Fraser River Estuary Study
Water Quality

Microbial Water Quality, 1970 - 1977

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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.

Since the water quality report was preliminary, a more detailed analysis of the information was undertaken by members of the water quality work group. As a result, eleven background technical reports, of which this report is one, are being 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 will be available at all main branches of the public libraries in the lower mainland.

Five auxiliary reports 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 Ministry of Environment, Parliament Buildings, Victoria, British Columbia.

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 are in public libraries, and extra copies will be available to interested parties from the Ministry of Environment in Victoria.

ABSTRACT

Fecal coliform data collected by various government agencies and the university community between 1970 and 1977 were reviewed. In order to organize and compare data from different areas of the Fraser River estuary, over one hundred sampling sites were grouped into 22 river reaches. The data were generally presented as annual geometric mean values, 10th and 90th percentiles, and compared with the relevant use criteria for each reach. Certain special data collection programs were conducted to study specific problems associated with the design of a monitoring program. These included investigations of variability on cross sections of the river, through tidal cycles, and between days of the week.

The data indicated an obvious improvement in microbial water quality subsequent to the start-up of the Annacis Island sewage treatment plant in 1975. Chlorination of sewage treatment plant effluents during the summer reduced fecal coliform counts below winter levels and provided acceptable water for irrigation and swimming at Spanish Banks beaches, adjacent to the study area. It was concluded that because of the diversity of inputs, which include storm sewers and upstream sources, the elimination of bacteriological contamination of molluscan shellfish in the estuary was not presently feasible.

A rough comparison of coliform loadings from sewage treatment plant (STP) effluents, storm sewer effluents, and the Fraser River upstream of the study area indicated that STP effluents are the principal source of coliform bacteria during the non-chlorinating months. Further studies would be required to identify relative contributions from these three major sources during chlorinating months.

A summer monitoring program was designed to assess microbial water quality at bathing beaches, in storm sewers, in sewage treatment plant effluents, and in the Fraser River upstream of the study area. A winter monitoring program was designed to assess microbial water quality in effluents and receiving waters during the period when unchlorinated effluents are discharged into the estuary. The principal relevant use of the Fraser River Estuary during the winter is non-contact recreation. Although water quality criteria for this use cannot be justified on the basis of measurable health hazards, acceptable levels can be defined from an aesthetic viewpoint. Special studies were recommended on the influence of the Fraser River on shellfish in the Strait of Georgia, and on the possible concentration of pathogens in sediments.

Substantial information was obtained from this review despite the number of agencies involved and the diverse purpose of their individual data collection programs. However, it is recommended that in future one or at most two agencies be responsible for coliform sampling in the estuary, and that the data be reviewed annually by a committee with expertise in aquatic microbiology.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

1.1 General Introduction

The Lower Fraser River, defined by the Fraser River Estuary Study as extending from an eastern boundary at the confluence with Kanaka Creek to a western boundary at Sturgeon and Roberts Banks, receives diverse inputs which may contain harmful microorganisms. These inputs include: agricultural runoff which contains animal wastes, landfill leachates, sewage treatment plant effluents which contain domestic sewage and industrial wastewaters, and storm sewers which carry ground water and runoff from urban areas. During periods of heavy rainfall, combined storm and sanitary sewers may discharge material which has bypassed or been diverted upstream of sewage treatment plants. The receiving waters of the Lower Fraser River dilute and transport these discharges to the sea, where various factors including dilution by and bactericidal properties of seawater ultimately reduce numbers of bacterial indicators of fecal pollution (coliforms) to below detectable limits.

There are several activities which may conflict with the use of the Lower Fraser River for the assimilation of sewage wastes. The Recreation Report of the Fraser River Estuary Study (38) has identified various sites of present or potential recreational activities which could be affected by the presence of pathogenic microorganisms. These activities include bar fishing, hunting, boating, picnicking, beach activities, and swimming. Shellfish harvesting, a potential activity on the banks adjacent to the Fraser River mouth, requires a high standard of microbial water quality owing to the ability of these organisms to concentrate bacteria and viruses during filter feeding. Pathogenic organisms may be a potential risk to fishermen, who frequently contact Fraser River water in the course of setting and retrieving their nets.

Previous studies carried out by Hall _et al_ (44) and B.C. Research (14) have indicated that coliform levels in areas of the Lower Fraser exceed certain published criteria. In response to the concerns of various users and to the warnings of previous investigators, the Water Quality Group of the Fraser River Estuary Study placed a major emphasis on the compilation and interpretation of unpublished coliform data from the Lower Fraser River.

For this report we have compiled coliform data collected by various agencies between 1970 and 1977 and entered it in EQUIS (Environmental Quality Indicator Systems), a B.C. provincial government computer based data storage and retrieval system. The data were grouped geographically into various river reaches, and mean values compared both between reaches and annually within each reach. Data from these reaches were compared with published use related criteria and standards. An attempt was then made to identify the major sources of fecal pollution, and to determine how past and future changes in effluent treatment have affected and would affect coliform levels. An attempt was made to determine whether implementation of various sewage treatment alternatives would affect coliform levels in areas where relevant criteria were exceeded. Finally, various approaches to a future monitoring program were discussed, including references to previous studies on other river systems.

1.2 Introduction to Coliforms as Indicators of Fecal Pollution

1.2.1 Disease-causing organisms in sewage Effluents

Raw sewage contains many disease-causing organisms which originate in the digestive tract; these organisms include representatives of bacteria, viruses, protozoa, and fungi. Pathogenic organisms which have been isolated from sewage include polio, hepatitis and *Herpes* viruses, bacteria which cause typhoid fever, shigellosis, and salmonellosis; and stages of parasitic life cycles such as *Entamoeba histolytica* cysts (amoebic dysentery) and beef tapeworm eggs. The *Salmonella* group of bacteria, which are by far the most common cause of infectious intestinal disease in temperate climates

(8), are consistently present in sewage treatment plant effluents. The numbers of these pathogenic organisms are considerably reduced by efficient sewage treatment processes and in particular, disinfection. Those pathogens which remain after treatment are eventually reduced below detection limits or eliminated in the receiving waters by one or more factors such as dilution, settling, low temperature, ultraviolet light, lack of nutrients, predators, and high salinities. Under certain circumstances, pathogens may accumulate and remain viable in estuarine sediments.

The detection of pathogenic organisms in receiving waters is technically feasible but impracticable and financially prohibitive (8, 49). Large volumes of water must usually be processed in order to detect a single organism and isolation methods frequently yield qualitative rather than quantitative results. Moreover, the absence of recoverable pathogens is no guarantee of safety due to the limitations of current sampling and analytical techniques. For these reasons public health microbiologists have sought an indicator organism which was present in sewage in high numbers and which, when isolated from the aquatic environment, would indicate the potential presence of pathogenic organisms.

1.2.2 Coliforms as Indicators of Fecal Pollution

The beginnings of sanitary water microbiology date back to the nineteenth century, when Von Fritch in 1880 described *Klebsiella pneumoniae* and *K. rhinoscleromatis* as organisms characteristic of human fecal contamination (82). Soon afterwards Escherich described *Bacillus coli* (later *Escherischia coli*) as a species which indicated the presence of fecal pollution. The present definition of "coliform" is based on morphological and biochemical criteria:

> ....the coliform group comprises all the aerobic and facultatively anaerobic, gram-negative, non spore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 h at 35 C. (5).

The definition includes representatives of the genera Escherischia, Klebsiella, and Enterobacter, which are present not only in the feces of man and animals, but also in soils and plant material. Since coliform bacteria (total coliforms) could originate from plant material, the "fecal coliform" test was devised. In this procedure coliforms of fecal origin (intestines of warm-blooded animals) are differentiated from total coliforms by growth and lactose fermentation at the elevated temperature of 44.5C. Currently, both total and fecal coliform tests are commonly used. However, the fecal coliform test is a more precise method for determining the presence of fecal contamination.

Recent reports (8, 79) have reevaluated the fecal coliform test and have voiced concern that it includes thermotolerant colonies of Klebsiella. As a result it has been suggested (8, 19) that, in future, the measurement of E. coli might replace total and fecal coliforms as an indicator of fecal pollution.

Members of the coliform group are not usually pathogenic (with the exception of Klebsiella pneumoniae and E. coli, in certain circumstances). The higher the number of coliform bacteria in a water sample, the greater the possibility of the coincident presence of pathogenic bacteria or viruses. However, it is recognized that there is no consistent pathogen: indicator ratio in sewage or in waters which receive sewage treatment plant effluents (49). The ratio changes according to the level of disease in the population served by the treatment plant, the type or degree of sewage treatment, the dilution rate or distance from the point source in the receiving waters, the die-off rates, and other factors (49).

Subject to the uncertainties noted above, the correlation between coliform numbers in receiving waters and risk of disease incidence in the population is clearly established with regard to waters used for drinking or for shellfish harvesting (82). However, no agreement exists on correlations between coliform numbers and diseases associated with swimming or other types of aquatic recreation. Studies in Britain have shown no causal relationship between incidence of polio and sea bathing; the only evidence found of health hazards was four cases of paratyphoid fever, all associated with beaches grossly polluted with fecal material (8). Swimmers have a higher incidence of ear, nose and throat diseases than non-swimmers (82), and Cabelli et al (18) have suggested that a causative agent of ear infections, Pseudomonas aeruginosa, be monitored in bathing areas. Fecal coliform counts have been correlated with the isolation of Salmonella (56, 59), and certain studies have demonstrated epidemiologically detectable health effects when coliform counts reach 2300-2400/100 ml (59). Cabelli et al (18) have demonstrated in an epidemiological study that measurable health effects are associated with swimming in sewage polluted waters. The best correlations between gastrointestinal disease symptoms and indicator densities were found using E. coli and fecal streptococci as indicators. It has also been suggested (76) that large numbers of pathogenic bacteria are required to produce disease symptoms, and that the minimal risk that exists for bathers comes from chance contact with fecal material from infected persons. An exception was the occurrence in the Mississippi River of Shigellosis, a disease which can be caused by the ingestion of only 10 to 100 organisms, in swimmers bathing in waters where the mean fecal coliform count was 17,500 organisms per 100 ml (65).

Despite the unclear relationship between coliform numbers and disease incidence, both total and fecal coliforms are commonly measured in waters used for swimming and recreation, as well as drinking and shellfish harvesting. So far, several alternative indicator species have been suggested but none, with the possible exception of E. coli, has been generally accepted for the measurement of fecal pollution in aquatic environments.

2. METHODS

2.1 MPN Technique

The most commonly used method for estimating numbers of total and fecal coliforms in estuaries is the "Most Probable Number" (MPN) technique. This technique involves the inoculation of various dilutions of a water sample into several (usually 3 or 5) test tubes containing a suitable nutrient broth and inverted fermentation tubes. After an incubation period at a selected temperature, the tubes are recorded as positive or negative for growth and gas production. The MPN calculation from these results is based on the proportion of positive and negative tubes at each dilution, and the accuracy of the MPN value depends on the number of tubes used. The MPN value, which is derived from certain probability formulae, is a high estimate of the actual coliform numbers and the disparity between the actual number and the estimate diminishes with increasing numbers of tubes in each dilution examined (5).

An abbreviated description follows of the MPN method for measuring total and fecal coliforms in waters of other than drinking water quality (5).

2.1.1 Total Coliforms

a) Presumptive Test

A series of lactose broth or lauryl tryptose broth tubes (a minimum of 3, preferably 5) are inoculated with quantities of water in a decimal dilution series, the selection of portion sizes to be dependent on the experience of the analyst with regard to the quality of the water. The tubes are incubated at 35C, and examined after 24 and 48 hours for growth and gas formation, indicating the fermentation of lactose. Presence or absence of growth with gas formation after 48 hours constitutes a positive or negative presumptive test, respectively.

b) Confirmed Test

All cultures showing a positive reaction to the presumptive test are transferred to confirmatory medium (brilliant green lactose bile broth in fermentation tubes or Endo or Eosin methylene blue on agar plates). A positive reaction for lactose formation on confirmatory medium after the appropriate incubation period indicates a positive confirmed test. Water samples from other than drinking water supplies, such as the Fraser River water samples, are usually taken through the presumptive and confirmed tests.

c) Completed Test

Two or more typical coliform colonies are transferred from Endo or EMB agar to lactose broth or lauryl tryptose broth, and to a nutrient agar slant. Gram stained preparations are obtained from those cultures which ferment lactose within 48 hours. The presence of gram-negative non sporeforming rod-shaped bacteria in these constitutes a positive completed test. The completed test is selectively employed and usually restricted to verification of counts in waters to be used as a drinking water source.

2.1.2 Fecal Coliforms

The fecal coliform test is used to differentiate between coliforms of fecal origin (intestines of warm-blooded animals) and coliforms from other sources. The presumptive test is carried out in the same way as for total coliforms. Transfers are then made from positive presumptive tubes to EC medium, and the tubes incubated for 24 hours at 44.5 C $\pm$ 0.2 C. Gas production within the 24-hour incubation period constitutes a positive fecal coliform confirmed test, and indicates the source of the coliform bacteria to be the intestines of man and other warm-blooded animals.

2.1.3 Statistics of the MPN Technique

For statistical presentation of coliform data, the geometric mean (recreational areas, swimming beaches) or median (shellfish harvesting areas) value is usually chosen to represent the central tendency of results from a number of samples. Pipes et al (62) have found that the negative binomial and lognormal distributions provide the best fit for coliform samples obtained periodically from flowing water. They observed that the negative binomial gave a better fit when there were a large number of zero counts and a few extremely high values. The lognormal gave a better fit when the counts were more tightly grouped about the mean. Use of the geometric rather than the arithmetic mean minimizes the effect of individual extreme values and generally provides a lower estimate of coliform densities.

It should be emphasized that MPN values are an approximation of the true coliform density, and have the inherent limitation of considerable variability and hence low precision (16). The accuracy of the MPN depends on the number of dilutions in the decimal series and on the number of tubes, usually 3 or 5, in each dilution. Theoretical confidence limits are available (5) for the MPN of each possible code, made up of the number of positive tubes in each dilution in the three and five tube tests. For example, the code 5, 2, 0 in the five tube test (i.e., five position reactions in the 10 ml dilution, two in the 1 ml dilution, 0 in the 0.1 ml dilution) has an MPN of 49/100 ml and 95% confidence limits of 17/100 ml and 130/100 ml. For the various possible MPN values obtainable by the 5 tube test, lower confidence limits vary between 8.3 and 40% of the MPN estimate and upper confidence limits vary between 227% and 362% of the MPN estimate. For the 3 tube test, lower and upper confidence limits vary from 2.8% to 25% and 224% to 555%, respectively.

MPN values are calculated on the assumption that coliform bacteria are randonly distributed in a water sample. Cochran (28) has shown that the logarithm of replicate MPN estimates are approximately normally distributed with a standard deviation of 1.77 (5 tube test) and a mean close to the logarithm of the bacterial density of the population. As the precision of the single MPN value is rather low, attempts have been made to determine the precision of replicate MPN values. Using the logarithmic distribution and Cochran's results McCarthy (55) has calculated the expected range of 10 replicate five tube MPN's. This expected range lies between 41% and 240% of the true coliform number, indicating that some replication does not necessarily produce higher precision in the MPN estimate.

2.2 Escherischia coli

The membrane filter procedure for thermotolerant E. coli (32) is not a "Standard Method" in the strict sense of the phrase, although the accuracy, precision, and selectivity have been evaluated and found satisfactory with various marine waters on the northeast coast of the United States.

Appropriate volumes of water sample are filtered through a sterile membrane, such that 20 to 80 colonies will result. The membranes are placed on the agar surface of mTEC Medium plates, and incubated at 35C for 2 hours (a resuscitation period for injured cells). MTEC Medium is composed of the following reagents: Proteose peptone, 5.0 g; Yeast extract, 3.0 g; Lactose, 10.0 g; NaCl, 7.5 g; K_2HPO_4, 3.3 g; KH_2PO_4, 1.0 g; Sodium lauryl sulfate, 0.2 g; Sodium desoxycholate, 0.1 g; Brom cresol purple, 0.08 g; Brom phenol red, 0.08 g; Agar, 15 g; Distilled water, to one liter. After the two hour resuscitation period, the filters are incubated in a 44 C waterbath for approximately 22 hours, and aseptically transferred from each plate to a filter pad saturated with urease reagent. After 15 to 30 minutes all yellow colonies are counted, indicating the number of thermotolerant E. coli in the sample volume tested. Yellow colonies may be confirmed as E. coli by transferring them to nutrient agar plates and incubating for 24 hours. A negative oxidase test on the nutrient agar cultures and no growth or colour change on Simmon's citrate agar is positive confirmation as E. coli.

2.3 Ratios of Microbial Indicators

Ratios of microbial indicators are, in some cases, used to obtain information on the sources of coliform bacteria in receiving waters. The higher the ratio of fecal coliforms to total coliforms, the more likely it is that the principal source of coliforms is fecal material.

It has been suggested (39) that human fecal material may be distinguished from fecal material of other warm blooded animals by the use of the fecal coliform: fecal streptococcus ratio. This premise is based on the observation that there are higher numbers of fecal coliforms than fecal streptococci (ratio > 4.0) in human feces. Conversely, there are lower numbers of fecal coliforms than fecal streptococci (ratio < 0.7) in the feces of other warm blooded animals. Results from the measurement of FC:FS ratios in receiving waters must be interpreted with care, due to the ubiquitous nature of some species of fecal streptococci and the differential die-off rates of the two groups of bacteria.

Fecal coliform: fecal streptococcus ratios and fecal coliform: total coliform ratios have been measured in the Lower Fraser River by Hall et al (44). Their findings will be discussed in the RESULTS Section of the report.

2.4 Methods of Collection and Analysis of Fraser River Coliform Samples

The Fraser River data which are analyzed in this report consist primarily of confirmed total and fecal coliform values measured by both the 3 tube and 5 tube MPN techniques. The majority of the samples were analyzed in the B.C. Public Health Laboratory, the B.C. Research Council laboratory and the Environmental Engineering Laboratory, Department of Civil Engineering, University of British Columbia. The data, which were compiled by staff from the B.C. Ministry of Environment (Water Investigations Branch) and the

Federal Inland Waters Directorate (Water Quality Branch), were collected from various sources including the Greater Vancouver Regional District, the Pollution Control Branch, the Water Investigations Branch, the Westwater Research Centre, the Richmond Health Unit and the Boundary Health Unit.

It was found that these coliform data had been collected at over one hundred sites in the Lower Fraser River area. For purposes of organization and comparison of data between geographical areas, these sites were grouped into 22 reaches which are illustrated in Fig. 1. The bathing beaches which were located adjacent to the study area and which were regularly sampled for coliforms are indicated in Figs. 2 and 3.

The form which the data take in the results section depends in part on the forms in which the data were submitted by the participating agencies, and on the statistical capabilities of the EQUIS computer programs. Every attempt has been made to present the data in terms of the relevant use criteria, which may be based on arithmetic means, geometric means, medians, and/or percentiles. Bathing beach data have been presented in terms of the arithmetic means, geometric means, and 90 percentiles; yearly reach summaries include geometric means, 10 and 90 percentiles. Monthly reach summaries contain single values or arithmetic means which are generally insufficient in numbers to permit valid seasonal comparisons. Monthly summaries are not discussed in detail and are located in Appendix B. Coliform values in effluents are presented as median values and ranges, as received from the GVRD offices. An attempt has been made to estimate the feasibility of analysis of variance and trend analysis using these data.

There are certain limitations to the interpretation of data which have been collected by various agencies and entered into a central computer bank. For example, conditions such as tide, rainfall, water temperature, or salinity may have been noted by the field investigator but are unobtainable or difficult to obtain

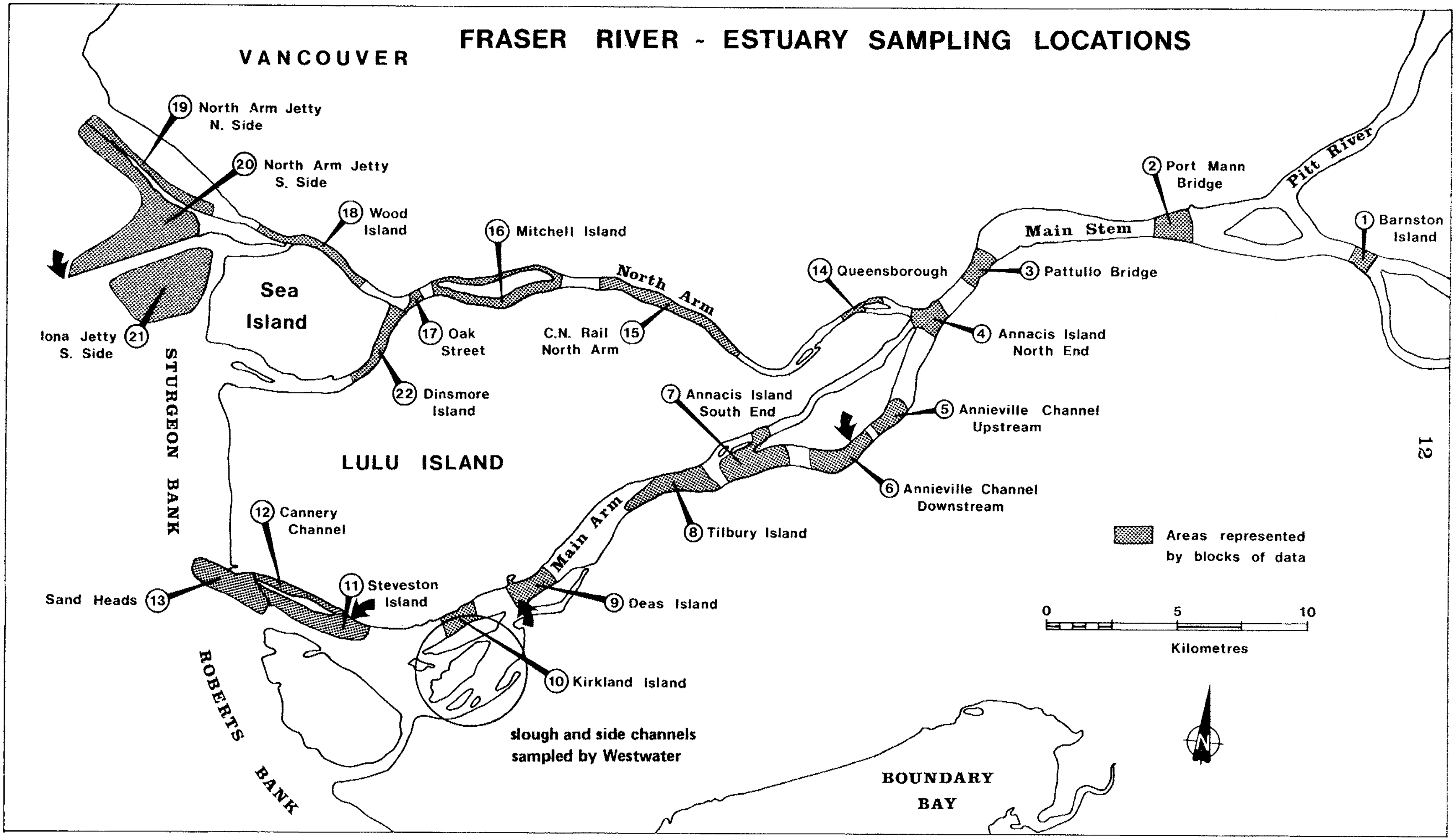


Figure 1. Location of 22 Lower Fraser River reaches. Arrows indicate location of major sewage treatment plant outfalls.

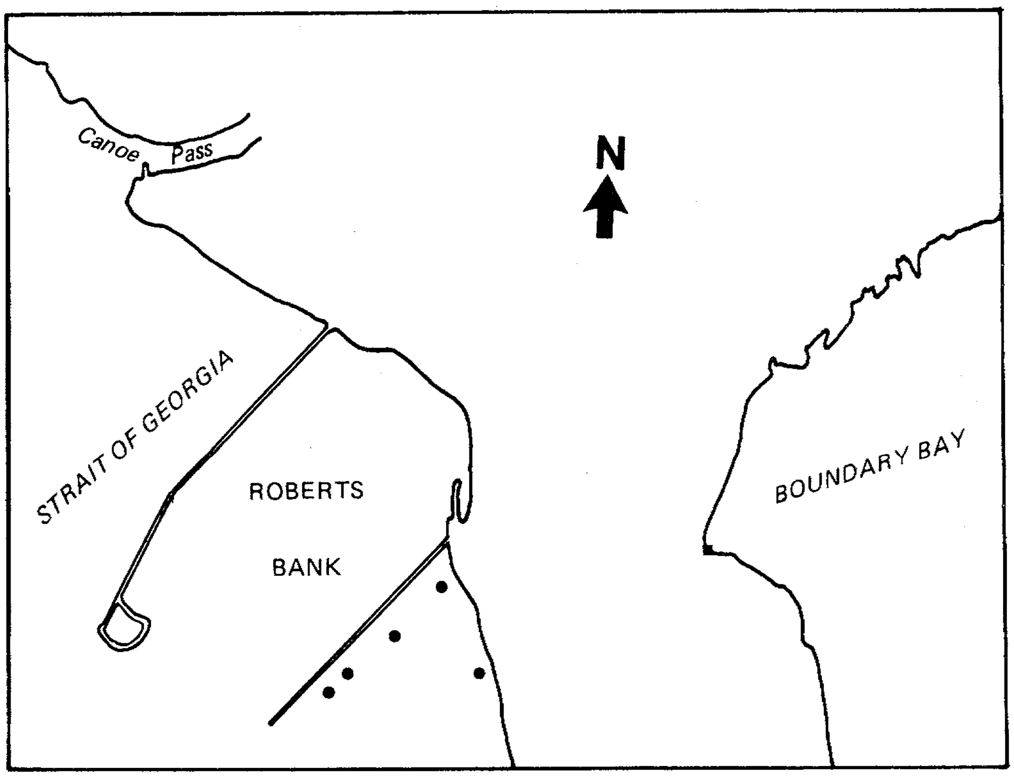


Figure . 2 Location of sampling stations at Tsawwassen Beach and Jetty.

Scale 1:100,000 0 1 2 3 4 5 kilometres

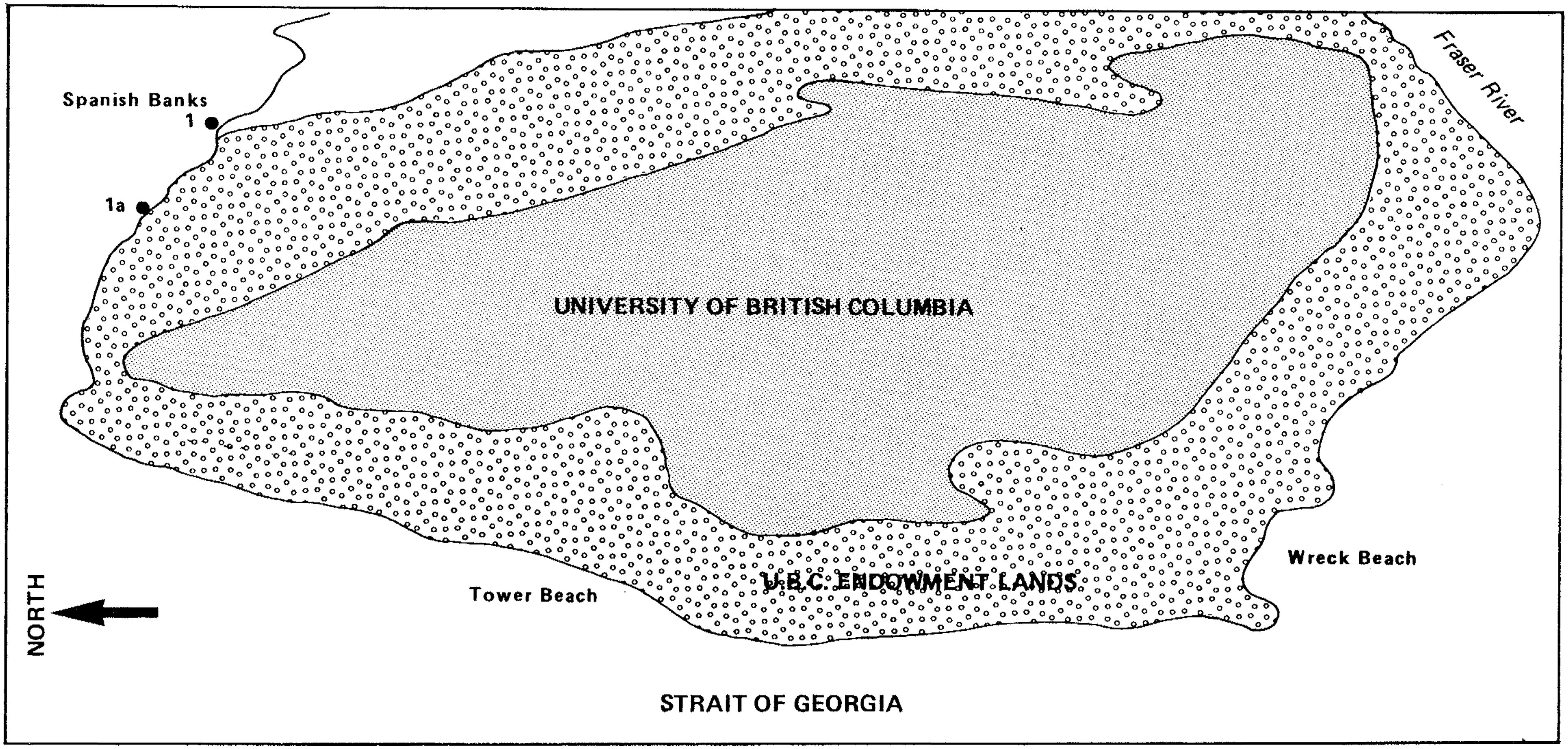


Figure 3 . Location of sampling stations at Spanish Banks, University of British Columbia Endowment Lands.

by the person who is interpreting the computer printout. Additionally, the field investigator may have had a problem-solving approach (i.e. investigation of cross-sectional variability or variability with depth) which is not apparent on the computer printout. Finally, samples collected and analysed by different agencies will have undergone different storage conditions, and, conceivably, different methods of analysis. The large number of results obtained will mitigate against errors in the assessment of average conditions. However, to relate bacteriological conditions to particular circumstances, such as slack tide and summer temperatures, would have entailed an accurate recording of the relevant physical and chemical parameters.

3. RESULTS

3.1 Sources of Indicator Bacteria

3.1.1 Upstream Levels

Little published or unpublished information exists on coliforms in the Fraser River upstream of the study area, above the influence of the major sewage treatment plant effluents discharged at Annacis Island, Lulu Island, and Iona Island. Reports by Rusch (66) and the B.C. Research Council (9, 11, 14) indicate that the maximum upstream penetration of Annacis Island effluent occurs at the Port Mann Bridge, on a winter high flood tide. Coliform bacteria upstream of this point originate primarily from STP effluents of communities such as Langley and Maple Ridge, and from agricultural runoff.

Two studies have indicated that coliform levels at Hope are relatively low and increase progressively with distance downstream. Hall et al (44) in their study conducted from February through May, 1973, found that arithmetic mean values of fecal coliforms in MPN/100 ml were 130 at the Hope Bridge, 775 at the Mission Bridge, and 2570 at the Pattullo Bridge. Clark (25) summarized coliform data entered in EQUIS between 1970 and 1975, and found that median fecal coliform levels were 80, 110, and 2,200 in reaches at Hope, Chilliwack, and Vancouver, respectively.

Figure 4 shows yearly summaries for fecal coliform data collected between Hope and Mission from 1970 to 1976. In this period geometric means for fecal coliforms ranged from 50 to 380/100 ml. Yearly summaries for Reach 1, Barnston Island (Fig. 5) show that, from 1971 to 1975, geometric means of fecal coliform values ranged between 150 and 400/100 ml.

It is impossible to calculate coliform loadings from the Fraser River upstream of the study area with any accuracy, due to the paucity of data. As an approximate estimate, assuming discharges of between 700 $m^3\ s^{-1}$ (25,000 cfs) and 5,700 $m^3\ s^{-1}$ (200,000 cfs), and geometric mean fecal coliform values of between 100 and 400/100 ml, potential loadings would range from 6×10^{13} fecal coliforms/day to 1.9×10^{15} fecal coliforms/day.

Coliform loading values may also be presented in terms of "population equivalents" (75), defined as the daily per capita contribution of coliform organisms in untreated waste. The total coliform contribution per capita per day has been determined as 1.6×10^{11} coliforms/person/day; 20% of this figure, 3.2×10^{10}, is generally considered to represent the fecal coliform contribution per person per day. Converted to population equivalents, fecal coliform loadings from upstream sources range from approximately 2000 to 60,000.

3.1.2 Sewage Treatment Plant Effluents

a) Background Information

The upstream levels discussed in the previous section are augmented from two major sources, sewage treatment plant effluents and storm sewers. Detailed information on these sources can be found in the Fraser River Estuary Study reports entitled Municipal Effluents (21) and Stormwater Discharges (37). In order to estimate the relative contributions to the

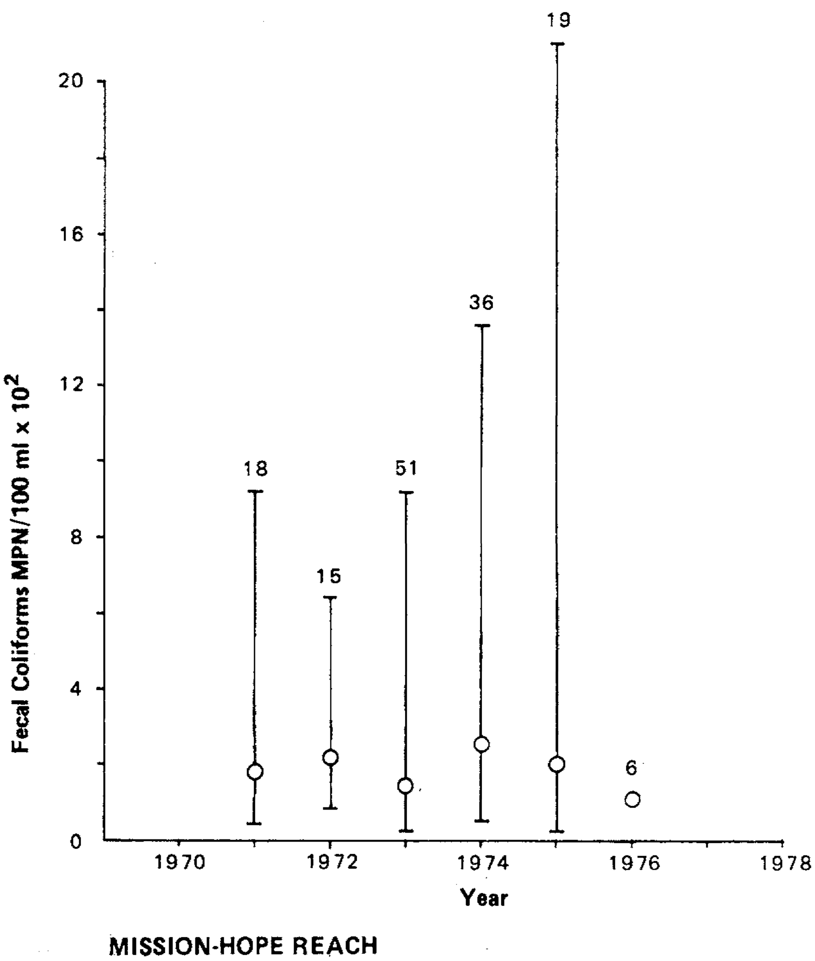


Figure 4 . Yearly summary of fecal coliforms at Mission-Hope Reach.
○- geometric mean. Vertical lines indicate the range between 10 and 90 percentiles.
Numbers above the vertical line indicate sample size.

