Fraser River Estuary Study
Water Quality

Water Chemistry, 1970-1978

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ABSTRACT

A review of the water chemistry data collected in the lower Fraser River between 1970 and 1978 is presented. In general, the water quality in the main flow of the river has not been degraded by discharges, and appears to be satisfactory for the support of aquatic biota. The main body of data, used in this report, is for the main flow of the river, but some data for sloughs and banks are included and discussed, as several problems have been identified in the slough and bank areas.

Particulate material in the water is naturally higher than in most B.C. rivers, especially during freshet. The suspended solids originate almost entirely from upstream erosion, with the various discharges to the river considered to have a minimal impact on overall turbidity.

Dissolved ion concentrations are generally acceptable for irrigation purposes most of the year, except during months of low river flow when marine waters are encountered on flooding tides near the river mouth. During freshet, criteria are met throughout the river. The pH range is acceptable for aquatic life and for recreational use. While the river is moderately buffered against acid discharges, it is found to be poorly buffered for alkaline wastes. Because high pH is a major factor contributing to ammonia toxicity, pH control of effluents to below 8.5 is recommended. In addition, intermittent discharges of both high and low pH wastes should be avoided.

Dissolved oxygen in the main river channels and most sloughs and side channels is high, generally exceeding 80% saturation, and poses no problem with respect to aquatic biota. However, bottom waters of some sloughs (Tilbury, Deas, McDonald) and side channels (Cannery Channel) have low oxygen levels, along with low pH, high conductivity and high organic content. Except for Tilbury Slough, these conditions are likely due to marine waters trapped in poorly flushed depressions; these situations may be aggravated by the accumulation of organic waste material from nearby log booms and land runoff or, in the case of Cannery Channel, by industrial waste from the fish-processing industry. Conditions in Tilbury Slough are mainly the result of poor flushing and organic material from land runoff.

Nitrogen and phosphorus levels are representative of low to moderately productive flowing waters; total phosphorus levels are higher than dissolved phosphorus and are associated with the suspended sediment. Annual loadings of nutrients from the

study area to the Strait of Georgia vary mostly as a function of changes in river flow. The average contribution of nitrogen from municipal, industrial and other sources to the total nitrogen present in the river from upstream sources is estimated to have been about 8% in 1967 and 16% in 1977. Nitrogen from the municipal sewage treatment plants does not appear to be causing a major problem in the study area and nutrient removal is not considered urgent.

Cadmium, chromium, lead and nickel are generally undetectable in the water. Total copper, total iron and total zinc are usually measurable and frequently exceeded certain water quality criteria. The potential biological impact associated with these metals is not known since these metals seem to be associated with the suspended sediment and may be biologically unavailable. Dissolved forms of these three metals rarely exceeded any water quality criteria. Over 90% of the copper, iron and zinc loadings originate from upstream, natural sources. Research on the different metal species present in the Fraser River, and their respective toxicities is recommended. Mercury in the water occasionally exceeds recommended criteria. Since it can be readily bioaccumulated, it is recommended that the sources of mercury, upstream and within the study area, be investigated.

Although high concentrations of trace metals are possible due to intermittent discharges from certain industries, the data indicate that no acute toxicity problem should occur in the main river flow. Nevertheless, source control to remove metals and other toxicants from effluents is considered appropriate. Additions of metals or of other toxic chemicals to poorly flushed areas can have a significant impact upon the local environment.

A receiving water monitoring program is presented, to be co-ordinated with those recommended for effluents, stormwater runoff, aquatic biota, sediments and microbiology. Additional programs will be required specific to localized problems as identified in the estuary.

PREFACE

The Fraser River Estuary Study was set up by the Federal and Provincial Governments to develop a management plan for the area. The study examined land use, recreation, habitat and water quality, and reports were issued on each of these subjects.

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

The major findings, conclusions and recommendations of the Water Quality Work Group were published as a Summary Report, December 1979. Subsequently eleven background technical reports, of which this report is one, have been prepared. These 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 are those of the authors and do not necessarily reflect formal government policies. Copies of these reports will be available at all main branches of the public libraries in the lower mainland, and from the issuing agencies.

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 all reports in this series will be available from the Ministry of Environment, Parliament Buildings, Victoria, British Columbia.

To bring all 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 overall recommendations. Some of the recommendations from the background reports may be omitted or modified in the summary report, due to the effect of integrating conclusions on related topics. Copies of the summary report have been placed in public libraries, and extra copies are available to interested parties from the Ministry of Environment in Victoria.

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1. INTRODUCTION

The Water Quality Group of the Fraser River Estuary Study was charged with the responsibility of reporting on and making recommendations concerning water, effluent and biological quality in the lower Fraser River. Member agencies of the group are the Environmental Protection Service (EPS) and the Inland Waters Directorate (IWD) of Environment Canada, the Waste Management Branch (formerly the Pollution Control Branch) and Water Investigations Branch (WIB) of the British Columbia Ministry of Environment and the Greater Vancouver Regional District (GVRD).

