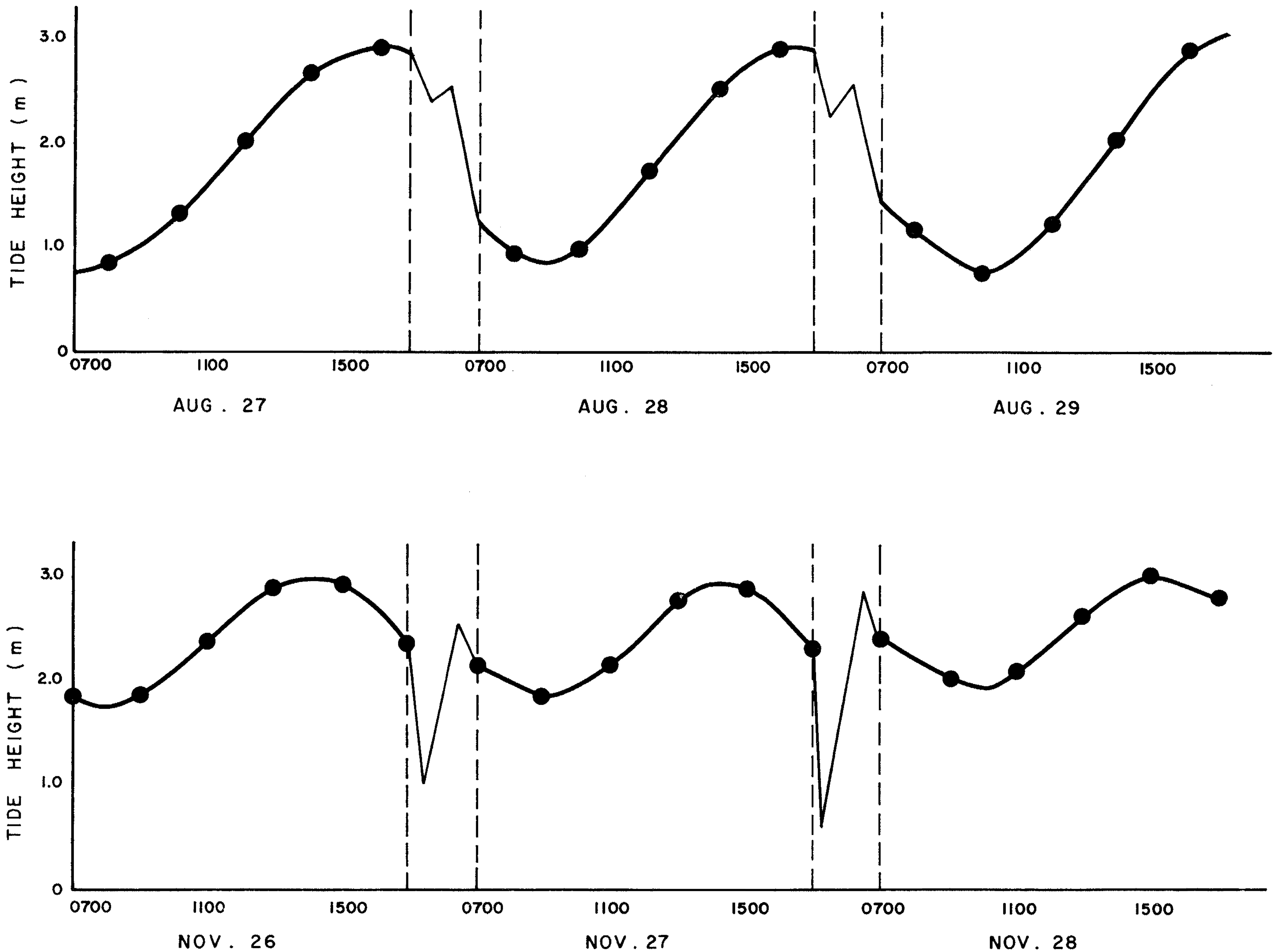

FIGURE 4 . TIDE HEIGHTS AT OAK STREET BRIDGE DURING COLIFORM SAMPLING , 1978

TABLE 1: DATA ON SAMPLING SITES

Site Name	Dates Sampled	EQUIS Site No.
Annacis Island South End	13-15 August, 1978 3-5 December, 1978	North Shore 0920236 Mid River 0920003 South Shore 0920245
Steveston Island North End	22-29 August, 1978 19-21 November, 1978	North Shore 0920630 Mid River 0920631 South Shore 0920632
Oak Street Bridge	27-29 August, 1978 26-28 November, 1978	North Shore 0030118 Mid River 0300002 South Shore 0300119