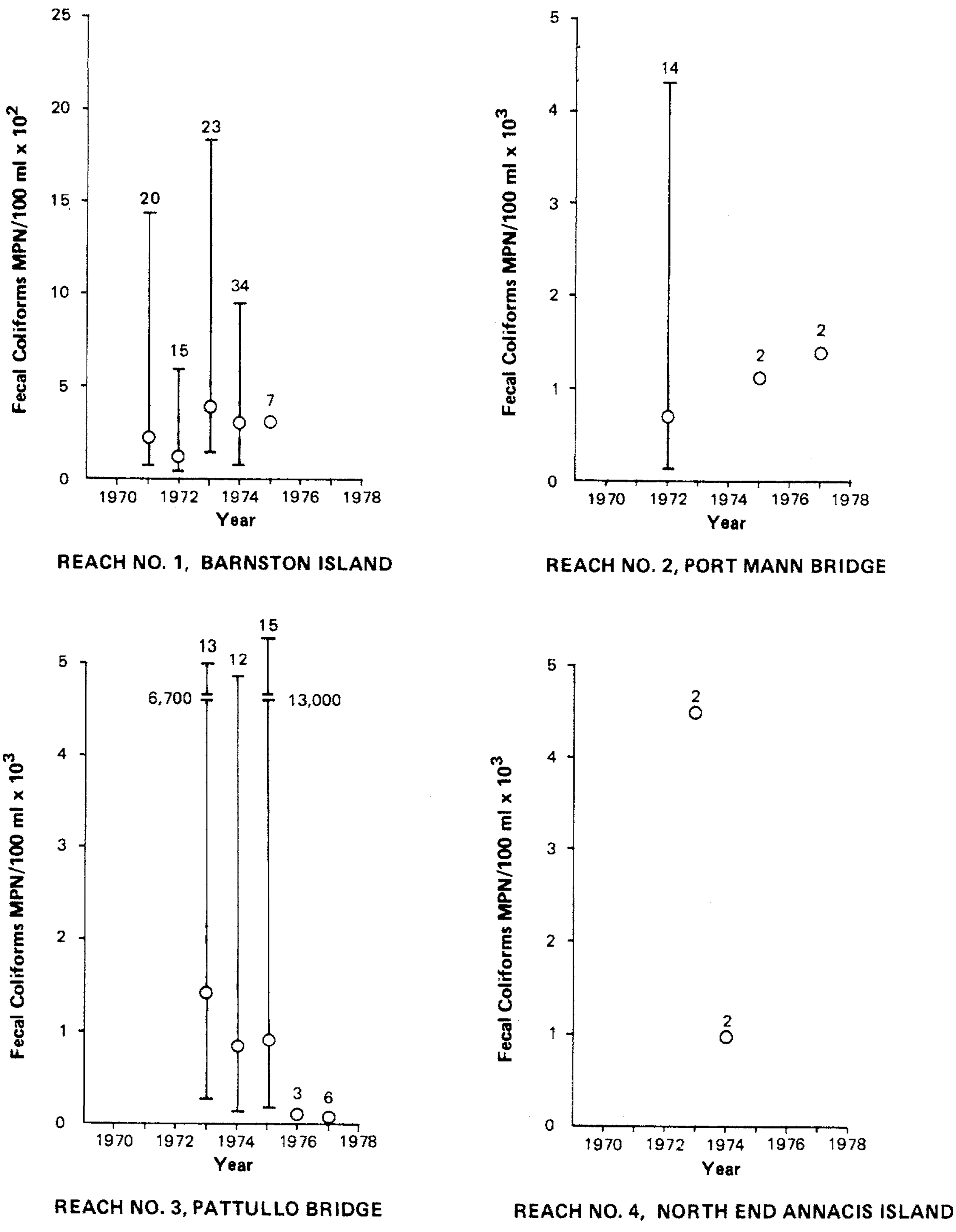


Figure 5 . Yearly summaries of fecal coliforms at Reach Nos. 1 to 4.
○ - geometric mean. Vertical lines indicate the range between 10 and 90 percentiles.
Numbers above the vertical line indicate sample size.

receiving waters from these sources, a brief description and summary of coliform data from effluents and storm sewers is included in this report.

Figure 6 shows the location of the sewage treatment plants in the study area and indicates the maximum discharge which is allowed under the Pollution Control permit. In practice, the volumes discharged from the sewage treatment plants are usually considerably less than those allowed by permit (21). Some general information on the three major sewage treatment plants at Annacis Island, Lulu Island, and Iona Island is found in Table I. Each STP presently has primary treatment, followed by chlorination from May to September, inclusive. Previously, Annacis Island effluent was chlorinated continuously from May, 1976 to September, 1977 and Lulu Island effluent was chlorinated continuously from January, 1974 to September, 1977. The present chlorination period was chosen in order to limit the discharge of pathogenic organisms during the season of maximum recreational use of the estuary and adjacent swimming beaches. The two major STP's on the Fraser River main arm also have dechlorination facilities to reduce the concentration of residual chlorine which is potentially toxic to migrating salmon.

The effectiveness of chlorine as a disinfecting agent is well known. The effect of chlorination on total coliform counts at the Annacis Island STP outfall is shown in Fig. 7. This figure shows monthly median, maximum, and minimum coliform

TABLE I General Information on Three Major Sewage Treatmement Plants Discharging into the Lower Fraser River

Sewage Treatment Plant	Area Served	Startup Time	Chlorination	Dechlorination
Annacis Island	Burnaby, Port Moody, Coquitlam, Port Coquitlam, New Westminster, Surrey, North Delta, Cloverdale, Langley, Whiterock. Small part of Vancouver.	August, 1975 - June, 1977	Continuous from May, 1976 - September, 1977. Chlorination in 1978 and future years from May - September, inclusive.	January - September, 1977; May - September in 1978 and future years.
Lulu Island	Richmond	1973	Continuous from January, 1974 - September, 1977. Chlorination in 1978 and future years from May - September, inclusive.	January, 1974 - September, 1977; May - September in 1978 and future years.
Iona Island	Greater Vancouver, Sea Island, University of B.C. University Endowment Lands. Small part of Burnaby.	1963 Expanded in 1972-1973.	Chlorination from May - September, inclusive from 1968 to present.	No

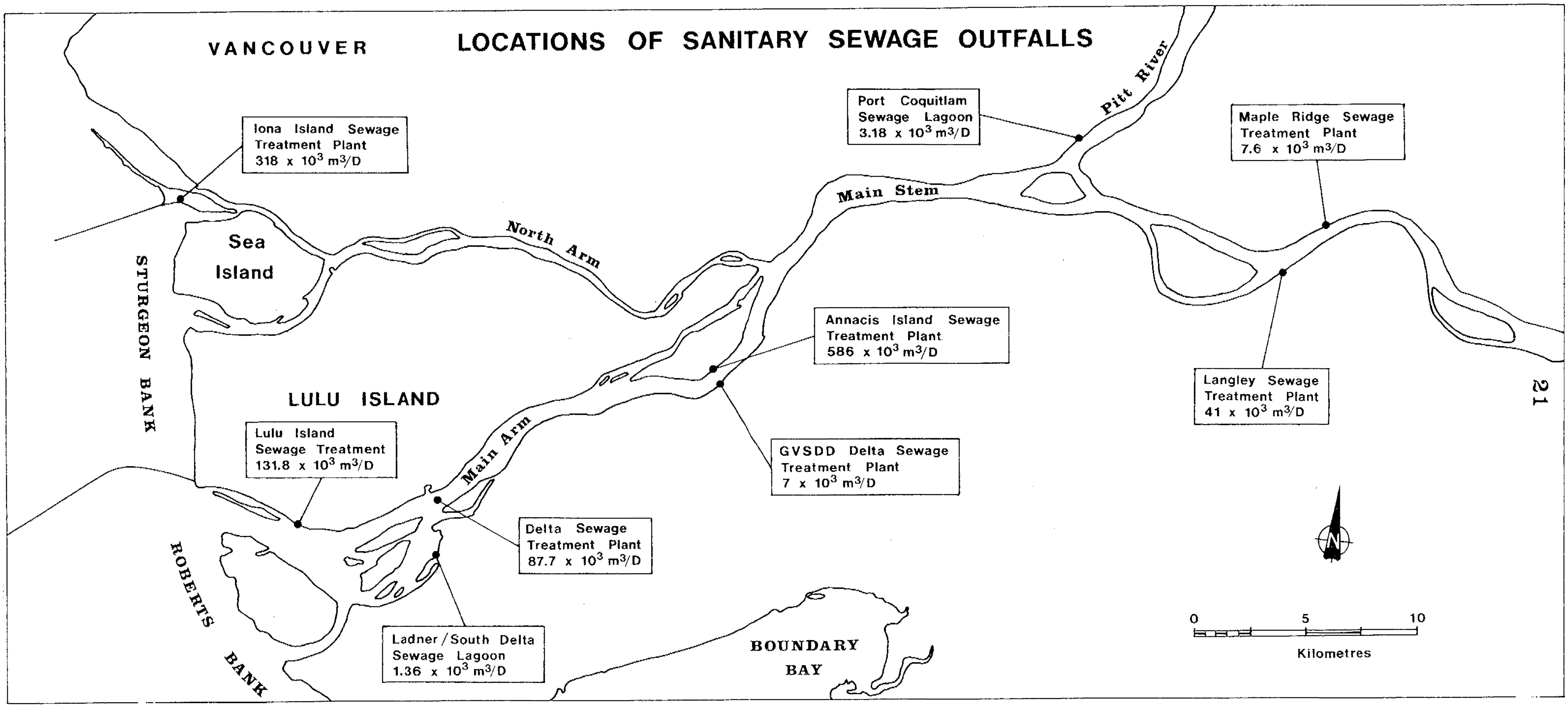


Figure 6. Location of major sewage treatment plant outfalls in the Fraser River study area. note: Indicated discharges are volumes allowed by permit, and do not necessarily represent typical or average volumes.

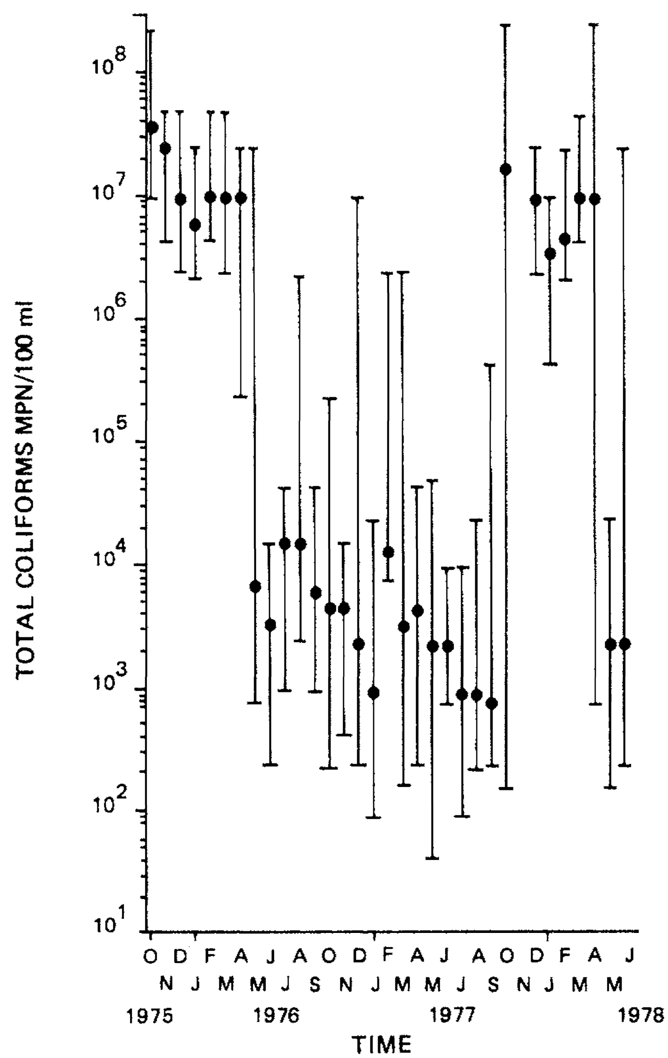


Figure 7 . The effect of chlorination on total coliform concentrations in Annacis Island STP effluents. •-monthly median. Vertical lines indicate range of monthly values.

counts for effluent samples which were tested twice daily. Total coliforms, rather than fecal coliforms, have been measured in sewage from the sewage treatment plants which discharge into the Fraser River. Median total coliform counts in Annacis Island effluent ranged from 3.3×10^6/100 ml to 3.5×10^7/100 ml during non-chlorinating months, and from 7.5×10^2 to 1.5×10^4/100 ml during chlorinating months. Fecal coliform counts, which would be approximately 20% or lower than total coliform counts would therefore range from 6.6×10^5/100 ml to 7.0×10^6/100 ml during non-chlorinating months and 1.5×10^2 to 3.0×10^3 during chlorinating months. The variability as indicated by the ranges was high, particularly in April and October as STP's do not necessarily change from chlorination to non-chlorination or vice versa on the first day of the month. A similar pattern occurred at Lulu Island and Iona Island, where median total coliform counts in unchlorinated effluent were generally in the order of 10^6 and median values in chlorinated effluent were generally in the order of 10^3. This reduction of approximately 10^3 in coliform values agrees with published results on the effectiveness of chlorination (52) and is related to the concentration of added chlorine and the contact time between the chlorine and the sewage. Increased coliform dieoff might be obtained by increasing one or both of these factors.

b) Coliform Loadings from Sewage Treatment Plants

In the Municipal Effluents Report (21), daily total coliform loadings have been calculated for each month in 1977 at Annacis Island, Iona Island and

Lulu Island. It should be emphasized that, in order to make comparisons with fecal coliform loadings from other sources, total coliform numbers should be reduced by approximately 80%. Geometric mean, maximum, and minimum daily coliform loadings are extracted from the Municipal Effluents Report and presented in Table II. Loading values were obtained by multiplying the geometric mean of approximately 50 coliform measurements per month by the monthly geometric mean of daily average flow measurements (calculated from a continuous flow record). Geometric and arithmetic means of flow measurements were similar for the month at each sewage treatment plant.

Table II indicates an obvious difference in coliform loading values between chlorinating and non-chlorinating months at all three sewage treatment plants. At Annacis Island, means of daily coliform loadings ranged from 1.24×10^{12} to 4.67×10^{13} total coliforms/day (10-300 population equivalents) in the period January to September, 1977. Data available for one full month of non-chlorination (December, 1977) shows total coliform loadings of 1.7×10^{16}/day (100,000 population equivalents). Means of daily coliform loadings in the chlorinating months of January to September at the Lulu Island STP ranged from 4.0×10^{10} to 1.19×10^{13} coliforms/day (0.25 to 75 population equivalents). Means of daily coliform loadings for the non-chlorinating months of November and December were 8.1×10^{15} and 6.5×10^{15} coliforms/day (50,000 and 40,000 population equivalents) respectively. Means of daily coliform loadings for chlorinating (June to September) and

TABLE II Mean Daily Total Coliform Loadings in Sewage Treatment Plant Effluents, 1977.

Total Coliform Loadings MPN/Day x 10^{12}

Month	Annacis Island			Lulu Island			Iona Island		
	Geometric Mean	Minimum	Maximum	Geometric Mean	Minimum	Maximum	Geometric Mean	Minimum	Maximum
January	2.54	0.13	46.2	0.6	0.09	23.5	7326	336	25100
February	45.7	1.07	4260	2.7	0.06	50.2	8836	1760	44700
March	12.3	0.36	4370	11.9	0.44	282.1	13200	2.44	170
April	6.22	0.41	74.3	6.5	0.52	55.7	9895	36.7	372000
May	5.12	0.07	72.2	1.1	0.007	53.5	4.2	0.29	18100
June	3.99	1.25	18.9	0.3	0.007	53.5	0.8	0.09	6.4
July	1.25	0.12	16.4	0.04	0.005	0.84	0.5	0.09	35.3
August	1.84	0.30	37.0	0.3	0.005	54.6	0.6	0.10	736
September	1.67	0.41	710	0.3	0.007	42.9	0.7	0.09	753
October	3000	0.26	513000	132.3	0.02	54600	8246	0.09	712000
November	-	-	-	8161	743	61200	17920	4080	56100
December	17160	4070	57800	6470	2240	29000	10870	96.7	73200

Note: Change over from chlorination to non-chlorination occurred in October.

non-chlorinating months at the Iona STP ranged from 5 to 8 x 10^{11} coliforms/day (3 to 5 population equivalents) and from 7.3 x 10^{15} to 1.7 x 10^{16} coliforms/day (46,000 to 100,000 population equivalents) respectively, excluding the transitional month of May.

Although confidence limits have not been calculated for the effluent loading data, the ranges indicate considerable variability, particularly in changeover months between chlorination and non-chlorination. The variability in Annacis Island and Lulu Island loading calculations is primarily due to variability in coliform numbers, rather than variability in flow. At Iona Island, variability in flow also contributes to variability in loading calculations.

In summary these data clearly indicate large differences, primarily due to chlorination patterns, in the microbial water quality of STP effluents which discharge into the Lower Fraser River. Hydrological conditions during these periods of chlorination and non-chlorination may also influence coliform concentrations in receiving waters. The current chlorination period between May and September includes the peak of Fraser River runoff, which occurs between May 1 and July 16 (81). Therefore, the period of minimum coliform concentration in effluents corresponds to the period of maximum dilution of effluents in receiving waters.

Since many factors influence coliform dieoff and/or recovery in receiving waters it is difficult to predict seasonal trends. Data collected after November, 1977 should be examined to determine whether the lack of chlorination at Annacis and Lulu Island STP's during the winter has resulted in higher receiving water coliform counts than previously recorded.

3.1.3 Storm Sewers

Another major source of coliform bacteria in the Lower Fraser River is storm sewers, which carry runoff from commercial, industrial, agricultural, residential, and open space land use areas. In addition to storm sewers there are outfalls from combined sewers which discharge stormwater and sewage to the Fraser River at times when the combined input exceeds the flow capacity of the sewage treatment plants. The volumes discharged by storm sewers are variable and dependent on precipitation, runoff, the time between storms, and tidal stage in some cases. Little is known about coliform levels in storm sewers which discharge into the Fraser River. The available information is presented and interpreted in a Fraser River Estuary Study report entitled Stormwater Discharges (37). In order to assess the relative contribution of various coliform sources which discharge into the Fraser River study area, certain information from the storm sewer report is summarized here.

There are approximately 175 storm sewer outlets which discharge effluent into the North and Main Arms of the Fraser River. Ferguson and Hall (37) have estimated approximate daily coliform loadings for each municipality in the Lower Fraser River area. These loadings were calculated from the proportion of each of five land use groups in each municipality, the average annual precipitation for each municipality, a runoff coefficient for each land use group, and literature values for stormwater pollutant concentrations for each land use. The limitations in this loading calculation, which are described in the stormwater report (37), include the use of literature values rather than values from the Fraser River study area, the lack of information on the effect of variable intensity and duration of storms, and the problems inherent in calculating daily loadings from annual runoff values. The approximate estimate of loadings from storm sewers was 5.65 x 10^{13} fecal coliforms/day (1700 population equivalents) to the Lower Fraser River area, including the North Arm and the Main Arm. Total coliform loadings were ten times as high as fecal coliform loadings.

Results are now available from a fecal coliform survey of stormwaters carried out during dry weather from July to October, 1978 (27). The data were grouped and the geometric mean, arithmetic mean, 10th and 90th percentiles calculated for storm sewers in urban sites, agricultural sites, industrial sites, commercial sites, and waste disposal sites. In order of decreasing geometric mean values, fecal coliform concentrations at the sites were ranked as follows: urban > agricultural > industrial > commercial > waste disposal. The individual storm sewers which contained the highest fecal coliform numbers were all located in areas designated as urban, specifically at the Fraser View Golf Course (greater than upper measurable limit of 240,000/100 ml) and Still Creek at 22nd Street (92,000/100 ml). These levels may indicate cross connections between storm sewers and sanitary sewers. A rough calculation, based on coliform counts and flow measurements from the September, 1978 stormwater survey, showed a dry weather loading of 2.6 x 10^{12} fecal coliforms/day (80 population equivalents).

3.1.4 Landfill Leachates

Detailed information may be found in the report by J.W. Atwater entitled Impact of Landfills (6). The coliform levels in landfill leachates are determined to a great extent by the local disposal practices of sewage sludge and septic tank pump-out. [1.] Limited data on coliform concentrations and leachate flow indicate that landfills discharge fewer coliforms than storm sewers, water upstream of the study area, or sewage treatment plant effluents.

1. Kay, B.H. Senior Environmental Microbiologist. Environmental Protection Service. Personal Communication.

Data available from a very limited sampling of 3 leachate sites indicated loadings as follows: Kerr Landfill site, 1.3×10^8 fecal coliforms per day; Stride Landfill site, 4.6×10^7 fecal coliforms per day; Port Mann Landfill site, 2.7×10^8 fecal coliforms/day (converted from a total coliform measurement by a factor of 0.2). Together these three landfill sites contribute a total of 0.01 population equivalents.

3.2 Relative Contributions from Sources of Coliform Bacteria

It is impracticable, given the limited data on coliform levels upstream of the study area and in storm sewers, to calculate accurately the relative contributions of sewage inputs to the Lower Fraser River. The very limited information available indicates that, during months of non-chlorination, the input of coliforms is higher from sewage treatment plants than from storm sewers and upstream sources. During months of chlorination, there are insufficient data to show a significant difference between the three sources. In order to better determine the relative significance of various coliform sources, a calculation of storm sewer loadings using data collected from the study area rather than literature values would have to be made. This is intrinsically difficult as coliform levels may vary radically during the progress of a storm and depend on the frequency and intensity of rainfall. Furthermore, manual sampling is of limited practical application and automatic sampling of storm sewers is technically rather complex (31).

Additional data must also be collected in order to calculate upstream levels with a greater precision than the range specified above. Accurate loading calculations for both storm sewers and upstream coliform inputs are difficult to obtain due to flow reversal during certain stages of the tide. An additional problem in developing relative loading estimates is the fact that total coliforms have previously been measured in STP effluents, and cannot be accurately compared with fecal coliform loadings from other sources.

3.3 Levels of Indicator Bacteria in Receiving Waters of the Lower Fraser River

3.3.1 Location of Reaches and Uses Within Each Reach

Figure 1 shows the location of the 22 reaches in which coliform data from the Lower Fraser River have been grouped. These data have been interpreted by comparing the annual geometric mean values for each reach with published criteria and/or standards of microbial water quality. Criteria may be defined variously as "....the scientific data evaluated to derive recommendations for characteristics of water for specific users" (76) or "a standard, rule, or test on which a judgement or decision of something can be made" (58). Although criteria and standards are, by definition, synonymous, the latter term when applied to water quality usually designates a limit which, when exceeded, may lead to future action, legal or otherwise.

Water quality criteria are generally related to water uses such as industry, irrigation, recreation, domestic consumption, or use by aquatic organisms. More specifically, microbial water quality criteria are related to various uses which may cause man to ingest or contact pathogenic organisms; these uses include drinking, shellfish consumption, swimming, recreation, and irrigation. Table III briefly summarizes certain information from the Recreation Report of the Fraser River Estuary Study (38), and indicates that recreation other than swimming is the principal activity relevant to microbial water quality criteria in the 22 reaches. At several locations in the Lower Fraser River, irrigation water is obtained from ditches which are linked by floodgates to Fraser River water. Swimming occurs at beaches adjacent to the study area.

Shellfish harvesting is a potential activity at Sturgeon Bank, Roberts Bank, and in the Boundary Bay area; these waters are presently closed for this use due to high fecal coliform levels. Commercial fishing is a major industry on the Lower Fraser River, and entails frequent contact with Fraser River water.

TABLE III Recreational Activities in Lower Fraser River Reaches (Recreation Report, Fraser River Estuary Study)

Reach #	Water Quality Reach Name	Adjacent Recreational Site(s)	Recreational Activities
1	Barnston Island	Barnston Island	Beach activities, boating, etc.
1	Barnston Island	Pitt Meadows street ends: Spicer, Baynes Harris	Fishing, etc.
2	Fraser River at Port Mann Bridge	Tree Island Coquitlam River mouth	Picnicking, fishing, boat launching etc.
3	Fraser River Pattullo Bridge	New Westminster Waterfront Walk	Fishing.
3	Fraser River Pattullo Bridge	Surrey Fishing bars (Plywood, Brownsville, Gypsum Bars)	Bar fishing.
4	North end Annacis Island	Annacis Island	Bar fishing.
5	Annieville Channel upstream	Annacis Island	Bar fishing.
6	Annieville Channel downstream	Annacis Island	Bar fishing, picnicking, beach activities.

TABLE III (Continued)

Reach #	Water Quality Reach Name	Adjacent Recreational Site(s)	Recreational Activities
7	Annacis Island South end	Annacis Channel Pembina Street South Dyke Road	Boating, bar fishing, etc.
7	Annacis Island South end	Annacis Island	Bar fishing, picnicking, beach activities.
8	Fraser River at Tilbury Island	Tilbury Island	Bar fishing, beach activities.
8	Fraser River at Tilbury Island	Richmond Landfill Beach	Beach activities, bar fishing etc.
9	Deas Island	Deas Island	Bar fishing, nature study.
10	Fraser River at Kirkland Island	Gilmore, Woodward Drive, Woodward Slough	Bar fishing, beach activities, canoeing.
12	Fraser River Cannery Channel	Gilbert Beach London Farm	Beach activities, bar fishing, boat launching, etc.
12	Fraser River Cannery Channel	Steveston Island	Beach activities, bar fishing.

TABLE III (Continued)

Reach #	Water Quality Reach Name	Adjacent Recreational Site(s)	Recreational Activities
14	Fraser River at Queensboro Bridge	Poplar Island 16th St. end 14th St. end Wood St. end, Ewen St. end Whonnock Dirt Road	Fishing, etc.
15	CN Rail Bridge North Arm	River Road foreshore	Bar fishing, picnicking.
15	CN Rail Bridge North Arm	Vancouver street ends Crompton, Knight Elliott & Gladstone	Fishing, picnicking, etc.
15	CN Rail North Arm	Big Bend	Fishing, picnicking.
16	Fraser River Mitchell Island	Big Bend	Fishing, picnicking.
17	Fraser River Oak Street	Vancouver street ends: Shaughnessy, Oak, Angus	Fishing, walking etc.
18	Fraser River Wood Island	Vancouver street ends: Shaughnessy, Oak, Angus	Fishing, walking etc.
18	Fraser River Wood Island	Vancouver street ends: Carrington, Celtic	Fishing, picnicking, etc.

TABLE III (Continued)

Reach #	Water Quality Reach Name	Adjacent Recreational Site(s)	Recreational Activities
20	South side of North Arm Jetty	Iona - Woods Island Park	Significant area for recreation and conservation. Beach activities, boating, nature study.
22	Fraser River Dinsmore Island	Richmond, Dyke Trail Cambie Road to Terra Nova	Fishing etc.
22	Fraser River Dinsmore Island	Dover Beach	Fishing, beachcombing
--	---	Crescent Beach Blackie Spit Boundary Bay Semiahmoo Bay	Beach activities, swimming nature study, boating.
--	---	Centennial Beach Boundary Bay Boundary Bay dyke	picnicking, beach activities, nature study, swimming.
--	---	Widgeon Valley	Canoeing, nature observation, limited hunting, limited hiking.
--	---	Ladner Marsh Island	Canoeing, hunting, nature interpretation, etc.

TABLE III (Continued)

Reach #	Water Quality Reach Name	Adjacent Recreational Site(s)	Recreational Activities
--	---	Pitt River Dyke Coast Meridian to Broadway	Picnicking, fishing, boat launching, etc.
--	---	Entrance to Canoe Pass South Shore	Bar fishing, fishing.
--	---	Tsawwassen Jetty	Boating, beach activities, swimming.
--	---	Derby Reach	Bar fishing.
--	---	Kanaka Creek	Fishing, hiking, etc.
--	---	Pitt Meadows Ford Road to Kennedy Road Jog.	Fishing etc.

3.3.2 Microbial Water Quality Criteria

Certain past and/or current water quality standards and criteria are listed and described in Table IV. The most stringent standards are applied to untreated drinking water and specify that, as a maximum permissible limit, 90% of samples in a consecutive 30-day period should be negative for total coliforms (30). It is exceedingly unlikely that water in the Lower Fraser River will ever be used or required for drinking, and it is also unlikely that, given the diverse sources of sewage inputs, the drinking water standard will ever be achieved. The next most restrictive standard is for shellfish harvesting, which requires that the fecal coliform MPN in water samples not exceed 14/100 ml, and that not more than 10 percent of samples exceed 43/100 ml (22). The shellfish harvesting standard is very stringent because these organisms concentrate pathogens during filter feeding and shellfish may be eaten raw. This 14/100 ml value is based on epidemiological evidence linking the incidence of typhoid fever with coliform populations of shellfish and shellfish waters (73). The standard for shellfish harvesting is probably not achievable in the Lower Fraser River area, and will be discussed in a future section on the effects of various sewage treatment alternatives on receiving water quality.

There is no agreement on the necessity of bacterial standards for swimming waters, and on the levels of total or fecal coliform bacteria which represent a potential hazard to swimmers. In 1968 the National Technical Advisory Committee to the U.S. Department of the Interior (74) recommended that logarithmic means of fecal coliforms in swimming waters should not exceed 200/100 ml, with no more than 10% of the samples exceeding 400/100 ml. This is the standard which is currently enforced by the B.C. Ministry of Health (29). The Committee on Water Quality Criteria (76) reviewed the epidemiological evidence linking disease incidence and swimming, and stated that no "specific recommendation is made concerning the presence or concentrations

Table IV Water quality standards, objectives, or criteria, according to use

Use	Standards, objectives, or criteria: Total Coliform Standards — Objective	Acceptable Limit	Maximum Permissible Limit	Reference
Drinking Water	No coliforms	95% of samples in consecutive 30-day period should be negative. Positive samples should not have an MPN index greater than 10 per 100 ml.	At least 90% of samples in a consecutive 30-day period should be negative. Positive samples should not have an MPN index greater than 10 per 100 ml.	Canadian Drinking Water Standards and Objectives 1968.

Table IV Water quality standards, objectives, or criteria, according to use

Use		Reference
	Total Coliform Standards	
Shellfish Harvesting	Coliform median MPN not to exceed 70/100 ml, and not more than 10 percent of the samples to exceed a mean of 230/100 ml for a 5-tube decimal dilution test (or 330/100 ml for a three tube test).	National Shellfish Sanitation Program Manual of Operations Part 1, Sanitation of Shellfish Growing Areas (PHS Pub. No.33, 1965).
	Fecal Coliform Standards	
Shellfish Harvesting	Fecal coliform median MPN not to exceed 14/100 ml, and not more than 10 percent to exceed 43/100 ml by a five tube dilution series.	Canadian Shellfish Safety Program: Interdepartmental Shellfish Committee Meeting, April 14, 1977. Ottawa.

Table IV Water quality standards, objectives, or criteria, according to use

Use	Fecal Coliform Criteria	Reference
Swimming	Log means not to exceed 200/100 ml, with not more than 10% of the samples exceeding 400/100 ml (during any 30-day period).	U.S. Department of the Interior. Federal Water Pollution Control Administration (1968), Water Quality Criteria: report of the National Technical Advisory Committee to the Secretary of the Interior (Government Printing Office, Washington, D.C.).
Swimming	Primary contact recreational water shall not exceed a minimum log mean of 200/100 ml, nor shall more than 10% of total samples during any 30-day period exceed 400/100 ml.	Recommended Water Quality Standards. Department of Health Services and Hospital Insurance. Province of British Columbia, Victoria, B.C. 1969.
Swimming	No specific recommendation due to paucity of valid epidemiological data.	Water Quality Criteria, 1972. A report of the Committee on Water Quality Criteria, E.P.A., Washington, D.C., 1972.
Direct contact recreation (swimming, bathing, wading, water skiing)	Fecal coliform organisms (median MPN) objective 20/100 ml; maximum 200/100 ml.	Inland Waters Branch, DOE, 1972. Guidelines for Water Quality Objectives and Standards.

Table IV Water quality standards, objectives, or criteria, according to use

Use	Fecal Coliform Criteria	Reference
Irrigation	Irrigation waters below the fecal coliform density of 1,000/100 ml should contain sufficient low concentrations of pathogenic microorganisms that no hazards to animals or man result from their use or from consumption of raw crops irrigated with such waters. (Maximum of 1,000/100 ml).	Water Quality Criteria, 1972.

Table IV Water quality standards, objectives, or criteria, according to use

Use	Objective	Acceptable Limit	Maximum Permissible Limit	Reference
		Total Coliform Standards		
Raw Water (Public Water Supplies)	At least 95% of the samples in any consecutive 30-day period should have a total coliform density of less than 100 per 100 ml.	At least 90% of the samples in any consecutive 30-day period should have a total coliform density of less than 1,000 per 100 ml.	At least 90% of the samples in any consecutive 30-day period should have a total coliform density of less than 5,000 per 100 ml.	Canadian Drinking Water Standards and Objectives, 1968.
		Fecal Coliform (MPN) Standards		
Raw Water (Public Water Supplies)	At least 95% of the samples in any consecutive 30-day period should have a fecal coliform density of less than 10 per 100 ml.	At least 90% of the samples in any consecutive 30-day period should have a fecal coliform density of less than 100 per 100 ml.	At least 90% of the samples in any consecutive 30-day period should have a fecal coliform density of less than 1,000 per 100 ml.	Same as above
		Fecal and Total Coliform Criteria		
Raw Water (Public Water Supplies)	Geometric means of fecal coliform and total coliform densities in raw surface water sources should not exceed 2,000 and 20,000 per 100 ml, respectively.			Water Quality Criteria, 1972. A report of the Committee on Water Quality Criteria EPA, Washington, D.C., 1972.

Table IV Water quality standards, objectives, or criteria, according to use

Use	Criteria	Reference
	Fecal Coliform Criteria	
Recreation other than Swimming (Non-contact Recreation)	Log means not to exceed 1,000/100 ml with no more than 10% exceeding 2,000/100 ml.	U.S. Department of the Interior. Federal Water Pollution Control Administration (1968).
	Fecal Coliform Criteria	
All Waters	Average not to exceed 2,000 fecal coliforms/100 ml and a maximum of 4,000/100 ml.	As above
Non-contact Recreation	Criteria concerning the presence of microorganisms in water for general recreation purposes are not known.	Water Quality Criteria, 1972.
	Fecal Coliform Criteria	
Recreational Waters	..... samples with fecal coli MPN's of greater than 2,000 per 100 ml should be deemed heavily polluted and objectionable. Fecal counts of between 1,000 and 2,000 would indicate distinct pollution and be suspect. Counts of 50 to 200 per 100 ml would indicate slight pollution and counts of less than 50 be considered highly satisfactory.	World Health Organization, Ostend, Belgium, 1972.

of microorganisms in bathing water because of the paucity of valid epidemiological data." A similar view is taken in Great Britain, where there are no bacterial standards for recreational waters (8). When considering the relative merit of these seemingly divergent viewpoints, there are two questions which might be considered. Firstly, should standards such as the 200/100 ml value be applied, despite the limited supporting epidemiological evidence, in order to ensure a high standard of microbial water quality at beaches? Secondly, do the aesthetic considerations associated with swimming in fecally polluted water suggest the application of a water quality standard, despite the low risk of infection by pathogenic organisms?

Water quality criteria have been described for irrigation waters and raw waters for public water supplies. The Committee on Water Quality Criteria, 1972 (76) recommended that irrigation waters contain a maximum fecal coliform concentration of 1000/100 ml, and that irrigation waters with lower coliform densities contain sufficiently low concentrations of pathogenic microorganisms so that no hazards to animals or man result from their use. These criteria are based on the isolation of Salmonella from irrigation waters containing fecal coliforms at a concentration of approximately 1000/100 ml or more.

Canadian Drinking Water Standards and Objectives (30) specify that, for treated public drinking water supplies, the maximum permissible density of fecal coliform bacteria in the raw water be less than 1000/100 ml in 90% of samples over a consecutive 30-day period. The Committee on Water Quality Criteria (76) recommended that fecal and total coliform densities in public water supplies before treatment should not exceed 2000/100 ml and 20,000/100 ml, respectively. These criteria are based on the observation that, at fecal coliform concentrations greater than 2,000/100 ml, Salmonella, Poliovirus, and ECHO viruses have been detected (76) in public water supplies.

It is unlikely that Lower Fraser River waters will be used for this purpose in the foreseeable future, as water supply in nearby mountainous watersheds is plentiful.