In August, 1978, an interim report on water quality was released based on a review of published reports (FRES, Water Quality, 1978). It was known at that time that a great deal more data existed in unpublished form at the many government, university and research agencies which routinely or periodically monitor water quality in the Fraser River.

This report consolidates all of the available water chemistry information collected between January, 1970 and December, 1978. A data report on each of the chemical parameters measured in the study area, has also been prepared (Clark et al., In Prep.). Geographic areas covered in this report are shown graphically in Figure 1, and include main flow, slough, and bank areas. Boundary Bay is discussed in another report.

2. METHODS AND DATA ANALYSIS

2.1 Data Collection

This report is a review of all the published and unpublished surface water data collected in the lower Fraser River between January, 1970 and December, 1978. These data are from a wide variety of agencies, some 17 in total. Tributary waters are not included; ditches and storm sewers are discussed in another report (Ferguson and Hall, 1979).

The initial process of the review was to incorporate the data into a single computer file, the Environmental Quality and Information System, or EQUIS, developed and maintained by the British Columbia Ministry of Environment (Clark and Ellis, 1976). Fraser River sampling in the past has been undertaken by groups and agencies with a variety of individual interests. As a consequence some 200 reporting stations are in existence for which data must be interrelated. The approach taken in this work has been to divide the River into reaches and to interpret and compare data as though each river reach is represented by one station.

As shown in Figure 1, these reaches are in the Main Stem (R1-R3), Main Arm (R4-R13), North Arm (R14-R19), Middle Arm (R22) and Sturgeon Bank (R20-R21). Reaches 23 and 24 are for the west and east basins of Boundary Bay (see Alexander et al, in prep.). Reach 25 was selected as an upstream control to the study area and incorporates all the data collected between Hope and Mission. In order to give an overview of the various parameters, all the data from the study area (excluding Sturgeon Bank, Boundary Bay and Reach 25) were combined (R26).

A great many different sampling procedures and analytical methods have been used by the various agencies. No attempt was made to determine what differences could be attributed to these factors. Approximately two-thirds of the samples were analyzed by either the Environmental Laboratory of the British Columbia Ministry of Environment or the Inland Waters Directorate Laboratory, Environment Canada, located in Vancouver. Both have published their analytical procedures (McQuaker, 1976 and Inland Waters Directorate, 1974, respectively).

Initial attempts were made to include stage of tide and river flow in the interpretation of these data, incorporating the use of the numerical model of the Fraser developed by A. Ages, Institute of Ocean Science, Fisheries and Oceans. However, it became clear that the Fraser estuary was too complex an environment and the data base too incomplete to do this successfully, except for specific studies dealing with the effects of tides.

2.2 Data Analysis and Presentation

Data have been presented in the various tables in a manner designed to answer the most commonly asked questions with respect to both absolute values and trends. Statistical medians and tenth and ninetieth percentiles have been given where considered relevant. (The 10th percentile is that value below which fall 10% of the data; the 90th percentile is that value above which 10% of the data lie; the median or 50th percentile is the middle value). Measurements that were below the detection limit were given a value equal to the minimum detectable concentration (MDC) when calculating means and standard deviations, unless indicated otherwise. In the discussion, median values were often used instead of means to minimize problems associated with MDC's and occasional extreme values (Zar, 1974). The following sections outline the more specialized methods of data treatment.

2.2.1 Reach Graphs

The data report (Clark et al., In Prep.) contains a graph for each parameter for which data exist. The more relevant of these have also been included in this report. These reach graphs display the statistical summary of the data for each of the twenty-two reaches in the study area (R23 and R24 in Boundary Bay are not included), plus the Hope to Mission reach (R25). The reaches are oriented (Figure 1) in a downstream sequence - Hope to Mission (R25), the Main Stem (R1-R3), the Main Arm (R4-R13), the North Arm (R14-R19), the Middle Arm (R22) and Sturgeon Bank (R20, R21). Opposite each reach number, which is printed at the left of the graph, is a horizontal line. The ends of the line represent the maximum and minimum values for that reach. Two vertical bars represent the 10th and 90th percentiles and the dark triangle is the 50th percentile or median concentration. The mean concentration is indicated by an open circle. At the right side of the graph are the number of analyses from each reach. Figure 5 is a suitable example.

For some parameters, data from the Main Stem, the Main Arm and the North and Middle Arms were combined to examine (t-test, mean values) geographical differences. The data from these three main areas were further separated into two time periods-January, 1970 to December, 1974 and January, 1975 to December, 1978. January, 1975 corresponds approximately to the time when the Annacis Island Sewage Treatment Plant began operating. Comparisons were made to test for possible differences (t-test, mean values) due to the changes in waste management procedures.

2.2.2 Random-Pair Statistic

The randomized-pairs test determines whether the values in a particular reach are higher (or lower) than in another reach more often than would occur by chance. Data were paired only if two samples had been collected within 48 hours of each other and if they had been analyzed by identical procedures. The former criterion increased the number of comparisons but did introduce possible differences due to tidal effects.

A search of the data on EQUIS was made between designated reaches. All adjacent and next to adjacent reaches were tested, plus all combinations for a number of selected reaches (R3, R7, R11, R13, R14, R17). Finally, all reaches were compared to the upstream reach, R25. Comparisons were considered significant at $p < 0.05$.