TABLE 2: FECAL COLIFORM DATA FROM THE ANNACIS ISLAND SAMPLING SITE

Date	Hour	Current Velocity (m/s)	MPN/100 mL South Shore	MPN/100 mL Mid River	MPN/100 mL North Shore
Aug.13	0800	1.1	210	50	80
			80	310	170
	1000	0.8	170	210	110
			50	170	130
	1200	0.3	170	220	220
			230	80	330
	1400	0.0	80	170	130
			330	130	220
Aug.14	1030	0.9	130	170	330
			110	220	130
	1200	0.5	60	70	220
			80	130	230
	1400	-0.0	230	80	80
			80	330	230
	1630	-0.05	90	270	170
			<20	70	80
	1800	0.3	70	50	170
			70	110	80
Aug.15	0900	1.2	50	110	330
			230	50	80
	1000	1.2	130	170	330
			130	330	220
	1200	0.8	220	490	1300
			80	130	130
	1400	0.1	330	330	790
			330	80	490
	1600	-0.3	50	110	110
			130	230	490
	1800	0.0	40	330	310
			80	110	210
Dec.3	0800	-0.7	230	490	5 400
			490	130	2 200
	0900	-0.7	230	790	790
			330	1 300	490
	1100	-0.3	790	1 700	1 800
			1 300	2 400	5 400
	1300	0.5	2 400	1 300	3 500
			1 800	790	2 400
	1500	0.6	790	2 400	3 500
			1 700	790	5 400
	1700	0.4	490	3 500	9 200
			1 700	1 700	5 400
Dec.4	0700	-0.4	230	460	310
			700	490	330
	0900	-0.8	330	1 100	1 700
			170	170	2 200
	1100	-0.5	940	790	1 300
			2 400	2 400	2 400
	1300	0.2	1 100	1 300	2 400
			1 400	2 400	1 700
	1500	0.7	1 300	3 500	5 400
			2 400	3 500	16 000
	1700	0.6	330	2 400	1 500
			1 700	1 300	2 400
Dec.5	0700	-0.1	130	330	460
			130	330	490
	0900	-0.7	260	220	1 300
			220	230	490
	1100	-0.7	790	490	9 200
			130	1 300	1 700
	1300	-0.1	170	790	1 400
			790	1 700	2 400
	1500	0.6	330	1 300	2 400
			700	1 700	2 200
	1700	0.8	700	1 300	3 500
			940	790	2 400

TABLE 3: FECAL COLIFORM DATA FROM THE STEVESTON ISLAND SAMPLING SITE

Date	Hour	Current Velocity (m/s)	MPN/100 mL South Shore	MPN/100 mL Mid River	MPN/100 mL North Shore	Date	Hour	Current Velocity (m/s)	MPN/100 mL South Shore	MPN/100 mL Mid River	MPN/100 mL North Shore
Aug.20	0800	0.5	70	130	50	Nov.19	0700	-0.6	1 100	790	5 400
			230	110	130				2 200	3 500	5 400
	1000	1.0	130	170	130		0900	-0.7	1 300	2 400	3 500
			230	80	130				1 100	940	3 500
	1200	1.3	50	170	230		1100	-0.4	490	9 200	5 400
			110	130	130				5 400	3 500	2 400
	1400	1.0	1300	170	1700		1300	0.0	5 400	9 200	9 200
			16000	330	330				9 200	3 500	3 500
	1600	0.2	130	80	50		1500	0.4	2 200	1 700	2 400
			170	50	170				5 400	2 400	1 300
	1800	-0.3	110	170	700		1700	0.3	2 400	2 400	3 500
			20	170	330				2 400		9 200
Aug.21	0800	0.3	90	50	50	Nov.20	0700	-0.5	9 200	1 700	9 200
			50	40	50				3 500	2 800	1 100
	1000	0.7	90	170	170		0900	-0.8	2 400	9 200	5 400
			110	50	170				2 400	1 700	2 400
	1200	1.1	70	20	170		1100	-0.6	1 100	2 400	3 500
			110	110	130				1 700	2 400	5 400
	1400	1.0	80	60	5400		1300	-0.2	2 200	3 500	3 500
			80	<20	9200				1 300	1 700	5 400
	1600	0.4	2400	1700	170		1500	-0.3	5 400	1 700	1 700
			1400	2200	490				1 700	5 400	3 500
	1800	-0.2	330	210	330		1700	0.4	1 700	2 400	700
			110	260	490				5 400	2 400	3 500
Aug.22	0830	0.2	170	60	790	Nov.21	0700	-0.3	3 500	5 400	9 200
			40	230	790				5 400	5 400	3 500
	1000	0.5	110	170	130		0900	-0.7	1 700	16 000	3 500
			70	70	80				3 500	3 500	2 400
	1200	0.8	50	110	80		1100	-0.7	2 800	1 300	1 300
			490	170	170				2 400	5 400	1 700
	1400	1.0	50	110	460		1300	-0.3	1 300	2 400	3 500
			70	90	330				1 300	1 700	2 400
	1600	0.6	330	170	490		1500	0.2	3 500	5 400	2 800
			130	80	80				2 400	3 500	2 400
	1800	0.0	40	490	>24000		1700	0.5	790	1 700	5 400
			170	330	>24000				5 400	9 200	1 700