Bar fishing, hunting, boating, picnicking, and nature study are the most common forms of recreational activity in the 22 reaches of the Lower Fraser River study area. Published microbial water quality criteria for recreation other than swimming (non-contact recreation) are even more debatable than swimming water criteria. In 1968, the National Technical Advisory Committee (74) recommended that geometric means of fecal coliform counts in waters used for non-contact recreation should not exceed 1,000/100 ml, and that no more than 10% of these water samples should exceed 2,000/100 ml. They also recommended that fecal coliform counts in all waters should average less than 2,000/100 ml and should not exceed 4,000/100 ml. Conversely, the Committee on Water Quality Criteria (76) concluded from their investigations that "criteria concerning the presence of microorganisms in water for general recreation purposes are not known". Presently, the non-contact recreation criteria are not enforced by the U.S.Environmental Protection Agency, and there are no B.C. Provincial or Canadian Federal standards or criteria for non-contact recreation.

Although criteria for non-contact recreation cannot presently be supported by epidemiological evidence, recommendations have been made on less quantifiable considerations such as aesthetics. Such an approach was taken by one of the groups convened by the World Health Organization in 1972 to develop environmental health criteria (72). They recommended that "samples with fecal coli MPN's of greater than 2,000 per 100 ml should be deemed heavily polluted and objectionable. Fecal counts of between 1,000 and 2,000 would indicate distinct pollution and be suspect. Counts of 50 to 200 per 100 ml would indicate slight pollution and counts of less than 50 be considered highly satisfactory."

In the case of the Lower Fraser River reaches where recreation other than swimming is the major activity, the annual geometric mean values can only be compared with general aesthetic categories such as those described by the WHO Committee. It should be pointed out that these categories do not represent Canadian Federal or B.C. Provincial standards or criteria, and that these categories cannot be related to known health hazards resulting from contact with pathogenic organisms.

3.3.3 Annual Geometric Means and Percentiles for Each Reach

Figures 5 and 8 to 12 show annual summaries including geometric means and 10 and 90 percentiles for each of the 22 Lower Fraser River reaches from 1970 to 1977. These annual summaries have been prepared from data stored in the EQUIS computer, compiled from various government agencies and university scientists.

Annual summaries have been prepared in order to give an overview of coliform levels in the various reaches, and in order to make rough comparisons geographically between reaches and between years within each reach. There are various reasons why confidence limits cannot be assigned to these data, and the data cannot be used for trend analysis or statistical comparisons. These reasons are discussed and certain selected reaches are examined in detail in the following section.

Historically, coliform values have not usually been subjected to rigorous statistical analysis, and they have been generally presented in terms of means, medians, and/or percentiles which are then compared to the appropriate criteria, based on use. In the case of the Fraser River reach data, the geometric mean of the fecal coliform values has been chosen as the most appropriate measure of central tendency, and has been compared to the subjective criteria previously described for non-contact recreation. Early in the 1970 to 1977 period, total coliform samples were collected more frequently than fecal coliform samples; by 1977 the latter test was more generally used and considered superior for the detection of fecal material. Annual summaries for total coliform values are presented in Appendix I.

Reaches 2 (Port Mann Bridge), 4 (North End Annacis Island), 12 (Cannery Channel) and 16 (Mitchell Island) contain insufficient fecal coliform data to be included in temporal or spatial comparisons. There is also insufficient fecal coliform data in reach 3 (Pattullo Bridge); this reach is of considerable interest due to its location upstream of the major sewage treatment plants, and because of the discontinuation of the Braid Street sewer in 1977. The geometric means of the few values obtained from 1976 to 1977 were approximately 100/100 ml (Fig. 5); these numbers agree with the results from a 24 hour sampling series carried out by the Inland Waters Directorate in January, 1978 (24). On this occasion fecal coliform counts in samples from two depths near the Pattullo Bridge were below 200/100 ml except at high slack tide, when values were as high as 900/100 ml.

Moving down the mainstem in the direction of the Annacis Island sewage treatment plant, geometric means in reach 5 (Annieville Channel Upstream) were below 1000/100 ml from 1974 to 1976, and below 250/100 ml in 1977 (Fig. 8). The geometric mean in reach 6 (Annieville Channel Downstream), which is located just downstream of the Annacis Island effluent pipe, ranged from 1000 to 2000/100 ml in 1974 to 1976, and below 1000/100 ml in 1977 (Fig. 8). Geometric mean values in reach 7 (Annacis South End) ranged from 1000 to 2000/100 ml in 1973 to 1975, and were below 1000/100 ml in 1976 to 1977 (Fig. 8).

It might be expected that the discharge of large volumes of effluent from the Annacis Island STP would result in a localized increase in fecal coliform numbers. However, the data did not indicate a rise in geometric mean values in the reaches adjacent to Annacis Island after the start-up of the sewage treatment plant

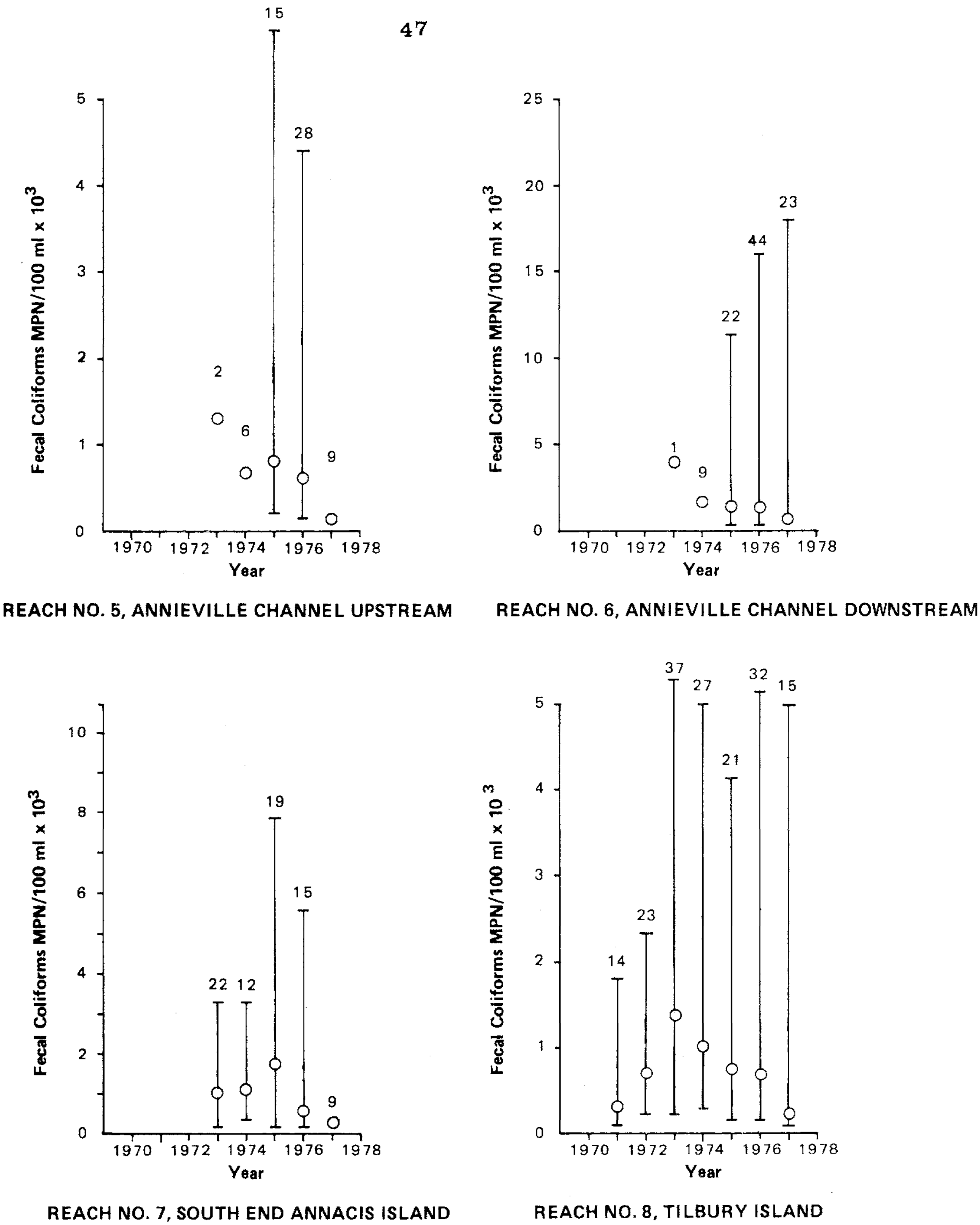
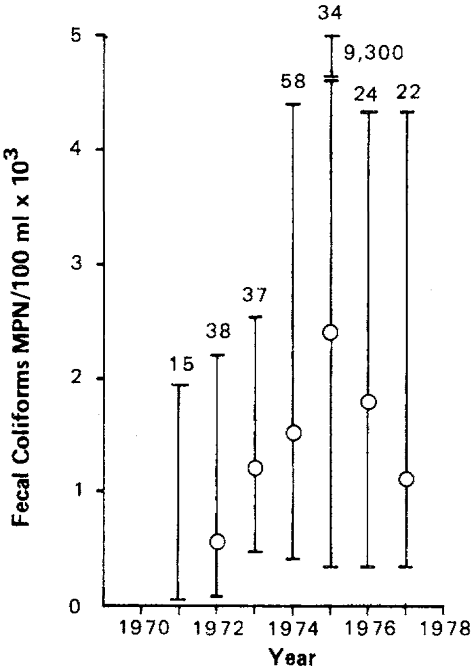


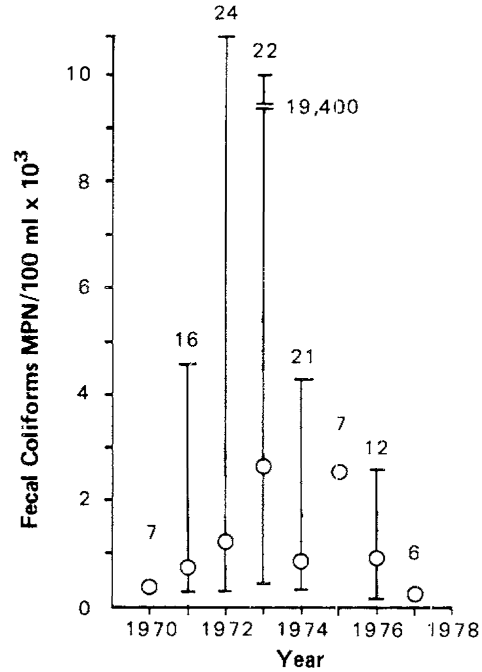
Figure 8 . Yearly summaries of fecal coliforms at Reach Nos. 5 to 8.
o - geometric mean. Vertical lines indicate the range between 10 and 90 percentiles.
Numbers above the vertical line indicate sample size.

from 1975 to 1977. This may reflect the effects of continuous effluent chlorination from May, 1976 through September, 1977 on receiving water quality. For this reason, the values for 1978 will be of considerable interest. It is also important to observe that, although geometric mean values in this area were usually well below the "grossly polluted" aesthetic criterion of 2000/100 ml, 90th percentile figures were often exceedingly high. The considerable variability in fecal coliform concentrations is largely due to changing effluent concentrations as a function of volume, tide, discharge, chlorination patterns and treatment efficiencies. Geometric means of fecal coliform values at reach 8 (Tilbury Island) were below 1000/100 ml from 1971 to 1977, with the exception of higher values from 1973 to 1974 (Fig. 8). Considerable variability in fecal coliforms was observed (24) in a 24 hour sampling series at Tilbury Island in February, 1978; hourly samples from two depths ranged from 100 to 2300 fecal coliforms/100 ml. Moving further downstream to reaches influenced by Delta, Ladner, and Lulu Island sewage treatment plants, geometric means of fecal coliform values in reach 9 (Deas Island) ranged from 1000 to 2000/100 ml in 1973 to 1977, with the exception of higher values in 1975 (Fig. 9). The sample size for reach 10 (Kirkland Island) is small and Fig. 9 indicates geometric means of approximately 1000/100 ml from 1970 to 1977, except for 1973 and 1975 (>2000/100 ml) and 1977 (< 1000/100 ml). Geometric means at reach 11 (Steveston Island) ranged from 500 to 2500/100 ml in 1972 to 1975, and were below 1000/100 ml in 1976 to 1977 (Fig.9). Intensive sampling (24) carried out at this reach indicated 24 hour ranges of approximately 400 to 2000 fecal coliforms/100 ml in December, 1977 and 50 to 750 fecal coliforms/100 ml in September, 1978. Variability at this site is also reflected in 10 and 90 percentile values ranging from 100/100 ml to >2000/100 ml in 1976 and 1977 (Fig. 9). Geometric means for reach 13 (Sand Heads) were below 1000/100 ml with the exception of values between 1000 to 1500/100 ml in 1972 to 1974 (Fig. 10).

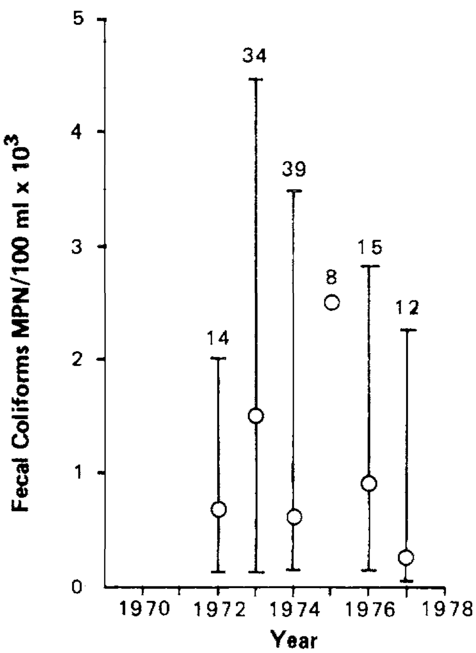
Reaches 14 to 18 are located on the North Arm of the Fraser River, which currently does not directly receive any sewage treat-



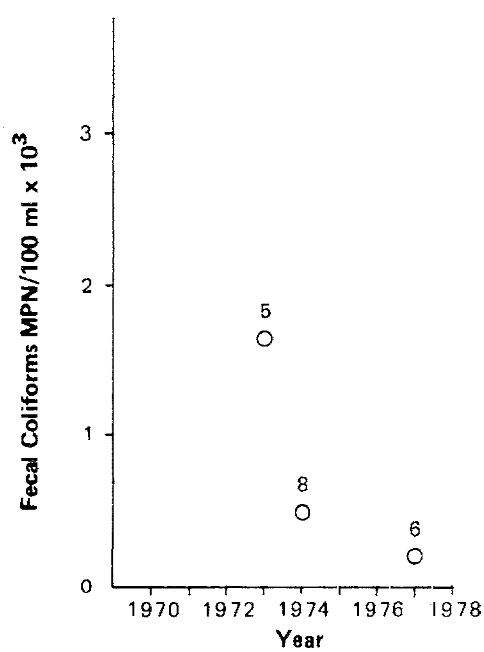
REACH NO. 9, DEAS ISLAND



REACH NO. 10, KIRKLAND ISLAND



REACH NO. 11, STEVESTON ISLAND



REACH NO. 12, CANNERY CHANNEL

Figure 9 . Yearly summaries of fecal coliforms at Reach Nos. 9 to 12.
O - geometric mean. Vertical lines indicate the range between 10 and 90 percentiles. Numbers above the vertical line indicate sample size.

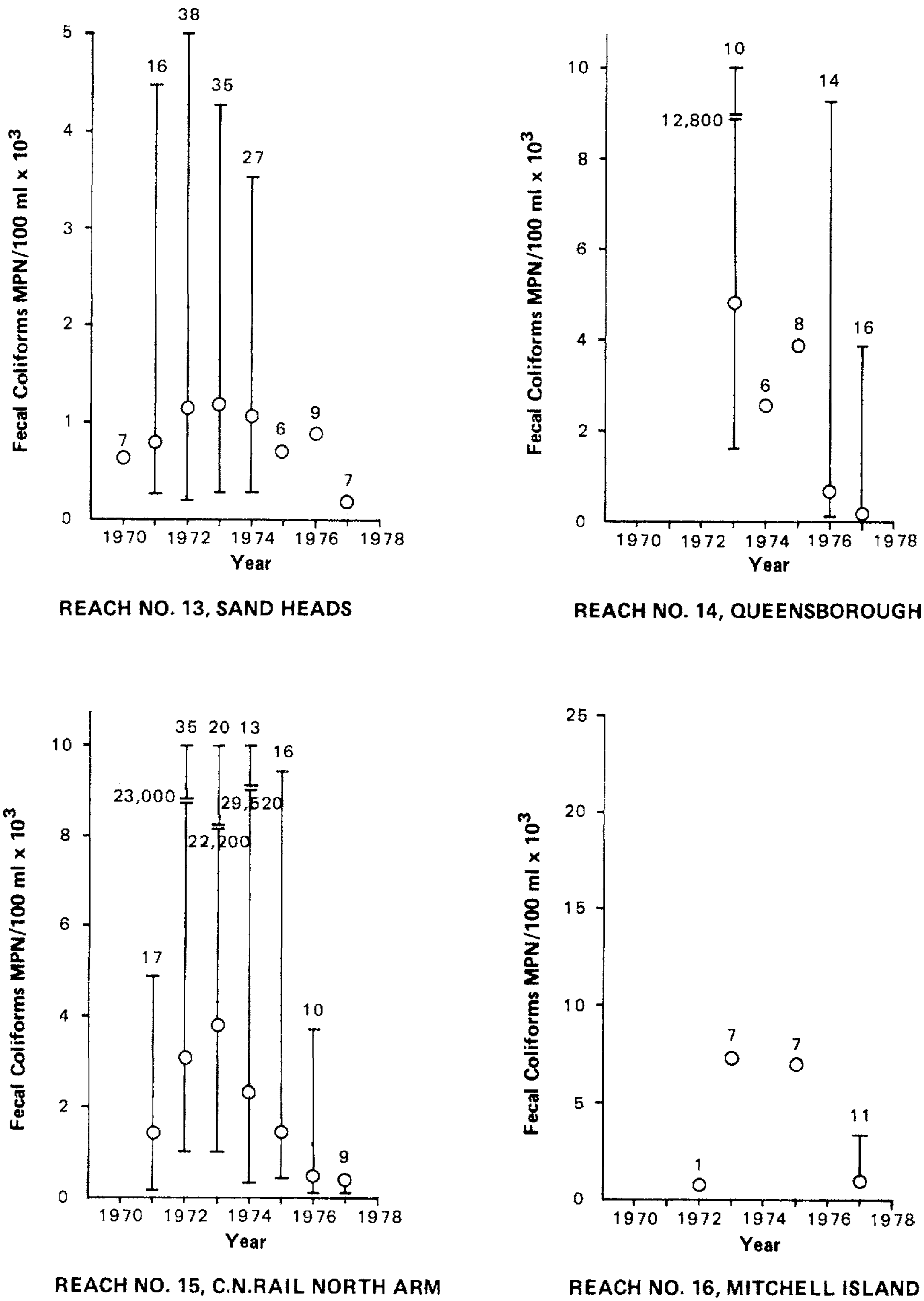


Figure 10 . Yearly summaries of fecal coliforms at Reach Nos. 13 to 16.
O- geometric mean. Vertical lines indicate the range between 10 and 90 percentiles. Numbers above the vertical line indicate sample size.

ment plant effluents. Previous to the Annacis Island hookup in 1975 the North Arm received effluents from the municipalities of Burnaby and New Westminster; low dilution rates in the North Arm resulted in high coliform values which were reported by previous studies (44). Presently, storm sewers and combined overflows are a potential source of fecal material, and sewage from Annacis or Iona could conceivably enter the North Arm during certain conditions of tide and river discharge.

The limited data from reach 14, Queensborough, shows geometric mean fecal coliform values between 2000 and 5000/100 ml in 1973 to 1975, and below 1000/100 ml in 1976 to 1977 (Fig. 10). At reach 15 (CN Rain North Arm) geometric mean values ranged from 1000 to 4000/100 ml in 1971 to 1975, with the peak value occurring in 1973 (Fig. 10). In the years 1972 to 1974, 90th percentiles were very high, ranging from 20,000 to 30,000 MPN/100 ml. Geometric mean fecal coliform values in this reach were less than 1000/100 ml in 1976 to 1977.

Geometric mean fecal coliform values in reach 17 (Oak Street) ranged from 2000 to 5000/100 ml in 1970 to 1975; the geometric mean was less than 2000/100 ml in 1976 and less than 1000/100 ml in 1977 (Fig. 11). At reach 18 (Wood Island) geometric mean values ranged from 2000 to 6500/100 ml in 1971 to 1975, and from 1000 to 2000/100 ml in 1976 to 1977 (Fig. 11). The Wood Island reach is located sufficiently close to the Iona Island STP that effluents may affect coliform concentrations on an incoming tide. In summary, fecal coliform values for each of the four North Arm reaches were lower in 1976 to 1977 than in previous years, indicating that previous high values were caused by effluents subsequently redirected to sewage treatment plants.

Geometric mean fecal coliform values for reach 19 (North Arm Jetty N. Side) varied from approximately 500 to 1500/100 ml in 1971 to 1977; the variation appeared to be random, with the lowest value occurring in 1977 (Fig. 11). By far the highest number of coliform

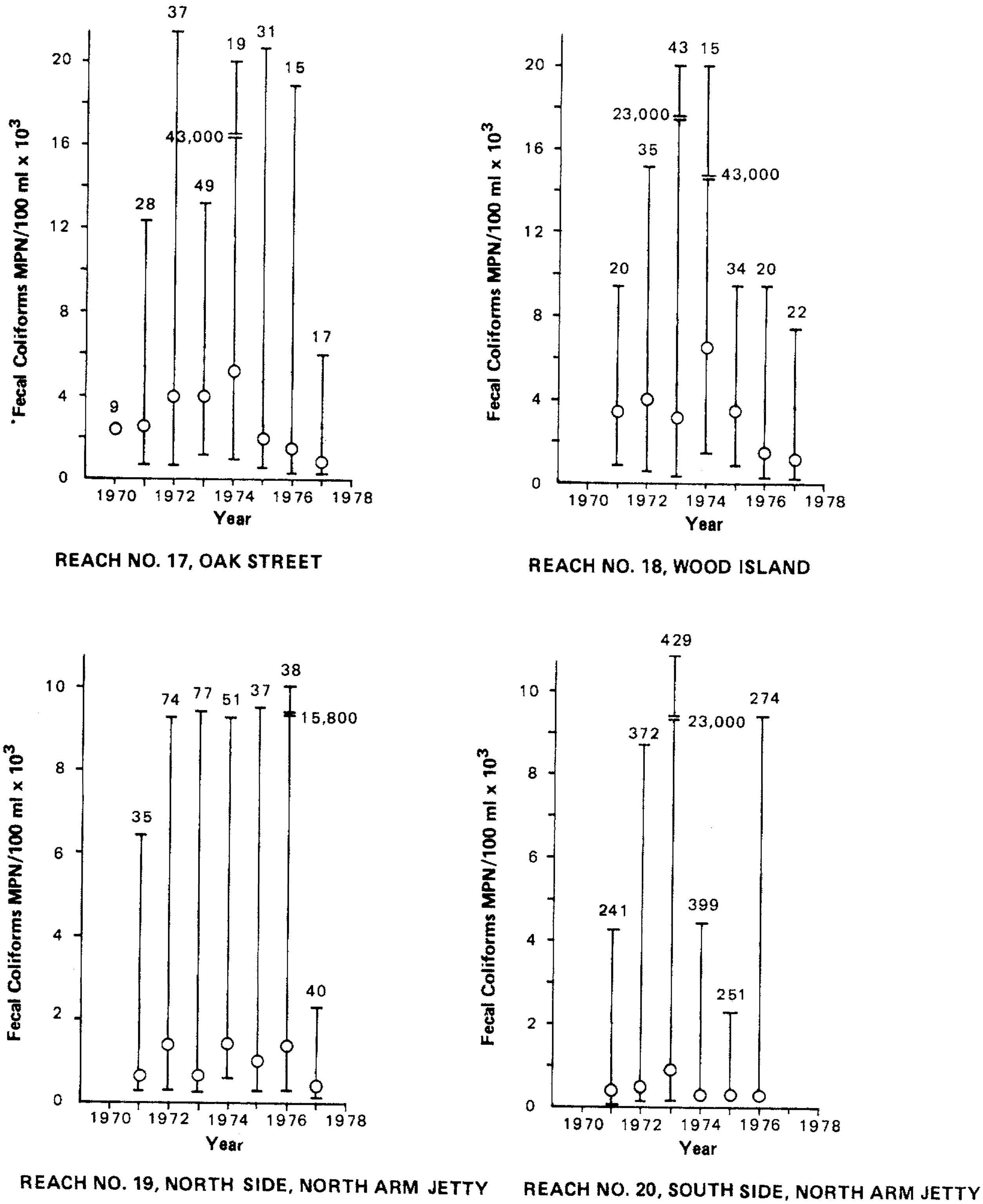


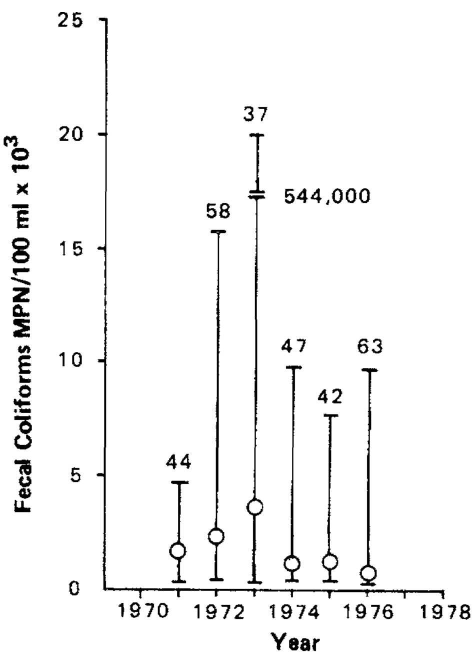
Figure 11 . Yearly summaries of fecal coliforms at Reach Nos. 17 to 20.
○ - geometric mean. Vertical lines indicate the range between 10 and 90 percentiles.
Numbers above the vertical line indicate sample size.

samples, ranging from 241 to 429/year, were collected in reach 20, South Side North Arm Jetty. Geometric mean fecal coliform levels were low in this reach, and did not exceed 500/100 ml except in 1973, when the geometric mean value was between 500 and 1000/100 ml (Fig. 11). Ninetieth percentile values at this reach were high relative to the low geometric means, and probably indicate the intermittent influx of Iona Island effluents. Geometric mean fecal coliform values in reach 21 (South Side Iona Jetty) range from 1000 to 2000/100 ml in 1971, 1974 and 1975; values in 1972, 1973, and 1976 were 2000 to 3000, 3000 to 4000, and <1000, respectively (Fig. 12).

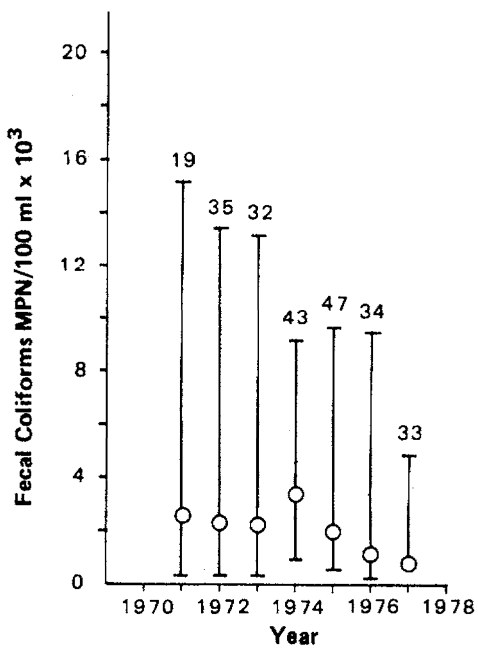
Reach 22 (Dinsmore Island) is located on the Middle Arm of the Fraser River. Geometric mean fecal coliform values ranged from 2000 to 4000/100 ml in 1971 to 1975, and were between 1000 and 2000/100 ml and <1000/100 ml in 1976 and 1977, respectively (Fig.12).

In summary, this overview of annual means in each reach suggests some overall patterns of fecal coliform concentrations in the Lower Fraser River. In the Fraser River Main Arm, geometric mean coliform values in 1976 to 1977 were invariably below the "grossly polluted" level of 2000/100 ml and generally below the "suspect" level of 1000/100 ml. There was no obvious increase in geometric mean values in reaches adjacent to the Annacis Island effluent pipe. High 90th percentile values in the Main Arm and indeed throughout the study area indicate periodically high sewage concentrations due to certain conditions of tide, discharge, rainfall, season, and effluent chlorination. Annual summaries for all North Arm stations and the Middle Arm station indicate that geometric mean coliform values have generally changed from "grossly polluted" levels above 2000/100 ml in 1970 to 1975 to below 1000/100 ml in 1976 to 1977. It is reasonable to suggest that this change has been effected by the diversion of effluents discharged to the North Arm to sewage treatment plants and in particular the Annacis Island STP constructed in 1975.

Due to various factors such as inequality of sample size and non-representative sampling regimes, the above conclusions are subjective and result from a descriptive interpretation of the data.



REACH NO. 21, SOUTH SIDE, IONA JETTY



REACH NO. 22, DINSMORE ISLAND

Figure 12 . Yearly summaries of fecal coliforms at Reach Nos. 21 and 22.
O- geometric mean. Vertical lines indicate the range between 10 and 90 percentiles.
Numbers above the vertical line indicate sample size.

Several reaches will be examined in further detail and the problems in assigning confidence limits to coliform data from the Lower Fraser River described.

3.3.4 Detailed Analysis of Reaches 9, 18, and 20

The sample sizes and distribution of samples throughout the year varied greatly throughout the 22 Lower Fraser River reaches and the 7 years of sample collection. Reaches 9 and 18 (Deas Island and Wood Island), which had relatively high numbers of coliform samples, were chosen to assess the feasibility of further statistical analysis of Fraser River coliform data. The data from these two reaches were exceedingly variable. Coliform samples were collected by three different agencies on random days during the year; samples were collected mainly in the morning and mainly during the summer months, particularly in the North Arm station at Wood Island. The usefulness of further statistical analysis was assessed by asking three questions: Are the MPN estimates consistent between agencies and can results from the three tube and five tube tests be grouped together? Are there distinguishable differences in coliform values obtained by sampling at different depths? Can diurnal, tidal, and seasonal changes be determined?

The validity of the MPN estimates was verified by determining the probability of occurrence of the MPN values reported for reaches 9 and 18. MPN estimates were found to be improbable in less than 1% of the Fraser River data; this agreed with results reported in the literature which showed that, due to the frequent occurrence of certain combinations, 49 out of 219 possible MPN codes occurred 99% of the time (83). The data in these two reaches was also checked to determine whether the correct dilutions had been selected in each MPN series. Incorrect dilutions occurred infrequently and were occasionally found for coliform counts lower than 100/100 ml.

Of the three agencies collecting data in reaches 9 and 18, two used the three tube MPN method and one the five tube method. In the 7 year period for which data was reported in reach 18, only 6 out of 188 samples were analyzed by the five tube method. The geometric mean fecal coliform value for the five tube analyses was 216/100 ml as compared to 3121/100 ml for the three tube analyses; despite the better precision of the former test, these results were eliminated due to small sample size and poor agreement of mean values with the results from the three tube test.

Data were grouped from 1970 to 1977 and comparisons were made of samples collected at the surface and a depth of 15 feet. The limited results (Table V) suggest that counts at reach 9 were somewhat higher in surface than depth samples, and that counts at reach 18 were roughly equivalent in samples from both depths.

It is not possible to determine diurnal or tidal patterns in the data because of the limited number of sampling days for each reach.

Seasonal patterns were examined by grouping the data into summer (April to September) and winter (October to March) categories, which correspond approximately to present periods of chlorination and non-chlorination at the major sewage treatment plants. Results for reach 9 are shown in Table VI, and indicate higher winter values for all years except 1977. The sample size of winter values in reach 9 is not sufficiently large to assign confidence limits to seasonal means; seasonal comparisons are not made for reach 18 due to the absence of coliform data for the winters of 1975 to 1977. Reach 20, Southside of North Arm Jetty, was also examined for seasonal patterns because of the large number of fecal coliform samples (1166) which were collected over the 7 year period. This examination revealed that, although more samples (10-12) were collected on any given day, the number of days sampled within the year were not generally higher than

TABLE V Fecal coliforms /100 ml at 0 and 15 feet, data pooled from 1970 to 1977.

Reach # 9

Depth	Arithmetic Mean	Geometric Mean	Number of Samples
0	2535	1514	165
15 feet	1252	734	53

Reach # 18

Depth	Arithmetic Mean	Geometric Mean	Number of Samples
0	6133	2628	136
15 feet	5328	3595	52

TABLE VI Fecal coliforms/100 ml in summer and winter at reach 9, Deas Island.

Year	Season	Arithmetic Mean	Geometric Mean	Number of Samples
1971	Summer	522	343	13
	Winter	1215	1181	2
1972	Summer	773	549	28
	Winter	2750	2628	4
1973	Summer	1391	963	23
	Winter	2051	1720	8
1974	Summer	2220	1128	32
	Winter	4297	3057	18
1975	Summer	3064	2018	11
	Winter	5418	3611	11
1976	Summer	1454	1170	11
	Winter	3627	3249	11
1977	Summer	2309	1353	11
	Winter	1366	956	9

for the other reaches. Fecal coliform values in reach 20 were usually higher in winter than in summer, although small sample sizes in the winter months made statistical comparisons difficult.

Low MPN values of below 100/100 ml occurred commonly in reach 20 during the summer months. These low values appeared to be correlated with high salinities, suggesting that tidal influences might mask seasonal differences in this reach.

3.3.5 Feasibility of Statistically Determining Annual Trends

The results from the detailed analysis of reaches 18 and 20 indicate that sampling days were not randomly distributed throughout the year, with higher sampling densities frequently occurring during the summer months. Upon examining the 1976-1977 data for all reaches, we found that sampling days were randomly distributed throughout the year for main stem reaches, and concentrated during the summer months for North Arm reaches. The results also indicate that values were generally lower in summer than in winter, suggesting that annual geometric mean values for North Arm stations do not necessarily represent a true annual mean and may be biased toward lower summer counts. The possibility of grouping the data from several adjacent reaches in order to increase the sample size was investigated. It was found that samples were usually collected from adjacent reaches on the same day, and therefore grouping the data did not effectively increase the sample size for annual trend analysis.

It may be concluded that due to insufficient sample size and non representative sampling regimes, annual trends cannot be statistically determined for the 22 Fraser River reaches. It should be noted, however, that a discernible trend toward lower values is observed in all North Arm reaches; this trend is apparent whether annual geometric mean values or seasonal geometric mean values are compared.

3.3.6 Ratios of Fecal Coliforms to Total Coliforms

The ratio of fecal coliforms to total coliforms has been used to determine the relative importance of fecal inputs as sources of coliform bacteria. Hall et all (44) in 1973 found that median FC:TC ratios varied from 0.11 - 0.29, and that there were no obvious downstream trends. They found that the highest ratio occurred at the Fraser Street Bridge on the North Arm (Reach 16), and the lowest ratio at the two stations closest to the Strait of Georgia. Comparison of these ratios to values observed in other river systems led the authors to conclude that a large percentage of the coliform bacteria in the Fraser River resulted from fecal inputs. Murphy (59) observed that FC:TC ratios averaged 0.14 in unpolluted streams, with ratios of 0.20 occurring in direct proximity to sewage outfalls. Fecal coliform to total coliform ratios were calculated for 15 reaches in 1977, using values obtained from the same water sample. The results are shown in Table VII, which lists sample size, range, arithmetic and geometric mean FC:TC values. The highest geometric mean ratios occurred on the main arm at reaches 11 (Steveston Island), 6 (Annieville Channel Downstream), 12(Cannery Channel), 8 (Tilbury Island) and 10 (Kirkland Island) with values of .41, .36, .35, .33, and .31, respectively. All North Arm stations had a geometric mean ratio of less than 0.15, with the exception of reach 14 (Queensborough), with a geometric mean ratio of 0.31. This difference in Main Arm and North Arm values may result from the direct input into the Main Arm of fecal bacteria from sewage effluents. Fecal coliform to total coliform ratios were extremely variable, with maximum values of 1.0 occurring in 14 out of 15 reaches examined. The variable ratio between fecal and total coliforms suggests the sporadic input of fecal material into all reaches, and suggests the continued use of the fecal coliform, rather than the total coliform analysis as the most suitable indicator of fecal contamination.