The data report (Clark et al., In Prep.) fully outlines the statistics and the computer program used for this test. Another reference to this general approach can be found in Siegel (1956).

2.2.3 Frequency of Occurrence

A great majority of the trace metals measurements fell below the minimum detectable concentration (MDC). For these parameters, the ratio of the number of analyses which were greater than the MDC over the total number of analyses was determined. This procedure minimizes the problem which exists due to the range of MDC's found for some parameters. Data from the individual reaches as well as the combined data for the Main Stem, Main Arm and North Arm were used. In addition, trace metal data from all the reaches (R26) were separated into high flow months (April to August, inclusive) and low flow months to look for seasonal differences.

2.2.4 Loadings

The amount of nutrients and trace metals present in the river over a specified period of time has been defined in this report as river loading. Because of the variability of the chemical data, the large changes which can occur in river flow and the complications due to tidal effects and non-homogeneous mixing (e.g., cross-sectional differences), these loading calculations are only rough estimates but are considered generally to reflect actual values.

Water quality data at Pattullo Bridge were used as the basis for upstream loadings, since it is the first reach with sufficient data. Section 3.1.1 in this report and the data report (Clark et al., In Prep.) outline in detail the procedure used to estimate river flow at Pattullo Bridge.

2.2.5 Water Quality Criteria

Data from the study area were compared to various water quality criteria collected by Clark (1978 a). This review incorporates the standards from several provincial, Canadian, American and international organizations for the protection of aquatic biota and recreational and industrial water uses. In all, 29 major references are included. A summary of the most recent, and major reviews on criteria is presented in Table 17.

This report also frequently refers to the median concentration of most B.C. streams. This is in reference to a report by Clark (1978 b) in which all the data from EQUIS were compiled, giving the maximum, minimum and 10th, 50th and 90th percentile concentrations for each parameter.

Upstream values referred to in this report were obtained from Clark (1978 c), a review of Fraser River water quality information in EQUIS, from the headwaters to the ocean.

3. RESULTS AND DISCUSSION

3.1 The Water Movement in the Lower Fraser River

3.1.1 River Discharges and Velocity

The portion of the Lower Fraser River discussed in this section extends from the mouth to the upstream limit of the tidal influence at Chilliwack, a distance of approximately 110 kilometers.

The water movement in the lower Fraser is a function of the tides in the Strait of Georgia (having a maximum range of 4.9 m at Point Atkinson) and the river discharge, which normally varies (at Hope) between 600 m^3/s in the winter and 8 800 m^3/s in the summer. A peak flow of 15 200 m^3/s was recorded on May 31, 1948. The discharges are measured at Hope, 185 km east of the mouth and well beyond the tidal limit upstream. It is below this point that the Fraser decreases its rapid rate of descent and begins to show tidal fluctuations in the records of water surface elevations.

The crest of the tidal wave initially travels upstream at a velocity of approximately 30 km/h, passing New Westminster about one hour after entering the river mouth at Sand Heads. Beyond New Westminster, the crest moves at a slower rate, reaching Mission three hours after Sand Heads. Low waters at these same locations occur about three and six hours after low water at Sand Heads. The time lags appear to be virtually independent of the discharge.

The tide in the Strait of Georgia propagates as far as Chilliwack at low discharges but does not move past Mission at high flow. The tide also propagates into Pitt Lake.

Not only the direction of the river flow but also the speed depends on the stage of the tide outside the estuary. This condition particularly applies to the lower portion of the river. During flood tide, the river flow backs up and accumulates in the delta and upstream river channels. At ebb tide, this stored water volume is released, increasing the outflow. The difference in discharge characteristics at flood and ebb tides becomes particularly pronounced in the river reaches below New Westminster due to the significant contribution in storage from Pitt Lake. As in all tidal rivers, the outgoing ebb lasts much longer than the incoming flood.

Table 1 is a summary of the monthly flow (10th, 50th and 90th percentiles) estimated for the Fraser River at Pattullo Bridge. These estimates were calculated from the average monthly flows of each of the major tributaries between Hope and Pattullo Bridge added to the flows recorded at Hope. Data were obtained from the records of the Water Surveys Branch, Environment Canada (Inland Waters Directorate, 1977).

The monthly percentiles at Hope were estimated from the 60-year (1916-1976) monthly means. Insufficient data exist to determine the 10th and 90th percentiles for many of the tributaries. Consequently these flows were estimated by comparing the mean values of each tributary to the mean flow at Hope, and multiplying this ratio by the flow (10th, 50th and 90th percentile) at Hope. The data report (Clark et al, In Prep.) presents data and calculations in detail.

The Fraser's drainage basin is about 233 000 square kilometres. Two thirds of the area's precipitation is in the form of snow. The snow starts melting in April, increasing the runoff to a maximum in late May or early June. Minimum flows generally occur in February and March.