TABLE 4: FECAL COLIFORM DATA FROM THE OAK STREET BRIDGE SAMPLING SITE

Date	Hour	Current Velocity (m/s)	MPN/100 mL			Date	Hour	Current Velocity (m/s)	MPN/100 mL		
			South Shore	Mid River	North Shore				South Shore	Mid River	North Shore
Aug.27	0800	0.9	220	230	490	Nov.26	0700	0.6	790	2 200	3 500
			460	330	490				3 500	1 300	1 300
	1000	0.9	490	130	310		0900	0.5	1 300	2 400	5 400
			490	330	330				2 400	5 400	5 400
	1200	0.8	490	2400	330		1100	0.0	3 500	1 300	940
			790	490	230				3 500	1 300	1 100
	1400	0.7	490	1300	1100		1300	-0.2	2 400	1 300	790
			790	790	1700				790	790	490
	1600	0.7	220	490	790		1500	0.1	2 400	2 400	1 300
			460	490	1700				5 400	790	790
	1800	0.8	700	700	790		1700	0.6	790	1 700	1 100
			790	790	1700				460	1 300	1 300
Aug.28	0800	0.9	330	940	270	Nov.27	0700	0.5	1 700	2 400	3 500
			210	700	1700				1 700	490	1 300
	1000	0.9	330	110	2400		0900	0.5	1 700	3 500	1 700
			330	230	700				1 700	1 700	1 300
	1200	0.9	130	170	330		1100	0.2	1 700	1 100	1 400
			130	170	90				5 400	2 400	790
	1400	0.7	790	790	260		1300	-0.1	460	790	3 500
			330	1100	170				1 400	1 700	3 500
	1600	0.7	330	1700	490		1500	-0.1	2 400	330	1 300
			220	330	490				1 700	1 100	790
	1800	0.8	260	330	790		1700	0.5	1 300	1 300	1 100
			790	330	1100				790	1 700	5 400
Aug.29	0800	0.9	490	1400	490	Nov.28	0700	0.4	790	1 700	3 500
			70	1100	1300				490	790	940
	1000	0.9	80	230	330		0900	0.6	2 400	1 700	2 400
			130	230	330				1 300	5 400	2 400
	1200	0.9	330	210	170		1100	0.4	1 300	1 300	1 100
			230	110	940				5 400	1 700	1 100
	1400	0.8	2200	1300	1700		1300	-0.0	1 300	1 700	3 500
			790	9200	700				1 300	1 100	790
	1600	0.6	330	230	790		1500	-0.1	1 100	3 500	2 400
			790	220	1100				790	490	1 400
	1800	0.7	490	700	2200		1700	0.4	790	1 300	1 100
			1300	1300	1400				1 100	1 700	460

TABLE 5: SUMMARY OF FECAL COLIFORM DATA FOR ALL SITES

Site, Date & Location	No. of Samples	Fecal Coliforms, NPN/100 mL		
		Maximum	Geometric Mean	90th percentile
Annacis Is./August				
North Shore	30	1 300	201.3	490
Mid River	30	490	152.3	330
South Shore	30	330	112.8	330
Overall	90	1 300	147.6	330
Annacis Is./December				
North Shore	36	16 000	2 025.8	5 780
Mid River	36	3 500	931.5	2 730
South Shore	36	2 400	113.1	3 280
Overall	108	16 000	1 056.8	3 280
Steveston Is./August				
North Shore	36	>24 000	310.0	6 160
Mid River	36	2 200	131.0	378
South Shore	36	16 000	146.5	1 330
Overall	108	>24 000	182.8	1 310
Steveston Is./November				
North Shore	36	9 200	3 309.9	9 200
Mid River	35	16 000	2 988.0	9 200
South Shore	36	9 200	2 513.2	5 400
Overall	107	16 000	2 924.2	6 200
Oak St. Bridge/August				
North Shore	36	2 400	625.7	1 700
Mid River	36	9 200	499.2	1 490
South Shore	36	2 200	380.6	790
Overall	108	9 200	492.0	1 460
Oak St. Bridge/November				
North Shore	36	5 400	1 567.7	2 800
Mid River	36	5 400	1 469.2	3 500
South Shore	36	5 400	1 498.6	4 070
Overall	108	5 400	1 506.6	3 310
ALL	629	>24 000	655.9	3 320