TABLE VII Fecal coliform to total coliform ratios in water samples from Fraser River reaches, 1977.

Reach #	Number of Samples	Range FC:TC Ratios	Arithmetic Mean FC:TC Ratio	Geometric Mean FC:TC Ratio
5	9	.03 - 1.0	.35	.24
6		.06 - 1.0	.43	.36
8	10	.08 - 1.0	.48	.33
9	20	.01 - 1.0	.22	.12
10	6	.08 - 1.0	.40	.31
11	6	.19 - 1.0	.48	.41
12	6	.17 - 1.0	.41	.35
13	7	.15 - .53	.26	.23
14	10	.01 - 1.0	.56	.31
15	9	.00 - 1.0	.35	.11
16	9	.03 - 1.0	.25	.15
17	8	.02 - 1.0	.21	.05
18	22	.00 - 1.0	.21	.10
19	39	.01 - 1.0	.25	.11
22	28	.01 - 1.0	.19	.10

3.4 Results from Other Studies

Clark and Drinnan (26) used a randomized pairs test to test for differences in coliform counts between: a) all coliform data in the study area and the area upstream of the study area to Hope b) all sites in the study area and neighbouring sites plus next neighbours c) several non-neighbouring key reaches.

The data was pooled from 1970 to 1977, and therefore the results do not necessarily represent conditions after the implementation of the Annacis Island sewage treatment plant.

Their results indicated that, from 1970 to 1977, both total and fecal coliforms were higher in the study area than in the reach between Hope and the study area. The random pairs test for total coliforms showed that total coliform counts increased with distance down the Main Arm. Total coliforms in the North Arm increased moving downstream from the trifurcation point to the Oak Street Bridge, and thereafter decreased towards the mouth, presumably due to salt water dilution. The Middle Arm (Reach 22) had lower levels than reaches upstream and the Wood Island reach, and the south side of the Iona jetty (Reach 21) had higher levels than the North side of the jetty (Reach 20).

The limited data available for fecal coliforms showed that the reach downstream of Annacis (Reach 6) and the Deas Island Reach (9) had higher counts than adjacent reaches on either side. Counts at Queensborough Bridge were higher than counts at the Pattullo Bridge, and Oak Street Bridge counts were higher than upstream North Arm counts. Fecal coliform counts in the Middle Arm were lower than those in the North Arm, and were greater south of the Iona Jetty than north of the Iona Jetty. For both the Main and North Arms, there was some indication of marine dilution of fecal coliforms.

Studies on levels of indicator bacteria in the Lower Fraser River have been carried out by Hall et al (44) and the B.C. Research

Council, for the Greater Vancouver Regional District (9-14). Hall et al sampled bi-weekly from February - May, 1973 at several stations in the Lower Fraser River area. They found that the highest coliform counts occurred at North Arm stations with peak values at the Fraser Street Bridge and lower values at downstream stations. Fecal coliform counts measured at the Fraser River station during the study ranged from 3300 to 79,000/100 ml, with an arithmetic mean value of 16,480/100 ml. These measurements were taken before the Annacis Island hookup, and the authors attributed the high North Arm values to discharges at New Westminster and Sapperton. Hall et al found that the fecal coliform to fecal Streptococcus ratios were greater than 4 at all stations except Pattullo Bridge and Garry Point, indicating human sources as the major input of fecal contamination. They also analyzed previous Greater Vancouver Sewage and Drainage District data and observed that the lowest values occurred in June and July during high runoff. The most frequent occurrence of higher values occurred in September and October, corresponding with increased rainfall, decreased river flow and water temperature.

Hall (43) investigated water quality conditions, including fecal and total coliform concentrations, at Williamson Slough, Development Sidechannel, and three stations in Ladner Sidechannel from June, 1976 to May, 1977. Values at Williamson Slough ranged from <2 to 790 fecal coliforms/100 ml, with a geometric mean for 10 samples of 149/100 ml. Four measurements taken at Development Sidechannel between January and May, 1977 ranged from <2 to 350 fecal coliforms/100 ml, with a geometric mean value of 100/100 ml. Fecal coliform values for 10 measurements at each of three stations in Ladner Sidechannel ranged from < 2 to 35,000/100 ml (g.m. = 761/100 ml), <2 to 1700/100 ml(g.m.= 308/100 ml) and <2 to 1700/100 ml) (g.m. = 122/100 ml). Fecal coliform to total coliform ratios were generally high at these sites, indicating fecal material as the predominant source of coliform bacteria.

The sample size in this study was not large enough to determine the presence or absence of seasonal patterns in coliform concentrations at the slough and sidechannel sites.

The B.C. Research Council (9,14) carried out studies for the Greater Vancouver Regional District which specifically investigated water quality conditions in the vicinity of major sewage treatment plant effluent inputs. They found that total and fecal coliform counts within the zone of influence of the Lulu Island (Gilbert Road) STP were extremely variable, with higher counts usually occurring in surface rather than in depth samples. Fecal coliform counts ranged from a low of 54/100 ml at Canoe Pass to a high of 17,000/100 ml at a site below Shell Road. At any particular site, high total coliform counts did not necessarily coincide with high fecal coliform counts perhaps due to the presence of agricultural wash from tidal flapgates and pumping stations in the Shell Road area (7). Studies carried out by the B.C. Research Council near Iona Island in 1973 (10) showed that the distribution of coliform bacteria in water followed the effluent pathway, with the highest values occurring near the outfall. Very high concentrations were noted in the sediment along the south side of the Iona Jetty. Further investigations (13) showed that the highest concentrations of coliform bacteria in sediments occurred directly beneath the effluent plume. Values in March and October, 1974 ranged from 6.1×10^4 to 2.0×10^6 and from 2.5×10^3 to 1.1×10^5/100 g sediment dry weight, respectively; the decrease in coliform numbers in October was thought to result from effluent chlorination during the summer months. The authors noted that the survival time in seawater was sufficient to permit a coliform buildup in sediments, and that *E. coli* appeared to adsorb preferentially to finer silt particles. They concluded that the survival of fecal coliform bacteria in bottom sediments was likely related to nutrient availability.

The B.C. Research Council carried out fecal coliform surveys at sites near Annacis Island before and after the hookup of the Annacis Island sewage treatment plant (9,12,14). Values ranged from 790 to 5400/100 ml in April, 1973 and from 330 to 2200 in September, 1973. When these sites were revisited on four sampling trips from July to December, 1975, there were no detectable changes in water quality under average and high flow conditions. However, under winter low flow conditions fecal coliforms were higher than previous levels (values as high as 160,000 fecal coliforms/100 ml). The authors noted that fecal coliform counts in the vicinity of the Annacis Island sewage treatment plant were frequently above the maximum recommended level for recreation (4000/100 ml).

Studies were carried out by the Water Quality Branch (24) and Water Investigations Branch (3) in 1977 to 1978, specifically to provide information required for the design of a monitoring program. The WQB investigated variations in chemical and microbiological indicators of fecal pollution through tidal cycles at four Lower Fraser River sites: Steveston at Buoy S-21, Tilbury Island, New Westminster at the Pattullo Bridge, and the Oak Street Bridge. Fecal coliform counts and total bacterial counts by epifluorescence were measured hourly for 24 hours using shipboard laboratory facilities; the fecal sterols coprostanol and cholesterol were analyzed by gas chromatography upon return of samples to the chemical laboratory.

Fecal coliform counts showed considerable variability with stage of the tide at each site studied. At Steveston, fecal coliform counts ranged from 500 to 2000/100 ml in December, 1977 and from 10 to 750/100 ml in September, 1978. The highest counts occurred on the outgoing tide or near the time of low slack water. The higher values at Steveston on the December sampling trip are attributed to the lack of chlorination at sewage treatment plants and to low river discharge. Data from the December, 1977 trip indicates that changes in fecal coliform counts cannot be correlated with changes in salinity. The Tilbury Island site was sampled in February, 1978 and fecal coliform counts ranged from 100/100 ml to 2300/100 ml.

At certain stages of the tide there were large differences in counts between samples obtained at the surface and at one meter above the bottom; highest counts at both depths occurred on the outgoing tide. Coliform counts at New Westminster were similar at two depths and ranged from approximately 100/100 ml to a maximum of 900/100 ml at high slack tide. Fecal coliform counts from the field trips to the Oak Street station (North Arm) were not useable due to the presence of contaminating bacterial colonies. Subsequent biochemical tests indicated that these bacteria were members of the Enterobacter-Klebsiella group. Epifluorescent counts were not related to fecal inputs and are not recommended for use in a future monitoring program; coprostanol and cholesterol are a potential monitoring tool and will be discussed in the section entitled: 'Suggested Studies'

The Water Investigations Branch survey was part of an interim monitoring program for 1978, to provide information for the design of a full scale monitoring program. They sampled intensively for 3 days in August and 3 days in November-December on cross-sections at Steveston, Annacis Island, and the North Arm at the Oak Street Bridge. The results showed an obvious seasonal difference between the two sampling times, with higher values occurring in the winter at all three locations. Geometric means in August for fecal coliform samples from Steveston, Annacis, and Oak Street ranged from 131-310/100 ml, 113-201/100 ml, and 381-626/100 ml, respectively; geometric means in November-December at the same sites ranged from 2513-3309/100 ml, 113-2025/100 ml, and 1469-1567/100 ml, respectively. Cross-sectional variability was low at all sites except at Annacis Island, during December, where high North Shore values reflected the local influence of effluent from the Annacis Island sewage treatment plant. Statistical analysis of these coliform data showed no significant difference at the 95% probability level in coliform counts due to the time of day that measurements were taken (other than in relation to flow and tidal height) and no difference in samples collected on weekends and weekdays. Two replicates were taken at each sampling time and location on a cross-section; the disparity between certain of these replicate values indicates the difficulty in obtaining a representative value from a small number of samples.

In summary, a published study by Hall et al (44) indicated considerable variability in coliform numbers and showed that coliform counts were higher at North Arm than Main Arm stations before the hookup of the Annacis Island sewage treatment plant. Investigations by the B.C. Research Council demonstrated periodic high levels of coliform bacteria in water and sediments adjacent to certain sewage treatment plant effluents. Studies by the Water Quality Branch and Water Investigations Branch documented tidal, cross-sectional, and seasonal variations, which will be taken into account in the design of a monitoring program.

3.5 Bathing Beach Data

There are several bathing beaches which are located in or adjacent to the Fraser River Estuary study area; these are located at Pitt Lake, Boundary Bay, Tsawwassen Beach, and the University of British Columbia Endowment Lands. Coliform sampling at these bathing beaches is primarily carried out by public health units, which are associated with the B.C.Ministry of Health. These health units serve municipalities such as Cloverdale, Delta, North Delta, North Surrey, and White Rock (Boundary Health Unit); New Westminster, Port Coquitlam, and Port Moody (Simon Fraser Health Unit). The Greater Vancouver Regional District samples at three locations along the Tsawwassen Jetty, and samples the University Endowment Lands for the Boundary Health Unit. The Community Health Service of the Municipality of Richmond samples bimonthly at three beaches in the North, Middle, and Main arms of the Fraser River; these beaches are currently posted as unfit for swimming. The Vancouver beaches, which are not in the study area, are under the jurisdiction of the Health Department of the City of Vancouver.

There is very little coliform data available for Pitt Lake, the few samples collected between 1974 and 1977 had fecal coliform counts below 20/100 ml. Coliform counts in the Boundary Bay area are described in a report by L.J. Alexander entitled: "Boundary Bay, a Summary of Data on Water Quality and Aquatic Biology" (4).

Fecal coliforms have been measured at several stations near Tsawwassen Beach, and at Spanish Banks in the U.B.C. Endowment Lands. Samples are collected twice a week, at approximately high tide, during months of maximum use (June, July, and August). These data are compared by the Boundary Health Unit with standards set by the B.C. Ministry of Health, which specify that geometric means of fecal coliform counts should not exceed 200/100 ml, and no more than 10% of samples should exceed 400/100 ml, during any consecutive 30 day period. In practice, beach closures occur when geometric means exceed the 200/100 ml standard. The small number of samples collected each month and the inherent variability of coliform data preclude the application of the 10% limit for beach closures.

The location of the five sampling stations in the Tsawwassen area is shown in Fig. 2. Four sampling stations are located along the length of the Tsawwassen Jetty, and one sampling station is located near Tsawwassen Beach, opposite Fourth Avenue. Three stations are monitored by the GVRD, and two stations (including the Tsawwassen Beach station) are monitored by the Boundary Health Unit. For the purposes of this study, the five stations were grouped and the area they encompassed treated as one reach; there were no obvious spatial differences in fecal coliform values. Arithmetic means, geometric means, and 90 percentiles have been calculated for each month of sampling in the period 1973-1977 (Fig. 13). The data show that all geometric mean values were well below the 200/100 ml standard. Ninetieth percentile values of fecal coliform counts did not exceed 400/100 ml, with the exception of July, 1974.

Data from 1976 to 1978 for two stations located near Spanish Banks in the U.B.C. Endowment Lands (Fig. 3) have been grouped and are presented in Fig. 14. Geometric mean values were higher than

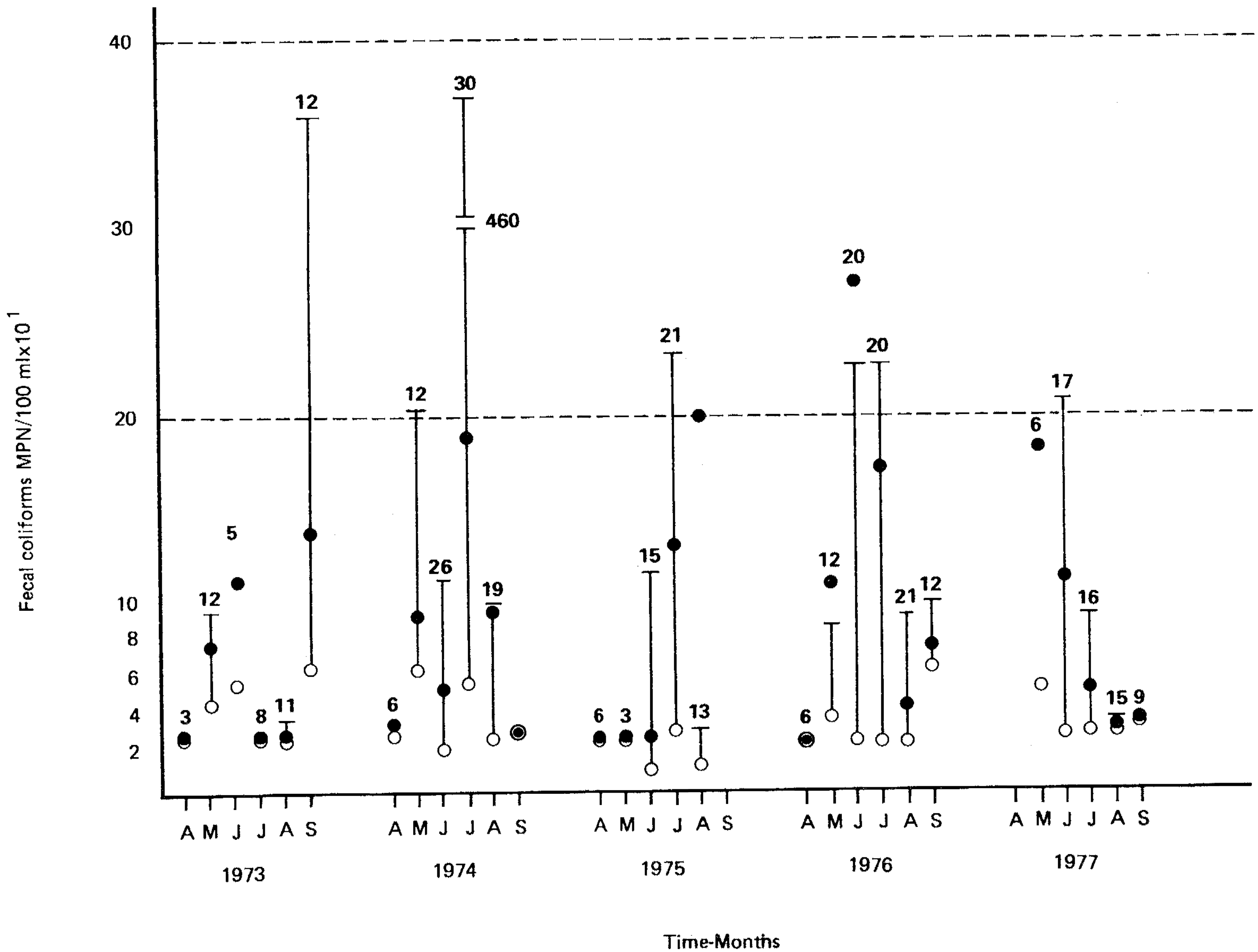


Figure 13 .Fecal coliforms at Tsawwassen Beach and Jetty, 1973-1977. ● -arithmetic mean, ○ -geometric mean. Vertical bar = 90 percentile. Numbers on graph = sample size. Horizontal lines indicate bathing beach standards for geometric means and 90 percentiles.

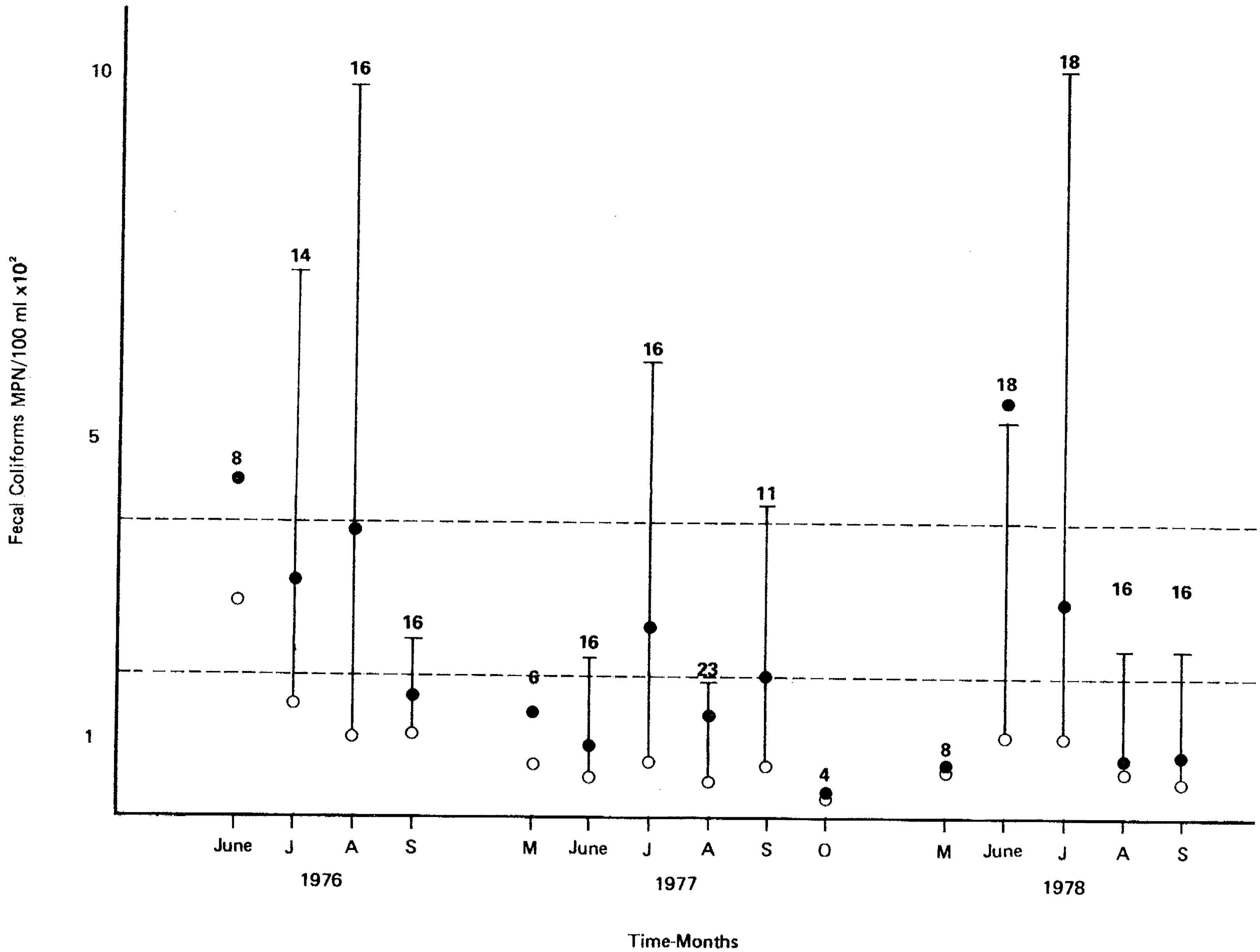


Figure 14 . Fecal coliforms at Spanish Banks, 1976-1978. ● -arithmetic mean, ○ -geometric mean. Vertical bar = 90 percentile. Numbers on graph = sample size. Horizontal lines indicate bathing beach standard for geometric means and 90 percentiles.

those at Tsawwassen and exceeded the 200/100 ml standard in June, 1976; ninetieth percentile values occasionally exceeded the standard of 400/100 ml.

In 1975 Tower Beach in the U.B.C. Endowment Lands was closed due to high fecal coliform levels. The closure resulted from the combined effect of stormwater and septic tank effluent discharged directly to the swimming area, and contaminated surface water discharge from the Fraser River North Arm (45). The beach was reopened in 1976, following corrective measures to eliminate the septic tank effluents.

In summary, the bathing beach data for the study area indicated that Tsawwassen beaches are well within safe limits for swimming. Very little data are available for Pitt Lake, and it would appear that this lack of information constitutes a data gap. High 90 percentile values at Spanish Banks are warning signs that these beaches are approaching the borderline of the B.C. Health Standard. It would be of considerable interest to determine whether the influence of the Fraser River North Arm currently results in high fecal coliform counts at other beaches in the University Endowment Lands. It should also be emphasized that the Vancouver beaches, although not in the study area, can be influenced by Fraser River water quality conditions during periods of high flow.

4. DISCUSSION

4.1 Significance of Coliform Levels to Users of the Lower Fraser River

This review of published and unpublished coliform data from the Lower Fraser River has indicated considerable improvement in fecal pollution conditions in the North Arm, and no obvious deterioration of conditions in the Main Arm since the hookup of the Annacis Island sewage treatment plant. Receiving waters close to the Annacis Island sewage treatment plant may have periodically high coliform counts, at high slack tide during winter low riverflow conditions. Chlorination at the major sewage treatment plants, required to keep coliform counts at adjacent swimming beaches within acceptable limits during the summer months, has resulted in large seasonal differences in coliform counts at sites throughout the Lower Fraser River. It should be emphasized that summer and winter geometric mean values would be lower and higher, respectively, than annual geometric mean values, upon which both spatial comparisons between reaches and annual comparisons within each reach have been based.

When fecal coliform counts are compared to various water quality criteria or standards based on use, it would appear that all Lower Fraser River water is unfit for drinking, shellfish harvesting, or swimming, with the exception of the swimming beaches adjacent to the study area at Tsawwassen and Spanish Banks in the University of British Columbia Endowment Lands. Fecal coliform counts at the former beach are well below the established swimming standard of 200 fecal coliforms/100 ml; counts at the latter beach do not generally exceed the geometric mean standard but occasionally exceed the 90 percentile standard of 400/100 ml. Tower Beach, also in the U.B.C. Endowment Lands, was closed for swimming in the summer of 1975.

Reaches 15 and 16 include agricultural ditches which, by the use of floodgates, can transport Fraser River water to agricultural areas for irrigation (27). Irrigation water may also be obtained from two Fraser River sloughs, Cohilukthan and Mason Slough, for which fecal coliform values are not available. Data for reaches 15 and 16 show that annual geometric means are below the fecal coliform criterion for irrigation of 1000/100 ml. However, detailed monthly reach summaries (Fig. B 15, B 16) indicate that annual geometric means were derived from summer values only. Therefore, if irrigation waters are taken from the North Arm in the period October through April, it is not known whether the fecal coliform criterion for irrigation is exceeded during these months. Counts obtained directly from agricultural ditches would be more indicative of irrigation water quality, due to additional inputs such as groundwater and stormwater.

Although it is unlikely that Fraser River water will be used, in future, as a source of drinking water, shellfish harvesting is a potential activity which is currently banned on the banks adjacent to the Fraser River mouth. Although there are very little data available on coliforms in water overlying Sturgeon and Roberts Banks, upstream values are considerably in excess of the current fecal coliform standard of 14/100 ml for waters where shellfish may be harvested. It is unlikely that any of the areas in the Fraser River estuary will be opened for shellfish harvesting due to the input of bacterial contamination from sources which are difficult to identify and control.

A survey in July, 1979 (54) indicated that fecal coliform levels at molluscan shellfish growing areas near Mayne Island exceeded the standard of 14/100 ml. Low salinity values at the sampling sites indicated that high runoff from the Fraser River was responsible for these elevated levels. Further studies (see 4.3.7) are required to define the geographical extent of this problem, to determine whether the elevated levels occur only during high runoff, and to determine what remedial measures are feasible.

No criteria based on epidemiological studies have been established for a major use of the 22 Lower Fraser River reaches, that of aquatic recreation other than swimming. Lacking these criteria, we have compared geometric mean values to aesthetic guidelines (72). Annual geometric means of fecal coliforms for all Fraser River reaches after 1975 were under "heavily polluted" levels of 2000/100 ml, and most reaches were under "distinct pollution" levels of 1000/100 ml. Studies conducted in 1977 to 1978 (3, 24) have indicated that summer values were usually well below 1000/100 ml, and winter counts frequently above this level.

The question will now be asked as to whether the microbial water quality of the Lower Fraser River and adjacent beaches can, with practicable technology, be upgraded to allow the restoration of shellfish harvesting, and to allow the continued safety of the swimming beaches. It can be anticipated that continued population growth in the Greater Vancouver Regional District and the Fraser River valley will result in an inevitable increase in fecal pollution from agricultural sources, storm sewers, and sewage treatment plants. In order to answer this question, it is necessary firstly to examine the relative contributions from major sources of fecal pollution. It was previously indicated in this report that during months of non-chlorination, sewage treatment plants were the principal source of coliform bacteria. It may therefore be concluded that an improvement in microbial quality of sewage treatment plant effluents may significantly improve the quality of receiving waters during the winter months. This conclusion leads to an examination of the effects of various sewage treatment alternatives on effluent quality.

4.2 Effect of Various Sewage Treatment Alternatives on Coliforms in Effluents

Data have been presented in Section 3 of this report which indicate the degree of reduction in coliform counts obtained by present treatment at sewage treatment plants which discharge into the Lower Fraser River. Several different publications (35, 71, 80) review various sewage treatment alternatives and discuss their effectiveness in removing pathogens and indicator organisms. Primary treatment consisting of plain sedimentation without disinfection provides incomplete removal of organisms including viruses, parasites, and bacteria. Laboratory and plant studies on the effects of sedimentation (71) show from 0-69% removal of polio viruses, 50% removal of beef tapeworm eggs, no removal to incomplete removal of E. histolytica cysts, 50% removal of tubercle bacilli, and 27-96% removal of coliform bacteria.

The most commonly used disinfection method in Canada is chlorination. The degree of inactivation of bacteria, parasites, and viruses is dependent on the residual chlorine level, effectiveness of mixing , the contact time between the added chlorine containing compound and the effluent, and the pH during chlorination. Current chlorination practices in B.C. and in Canada generally achieve greater than 99% reduction of coliform numbers. Ninety-nine percent or more of certain tested viruses and parasites can be inactivated by chlorination (71), but the contact times and residual chlorine levels must be higher than those currently used in wastewater disinfection (80). Berg et al (15) observed that quantities of combined chlorine which destroyed >99.999% of fecal coliforms destroyed only 85-99% of the indigenous viruses. Satter and Westwood (67) observed that chlorination of STP effluents discharging into the Ottawa River produced a ten to fifty fold reduction in viruses, leaving a virus loading of 1×10^{10} viruses/day. These studies indicate that low counts of coliform bacteria in chlorinated effluents do not necessarily indicate the absence of a potential public health hazard from pathogenic viruses. Limitations on the concentrations of chlorine residuals remaining in effluents after chlorination are necessitated by the toxicity, both to man and to aquatic life, of certain chlorinated compounds. Current information on toxicity of chlorinated effluents to marine and freshwater organisms has been reviewed by Environment Canada (80). Studies have demonstrated that chlorinated compounds are acutely toxic to fish, and that reactions to these compounds can interfere with normal patterns of spawning and feeding movements. Because of the concern that chlorinated compounds might be deleterious to the salmon fishery on the Fraser River, chlorination is presently limited to the summer months and dechlorination is carried out at both the Annacis and Lulu Sewage Treatment plants. Dechlorination removes residual chlorine and there is some suggestion that effluent that is chlorinated and dechlorinated is less toxic than unchlorinated effluent (80). However, the long-term effect on the aquatic ecosystem of chlorinated and dechlorinated effluent by-products is as yet undetermined.

The various types of secondary treatment processes have different effects on microbial quality of effluents. Laboratory and plant studies (71) indicate that the trickling filter process removes up to 94% of viruses, 30% of beef tapeworm eggs, up to 99.9% of E. histolytica cysts, 45% of tubercle bacilli, and 98% of coliform bacteria. Similar studies (71) indicate that the activated sludge process removes 53 to 99% of viruses, no beef tapeworm eggs, an imcomplete number of E. histolytica cysts, greater than 90% of tubercle bacilli, and 97% of coliforms. Limited data available on the anaerobic sludge process (71) show 54 to 99.999% inactivation of viruses, greater than 50% inactivation of parasites, 70 to 85% removal of tubercle bacillia, and 25% removal of Salmonella.

Generally speaking, the various forms of secondary treatment mentioned above do not achieve the degree of disinfection of viruses, parasites, and particularly bacteria that is obtained by chlorination. Chlorinated secondary effluents may contain chlorinated organic compounds which are toxic to aquatic life, as may chlorinated primary effluents.

In summary, chlorination with or without dechlorination effectively inactivates bacteria, although it is considerably less effective in the inactivation of viruses. The E.L.U.C. Secretariat Report on sewage treatment at Annacis Island (35), the Environment Canada report on Wastewater Disinfection in Canada (80), and a study by Grabow (41) state that high pH lime treatment of effluents, designed for phosphate removal, effectively inactivates viruses as well as coliforms. The various conventional forms of secondary treatment such as activated sludge, trickling filter, and anaerobic digestion are less effective in inactivating bacteria, parasites, and viruses.

Chlorination of effluents would considerably improve the microbial water quality of receiving waters during the winter months. However, during low flows toxic concentrations of chlorinated organic compounds may result in a potential danger to migrating salmon. In the summer months, all effluents from major sewage treatment plants are chlorinated, with a resulting improvement of microbial quality over winter levels. Coliform counts during the summer months suggest that, without a drastic change in coliform concentrations in one or all of STP effluents, storm sewer effluents, or upstream inputs, there is no hope of restoring shellfish harvesting adjacent to the Fraser River mouth. Geometric mean fecal coliform counts at the adjacent Tsawwassen and Spanish Banks bathing beaches are well above the shellfish standard of 14/100 ml, implying that Sturgeon and Roberts Banks would also exceed this standard. Levels of fecal coliforms at several sites in Boundary Bay also exceed the shellfish standard (4).

Meeting the requirements for shellfish harvesting would require extensive changes in processing the effluents from the sewage treatment plants and may well require treatment of storm sewer effluent and upstream inputs (from sources upstream of the study area). It is therefore concluded that, given the present effluent treatment technology and diversity of inputs into the Lower Fraser River, shellfish harvesting is not currently a feasible use of the estuary.

4.3 Recommendations for a Fraser River Monitoring Program

4.3.1 Complexities in System which Affect Dispersal

Before the various alternatives for a monitoring program design are explored, we will develop a conceptual model which attempts to describe the behaviour of coliform bacteria from source to sink in the Fraser River estuary. Many of the pathways in this conceptual model are based on extrapolation from studies on other estuaries, and on results from laboratory studies which investigate the effects of environmental variables on the growth of pure cultures of coliform bacteria. The conceptual model is illustrated by a simple diagram in Figure 15.

Major inputs of fecal coliform bacteria to the Lower Fraser River are effluents from sewage treatment plants, storm sewers, combined sewer outfalls and river water upstream of the study area.

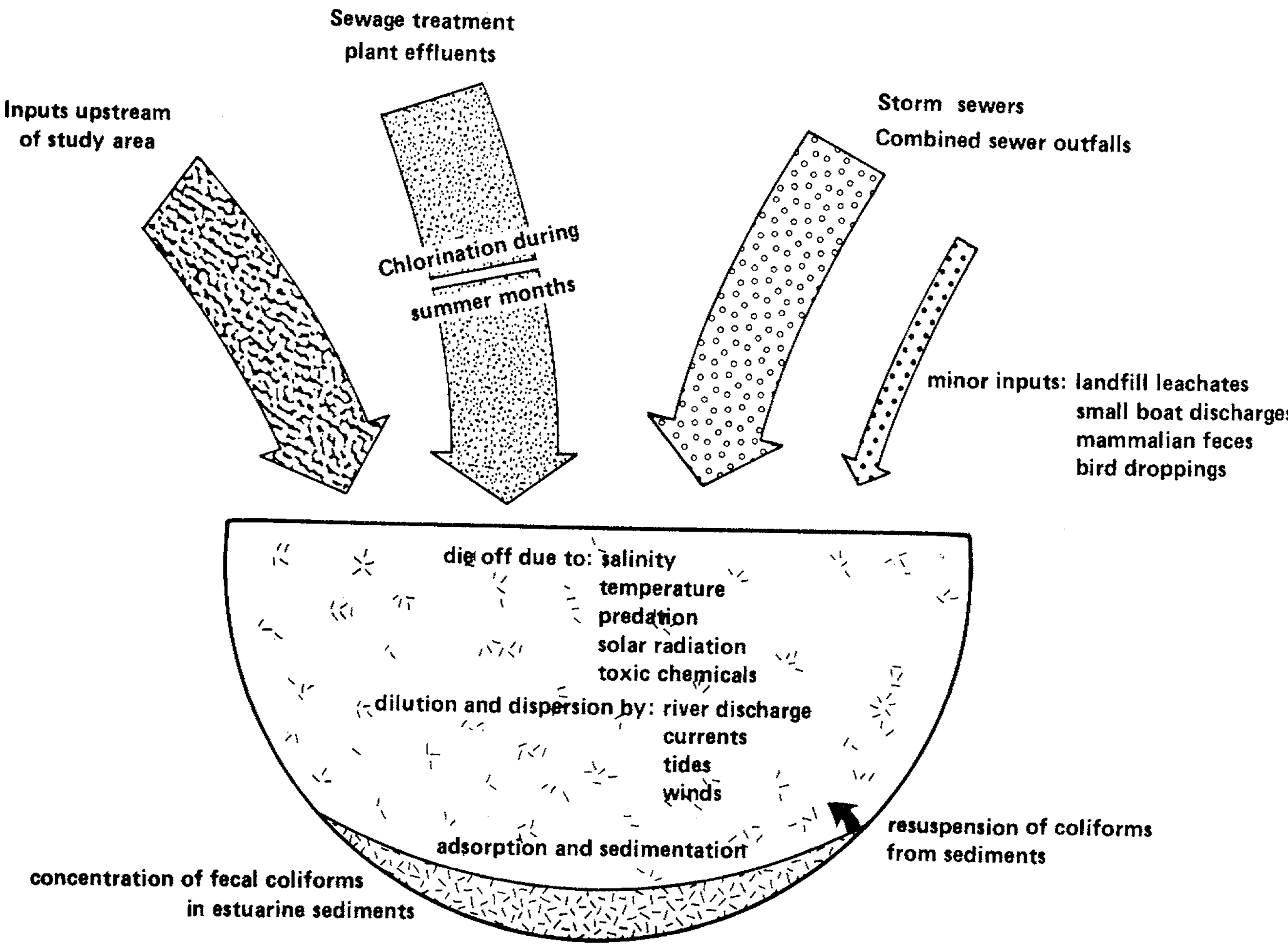


Figure 15. Conceptual model of fecal coliforms in the Lower Fraser River.