At New Westminster, the river divides into two main tributaries - the Main Arm and the North Arm, with average minimum depths of 10 and 5 metres respectively. Exact percentages of the flow distribution at the New Westminster trifurcation are difficult to define, since they vary with tides and discharges. However, in general terms 15% of the outflow enters the North Arm and the remainder enters the Main Arm (79%) and Annacis Channel (6%). At a bifurcation further west in the North Arm, roughly 45% of the outflow (in the North Arm) is diverted into the Middle Arm (Figure 1).

Figure 2 shows maximum ebb and flood tide velocities of the river flow in the study area based upon low, moderate and high flow conditions (measured at Hope) - 700 m^3/s, 2 800 m^3/s and 10 800 m^3/s, respectively. The values represent vertically integrated velocities, produced by a computer model, and have not been verified by actual measurements (A. Ages, pers. comm.). Observations of river current at selected locations in the form of time series have been initiated only quite recently, in response to the increased demand for such data.

During high flow (ca 10 000 m^3/s) ebb tide current velocites may reach 3.3 m^3/s. Velocity is greatest near the mouth of the Main Arm (R11, R13) where river training structures channel the water as a method of self-scouring of sediment from the bottom. Maximum values in the North Arm occur near the North Arm Jetty (R19) near Iona Island.

In the river delta between the Strait of Georgia and the trifurcation at New Westminster, significant flow reversals during flood tide occur only during low discharges (ca 700 m^3/s). Flood tide velocities rarely exceed 1 m/s in the seaward reaches of the delta.

Considerable cross-sectional variability in flow can exist, especially near bends in the river (Tamburi and Hay, 1978). This can affect water quality measurements and must be considered in designing sampling programs.

3.1.2 Salt Water Intrusion

An important feature affecting the flow distribution in the river delta is the intrusion of dense saline water from the Strait of Georgia, this saline water being forced upstream in the form of a wedge by a rising tide and subsequently swept out by the river at a falling tide. The salt wedge, in essence, reduces the cross-sectional area of the river outflow, accelerating the surface currents.

At very low flow and high tides, saline water from the Strait of Georgia may penetrate the Main Arm as far as New Westminster, and retreat to the outer reaches west of Steveston at low tides.

During the freshet, the salt wedge reaches Steveston at an average high tide, and is washed out completely past Sand Heads at a low tide. Above 9 000 m^3/s, little or no salt penetration is found upstream of Steveston (Ward, 1976).The salinity wedge has been observed to move upstream at a velocity of 0.6 m/s in the Main Arm near Steveston (A. Ages, pers. comm.).

The much shallower North Arm prevents the salt wedge from moving upstream as far as New Westminster. Preliminary observations indicate that the delta waters between Canoe Pass and the Main Arm remain fresh at all tidal stages during the freshet.

Figure 3, prepared by A. Ages and based on recent data, illustrates the behaviour of the salt water intrusion and the related current pattern. The observed water surface elevations near Steveston were plotted for almost two full tidal cycles during a period of low discharge. As the sketch demonstrates, the saline water enters the river as a distinct wedge at a rising tide, moves to the upper layer at high water and may lose its stratification completely at a falling tide. The surface outflow reaches its peak shortly before low water; slack water occurs a few hours after the tide turns. The upstream movement of the bottom water in the salt wedge may persist several hours after the surface flow has turned from flood to ebb. Detailed studies by the Institute of Ocean Sciences, Patricia Bay, on the water movement inside the wedge are still in progress.

Water quality data on chloride measurements are discussed in Section 3.4. The data suggest that marine water may intrude in the North Arm to Queensborough Bridge (R14) and in the Main Stem (R2, R3) further upstream than the salt wedge has been observed to date. Chloride values from 100 mg/L to 1 200 mg/L (latter about 2 ppt salinity) have been measured at Port Mann Bridge, these values being 2 to 3 orders of magnitude higher than background levels. Similarly in the North Arm, twelve measurements between 25 and 1 400 mg/L chloride were obtained at Queensborough. All but one value occurred during the months November to April when river flows are at their lowest.

3.1.3 Sturgeon - Roberts Banks

Water movement over Sturgeon Bank is a complex function of tide, wind, and topography. In general, water moves in an easterly or northeasterly direction on a flood tide, and in a westerly or southwesterly direction on an ebb tide. Speeds of less than 1 m/s are common. Wind and river runoff can modify the basin's tidally-induced flow both in speed and direction. Winds even less than 5 km/h can significantly influence water movement (Giovando, 1975).

A narrow (1-3 km) surface current appears to be present just seaward of the Sturgeon Bank (at least during high river flows) moving in a northerly direction at 0.5 to 1 m/s. During freshet, water flow from the North Arm prevents this current from entering the arm or Burrard Inlet. During low river flow and especially on flood tides, direct movement of the surface current into these areas is likely (Giovando, 1975). The random-pair statistic showed that Wood Island (R18) was significantly higher than the Middle Arm (R22) in salinity, chloride, total and fecal coliforms, and significantly lower in dissolved oxygen levels (Clark et al., in prep.). This implies that seawater intrudes to a greater degree into the North Arm compared to the Middle Arm, possibly due to the shallower depth at the mouth of the latter.