TABLE 6: RESULTS OF 3-WAY ANALYSIS OF VARIANCE ON DATA FROM ANNACIS ISLAND

Variable	Sums of Squares	Degrees of Freedom	Mean Squares	F	Significance of F
August, 1978*					
Main Effects:					
Day	0.360	2	0.180	2.099	0.139
Shore	0.558	2	0.279	3.250	0.051
Hour	0.230	2	0.115	1.340	0.276
2-Way Interactions:					
Day-Shore	0.194	4	0.049	0.566	0.689
Day-Hour	0.444	4	0.111	1.293	0.293
Shore-Hour	0.253	4	0.063	0.738	0.573
3-Way Interactions:					
Day-Shore-Hour	0.305	8	0.038	0.445	0.885
Error	2.833	33	0.086		
December, 1978					
Main Effects:					
Day	1.559	2	0.780	12.788	<0.001
Shore	5.507	2	2.753	45.161	<0.001
Hour	7.842	5	1.568	25.726	<0.001
2-Way Interactions:					
Day-Shore	0.403	4	0.101	1.653	0.174
Day-Hour	0.748	10	0.075	1.227	0.296
Shore-Hour	0.220	10	0.022	0.360	0.958
3-Way Interactions:					
Day-Shore-Hour	2.487	20	0.124	2.039	0.020
Error	3.292	54			

* Data lacking for certain hours of each day.

TABLE 7: RESULTS OF 3-WAY ANALYSIS OF VARIANCE
ON DATA FROM STEVESTON ISLAND

Variable	Sums of Squares	Degrees of Freedom	Mean Squares	F	Significance of F
August, 1978					
Main Effects:					
Day	6.055	2	0.028	0.337	0.715
Shore	3.155	2	1.577	19.311	<0.001
Hour	5.261	5	1.052	12.882	<0.001
2-Way Interactions:					
Day-Shore	1.466	4	0.367	4.488	0.003
Day-Hour	8.658	10	0.866	10.599	<0.001
Shore-Hour	6.382	10	0.638	7.813	<0.001
3-Way Interactions:					
Day-Shore-Hour	7.995	20	0.400	4.893	<0.001
Error	4.411	54	0.082		
November, 1978					
Main Effects:					
Day	0.042	2	0.021	0.262	0.771
Shore	0.313	2	0.157	1.944	0.153
Hour	0.175	5	0.035	0.433	0.823
2-Way Interactions:					
Day-Shore	0.396	4	0.099	1.229	0.309
Day-Hour	1.573	10	0.157	1.952	0.058
Shore-Hour	0.671	10	0.067	0.833	0.599
3-Way Interactions:					
Day-Shore-Hour	1.296	20	0.065	0.804	0.698
Error	4.352	54	0.081		

TABLE 8: RESULTS OF 3-WAY ANALYSIS OF VARIANCE
ON DATA FROM OAK STREET BRIDGE

Variable	Sums of Squares	Degrees of Freedom	Mean Squares	F	Significance of F
August, 1978					
Main Effects:					
Day	0.505	2	0.253	4.007	0.024
Shore	0.841	2	0.421	6.673	0.003
Hour	3.968	5	0.794	12.585	<0.001
2-Way Interactions:					
Day-Shore	0.115	4	0.029	0.458	0.766
Day-Hour	2.246	10	0.225	3.562	0.001
Shore-Hour	1.594	10	0.159	2.528	0.014
3-Way Interactions:					
Day-Shore-Hour	2.499	20	0.125	1.982	0.024
Error	3.405	54	0.063		
November, 1978					
Main Effects:					
Day	0.053	2	0.027	0.429	0.653
Shore	0.010	2	0.005	0.078	0.925
Hour	1.165	5	0.233	3.747	0.006
2-Way Interactions:					
Day-Shore	0.224	4	0.056	0.901	0.470
Day-Hour	0.689	10	0.069	1.108	0.373
Shore-Hour	1.509	10	0.151	2.427	0.018
3-Way Interactions:					
Day-Shore-Hour	1.301	20	0.065	1.046	0.429
Error	3.358	54	0.062		