Minor sources of fecal coliforms are landfill leachates, bird droppings, feces of marine mammals, and discharges from boats. Coliform bacteria may survive in estuarine sediments, resuspension of which may increase coliform concentrations in overlying waters. With the exception of STP effluents, these sources of coliform bacteria generally receive no treatment prior to discharge into the Lower Fraser River.

The ratio of coliform bacteria to specific pathogens in effluents will depend on the nature of the input and the treatment given to each discharge. For example, the most consistent ratio is found in municipal effluents from large metropolitan areas (20), because enteric pathogens occur at more or less constant concentrations in high density populations. Subsequent to chlorination, differential mortalities will alter the ratios of fecal coliforms to pathogens. The greater the number of small point sources such as septic tank effluents or boat discharges, the more inconsistent the ratio between fecal coliforms and pathogens; for example, the septic tank discharge from the home of a single infected individual may result in an abnormally low ratio. Storm sewer discharges, which may contain fecal coliforms of animal origin, will have a different fecal coliform to pathogen ratio than inputs from human sources. In summary, the diversity of sources and treatment of fecal inputs implies that no consistent ratio between fecal coliforms and pathogens can be assumed to exist in Fraser River receiving waters.

The fecal outputs described above will be dispersed and diluted at varying locations in the estuary dependent on river discharge, tide, and wind conditions. Modelling studies of mass transport of pollutants under tidally averaged and tidally varying conditions have been carried out by Joy (51). Ages (1,2) and Hodgins (48) have investigated tides and salt wedge intrusion into the Lower Fraser River. The B.C. Research Council (9, 14) has carried out dye and drogue studies to describe effluent movements from the major sewage treatment plants at Iona Island, Lulu Island, and Annacis Island.

Water movement studies (10, 13) indicate that wind action is of considerable importance in the dispersal of Iona Island effluents, and under certain conditions counteracts the prevailing northerly current. Winds blowing effluent to the south may create a concentration buildup over a large area of Sturgeon Bank. Under certain conditions, it is probable that Iona effluent may be transferred onto the shores of Western Burrard Inlet and Howe Sound (10).

Water movement studies in the South Arm of the Fraser River (9) indicated that effluent from the Lulu Island STP showed limited lateral mixing, following the North shore in both the upstream and downstream directions. Maximum upstream penetration of Lulu Island STP effluents was 10 to 13 km, with surface water carried onto Sturgeon Bank on an outgoing tide and directly into Georgia Strait on lower low tides.

Several studies have been carried out by the B.C. Research Council (9, 11, 12, 14) on effluent dispersion in the area of the Annacis Island sewage treatment plant. They found that Annacis Island effluents were dispersed, under various conditions, throughout the estuary below the Port Mann Bridge including movement into Annacis Channel, Ladner Reach, and Canoe Passage, as well as limited movement into the North Arm and New Westminster Harbour (13). Dye studies during conditions of low river discharge, no wind, and small tidal fluctuations (13) showed that effluent dilution was usually 100 fold at the outfall, with dilutions less than 10 fold during high slack tide. Residence times of Annacis Island effluents in the estuary were variable dependent upon conditions of river discharge and tide. During freshet, there was no upstream movement of the river (14), and the residence time (with the exception of increased residence times in sloughs and sidechannels such as Ladner Marsh) was the same as the time taken for the effluent to travel downstream into Georgia Strait (11). Except during freshet the distance travelled upstream was more dependent on tidal height at high tide and its difference from the subsequent low tide, than on river discharge (14). The maximum reported upstream incursion of Annacis Island effluents reached the Port Mann Bridge (9). These findings agreed with the model developed by Rusch (66) which predicted that Annacis effluents would not be carried much further upstream than Port Mann on the reverse tidal flow and even under extreme conditions would not enter Pitt Lake. Except during freshet the distance travelled downstream by Annacis effluent was controlled by the difference between high and subsequent low tides (14). The residence time of Annacis effluent in the tidal Fraser River was predicted to be at least three tidal cycles from the point of upstream penetration, and at least two tidal cycles from the outfall site (11). This residence time will be longer during the period when low winter flows combine with one or more low and high tides of similar amplitude (11).

At certain tidal stages and locations in the estuary the presence of the salt wedge may result in a salinity stratification (2) of the water column, which can result in stratification of effluents.

Coliform bacteria and pathogens which have survived primary treatment and/or chlorination may be discharged directly to the Strait of Georgia or be dispersed throughout the estuary and reside for several tidal cycles in the Lower Fraser River. When sewage treatment plant effluents are dispersed in receiving waters, indicator species may be injured, killed or removed by various environmental factors including salinity, temperature, predators, sedimentation, solar radiation, and toxic chemicals. Although dieoff of coliforms in Fraser River receiving waters has not been studied, results from laboratory experiments and investigations on other rivers give some indication of their fate in the estuarine environment.

Roper and Marshall (64) found that "biological control agents", members of the natural microbial population, increased in numbers in the area of a marine sewage treatment plant outfall and decreased in numbers with increased distance from the outfall. Members of the genera *Vexillifera* (amoeba) and *Polyangium* (myxobacteria) were efficient predators of coliform bacteria in laboratory cultures and commonly occurred in seawater contaminated with sewage.

Various investigators (17, 40, 50, 61, 68) have studied salinity, alone and in combination with other parameters, as a factor in coliform dieoff. Brezenski and Winter (17) found that toxicity varied with seawater concentration, and recommended that coliform analysis begin within one hour of sample collection. Jamieson et al (50) found that cultures of E. coli did not survive beyond 5 days at salinities of $5^{0}/oo$, $20^{0}/oo$ and $35^{0}/oo$; at each salinity studied, survival was longest at the lowest incubation temperatures ($4^{0}C > 25^{0}C > 37^{0}C$). Gerba and McLeod (40) found that the addition of sediment to seawater cultures increased the survival of E. coli. Sayler (69) observed that, in an estuarine environment, a significant number of viable bacteria and fecal pollution indicators were associated with particulate material. Savage and Hanes (68) found that, in laboratory experiments, seawater toxicity was affected by biochemical oxygen demand, and demonstrated that fresh seawater with an initial BOD between 1 and 10 mg/l was not toxic to fecal and total coliforms.

Chamberlain (23) developed a decay model for enteric bacteria in natural waters, and concluded that coliform dieoff in seawater is principally the result of light induced cell damage. The coliform decay rate was found to be linearly related to light intensity rather than solely ultraviolet light. The author stated that light may not be the most important contributing factor to coliform dieoff in sediments or extremely turbid waters, and may operate jointly with other factors such as predation.

The above studies show that coliform mortalities in receiving waters can be caused by various interacting environmental factors. Under certain nutrient and temperature conditions, coliforms may reproduce in the aquatic environment (68). It is very difficult to determine whether pathogenic organisms die or increase at the same rates as coliform bacteria, and hence whether coliform bacteria are good indicators of potential disease hazards associated with recent fecal contamination.

To summarize the conceptual model which attempts to describe the pathways of indicator bacteria in the Lower Fraser River, fecal contamination inputs originate from diverse sources which do not necessarily contain fecal coliforms and human pathogens at any consistent ratio. Dispersion studies indicate that, dependent on the location of the sewage treatment plant, various specific areas of the river are affected by fecal inputs; Annacis Island effluents may be dispersed throughout much of the Lower Fraser. Coliform bacteria from sewage treatment plants and other sources may reside for as long as four tidal cycles in the estuary, and are subject to dieoff and possibly regrowth as influenced by physical, chemical, and biological factors such as salinity, sunlight, predation, and sedimentation. Those bacteria which are not previously killed or removed from the water column by sedimentation will reach Georgia Strait, where large volumes of seawater will eventually dilute indicator bacteria to levels below detectable limits. In the process of transport from source to sink, certain coliform bacteria will be carried by combinations of river discharge, tides, currents, and/or wind to areas of recreational use, such as the bathing beaches at the University Endowment Lands or Tsawwassen. The task of a monitoring program is to measure fecal pollution indicators at these sites, and to determine whether there is a health risk to recreational users. If such a health risk exists, pathways of indicator bacteria may be traced and relative contributions from sources examined, in order to implement remedial measures.

4.3.2 General Objectives of a Fraser River Monitoring Program

A general definition of microbial water quality monitoring has been provided by Barrow (8), as: "the regular and systematic measurement of specified microbial populations in the environment to ensure that particular criteria are not only being attained but maintained". The "specified microbial populations" are usually indicator micro-organisms or chemicals which can be quantitatively related to potential health hazards resulting from recreational use, particularly from activities which expose the upper body orifices to the water (20). Water quality criteria or standards are ideally developed from empirically derived relationships between indicator densities and health hazards, dependent on use. The ultimate aim of a monitoring program, as described above, is to identify principal sources of fecal contamination when criteria or standards are exceeded, with a view to eventual remedial action. In the context of the Lower Fraser River, the principal use which entails the risk of disease from waterborne pathogens is swimming, with a considerably lower and unquantifiable risk (perhaps none) from various forms of recreation and industry which bring users into limited contact with Fraser River waters. Given the diversity of inputs and present effluent technology, shellfish harvesting is not currently a feasible use of the estuary. Monitoring for the irrigation water use should best be directed towards sampling the appropriate agricultural ditches, and is not considered in this report.

A general objective for the Fraser River microbial water quality monitoring program may be stated as follows: to monitor various sites in the Lower Fraser River with regard to maintaining microbial water quality at or above a suitable level for the appropriate use, with a view to identifying sources of contamination when critical levels are exceeded. Specifically, the two uses for which it is suggested that the estuary be monitored are swimming and recreation other than swimming (non contact recreation), the former activity assuming more importance than the latter.

4.3.3 Bathing Beach Monitoring Program

a) Objectives

The assumption will be made with regard to monitoring the bathing beaches that until criteria resulting from epidemological studies are developed (18) the current standard of 200 fecal coliforms/100 ml will be used. Beaches at the University Endowment Lands and Tsawwassen will be monitored to determine compliance with these standards, and the relative inputs of fecal pollution to the study area will be assessed in case of a need to implement remedial measures. Due to the complexities of dieoff and regrowth in receiving waters, pathways of fecal material between sources and bathing beaches will not be traced unless standards are exceeded and the source of contamination cannot be identified. Monitoring the quality of inputs to the bathing beaches will logically be confined to the months of maximum use, May through September. These months correspond to the period of chlorination at major STP's, high river discharge, and maximum light intensity; the combined effects of these factors reduce coliforms in receiving waters to well below winter levels. The implications of this approach are that, with regard to bathing beach use, there is no need to monitor the North Arm and Main Arm of the Fraser River and no need to monitor bathing beaches during the winter months. However, assuming a need to define the extent of high winter coliform levels in the North Arm and Main Arm, a monitoring program is suggested to assess receiving water quality during the period October through April. For the purpose of the monitoring program design, "summer" and "winter" are defined as chlorinating and non-chlorinating months, respectively.

b) Parameters

Total and fecal coliforms, historically measured on Fraser River water samples, are currently under some criticism as suitable indicators of fecal pollution. Total coliforms, which do not specifically indicate fecal inputs, have more or less been rejected according to reports in the current literature. While total coliforms err on the side of safety in relatively pristine areas, they provide no information as to the magnitude or likely source of the problem near areas of urban population. There is no sound reason for continuing the measurement of this parameter on samples from receiving waters, bathing beaches, or effluents. The lack of consistent fecal coliform to total coliform ratios in Fraser River water samples further negates the use of total coliforms. The use of fecal coliforms as sole indicators of fecal pollution has also been criticized. Sayler *et al* (69) recommended the re-evaluation of the coliform MPN estimate, and suggested the measurement of specific bacterial pathogens, viral pathogens, and environmental quality indicators. Cabelli (20) stated that the isolation of microbial pathogens from waters used for recreation should be interpreted cautiously in terms of risk assessment, and concluded that there were no good, much less ideal, indicators available. *Escherischia coli* has been suggested as a better indicator than fecal coliforms, and studies by Cabelli et al (18) showed a good correlation between *E. coli* counts and incidence of gastrointestinal disease at swimming beaches. The introduction of a new indicator as a component of a monitoring program requires preliminary studies which relate concentrations of the indicator with concentrations of pathogenic species in effluents and/or receiving waters, and preferably with disease incidence. The investigation of possible indicators to replace or augment the fecal coliform count will be described in the section on "suggested studies." Until more suitable indicator species are defined, the fecal coliform test should continue to be used. Current bathing beach standards are based on the fecal coliform count, and would have to be changed should this test be supplanted. It is hoped that the data collected during a monitoring program would be reviewed annually by a committee with expertise in aquatic microbiology, and that part of the task of this committee would be the recommendation of new indicator species.

This review of published and unpublished information has indicated the need for information on certain physical and chemical parameters to accompany the interpretation of microbiological data from the Fraser River estuary. The necessary information is as follows: sampling time, depth, location, salinity, water temperature, river discharge at Hope, tidal stage, and precipitation. In cases when critical limits are approached or in special studies which attempt to predict unusually high levels of fecal pollution indicators, current direction and velocity should be included in this list.

c) Sites

i) Beaches

Bathing beaches within the study area are located at Tsawwassen, the University Endowment Lands, and Pitt Lake. Examination of data from Tsawwassen shows low and equivalent counts at all five stations and suggests that their number be reduced to the two currently sampled by the Boundary Health Unit. These stations are located near the Tsawwassen Jetty and at Tsawwassen Beach.

Fecal coliform counts at Spanish Banks are considerably higher than those at Tsawwassen and 90 percentile values occasionally exceed B.C. health standards. These results suggest that other sites on the University Endowment Lands should be investigated, particularly popular bathing areas such as Tower Beach and Wreck Beach. It is therefore suggested that either additional locations at Tower and Wreck Beaches be monitored, or that comprehensive surveys be regularly carried out around Point Grey to ensure that the present sampling stations at Spanish Banks provide representative data for beaches closer to the

North Arm of the Fraser River. The current lack of data from Pitt Lake suggests that a preliminary survey be carried out at the bathing beach to determine the location of potential sampling sites.

ii) Inputs

Major inputs of fecal pollution which may affect microbial water quality of bathing beaches are sewage treatment plants, storm sewers, including agricultural ditches and combined overflows, and sources upstream of the study area. It is beyond the scope of this report to describe methods of monitoring effluents or storm sewer discharges, beyond the statement that analytical methods should be consistent for all samples. Although it is impracticable to regularly monitor storm sewers, some attempt should be made to assess their relative importance in comparison to STP effluents and upstream levels, during periods of maximum recreational use of the estuary. Recommendations for measurements of fecal coliforms in stormwater are made in the report by Ferguson and Hall (37).

d) Sampling Strategies

Before the implementation of a monitoring program with a systematic sampling schedule, it is necessary to carry out preliminary investigations of various physical, chemical, and biological factors in the aquatic environment. Rodina (63) states that the selection of sampling locations and the design of microbiological investigations should be preceded by the collection of data on morphometric features, dimensions, depth, geological structure, sediment distributions, and vertical and horizontal composition of the water mass. Barrow (8) states the need for preliminary investigations to determine whether monitoring or surveillance is required, what type of samples to collect and how they should be collected, the location and frequency of sampling, the choice of organisms, and the selection of isolation methods. In the case of certain potential monitoring sites on the Lower Fraser River, the preliminary information may be available from previous published or unpublished studies.

The twice per week sampling frequency for bathing beaches is higher than the five times per month specified by the Federal Water Pollution Control Association (74). This sampling frequency is higher than for any other location in the estuary, and may be adequate to determine whether the standard of 200 fecal coliforms/100 ml is exceeded. However, some intensive work is recommended to determine whether data from these twice weekly collections are representative with regard to stage of the tide, and day of the week. Data should either be collected randomly with regard to these variables, or an intensive study carried out to ensure that there is no difference in coliform counts between tidal stages and days of the week. This is of particular importance at bathing beaches, which are more heavily used on weekends than during the week.

Although an effluent monitoring program will be recommended elsewhere (21) it can be pointed out that, with regard to sampling frequency, the most numerous coliform data available in the study area have been collected from STP effluents. As of January 1, 1979 fecal coliform measurements have replaced total coliform measurements in STP effluents, and effluent samples are analyzed three times per week. It is recognized that it is not feasible to monitor storm sewers regularly and it is therefore suggested that one or more short term intensive surveys be carried out to determine the contribution of storm sewers to coliform levels in receiving waters.

It is suggested that a location near New Westminster be selected for sampling the Fraser River upstream of the study area. There are few previous data available to suggest sampling frequencies and suitable sites. Hourly sampling at two depths near the Pattullo Bridge throughout 24 hours in February, 1978 (24) showed uniform and low coliform counts at two depths with the exception of the period during and after high slack tide. The suggested sampling strategy is, therefore, to sample at one depth on the outgoing tide. Cross-sectional sampling should be carried out, initially, in order to determine whether coliform counts are homogeneous at this site. Previous data for Reach 3 (Pattullo Bridge) does not indicate the sampling frequency necessary to determine a representative geometric mean for the summer months. Using the example of previous data collected on North Arm reaches, 20 to 25 sampling days (primarily during the summer months) per year were sufficient to detect an obvious annual trend. Therefore one can assume that 20 sampling days, randomly selected during the chlorinating months, may be sufficient to obtain a representative seasonal geometric mean for the station at New Westminster. It should be emphasized that New Westminster values will not be compared with swimming standards, but will be collected in order to better estimate relative inputs from upstream sources during the summer months. In particular, should coliform counts eventually rise at bathing beaches and exceed current standards, results from monitoring upstream inputs and effluents and estimating storm sewer inputs may indicate which remedial measures should be implemented. If coliform levels from upstream sources should be consistently lower than other inputs, monitoring at this station may decrease in frequency or be discontinued. If bathing beaches are closed, supplementary information on pathways of fecal coliforms in receiving waters may have to be collected.

In summary, the bathing beach monitoring program should be directed towards measurements of indicator organisms at appropriate beaches during the summer months, and results compared with current standards based on health hazards associated with swimming in areas contaminated by fecal material. Concurrently, sources of fecal contamination should also be measured, in order to a) estimate relative inputs during the summer months;

b) observe changes in concentrations of fecal pollution indicators, to aid in the identification of remedial measures should critical levels at bathing beaches be exceeded.

4.3.4 Non Contact Recreation Monitoring Program

a) Objectives

Monitoring related to bathing beach use will be restricted to the months May to September, when coliform levels in Fraser River receiving waters are low. The limited information available indicates that winter levels in the river may be as high as 2000 to 3000 fecal coliforms/100 ml (3, 24), dependent on location. The question now arises as to whether, given the lack of epidiomiological information on which to base criteria or standards, there is any justification for a winter monitoring program. There are no data available to assess the health risks which users of the river during this period might experience, and such data would be extremely difficult to collect. Examination of current literature does not indicate any concern with the hazards resulting from limited contact with fecally-polluted waters, beyond that of aesthetics. Nevertheless, should the Fraser River during low flow influence shellfish harvesting in the Gulf Islands, a winter monitoring program would be justified. Input from the users of the Lower Fraser River, possibly in the form of public hearings, might be appropriate in deciding the necessity of monitoring microbial water quality during the winter.

In this report we will assume that the various users are concerned that microbiological water quality in the Fraser River be known during the winter months, and a monitoring program will be designed accordingly.

The objectives of a non-contact recreation monitoring program would be as follows. Firstly, the current winter levels of fecal coliforms at various sites in the Main Arm and North Arm would be established; this information has not been supplied by previous data which were mainly collected during the summer months. Secondly, a level of fecal coliforms should be defined beyond which further degradation is unacceptable. Thirdly, selected sites should be monitored during the winter months every year to determine whether degradation of current microbial water quality conditions has occurred and whether the established criteria have been exceeded. The variable occurrence of coliform bacteria in receiving waters would result in the detection of large changes only, probably in the order of 1000 fecal coliforms/100 ml (as was detected in the Fraser River North Arm). Fourthly, if such degradation should occur the advantages and disadvantages of remedial action such as chlorination of sewage treatment plant effluents could be considered. Monitoring of STP effluents and the main stem at New Westminster is recommended to determine relative inputs from these sources. The routine monitoring of storm sewers is not suggested, due to the limitations of current sampling methods.

b) Parameters

The same parameters are recommended as are described in the section on Bathing Beaches, with the provision that these may be replaced or augmented subsequent to concurrent research studies.

c) Sites

Four sites are suggested for the winter monitoring program on the Fraser River estuary: The North Arm at the Oak Street Bridge, the Main Arm at Steveston and Deas Island, and the Main Stem at New Westminster. The first two sites are selected because a) they are downstream of all major inputs (with the exception of the Iona Island sewage treatment plant, primarily a marine discharge), b) previous studies (3) have shown that cross-sections at these locations are homogeneous with regard to coliform counts, c) previous studies (3, 24) have provided information on spatial and temporal variations in microbial water quality at these sites, eliminating the need for preliminary studies. The Deas Island site is selected because a) it is further upstream of salinity and tidal effects than Steveston b) it is the Main Arm reach with the highest fecal coliform counts c) changes attributable to increasing loads from the Annacis Island STP may be observable here. The Fraser River at New Westminster is chosen to allow an estimation of fecal coliform inputs from upstream sources.

d) Sampling Strategies

Studies by Alexander and Drinnan (3) have shown little lateral variability in coliform counts at Oak Street and Steveston, suggesting that intensive cross-sectional sampling is not necessary at these sites. These preliminary studies have indicated the confidence limits associated with the number of samples collected. Six samples on a cross section are recommended for the monitoring program (78).

Alexander and Drinnan indicate that, at the .05 probability level, the mean fecal coliform count from six samples will fall within ± 60% of the population mean. Surface samples only will be obtained, because previous studies (24, 66) and the present data review have indicated that coliform counts in surface waters are equal to or higher than those deeper in the water column. Alexander and Drinnan (3) have shown that day of the week and time of the day do not significantly increase coliform concentrations. There is evidence (3, 24), however, that tidal stage and the effect of tide on direction and velocity of river discharge do influence fecal coliform concentrations at these sites. Therefore, although it does not appear necessary to randomly select sampling times or days of the week, samples should be collected randomly with regard to the stage of the tide. Preliminary studies have not indicated how many daily samples should be collected in order to obtain a representative geometric mean for the winter season. As in the case of the New Westminster station, reference will be made to that sampling frequency which was required to demonstrate a trend in the North Arm. Therefore sampling on 20 days, randomly distributed throughout the months when effluents are not chlorinated, will be suggested as appropriate for monitoring at the North Arm and Main Arm Stations.

Due to the influence of sewage treatment plant effluents on receiving water quality during the winter months, it is recommended that monitoring of fecal coliforms in effluents continue during this period.

In summary, the monitoring program as outlined in this report eliminates some of the coliform sampling which is currently taking place in the Lower Fraser River. The emphasis has been removed from the North and Main Arms of the river and placed on the bathing beaches, and on the identification of relative contributions to the estuary from the various sources of fecal pollution. In the winter months a limited monitoring program is suggested, in order to establish current levels of microbial water quality and to observe gross changes in concentrations of indicator species, should they occur. Major emphasis should also be placed on concurrent research studies, which are required to investigate the addition to or replacement of the fecal coliform test by more suitable indicators of fecal pollution.

4.3.5 Suggested Number of Samples and Man Year Estimates

Due to the impossibility of determining the exact number of analyses required for the recommended preliminary studies, number of samples and man years will be roughly estimated and should be more precisely defined by the agency or agencies which carry out the monitoring program. The sampling program described here suggests the collection of 1534 coliform samples, compared to the collection of 1900 samples in 1976 (a decrease of 20%). Costs, which vary according to the volume of MPN samples processed by each laboratory, have not been assigned for coliform samples. The necessary sampling devices and river transport may be available without cost from one or more of the agencies which are currently sampling on the Fraser River. It is also suggested that sampling devices and vessels be shared between different components of the monitoring program. Estimates will not be made for the monitoring of effluents or storm sewers, which will be considered in the reports which treat these subjects.

4.3.6 Administrative Framework and Review Mechanism

There has been considerable overlap between the various agencies sampling the Fraser River and the bathing beaches adjacent to the river mouth. To avoid unnecessary duplication of effort, it is recommended that one or at most two agencies be responsible for coliform sampling in the estuary, and that data be freely available between agencies. For example, it might be appropriate for GVRD to continue to sample effluents and river stations, while the Health Units continued to sample the bathing beaches.

It is essential to the success of the monitoring program that the data be regularly reviewed and published, preferably by a microbiologist or public health officer on the staff of the responsible

Estimates

Intensive Sampling During Summer Months

U.B.C. Endowment Lands		No. Samples	Man/days
2 surveys around Point Grey 10 sites, 2 replicates, 2 days		40	2
Intensive sampling for tidal effects, days of week 1 station, 7 days, 4 x day, 2 replicates, 2 weeks		112	20
New Westminster			
Cross-sectional sampling 15 samples 2 days		30	2
Pitt Lake			
2 intensive surveys		40	2
Program Design and Data Analysis			10
	Total	222	36

Regular Sample Collections During Summer Months

U.B.C. Endowment Lands		No. Samples	Man/days
5 stations 2 replicates 2 x /week for 22 weeks		440	22
Tsawwassen			
2 sites 2 replicates 2 x /week for 22 weeks		176	22
Pitt Lake			
2 sites 2 replicates 2 x /week for 22 weeks		176	22
New Westminster			
20 x 2 replicates (assuming well mixed)		40	10
Program Design & Data Analysis		———	10
	Total	832	86

Winter Sampling Program		No. Samples	Man/days
4 Sites (Oak Street, Steveston, Deas Ialnd, New Westminster)			
6 Samples/day			
20 days		480	20
Program design and data analysis			10
	Total	480	30

agency.

Additionally, an annual review of the information collected during the monitoring program by a committee with expertise in the field of aquatic microbiology is suggested. Various groups which might be represented on this committee are as follows: the universities, Inland Waters Directorate, B.C. Waste Management Branch, Environmental Protection Service (Aquatic Microbiology Laboratory), B.C. Water Investigations Branch, B.C., Ministry of Health, Greater Vancouver Regional District. The job of this committee would be to assess the information collected during the current year, and review the program for the upcoming year, including the selection of fecal pollution indicators. It is hoped that such an annual review mechanism will reveal changes or trends in microbial water quality, and will ensure a dynamic program which adapts to current developments in the field of aquatic microbiology. A final and necessary component of the Fraser River monitoring program is liaison and cooperation with the research community, including the universities.

4.3.7 Suggested Studies

Ample evidence has been presented to demonstrate that fecal coliforms are not an ideal fecal pollution indicator, and that the use of several indicators may be preferable. The fecal coliform test indicates an incipient problem but does not, in itself, definitely indicate a degree of risk. However, until more suitable fecal pollution indicators are developed, the fecal coliform test errs on the side of safety.

The consensus of various investigators is that regular measurements of pathogenic species such as Salmonella, for which large volumes of water must usually be processed, is impracticable and does not necessarily reflect any real health hazard. Concentrations of indicators do not necessarily correlate with concentrations of pathogenic species. Cabelli (20) states:

> "The question of indicator to pathogen survival and its importance remains a moot point pending the availability of more definitive data obtained under more realistic conditions."

Various microbial indicators have been suggested as alternatives to fecal coliforms. Fecal streptococci are described as a heterogeneous group, with potential sources other than fecal material. Clostridium perfringens can be resuspended from bottom sediments, and Candida albicans is only found in 18% of the population. Cabelli states that Bifidobacteria are potential indicators which need more investigation; Pseodomonas aeruginosa, Aeromonas hydrophila, and coliphages have been suggested but are not consistently associated with fecal wastes. Clostridium perfringens spores, C.albicans, and possibly some mycobacteria may be better indicators of enteroviruses than coliforms. Escherischia coli is preferred to fecal coliforms as an indicator by European workers and some Americans, but is sensitive to chlorination and does not survive as long in natural waters as do enteroviruses.

Metcalf (57) has described the potential use of viruses as fecal pollution indicators. He states that Hepatitis A, the polioviruses, and Norwalk agents (gastroenteritis viruses) are the only members of the more than 100 known viruses in sewage which are strongly suspected of causing diseases transmitted by water. No current culture techniques exist for the detection of hepatitis or gastroenteritis viruses. Current techniques for virus measurement involve the concentration of viruses from as much as 100 gallons of water, followed by 3 or 4 week's incubation of cell cultures. The author states that fecal wastes have the greatest potential for virus transmission to recreational water. He suggests that, although improving methodology may eventually allow the direct examination of water for enteroviruses, bacteria are currently the most acceptable indicators for routine monitoring purposes.

Chemical indicators, in particular the sterols coprostanol and cholesterol, have been suggested as potential fecal pollution indicators (33, 34, 46, 47, 53). The former compound is found exclusively in the gut of warm blooded animals, and has the advantages that it is not broken down by chlorination and is not quickly degraded by environmental factors such as sunlight, temperature, and salinity. For this reason, coprostanol has been suggested as a better indicator than fecal coliforms for the detection of viruses. Studies carried out by the Water Quality Branch (24) have indicated that these sterols are present in measurable quantities at all locations tested in the Fraser River estuary, and that replicate sterol measurements show considerably less variation than replicate fecal coliform measurements. The disadvantages of sterols as fecal pollution indicators are the present high cost of analysis (@ $100/sample), and the lack of information available in the literature from which to derive criteria or standards. Additionally, research should be carried out to establish the relationship between viruses and sterols in sewage treatment plants, and receiving waters.

Ideally, an epidemiological study should be conducted at bathing beaches to determine relationships between various biological and chemical indicators, and disease incidence.

In summary, no indicator currently in use completely meets the requirements necessary for the detection of health hazards associated with fecal pollution in aquatic environments. It is doubtful whether a single ideal indicator exists or will ever exist for the indirect enumeration of bacterial, protozoan, or viral pathogens (57). Continuing familiarity with current research on fecal pollution indicators in other aquatic systems is necessary in order to arrive at a suitable combination of indicators. Meanwhile, use of the fecal coliform test results in a conservative estimate of the potential risks associated with fecal contamination.

Additional research is needed on the ability of bacteria, viruses, and sterols to concentrate in sediments, which may then be resuspended in the water column and pose a potential health hazard. Levels of coliforms, fecal coliforms and fecal streptococci have been observed to be 100-1000 times higher in the upper 2 inches of mud than in overlying waters, and higher coliform levels have been observed in bottom feeding fish than in anadromous fish (77). Salmonellae have also been isolated from bottom sediments with far greater frequency than from overlying waters. Smith et al (70) found that Echovirus 1, Coxsackieviruses B3 and A9, and Poliovirus 1 survived for prolonged periods in estuarine sediments which had been polluted with secondary treatment plant effluents. Various studies (34, 47, 53) have shown that fecal sterols can be bound to particulate material and that higher concentrations occur in bottom sediments than in overlying water.

The concern with pathogens in sediments is particularly relevant to the Fraser River estuary, where dredging is frequent and dredged materials may be disposed on land. Grimes (42) showed that fecal coliform concentrations increased significantly in the immediate vicinity of a maintenance dredging operation in the Mississippi River navigation channel. The increased counts were attributed to the disturbance and relocation of bottom sediments by dredging, and the release of sediment bound fecal coliforms. The association of pathogens and indicators with sediments has not been investigated in the Fraser River estuary, although very high coliform counts have been measured in dredged sediments used as fill.[2] Because of the potential health hazards from fill, beach sands, and resuspended sediments during dredging it is strongly recommended that the adsorption of indicators and pathogens to sediments be investigated. It is possible that sediment bound coliforms may be equally as important as other inputs, should bottom sediments be resuspended near bathing beaches during the summer months.

[2]Hartigan, C.F. Chief Public Health Inspector, Boundary Health Unit, Personal Communication.

Recent evidence (54) of elevated fecal coliform levels near Mayne Island during the summer of 1979 suggests that further studies be conducted to define this problem. It is of particular interest to determine the geographical extent of fecal coliform contamination during periods of high river runoff. It is also necessary to determine whether Fraser River runoff at low flow, when STP effluents are not chlorinated, affects microbial water quality in the Gulf Islands. When these results are obtained, the question should be asked if further treatment, at one or more of upstream sources, storm sewers, or STP effluents will lower fecal coliform levels below the shellfish standard in waters adjacent to the Gulf Islands.

5. SUMMARY

1. Median monthly total coliform levels in sewage treatment plant effluents are in the order of 10^6/100 ml during months of non-chlorination (October-April) and 10^3/100 ml during months of chlorination (May-September).

2. A rough comparison of coliform loadings from sewage treatment plant effluents, storm sewer effluents, and the Fraser River upstream of the study area indicated that STP effluents are the principal source of coliform bacteria during the non-chlorinating months. Further studies would be required to identify relative contributions from these three major sources during chlorinating months.

3. Results from fecal coliform analyses of water from the Fraser River North Arm and Main Arm were grouped geographically into 22 reaches. Annual geometric mean values for each reach were compared to published criteria and standards, according to use. The use most relevant to microbial water quality concerns was found to be recreation other than swimming. (cf Recreation Report, Fraser River Estuary Study).

4. In the Main Arm reaches annual geometric mean fecal coliform values for 1976 to 1977 were invariably below 2000/100 ml and generally below 1000/100 ml. Subsequent to the Annacis Island STP startup, there was no apparent increase in geometric mean coliform levels in reaches adjacent to the Annacis Island effluent pipe. However, high fecal coliform counts may occur near the effluent outfall at low flow during the non-chlorinating months.

5. Annual summaries for all North Arm reaches and the Middle Arm reach indicate that annual geometric mean fecal coliform values have generally changed from above 2000/100 ml in 1970 to 1975 to below 1000/100 ml in 1976 to 1977. This change is attributed to the diversion of sewage effluents from the North Arm to the Annacis Island STP.

6. Results from recent studies and a detailed examination of data from three reaches showed that higher coliform values occurred in winter, when sewage treatment plant effluents were not chlorinated, than in summer.

7. Calculation of fecal coliform to total coliform ratios for Fraser River water samples showed that a large percentage of coliform bacteria originated from fecal inputs.

8. Bathing beach data for the study area indicated that Tsawwassen beaches were well within safe limits for swimming. With the exception of data for June, 1976, geometric mean fecal coliform values at Spanish Banks did not exceed the B.C. Health Standard of 200/100 ml; 90 percentile values occasionally exceeded the B.C. Health Standard of 400/100 ml. Further work is required to establish the microbial water quality of water adjacent to other University Endowment Lands beaches, located close to the Fraser River plume.

9. It was concluded that, due to the diversity of inputs into the Lower Fraser River, it is not presently feasible to meet the stringent bacteriological standard for shellfish harvesting in the estuary.

6. RECOMMENDATIONS FOR FRASER RIVER MONITORING

1. Detailed recommendations for monitoring may be found in the Discussion Section of the Technical Report.

Monitoring during the summer months should be directed towards preserving the quality of the bathing beaches, and towards identifying the relative contributions of STP effluents and upstream inputs to fecal pollution in the estuary. The relative contribution of storm sewers may be assessed by one or more intensive studies. Sampling in the North Arm and Main Arm of the Fraser River is not presently necessary with regard to the bathing beach use.

2. It is recommended that fecal coliform analyses be carried out on all effluent and water samples until more suitable or supplementary indicators are defined.

3. Winter monitoring should be directed towards determining fecal coliform levels in the Main Arm and North Arm of the Fraser River during the period when unchlorinated effluents are discharged into the estuary. Although specific criteria cannot be justified on the basis of measurable health hazards in the study area, a broad upper limit can be established based on aesthetic considerations.

4. It is recommended that, to avoid duplication of effort and maintain the consistency of measurements, one or at most two government agencies carry out the coliform sampling in the Fraser River estuary.

5. It is recommended that the results from the coliform monitoring be reviewed annually by a committee with expertise in aquatic microbiology, to ensure that potential problems are identified and new techniques are incorporated into the program.

6. If possible, the microbiological program should be coordinated with other monitoring programs to reduce manpower and equipment requirements.

7. The current review includes data to the end of 1977. It is recommended that this review be updated at least once every 5 years.

8. It is recommended that the role of sediments in the accumulation and transport of pathogenic and indicator organisms be investigated.

9. It is recommended that the influence of Fraser River runoff on the microbial water quality of shellfish growing waters in the Gulf Islands be investigated.

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APPENDIX A

Yearly summaries of total coliforms in Lower Fraser River reaches.