3.1.4 Dispersion of Effluents

Flow reversals in the river complicate the understanding of the impact of point source discharges on the river. Velocities vary widely in magnitude and direction as a result of temporal changes in base flow and tidal conditions. This results in varying dilutions of effluents and varying residence times of contaminants in the river.

The effects of tides on effluent dispersion in the Fraser River have been studied with a computer model (Joy, 1975). Four peaks in the concentration of effluent in the river from a point discharge were predicted over a 24-hour period, corresponding to slack water. Since the river can reverse flow on occasion (due to changes in tide) the same segment of water may pass a discharge point several times, receiving multiple doses of effluent. These peak concentrations, cross-sectionally averaged, would be from one to ten times greater than the predicted concentration of effluent in the river, averaged over the entire 24 hours. Because of the smaller flows in the North Arm, the tidally varying concentrations would be higher there than in the Main Arm.

Assuming a river flow at Hope of 1 000 m^3/s, it is estimated that the average residence time in the river of a theoretical particle from the Annacis Island (STP) outfall is about 1.7 days (Associated Engineering, 1977). Effluent discharged from the Lulu Island STP on a flood tide moves out onto the estuary at Sturgeon Bank on the following ebb tide.

Recent studies have been made on dilution and transportation of primary sewage effluent from the Annacis Island outfall (B.C. Research, 1974, 1975, 1976) and the Lulu Island outfall (B.C. Research, 1972). Drogue, dye and current studies, performed by B.C. Research, suggest that effluent is mixed vertically off the Annacis Island outfall. Little lateral dispersion was found at Annacis or off the Lulu Island outfall. The rate of vertical dilution was found to be dependent on river speed.

In a dilution test, during low flow in February, 1975, indicator dye discharged at the Annacis Island STP was diluted over 600-fold at 60 metres downstream (B.C. Research, 1975). During a high slack tide, dilution of indicator dye was as low as five-fold directly over the outfall, although dilutions were generally much greater (Table 2). Under adverse tide and river flow, slack water could last as long as one hour (B.C. Research, 1978). These dilution measurements were well within predicted values (Western Canada Hydraulics, 1973).

Current measurements at the Annacis Island STP outfall (Associated Engineering, 1977) indicated there was a net downstream movement of material over 22 hours in a day. However, in a short period of six hours, material could move 7.5 km upstream. Surface velocities in the river exceeded those at the bottom by as much as 44 cm/s. On average, the velocity differential was 18 cm/s, over 18 hours. Maximum velocities measured on the bottom exceeded 50 cm/s on a flood tide, and 90 cm/s on an ebb tide, with a flow at Hope of 1 000 m^3/s. Under freshet conditions, water from Annacis Island would reach the Strait of Georgia in five hours; under the most adverse conditions (which occur 15-20 days/year) effluent may take as long as five days to reach the Strait. Generally, the time is about 1.7 days, under moderate flow (B.C. Research, 1978).

Theoretical and physical models of the Fraser River have been prepared in the design of additional training walls to provide a 12 metre draft navigation channel. The training walls will increase the river velocity, thereby reducing sedimentation and increasing the depth of the channel. The environmental impact of the proposal is still under study (Beak, in prep.). The overall effect will be to increase the velocity of the river, especially on the ebb tide. As flood tide velocities are expected to be less affected, the basic patterns of salt water penetration are not expected to be greatly altered.

Depending on the final nature of the river training project, the average time for particles at Annacis Island to enter the estuary will decrease by 1.25 to 1.75 hours during high flow and by 6.5 hours at low flow (Beak, In Prep.).

Other possible effects include changes in sedimentation patterns, creation of areas of slack water behind the walls which may effect oxygen levels and the leaching of nutrients and toxic materials from resuspended bottom material. These are discussed in Sections 3.3.5, 3.6.8, and 3.7.10.

3.2 Temperature

Predictably, surface water temperatures in the Fraser showed a seasonal pattern with the maxima during the late summer (August -September) and minima during December and January. The 10th and 90th percentiles for most reaches were about 4°C and 17°C respectively. Figure 4 shows the seasonal pattern for the combined data in the study area.

There was no apparent yearly trend between 1972 and 1978. The calculation of the 12-month running mean (in which the mean for each month is computed from the data from the 12 previous months) was used to detect trends within cyclic patterns. Over the past 8 years, those means rarely differed more than $2^{o}C$.

There was no apparent difference between individual reaches (Figure 5). However, when all the data (1970-1978) from the North Arm, Main Arm and Main Stem to Hope were compared using a t-test, the mean of the North Arm ($\bar{x}$ = 10.2^{o}C) was significantly higher ($p < 0.001$) than either the Main Arm ($\bar{x}$ = 8.8^{o}C) or upstream ($\bar{x}$ = 8.7^{o}C). However, insufficient data pairs are recorded to allow a random pairs comparison. It should be noted that Bergerud and Alexander (in prep.) observed the North Arm to be significantly colder than the Main Arm for August 1978.

Field temperatures were frequently not recorded when other measurements were taken. This parameter is an essential factor in calculating oxygen saturation, in determining the amount of undissociated ammonia present, or for similar calculations. Therefore, it is recommended that temperature be measured and reported on all field surveys.