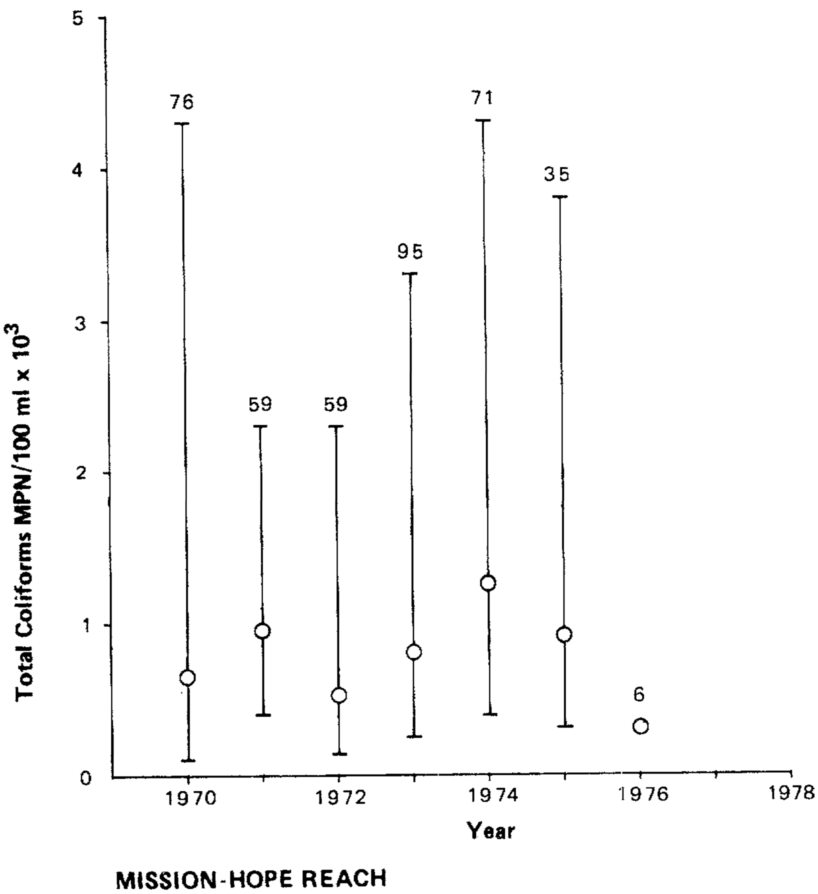
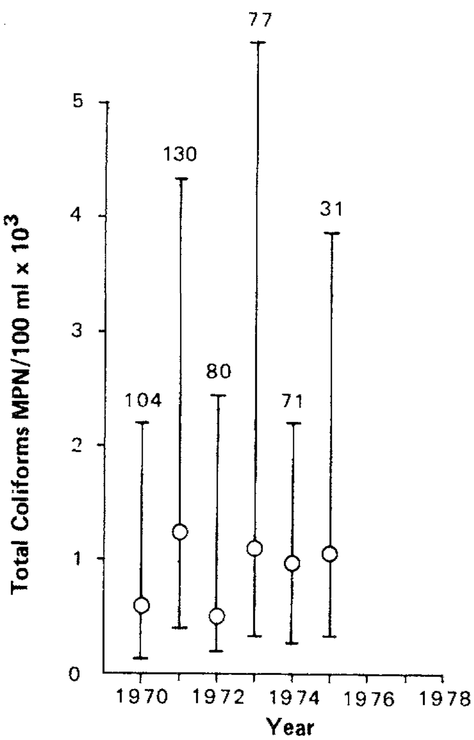
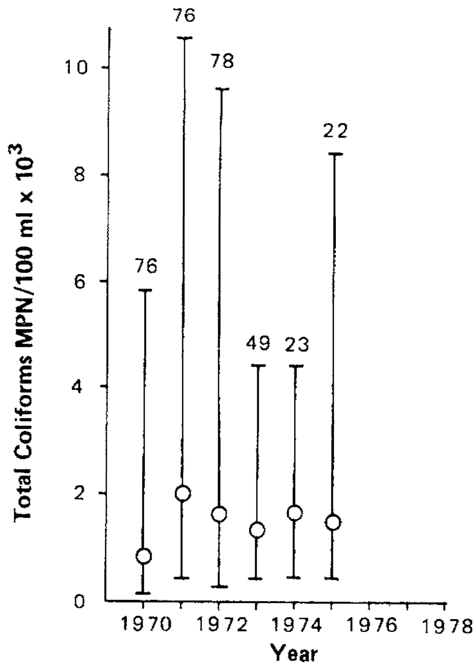


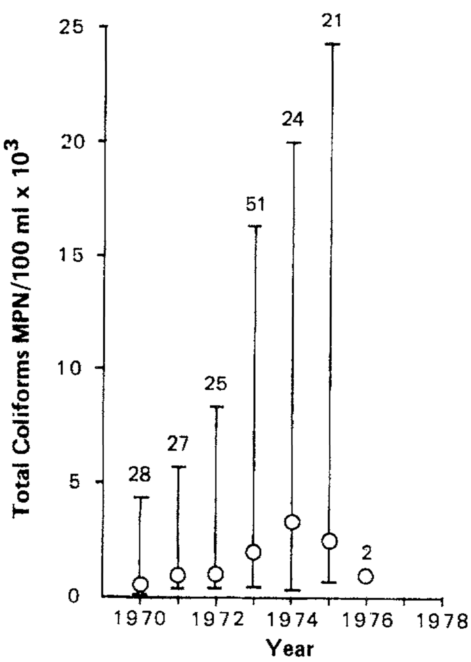
Figure A-1. Yearly summaries of total coliforms at Mission-Hope Reach.
o - geometric mean. Vertical lines indicate the range between 10 and 90 percentiles.
Numbers above the vertical line indicate sample size.



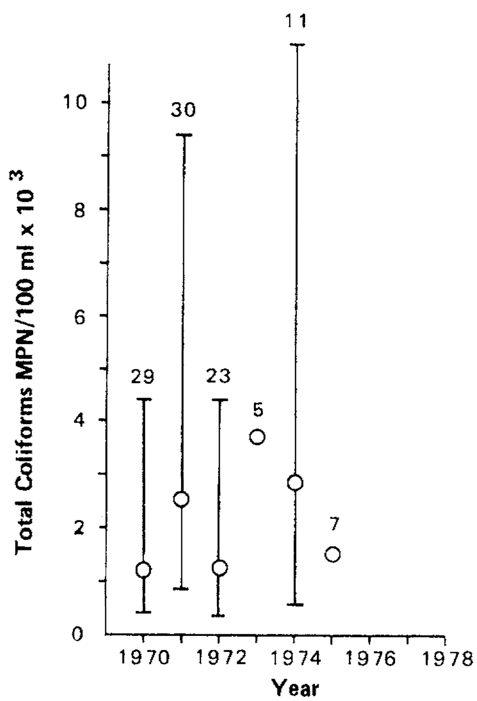
REACH NO. 1, BARNSTON ISLAND



REACH NO. 2, PORT MANN BRIDGE

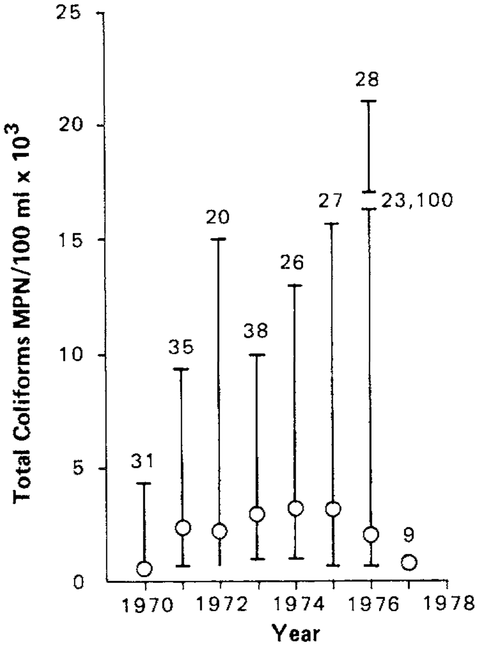


REACH NO. 3, PATTULLO BRIDGE

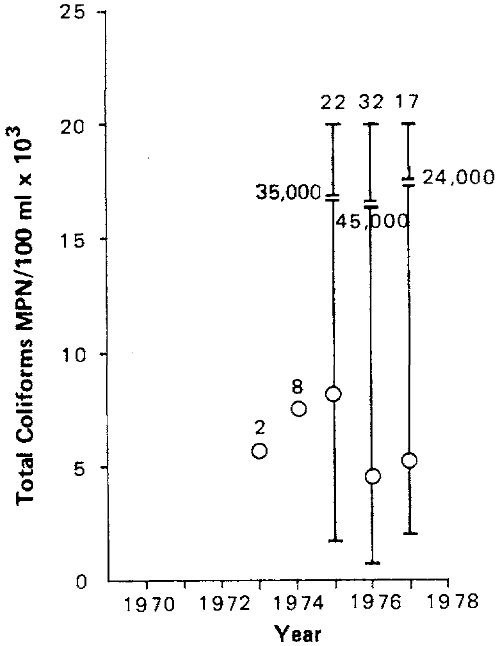


REACH NO. 4, NORTH END ANNACIS ISLAND

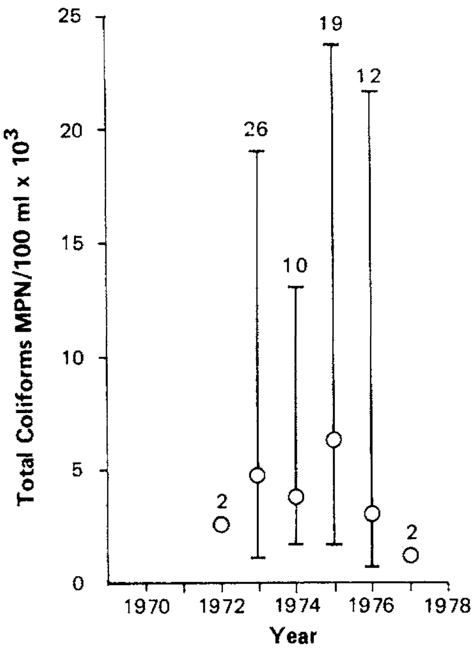
Figure A-2. Yearly summaries of total coliforms at Reach Nos. 1 to 4.
○ - geometric mean. Vertial lines indicate the range between 10 and 90 percentiles.
Numbers above the vertical line indicate sample size.



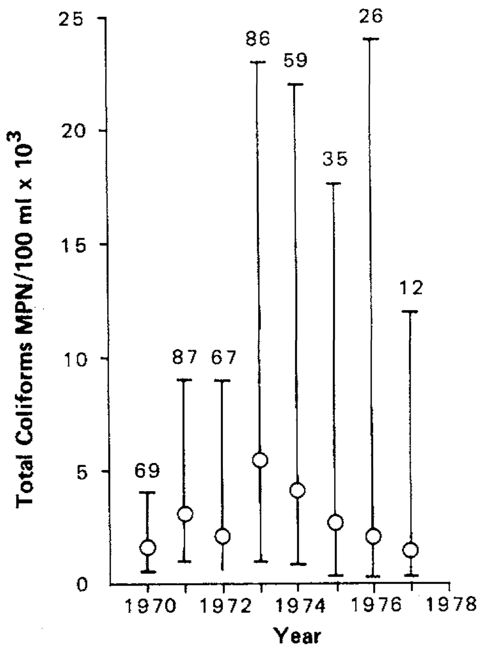
REACH NO. 5, ANNIEVILLE CHANNEL UPSTREAM



REACH NO. 6 ANNIEVILLE CHANNEL DOWNSTREAM



REACH NO. 7, SOUTH END ANNACIS ISLAND



REACH NO. 8, TILBURY ISLAND

Figure A-3. Yearly summaries of total coliforms at Reach Nos. 5 to 8.
○ - geometric mean. Vertical lines indicate the range between 10 and 90 percentiles. Numbers above the vertical line indicate sample size.

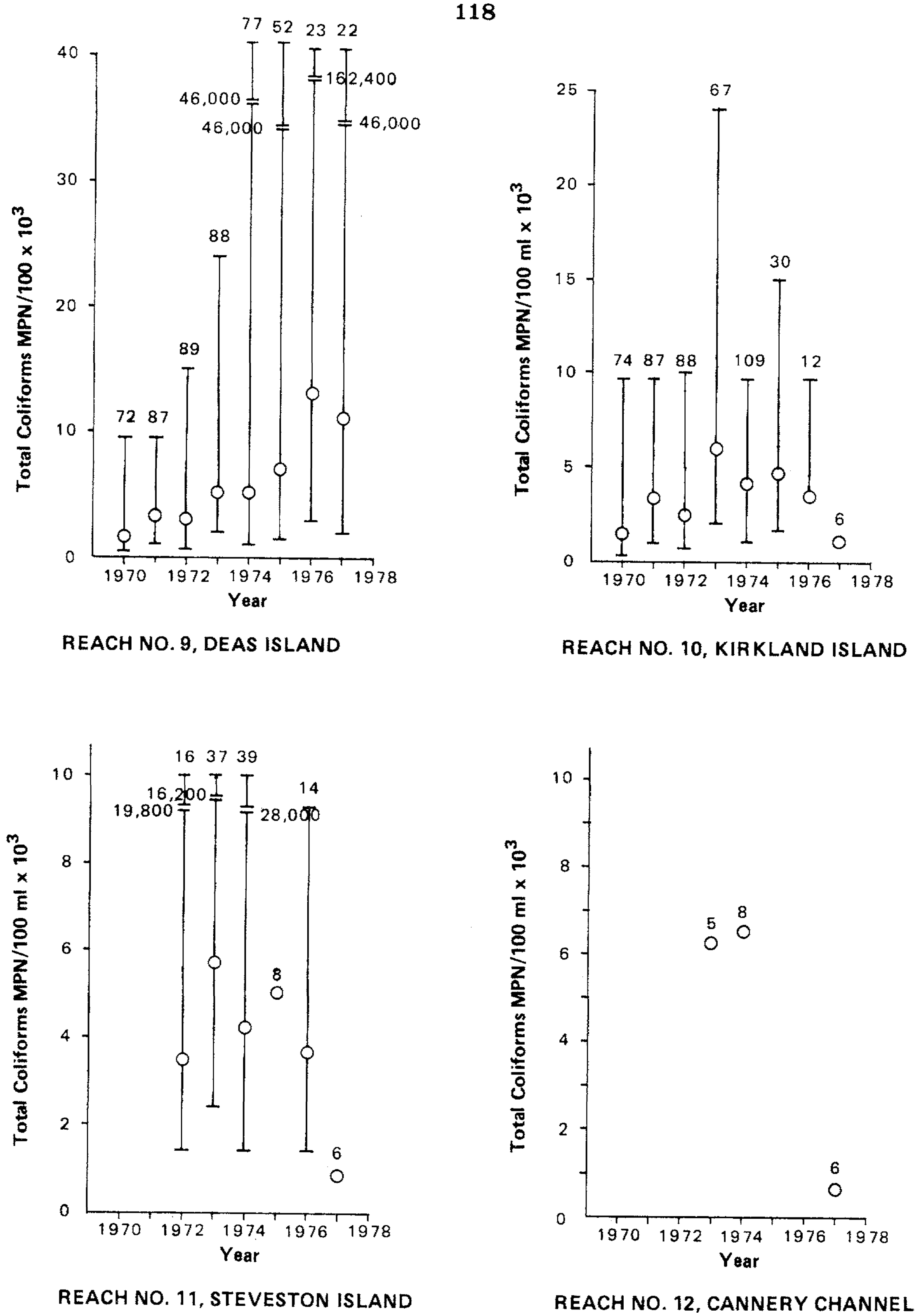


Figure A-4. Yearly summaries of total coliforms at Reach Nos. 9 to 12.
O- geometric mean. Vertical lines indicate the range between 10 and 90 percentiles.
Numbers above the vertical line indicate sample size.

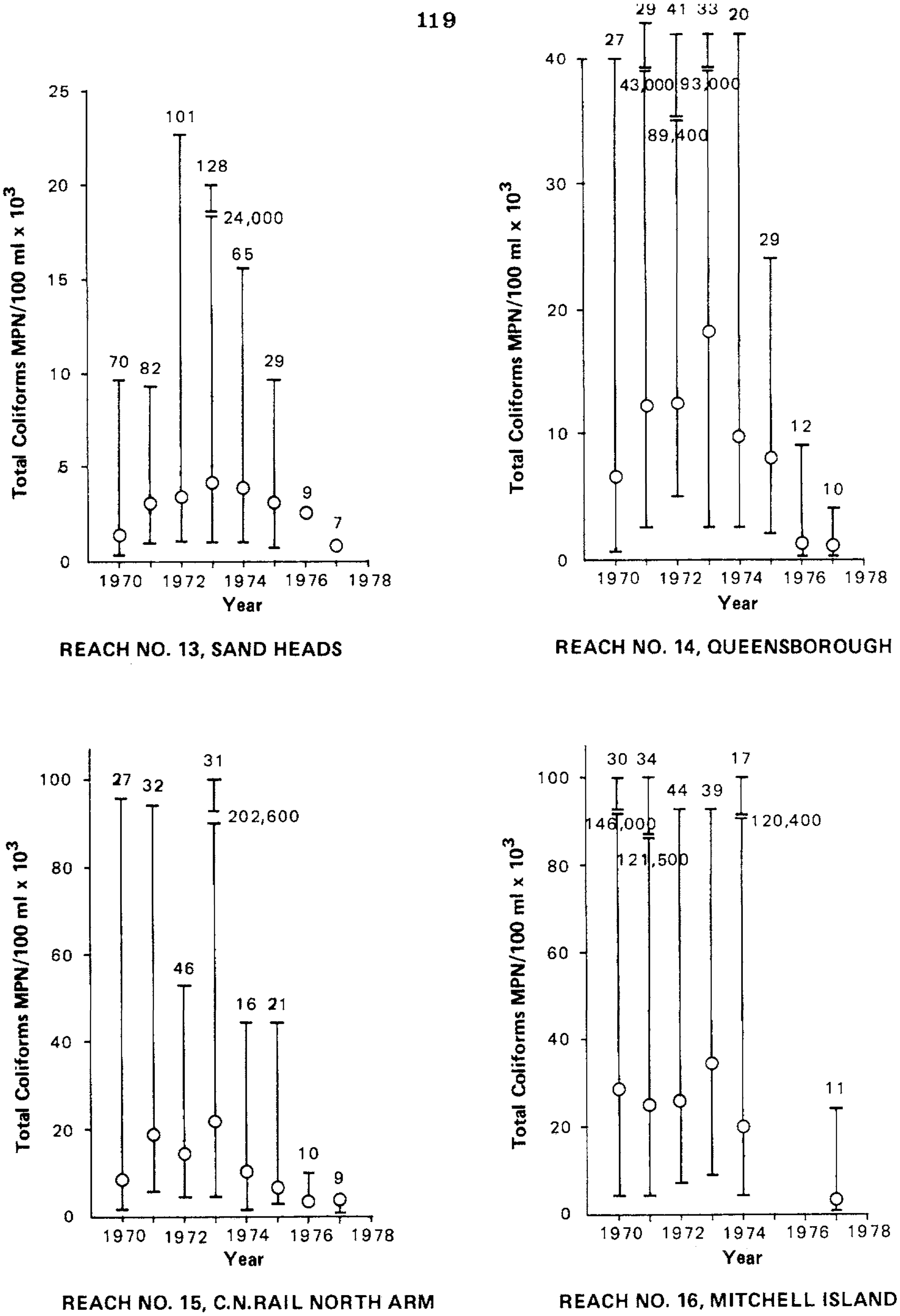


Figure A-5 . Yearly summaries of total coliforms at Reach Nos. 13 to 16.
○ - geometric mean. Vertical lines indicate the range between 10 and 90 percentiles.
Numbers above the vertical line indicate sample size.

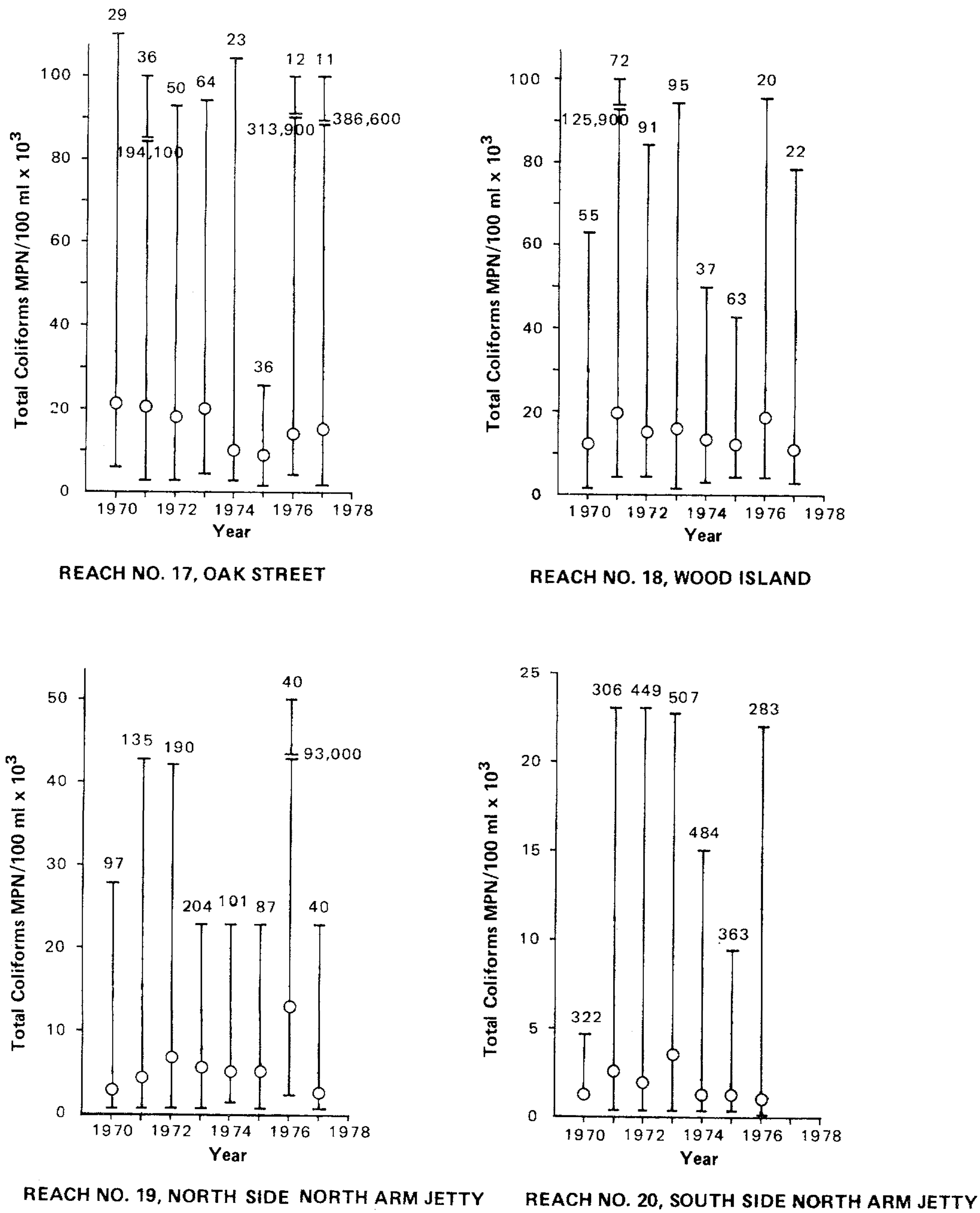


Figure A-6. Yearly summaries of total coliforms at Reach Nos. 17 to 20.
○ - geometric mean. Vertical lines indicate the range between 10 and 90 percentiles. Numbers above the vertical line indicate sample size.

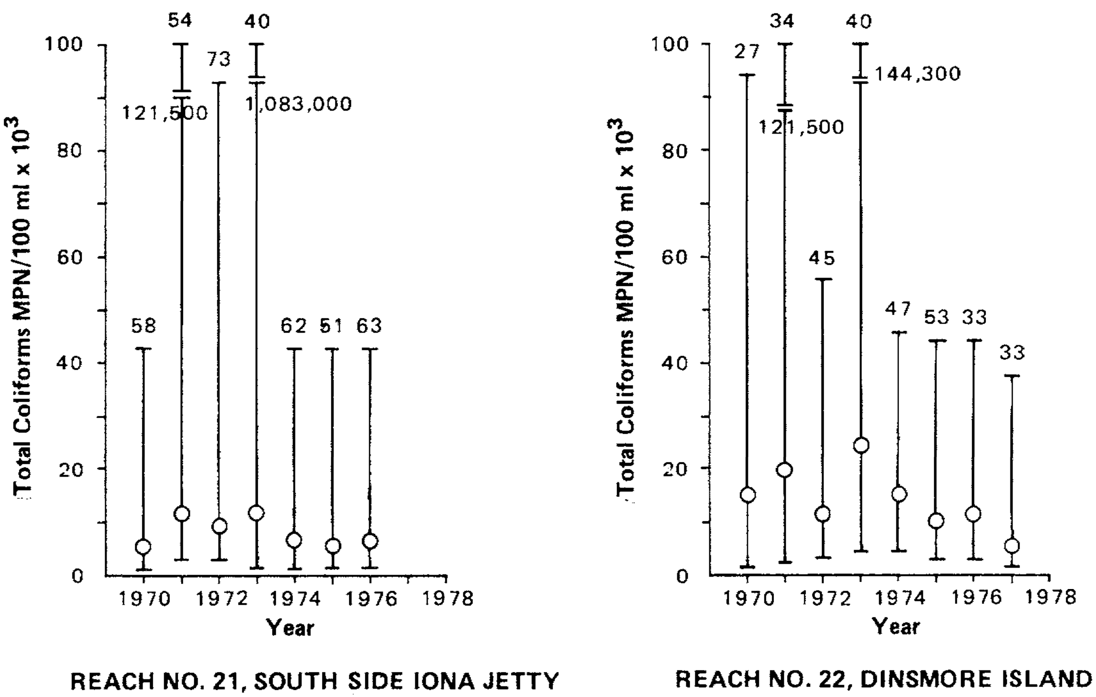


Figure A-7 . Yearly summaries of total coliforms at Reach Nos. 21 to 22.
o - geometric mean. Vertical lines indicate the range between 10 and 90 percentiles.
Numbers above the vertical line indicate sample size.

APPENDIX B

Monthly summaries of fecal coliforms in Lower Fraser River reaches. Symbols may represent means or single **samples**.