3.3 Colour and Particulate Material

Parameters discussed in this section are non-filterable residue (suspended solids), turbidity, and apparent (unfiltered) and true (filtered) colour. True and apparent colour are included because particulates will affect colour values. Suspended solids and stain (i.e., dissolved coloured material) show similar responses to the main hydrological events of the area.

3.3.1 Apparent Colour

Apparent colour is a function of both stain and particulate matter. In the study area there was a significant decrease in median values seaward of Deas Island (R9). In the reaches upstream, median values ranged between 19 and 23 relative units but dropped downstream from Deas Island to 10-14 units. In the North Arm, there was a sharp change below Mitchell Island (R16) from about 30 relative units upstream to about 20 units below. Values from the North Arm generally appeared to be higher compared to the Main Arm and there was a noticeable increase in the median values from Pattullo Bridge (R3) to the Queensborough reach (R14). A summary of the data from each reach is illustrated in Figure 6.

The Fraser River is much higher in apparent colour than most B.C. streams which have a median of 5.5 relative units. Seasonally, apparent colour increased from winter minima of 10 to 20 relative units to maxima of 30 to 40 units during freshet. Suggested criteria range between 15 and 75 units (Clark, 1978 a). The lower criterion is exceeded during periods of freshet due to the high turbidity from upstream erosion.

Several high values for apparent colour were measured during low flows near Annacis Island and in Cannery Channel. These were likely due to effluent discharges in the two areas - a sewage treatment plant and fish-processing industries, respectively. In each case turbidity was not high, but higher levels of ammonia and organic nitrogen were found.

Although measurements are not frequently taken, high colour levels in the plume from storm ditches are commonly observed. Extensive peat bogs behind dykes on both sides of the river most likely account for this colour.

3.3.2 True Colour

True colour is measured after the sample has been filtered through a 0.45 μm filter (alternatively samples may be centrifuged) and should reflect stain in the water. There were insufficient data for reach by reach comparisons. Median values ranged between 10 to 25 relative units, much higher than the median of 5.5 units for B.C. streams in general. Nearly two thirds of the data were from Tilbury Island (R8). These data suggest that true colour increases during freshet, although the change is not large (from 10-15 units to 20-40 units).

3.3.3 Non-Filterable Residue

Non-filterable residue is analogous to suspended solids; it is that portion of a water sample retained on a 0.45 μm filter. In the Main Arm, an apparent increasing trend in median values from Annacis Island (R6) to Tilbury Island (R8) (Figure 7) is believed to be an artifact caused by an increase in the abundance of samples collected during freshet. The decrease in median values downstream from Deas Island (R9) did not appear to be a sampling artifact, and may be due to dilution by less turbid marine water. In the North Arm, no trends were noted, although the median at Oak Street Bridge (R17) was less than at Queensborough (R14).

Highest values for residue were measured during freshet and there is a suggestion that the higher values are greatest during the early stages (Figure 8). Maximum mean values in the study area during freshet were about 50 to over 150 mg/L (maximum 1 459 mg/L), compared to the winter low flow levels of 10-30 mg/L. There were no indications of any trends between 1970 and 1978.

Non-filterable residue was generally lower in the study area (30 mg/L) than median values between Hope and Mission (R25 - 45 mg/L) and above Hope (about 100 mg/L). Values from the study area are much higher than the B.C. streams median of 6 mg/L.

3.3.4 Turbidity

Turbidity is a record of the amount of light reflected by particles in the sample; the results are affected by stain in the water and by particle size distribution.

Median values in the reaches upstream from Deas Island (R9) were higher (10-27 Jackson Turbidity Units (J.T.U.)) compared to downstream (8-9 J.T.U.). There was no apparent trend in the North Arm (Figure 9). Median values for turbidity were over 20 J.T.U. above Hope, 16 J.T.U. between Hope and Mission (R25) and generally less than 15 J.T.U. in the study area (Clark, 1978 c). Values from the Fraser are much higher than the median of 2.2 J.T.U. for most B.C. streams.

The random-pair statistic showed higher levels near Annacis Island (R6) compared to downstream reaches (R7, R8); this may represent an effect of the effluent plume. Several reaches (R5, R6, R7, R8) were shown to be significantly lower than the Hope to Mission reach (R25).

Turbidity increased from minimum values of 8 to 10 J.T.U. during the winter months of December and January, to a median of over 60 J.T.U. in freshet. The greatest increase occurred in April. There was no apparent trend between 1970 and 1978 (Figure 10).

Criteria for water recreation set by the B.C. Ministry of Health (1969) suggest maximum levels of 25 J.T.U., except when naturally higher. In the study area, the natural sediment load usually causes turbidity to exceed this level during the summer months.