Figure B-1 FRASER: MISSION-HOPE REACH
MONTHLY MEANS FOR: COLIFORMS:FECAL

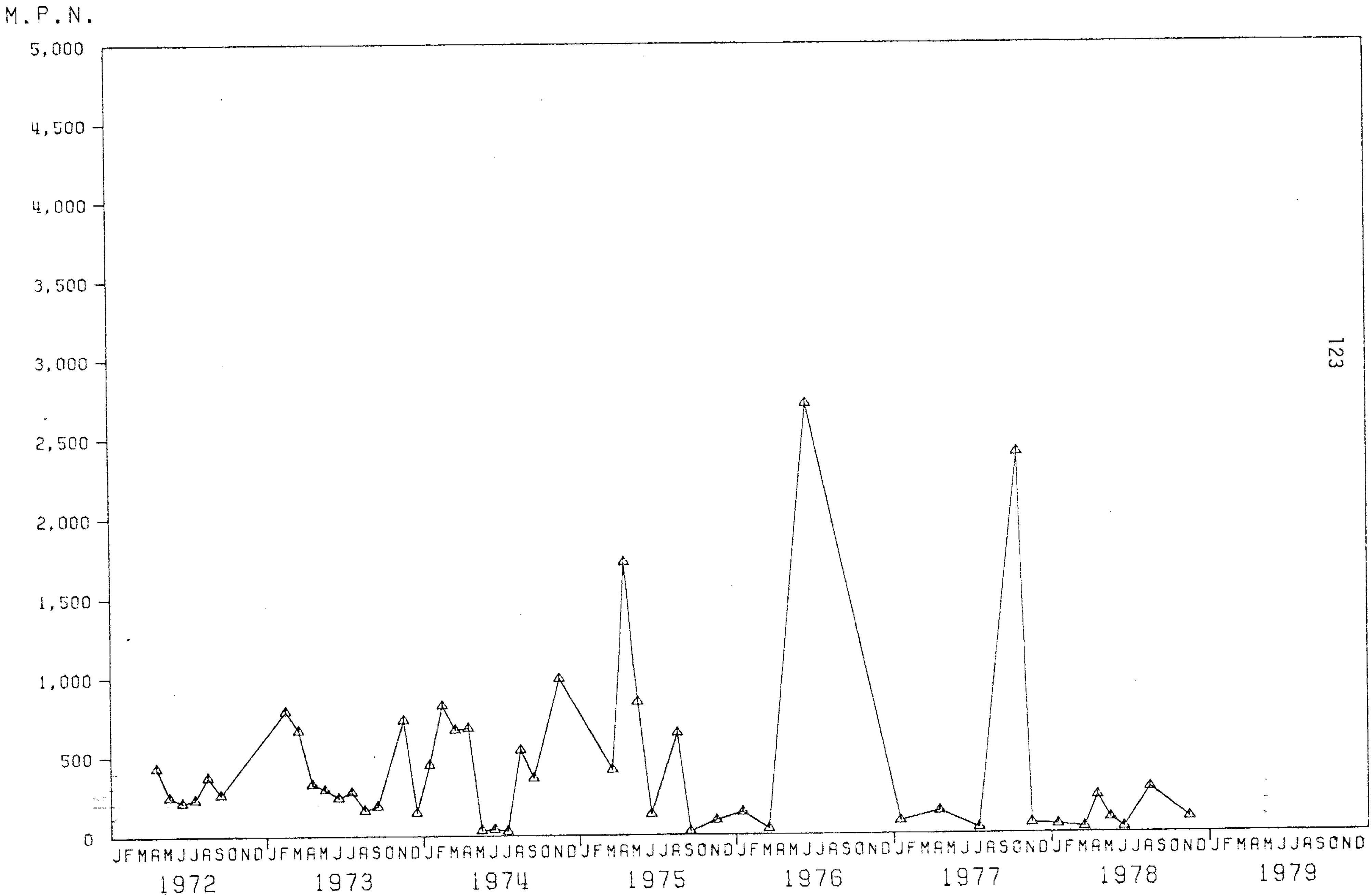


Figure B-2 BARNSTØN ISLAND

MØNTHLY MEANS FØR: CØLIFØRMS:FECAL

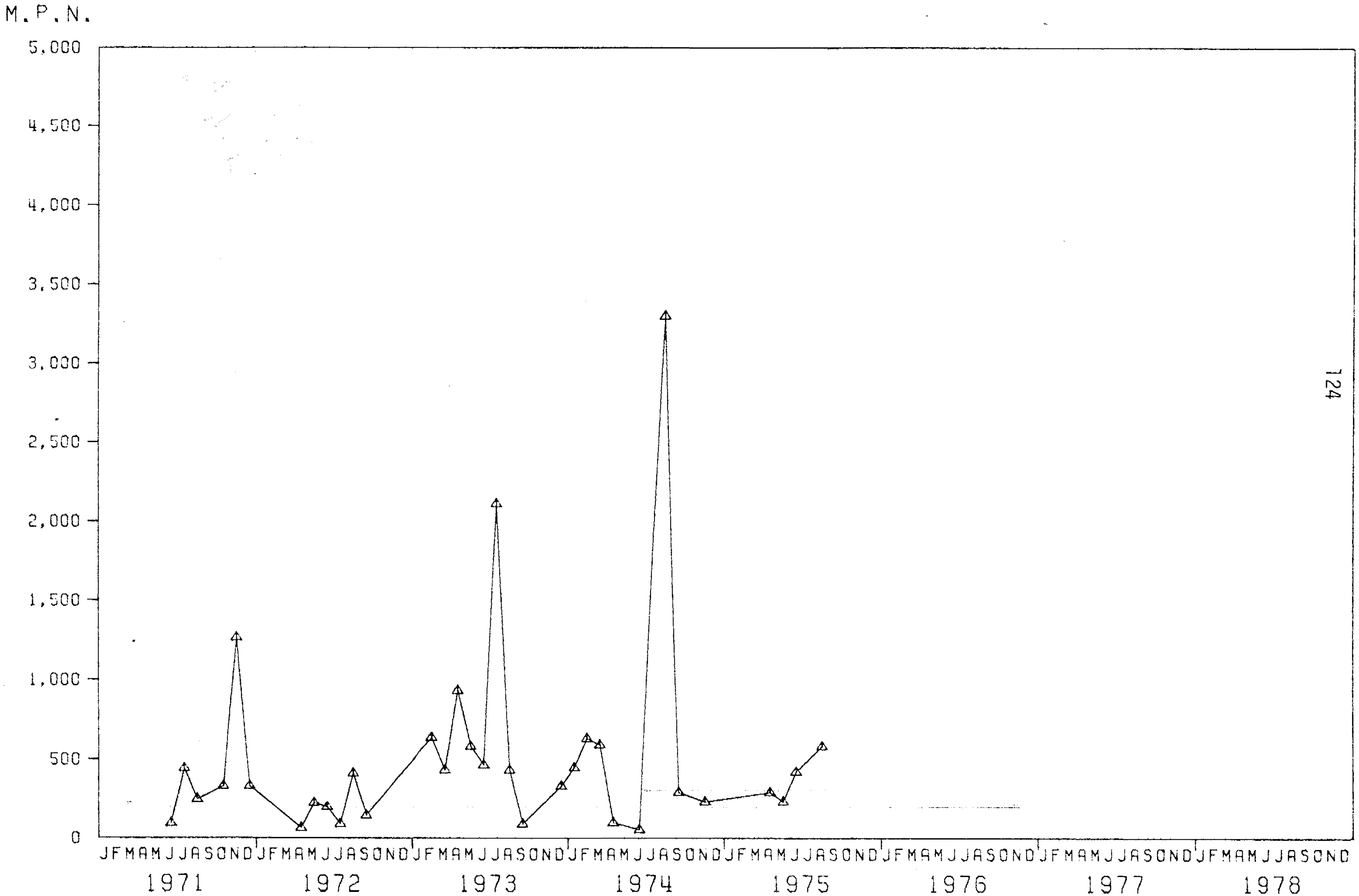


Figure B-3 PØRT MANN BRIDGE

MØNTHLY MEANS FØR: CØLIFØRMS:FECAL

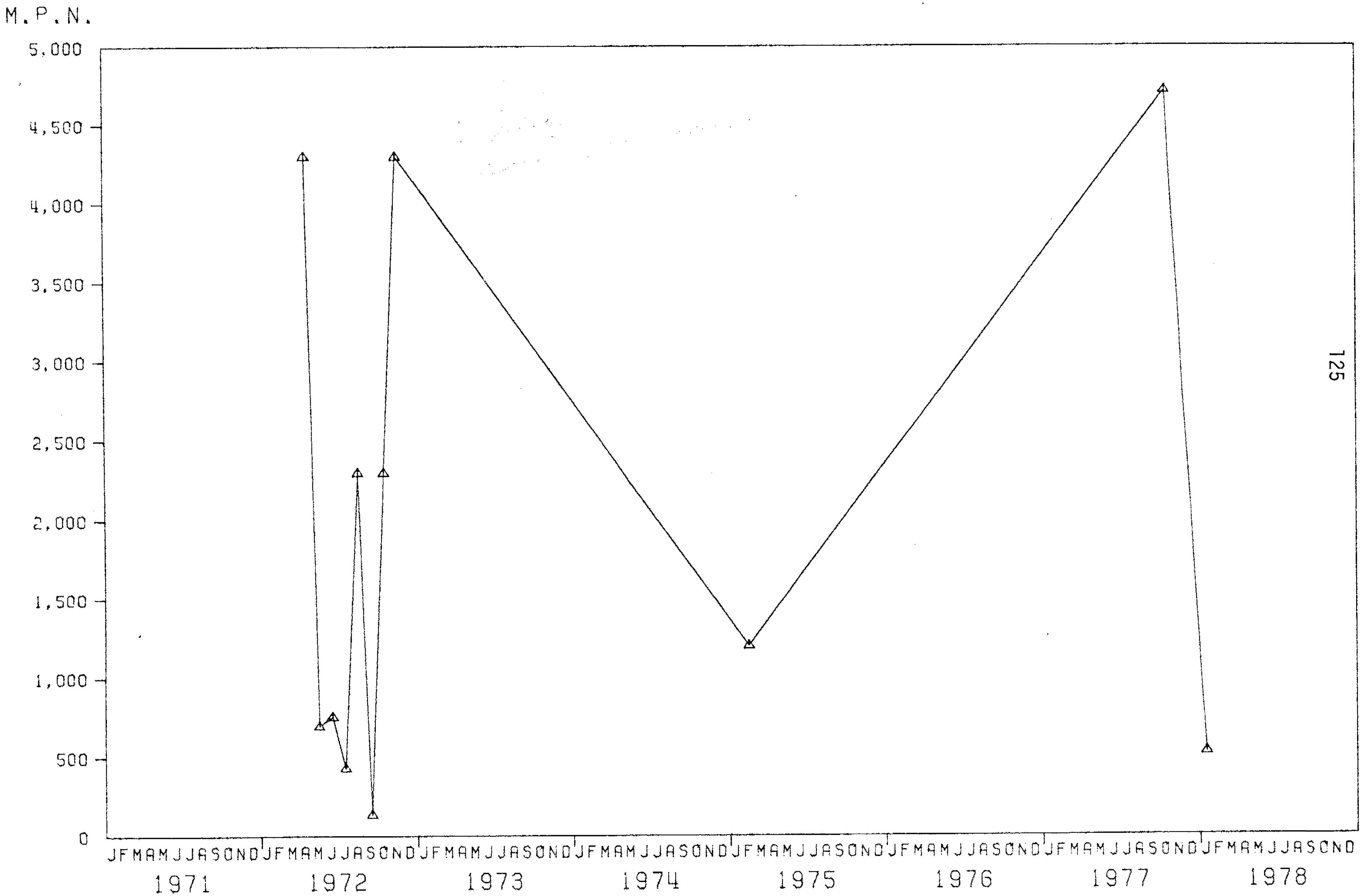


Figure B-4 PATTULLØ BRIDGE

MØNTHLY MEANS FØR: CØLIFØRMS:FECAL

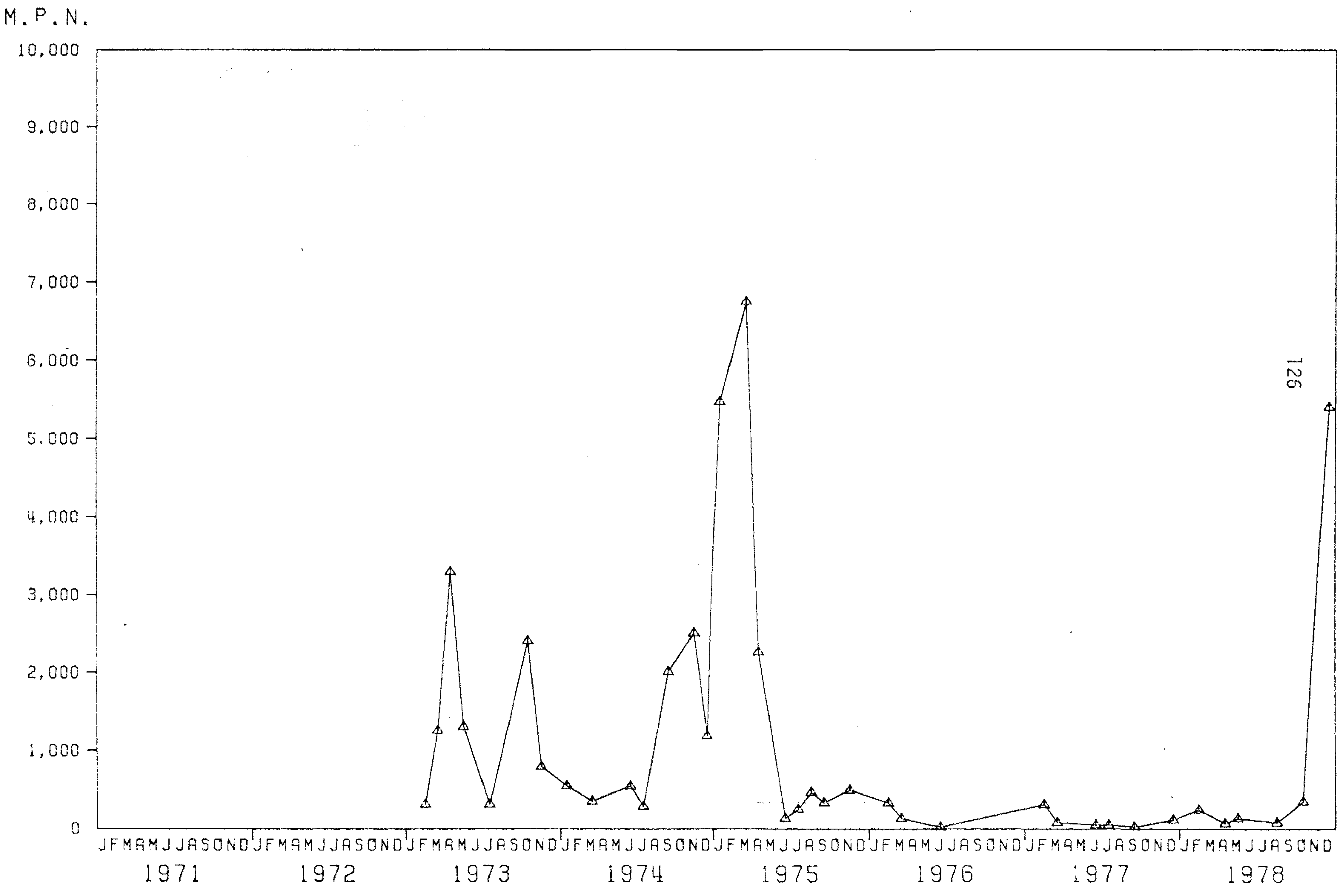


Figure B-5 N. END ANNACIS ISLAND

MONTHLY MEANS FOR: COLIFORMS:FECAL

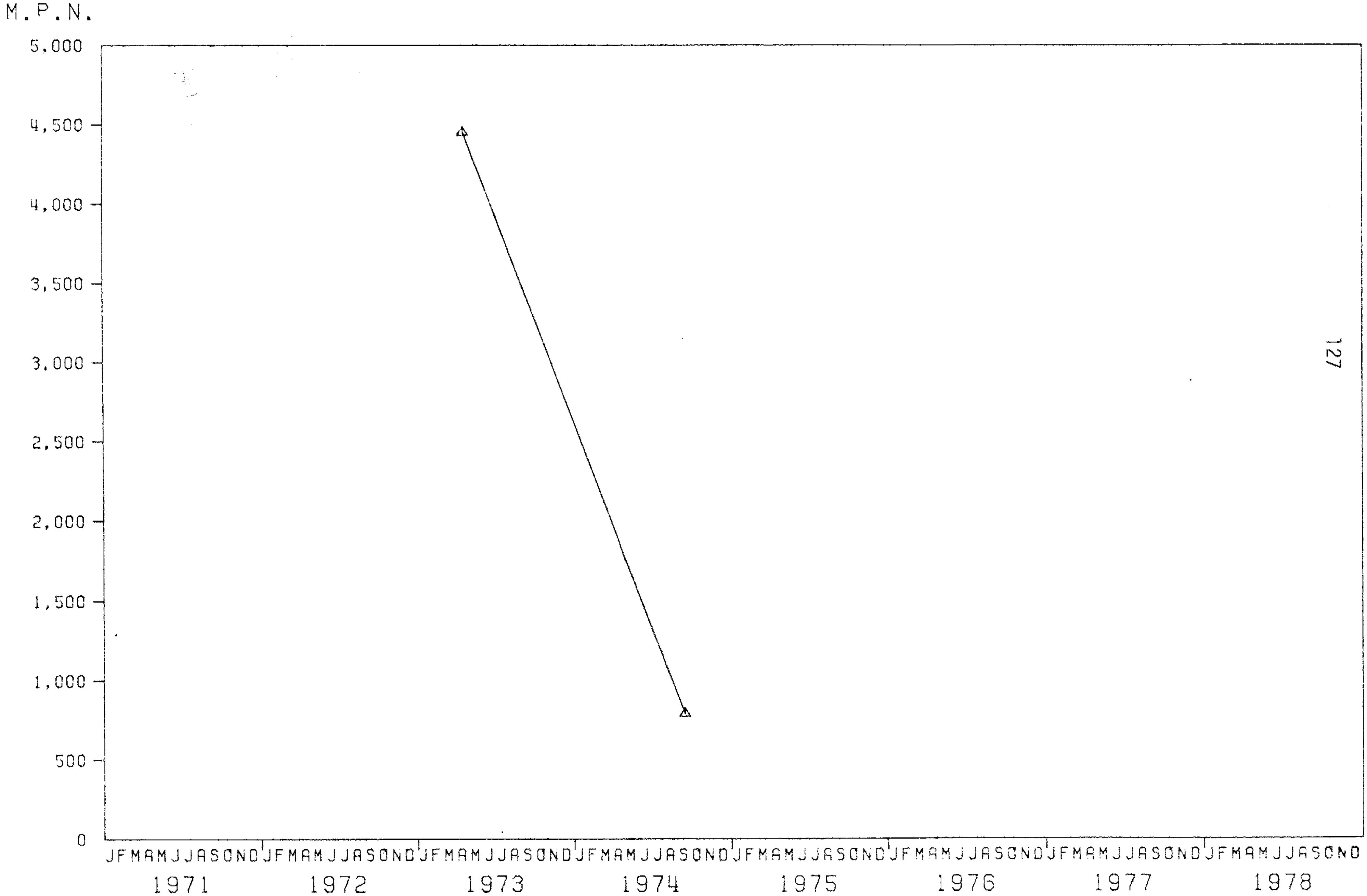


Figure B-6 ANNIEVILLE CHAN. UPSTREAM

MONTHLY MEANS FOR: COLIFORMS:FECAL

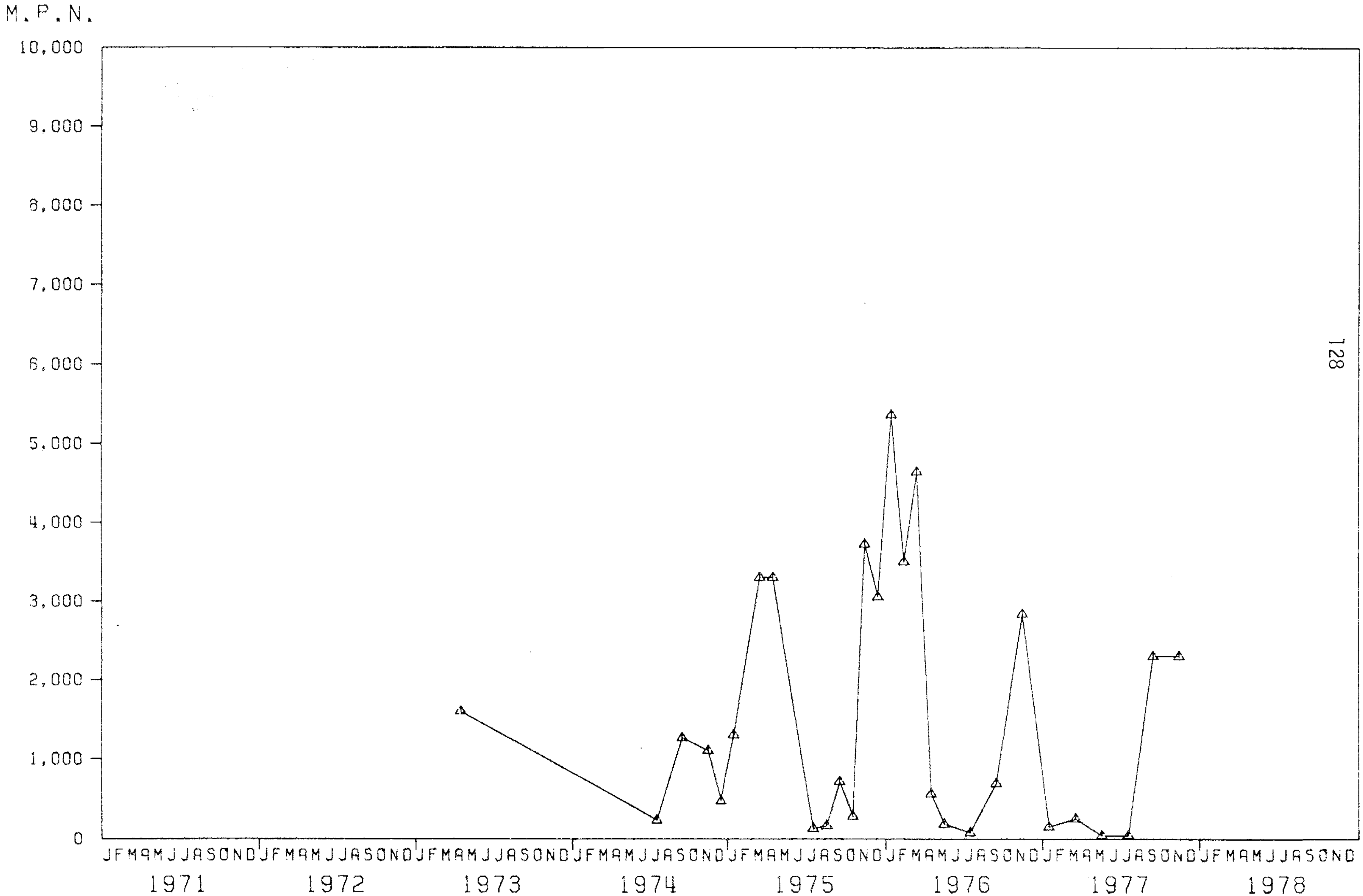


Figure B-7 ANNIEVILLE CHAN. DØWNSTR.

MØNTHLY MEANS FØR: CØLIFØRMS:FECAL

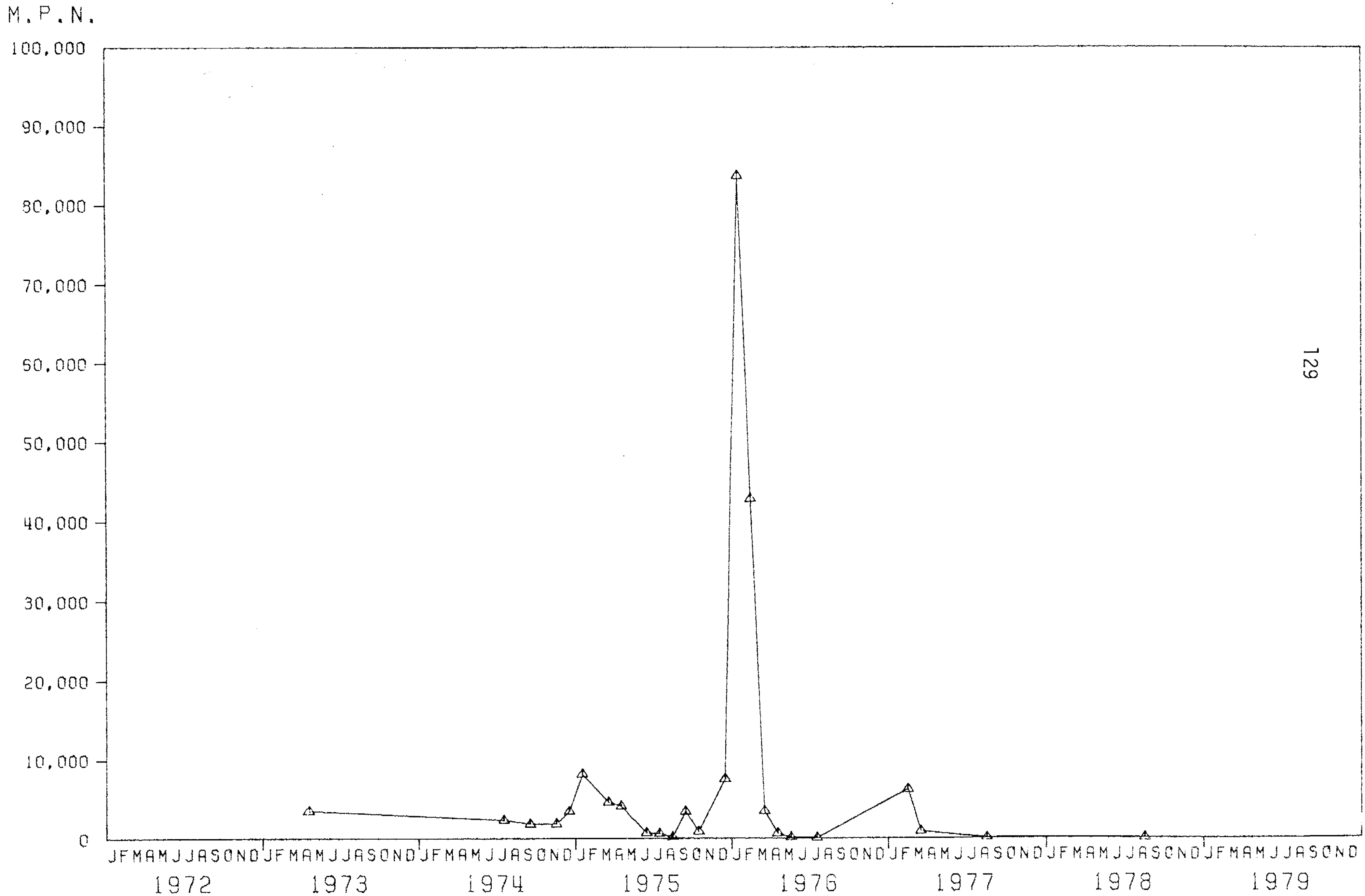


Figure B-8 TILBURY ISLAND

MONTHLY MEANS FOR: COLIFORMS:FECAL

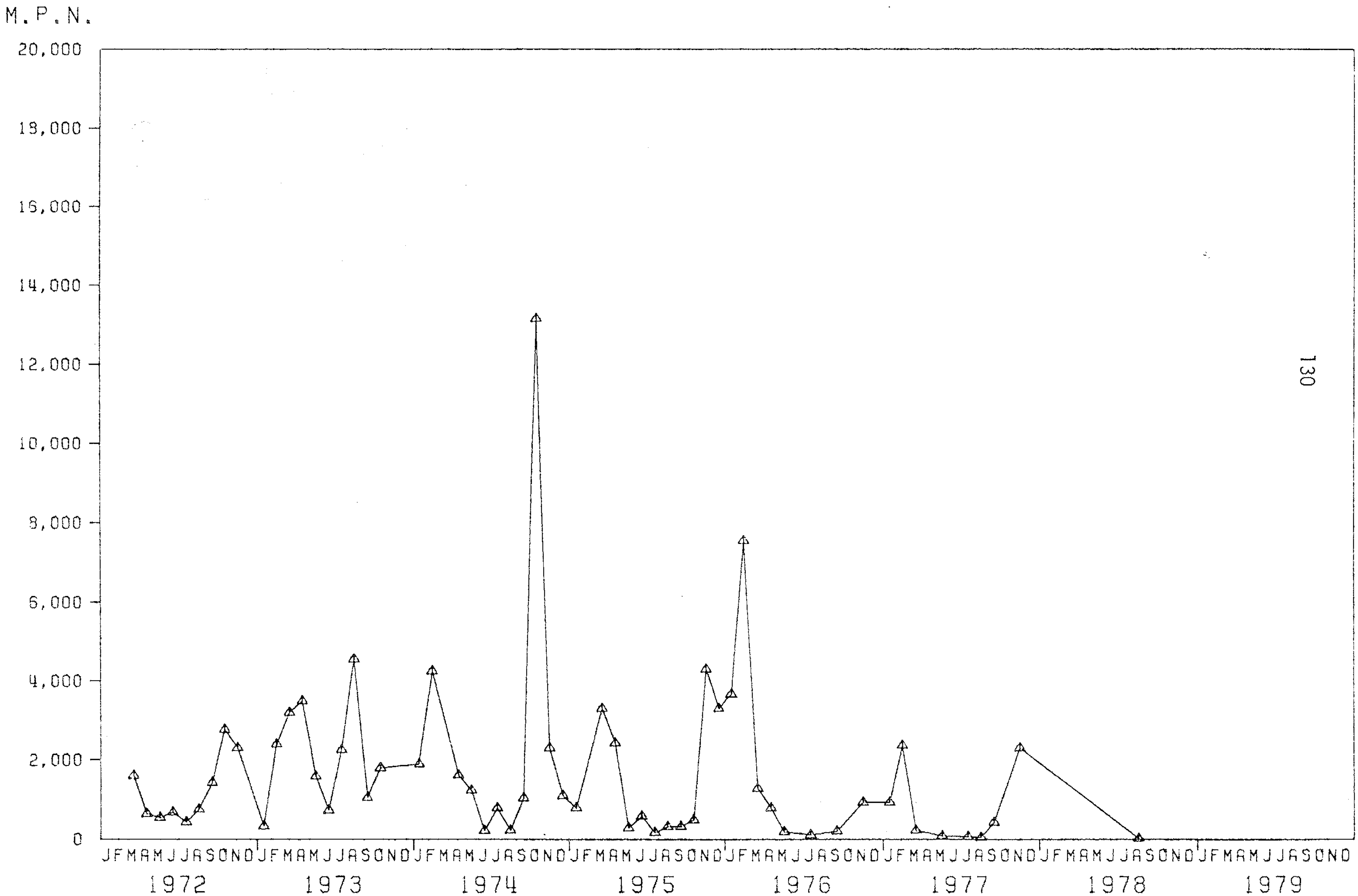


Figure B-9 DEAS ISLAND

MONTHLY MEANS FOR: COLIFORMS:FECAL

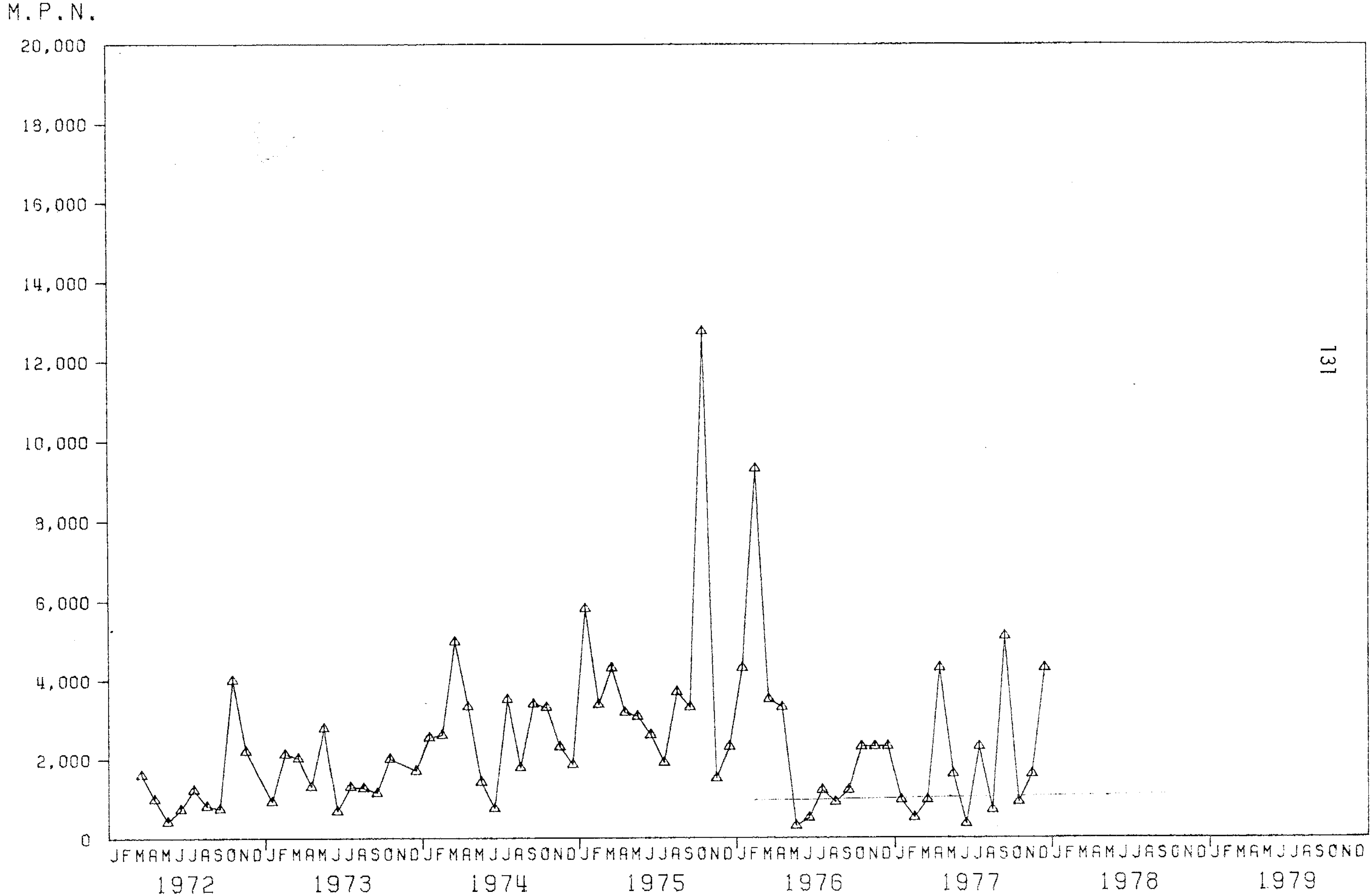


Figure B-10

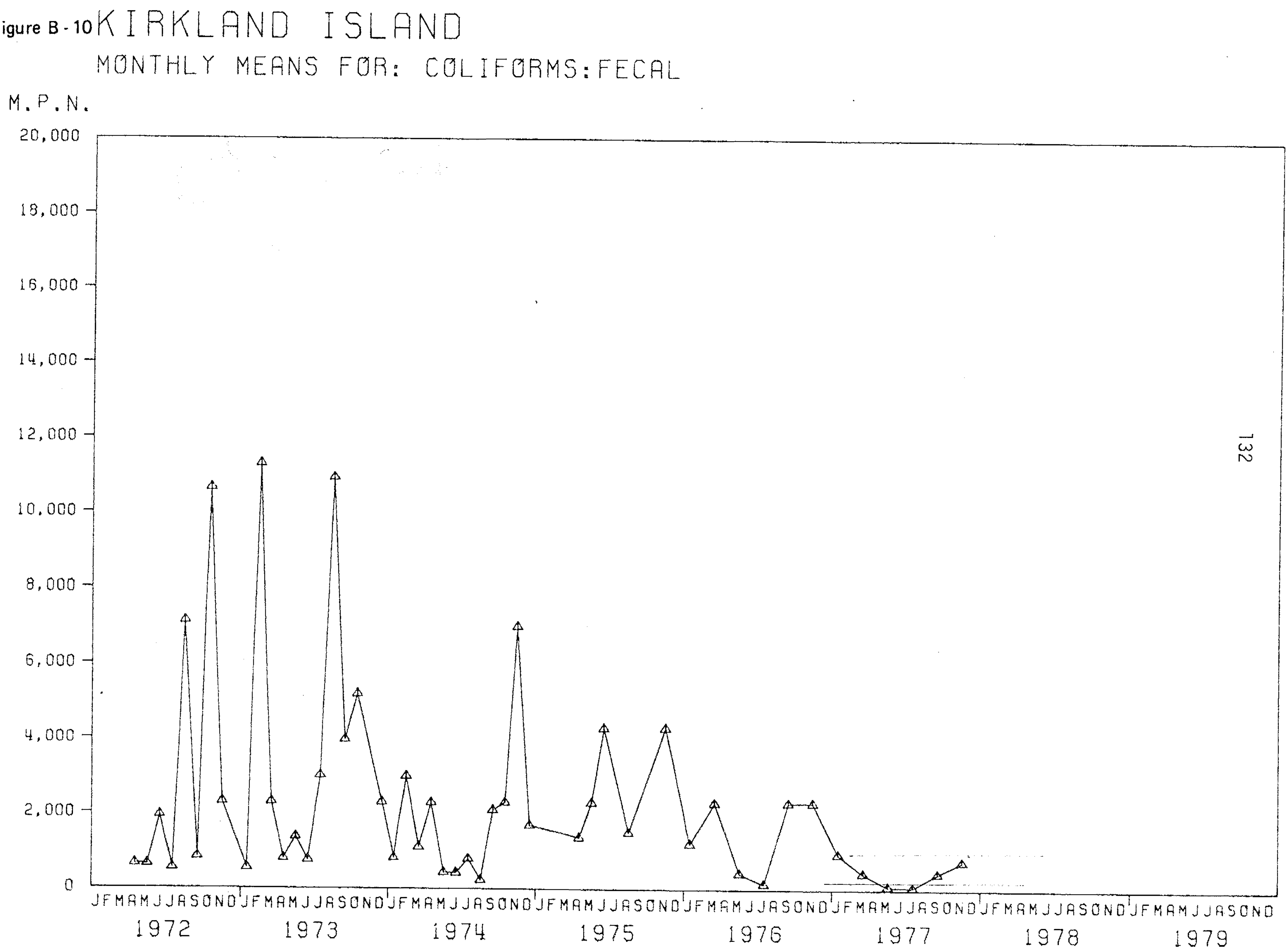

KIRKLAND ISLAND
MONTHLY MEANS FOR: COLIFORMS:FECAL
M.P.N.
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
JFMAMJJASOND JFMAMJJASOND JFMAMJJASOND JFMAMJJASOND JFMAMJJASOND JFMAMJJASOND JFMAMJJASOND JFMAMJJASOND
1972 1973 1974 1975 1976 1977 1978 1979

Figure B-11 STEVESTØN ISLAND

MØNTHLY MEANS FØR: CØLIFØRMS:FECAL

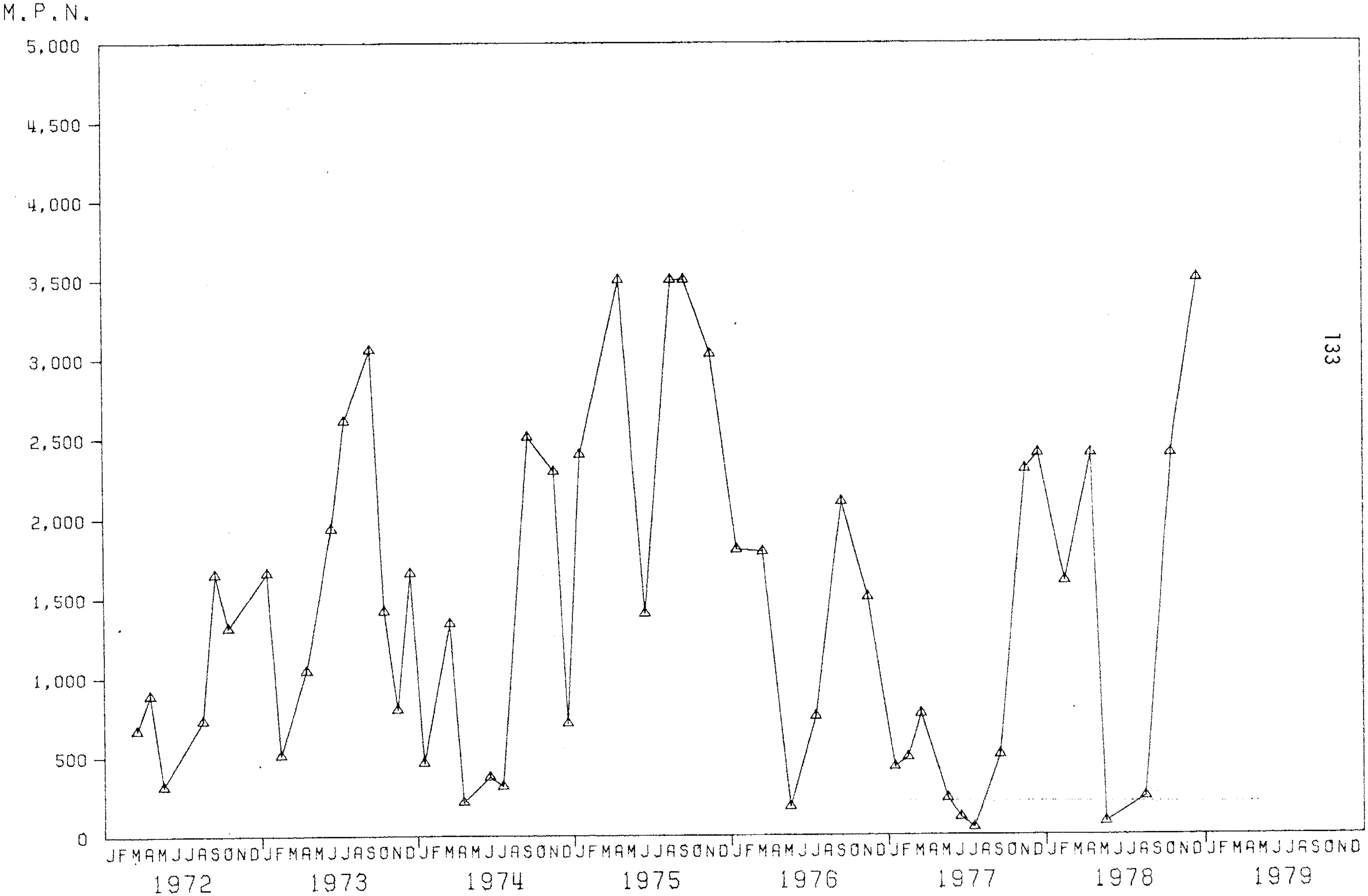


Figure B-12 CANNERY CHANNEL

MONTHLY MEANS FOR: COLIFORMS:FECAL

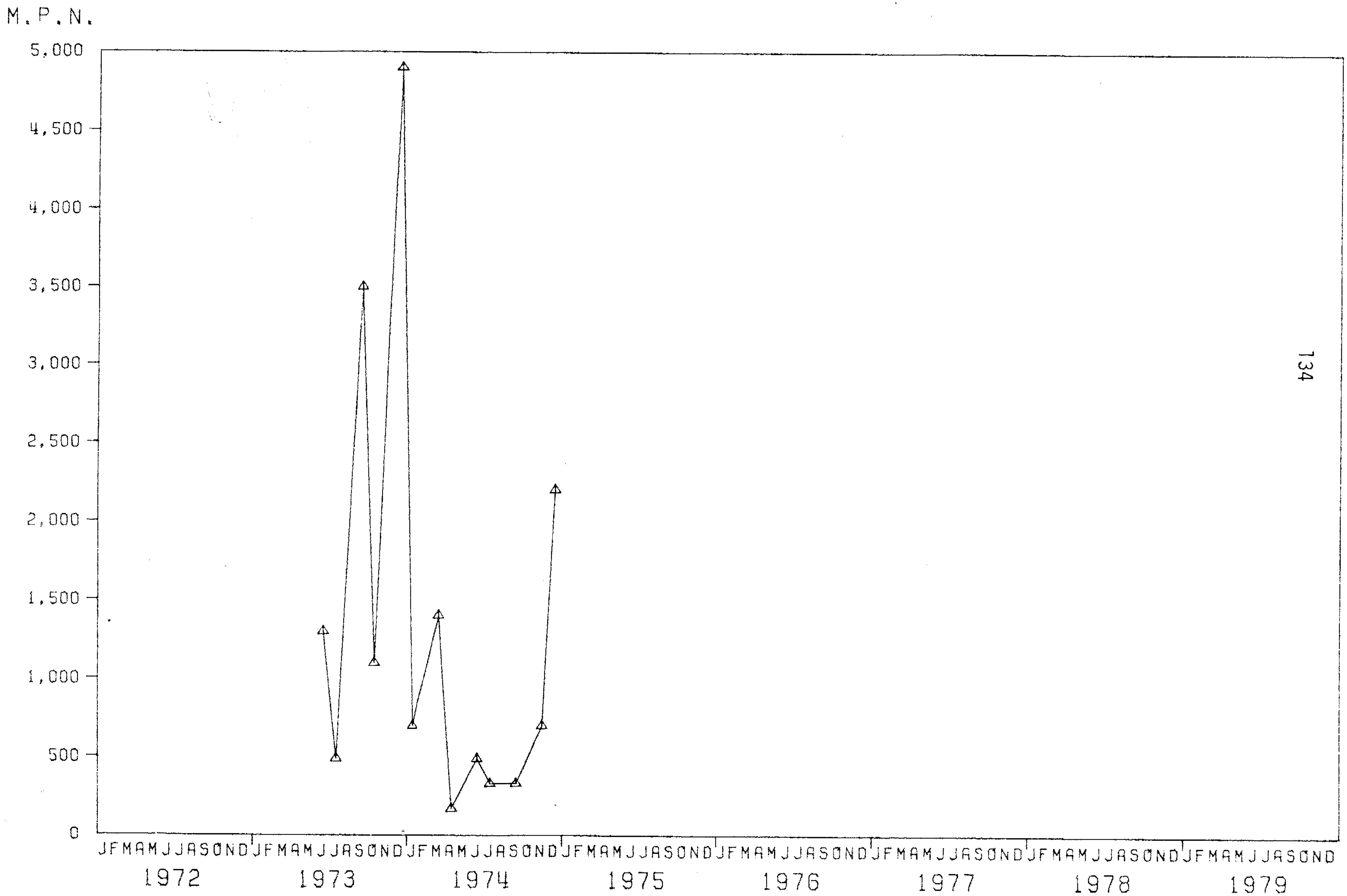


Figure B-13

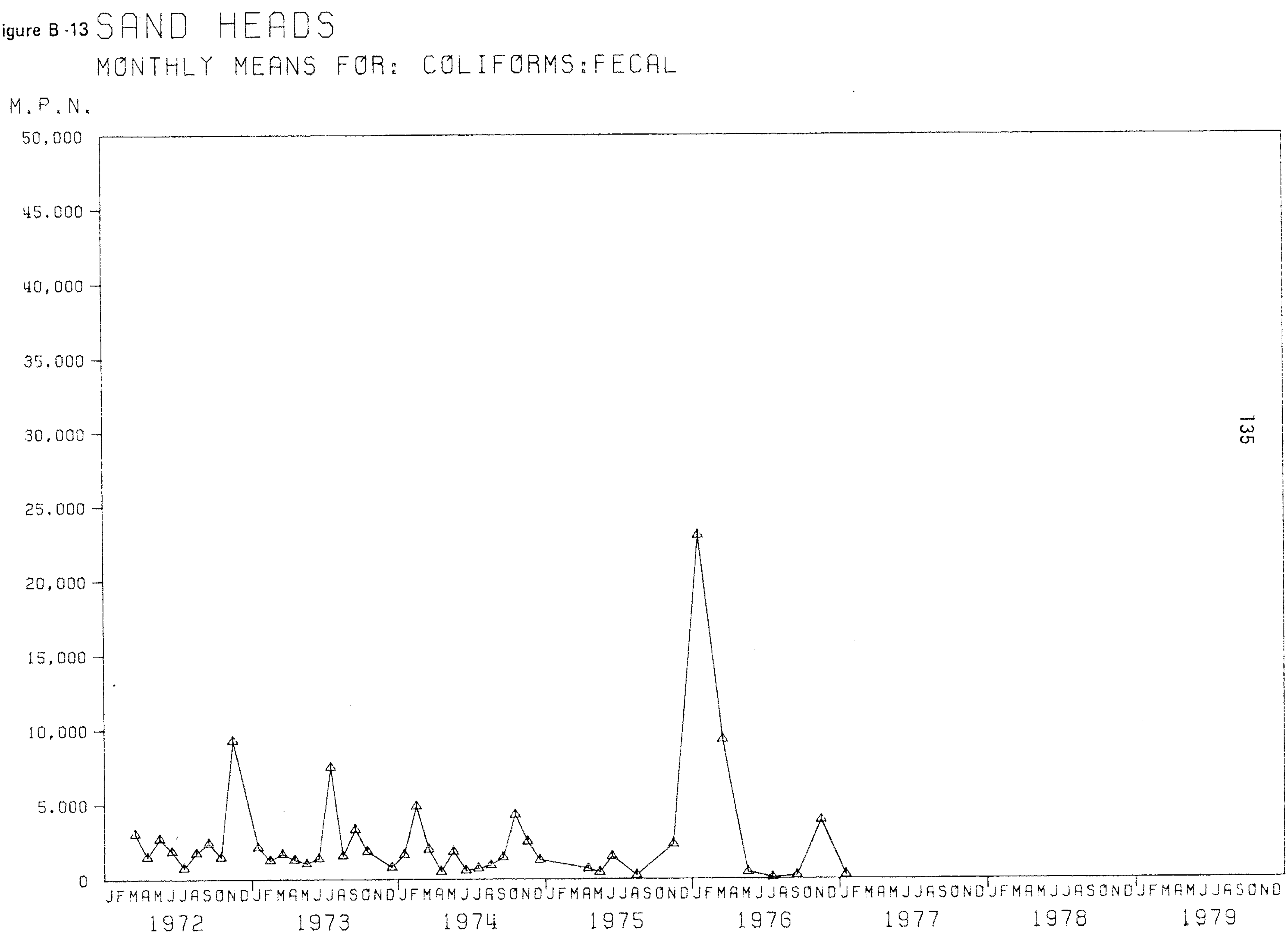

SAND HEADS
MONTHLY MEANS FOR: COLIFORMS:FECAL
M.P.N.
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
JFMAMJJASOND
1972
1973
1974
1975
1976
1977
1978
1979

Figure B-14 QUEENSBØRØUGH

MØNTHLY MEANS FØR: CØLIFØRMS:FECAL

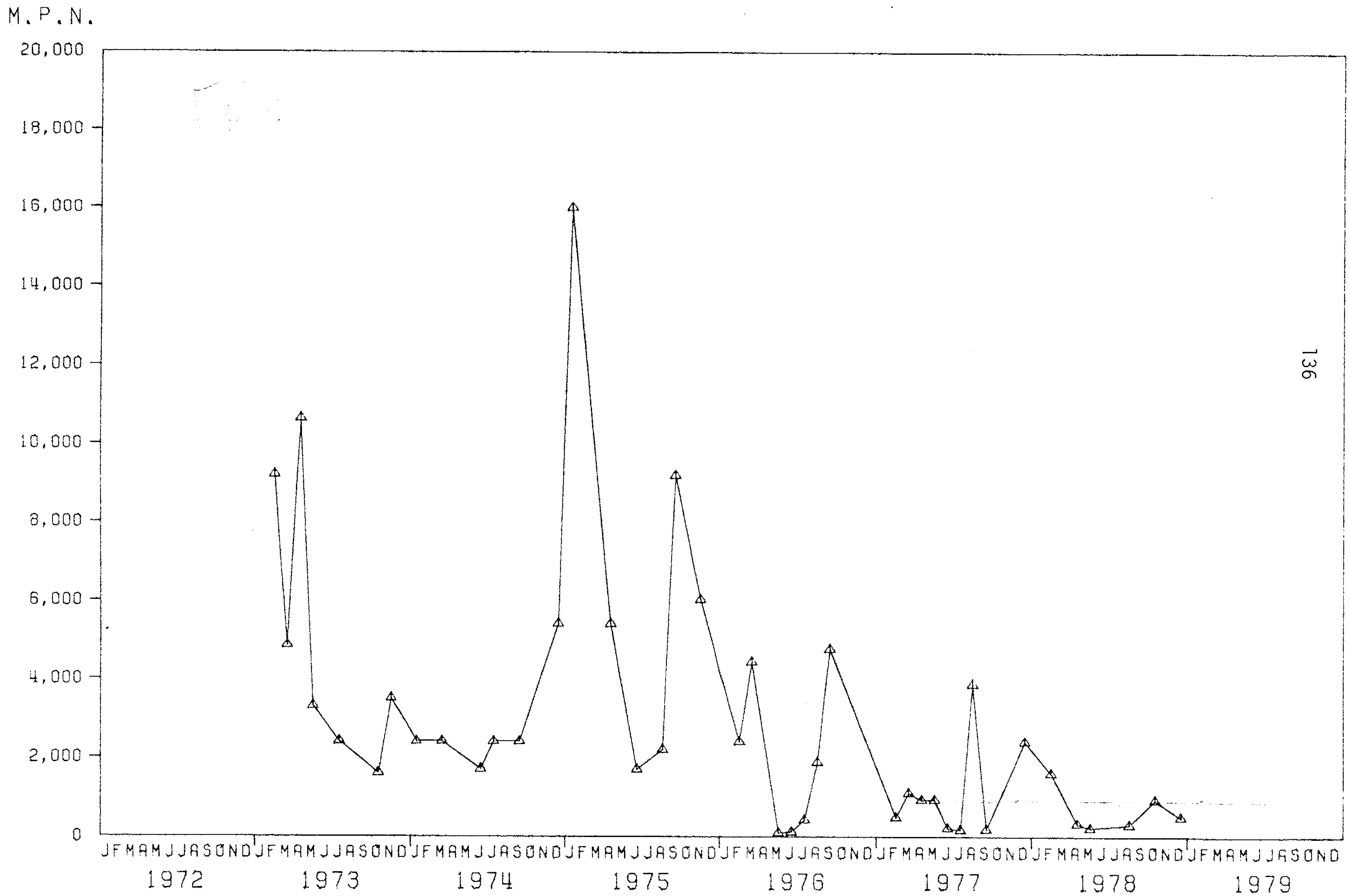


Figure B-15 CN RAIL N. ARM

MONTHLY MEANS FOR: COLIFORMS:FECAL

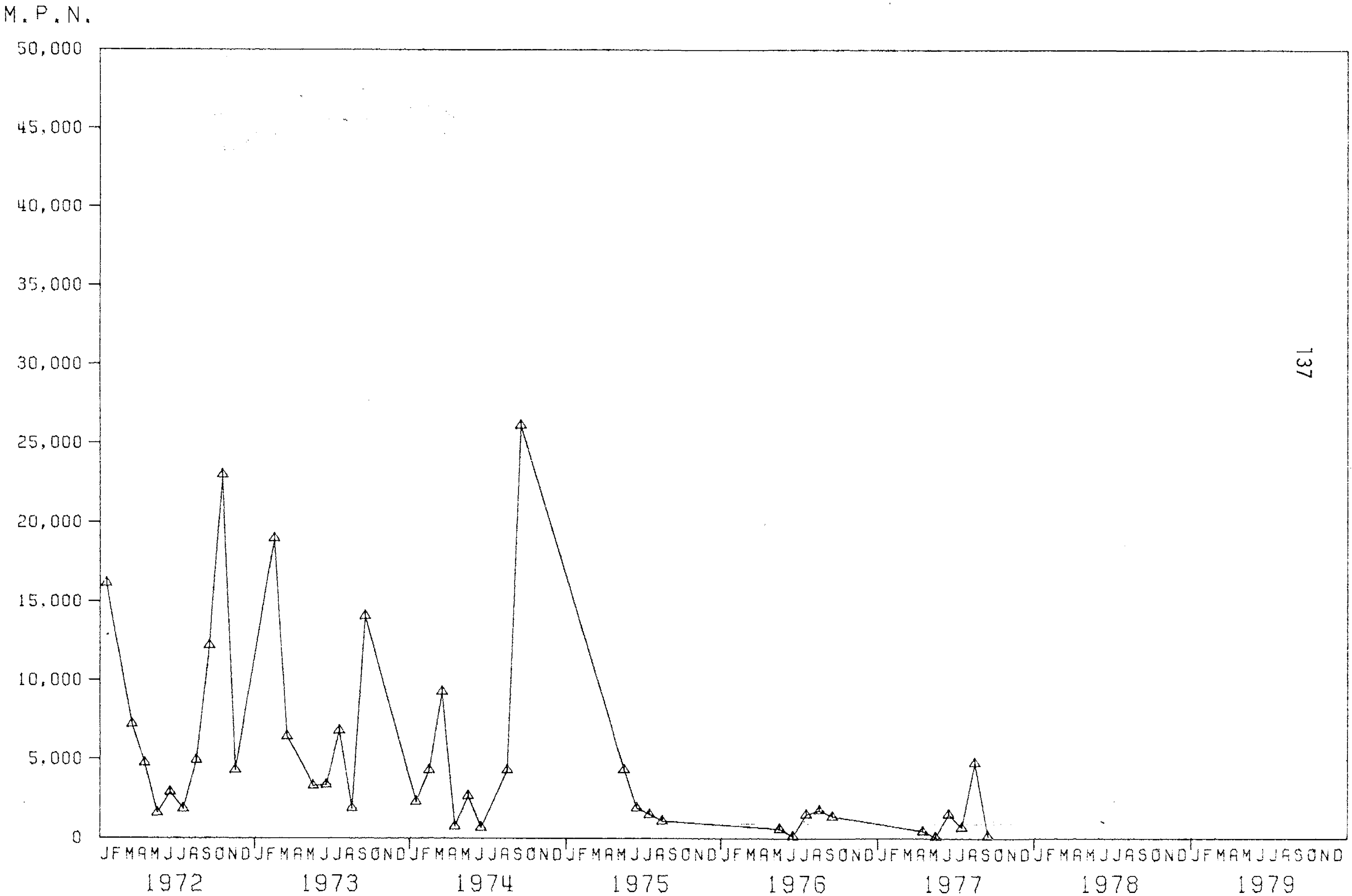


Figure B-16 MITCHELL ISLAND

MONTHLY MEANS FOR: COLIFORMS:FECAL

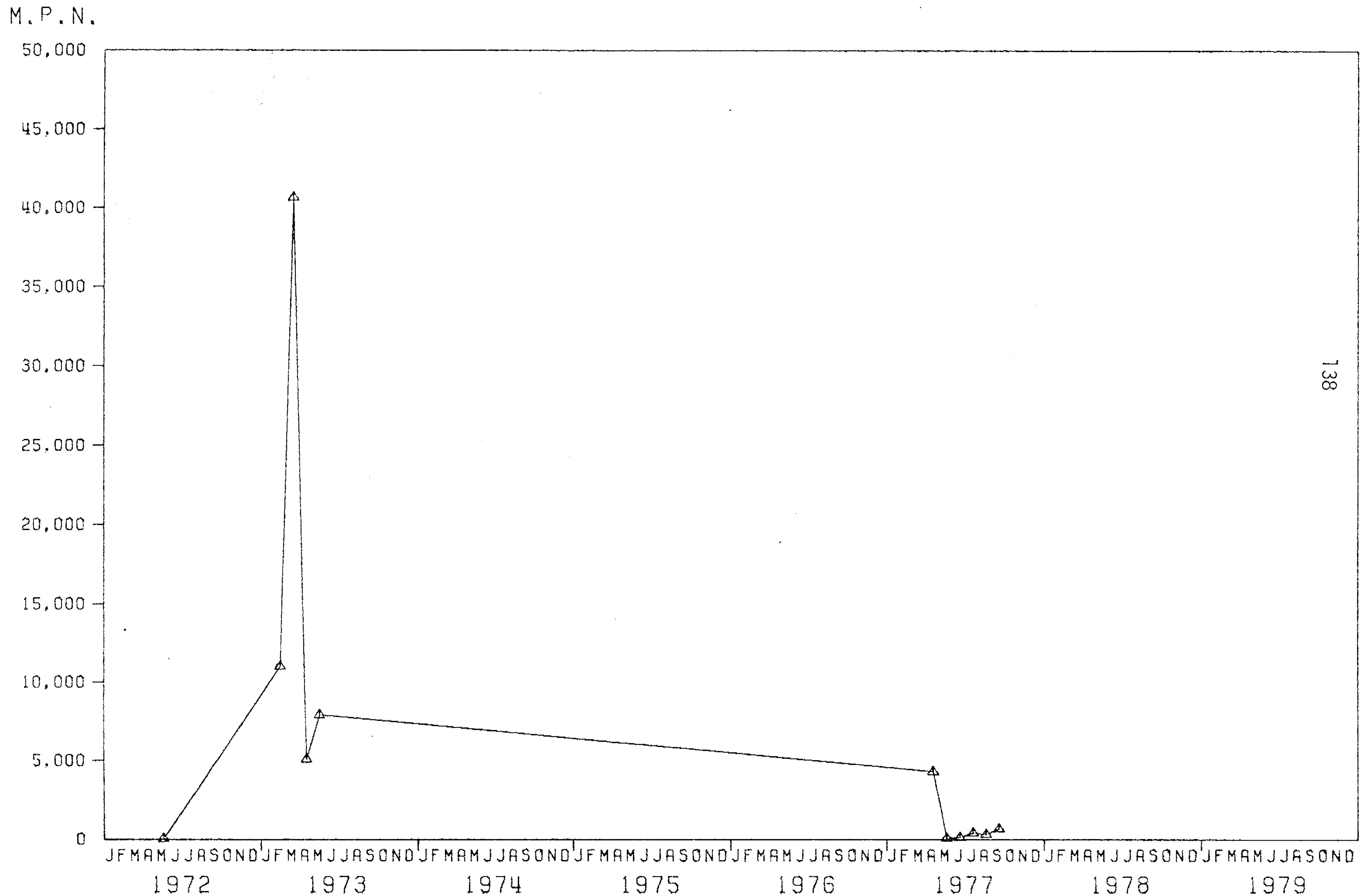


Figure B-17 ØAK STREET

MØNTHLY MEANS FØR: CØLIFØRMS:FECAL

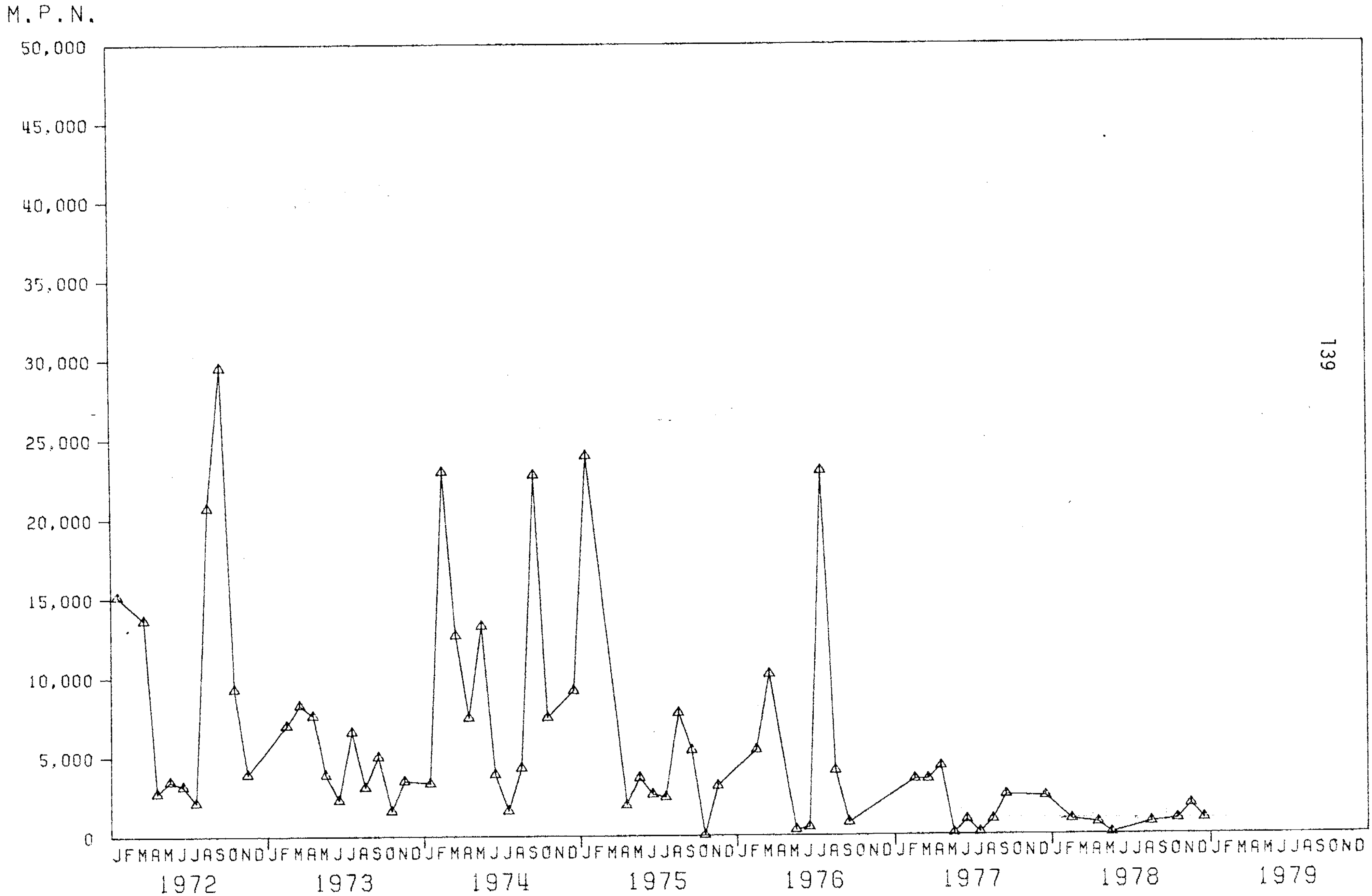


Figure B-18 WØØD ISLAND

MØNTHLY MEANS FØR: CØLIFØRMS:FECAL

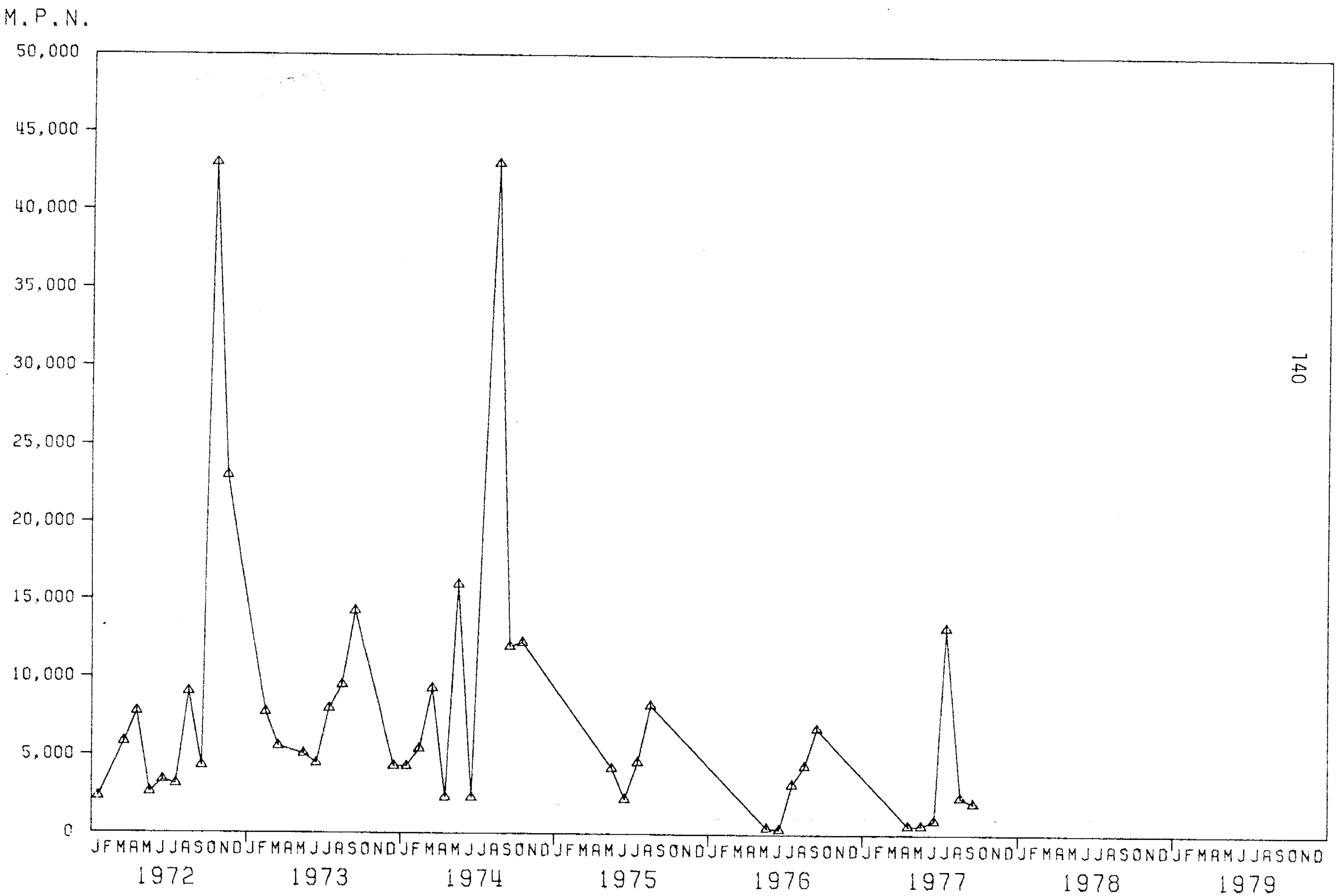


Figure B-19 N. SIDE N. ARM JETTY

MONTHLY MEANS FOR: COLIFORMS:FECAL

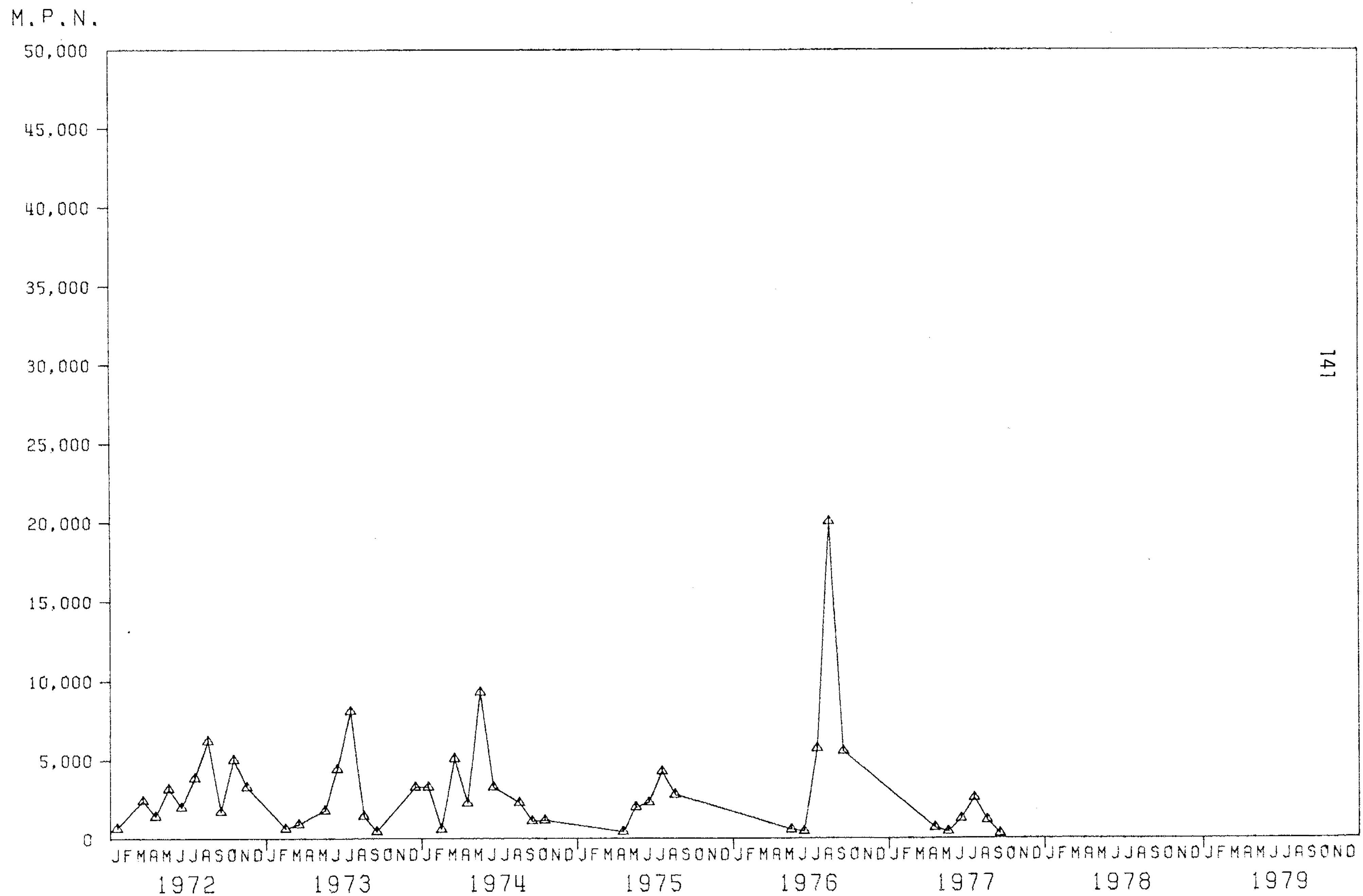


Figure B-20 S. SIDE N. ARM JETTY

MØNTHLY MEANS FØR: CØLIFØRMS:FECAL

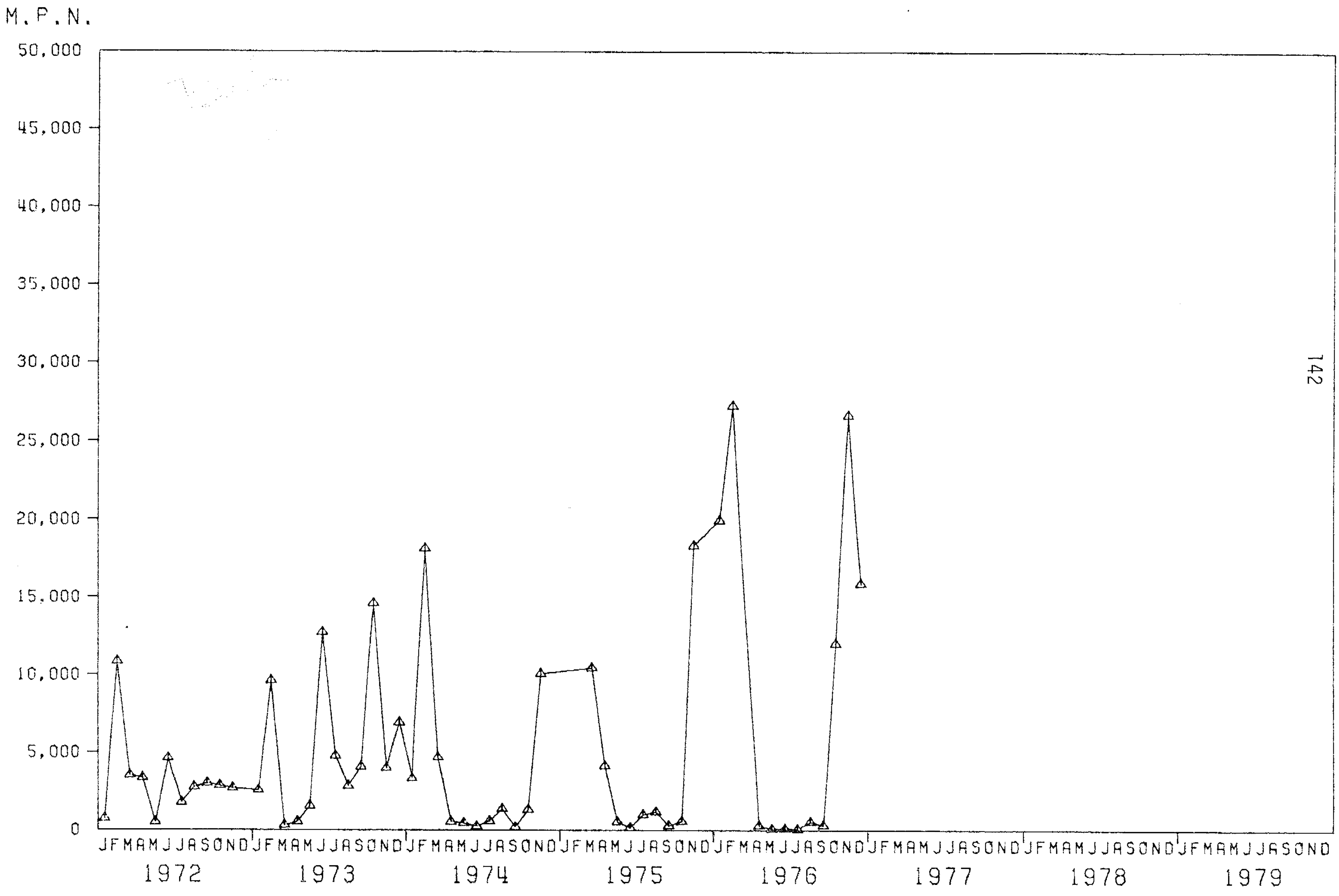


Figure B-21 S. SIDE IØNA JETTY

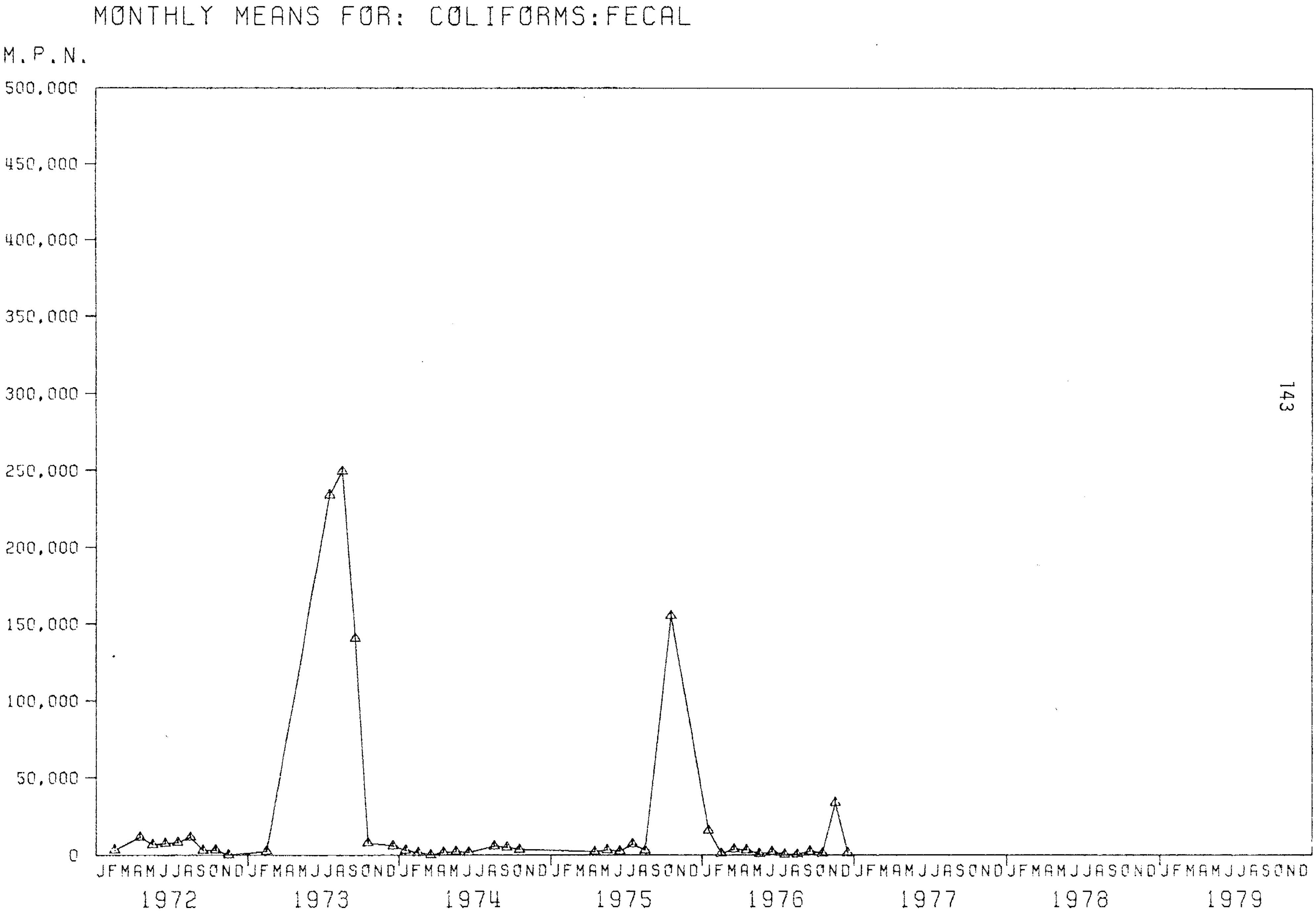


Figure B-22 DINSMØRE IS.

MØNTHLY MEANS FØR: CØLIFØRMS:FECAL