3.3.5 Discussion

The parameters relating to colour, turbidity and suspended matter in the water generally exhibited similar trends. Between March and July, average river flows increase by a factor of six, from about 1 100 m^3/s to 6 700 m^3/s. This results in the resuspension and erosion of bottom and bank material upstream from the study area and imparts a considerable muddy appearance to the river. Maximum levels of most parameters actually precede the highest river flows suggesting that sediments are resuspended, rather than eroded. Turbidity values for the entire data set illustrate this trend (Figure 10). It should be pointed out that cross-sectional variability can be significant due to changes in flow caused by bends in the river (Tamburi and Hay, 1978).

The particulate material appears to be settling out along the length of the Fraser, as median values of most parameters decrease from the upper reaches of the river to the study area. There is a noticeable reduction of particulates below Deas Island in the Main Arm and possibly below Mitchell Island in the North Arm. Most likely this is a dilution and coagulation effect due to the increasing influence of seawater, as this inflection point in particulates occurs in the same areas as the increase in dissolved ions (Section 3.4).

Isolated higher values were found near Annacis Island and in Cannery Channel and could be attributed to samples collected near the effluent plumes of the sewage treatment plant and the fish-processing industries. However, the impact by the industries discharging to the river on the overall turbidity is considered to be small. Assuming a low flow in the Main Arm of 6.6×10^7 m^3/day and a suspended solids concentration of 10 mg/L during that period, a rough loading in the river is about 660 000 kg/day. The total suspended solids discharged to the Main Arm plus Main Stem is about 34 000 kg/day or less than six percent of the total. The Annacis Island STP contributes less than 2% of the total, although the solids in the effluent are more organic in character and will behave differently.

Future concerns related to the proposed training wall development lie with the redistribution of sediment in the estuary and the possible leaching of toxicants from previously deposited sediments. The purpose of the training walls is to increase river velocity in order to deepen the main channel for navigation in the Main Arm. The main impact with respect to sedimentation will be on the outer banks, but the effect of the project on sedimentation in Ladner Reach, Sea Reach and Canoe Pass remains uncertain. A slight reduction in grain size and quantity of sediment is expected which could result in a reduced rate of sedimentation on Ladner Marsh. A buildup of sediment behind the walls, where extensive slack water flows will be created, is also expected.

Colour and particulate levels in the study area, and in the Fraser River as a whole, are much higher than in streams and rivers in the rest of the province. Several recreational water-use criteria are exceeded but since the high particulate levels are natural, these criteria may not be applicable. However, the standards are based on visibility and aesthetic factors and thus should be considered by those wishing to swim in the river.

3.3.6 Recommendations for Monitoring

For routine monitoring purposes non-filterable residue is recommended, especially if trace metal analyses are also being considered. The test is relatively easy to do, is more precise than turbidity and allows for the measurement of organic content (volatile residue) if required. Aerial photographs and visual fly-overs are recommended for locating site-specific problems.

True colour or TAC colour is preferable to apparent colour since the latter will be significantly affected by particulate material.

While the overall colour in the river is generally low, levels along the shore can be high, possibly due to storm ditches, creating an aesthetic and possibly a biological problem. These are site specific and should be investigated as such. However, colour is not recommended as a routine monitoring parameter in the main river channels.

3.4 Dissolved Materials

This section deals with those conservative parameters which are generally unaffected by biological activities and are considered to be non-toxic. Included are filterable residue (dissolved solids), specific conductivity, chloride, fluoride, hardness, sulphate, calcium, magnesium, potassium and sodium.

3.4.1 Filterable Residue

Upstream from Tilbury Island (R8) in the Main Arm, and Mitchell Island (R16) in the North Arm, median values ranged between 70 and 100 mg/L, similar to values found in the upper sections of the Fraser. In general the Fraser has lower concentrations of filterable residues than most B.C. streams (median 112 mg/L). Values increased several-fold with the influence of salt water; this trend was most apparent below Tilbury Island and Mitchell Island (Figure 11).

The random-pair statistic showed a trend of increasing concentration moving downstream in both the Main Arm and the North Arm. Two exceptions were Cannery Channel (R12), which had higher filterable residues than either up or downstream reaches (R11, R13), and Pattullo Bridge (R3), which had higher values than at Queensborough in the North Arm (R14).

Filterable residue was generally higher during the winter. There was an apparent decrease in the winter maxima after 1975 but this is believed to be an artifact resulting from more frequent winter sampling near the seaward reaches before 1975.

A criterion of 200 mg/L for irrigation purposes (Clark, 1978 a) would be met upstream from Tilbury Island and Mitchell Island most of the year, and throughout the river during the summer months.

3.4.2 Specific Conductivity

Median values were less than 150 µS/cm upstream from Deas Island (R9) and Mitchell Island. These values were similar to levels in the upper sections of the Fraser (100-150 µS/cm) but the overall Fraser appears to be slightly lower than most B.C. waters (median of 168 µS/cm).

Specific conductivity increased sharply seaward from Deas and Mitchell Islands (Figure 12). The random-pair statistic showed a trend of increasing values downstream for several reaches, with the exception of Cannery Channel, which was higher compared to Sand Heads, and at Pattullo Bridge, which had higher specific conductivities compared to Queensborough.

There was no apparent trend between 1970 and 1978. Seasonally, specific conductivity was generally higher during the winter, especially at those reaches near the mouths of the North and Main Arm.

Criteria for irrigation suggest that values below 250 µS/cm are acceptable for most crops (Richards, 1969). This criterion would be met most of the time upstream from Annacis Island (R6) in the Main Arm and Mitchell Island in the North Arm. A criterion of 750 µS/cm for crops with moderate salt tolerance (e.g., forage crops such as rye grass, tall fescue, rye and oats, and vegetable crops such as broccoli, cabbage and onions) would be met upstream from Deas Island or further downstream during the summer months.

3.4.3 Chloride

Dissolved chloride was one of the most frequently sampled parameters in the study area with over 6 400 analyses. Interpretation is complicated by the fact that a great many of these analyses had a high MDC of 5 mg/L. However, the parameter does generally illustrate the extent of salt water penetration.

Median values were less than 10 mg/L upstream from Kirkland Island (R10) in the Main Arm and Oak Street Bridge (R17) in the North Arm, but increased several fold seaward from those reaches (Figure 13). Levels upstream from Hope are about 1-2 mg/L and the median for most B.C. streams is 1.2 mg/L.

The random-pair statistic showed a trend of increasing concentrations downstream for several reaches except at Cannery Channel and Pattullo Bridge which were higher than the immediate reaches downstream (Sand Heads and Queensborough, respectively). Chloride levels in the North Arm at Wood Island (R18) were significantly higher than in the Middle Arm (R22). Salinity showed a similar trend.

Chloride was generally higher during low flow in the winter and decreased through freshet (Figure 14). The apparent decrease in the maxima after 1975 is believed to be an artifact due to a reduction in the sampling frequency during the winter (low flow) months.

A criterion of 100 mg/L has been reported as safe for most irrigation and some industrial uses (Clark, 1978 a). This would be met as far downstream as Annacis Island and Mitchell Island in the North Arm 90% of the time and probably much further downstream in summer when flows are higher.

3.4.4 Fluoride

Very few measurements (ca 100 values) have been taken for fluoride in the study area. Median values for the different reaches ranged between 0.05 and 0.21 mg/L, comparable to the median of 0.12 mg/L for most B.C. waters. Fluoride criteria of 1 mg/L for irrigation use and 2 mg/L for use by livestock have been reported (Clark, 1978 a). All values but one (1.18 mg/L) from the study area were well below these levels.

3.4.5 Hardness

Upstream from Deas Island in the Main Arm, median values for the different reaches ranged between 40 and 60 mg/L, but increased considerably seaward. Apart from the effects of seawater, hardness levels in the Fraser were generally lower than for most B.C. waters (median 67 mg/L) and would be considered as "moderately soft" water (i.e., less than 75 mg/L as $CaCO_3$).

3.4.6 Sulphate

Relatively few sulphate measurements have been made in the study area. Upstream from Tilbury Island and Queensborough median values were about 6 and 7 mg/L, somewhat lower than the median of 10.9 mg/L for most B.C. streams. Due to intrusion of salt water, values can increase considerably, to over 500 mg/L.

Suggested levels for use by livestock (250 mg/L desirable; 1 000 mg/L permissible; Clark, 1978 a) would be met in most of the study area except the most seaward reaches.

3.4.7 Calcium

Calcium was measured as both dissolved (filtered) and total (unfiltered). Both forms showed little changes from upstream levels until Kirkland Island and Mitchell Island where the influence of salt water was apparent. In the upstream reaches, median values were about 12 to 13 mg/L for dissolved calcium and 13 to 16 mg/L for total calcium, somewhat lower than the median for most B.C. waters (19.5 mg/L and 26.5 mg/L, respectively).

The random-pair statistic showed a trend for increasing concentration downstream for several reaches except for Cannery Channel and Pattullo Bridge (which were higher than the reaches immediately upstream).

3.4.8 Magnesium

Magnesium was measured as both dissolved and total forms, with the latter contributing most of the data. Median values for both forms ranged between 2 and 4 mg/L upstream from Tilbury Island and Queensborough Bridge. Values appear similar to those from most B.C. waters, which had a median of 4.2 mg/L for dissolved and 5.2 mg/L for total magnesium.

The random-pair statistic for magnesium was similar to that for other parameters in this section, with a general trend of higher values downstream, except for Cannery Channel and Pattullo Bridge (which were lower than upstream reaches).

3.4.9 Potassium

Less than 300 measurements for potassium (dissolved plus total) were available. Median values for those reaches away from the influence of seawater were below 1.0 mg/L. Levels were comparable to the B.C. median of 0.8 mg/L and 1.1 mg/L for dissolved and total potassium, respectively.

3.4.10 Sodium

Both dissolved and total sodium were measured, with most of the data as total. Median values ranged between 2 and 4 mg/L upstream from Tilbury Island in the Main Arm and the CN Rail Bridge (R15) in the North Arm. With the presence of seawater, levels increased considerably, up to 5 000 mg/L. Levels in the study area appear similar to most B.C. waters which have a median of 2.5 mg/L and 3.8 mg/L for dissolved and total sodium respectively.

The random-pair statistic indicated an increasing downstream trend for several reaches. Cannery Channel was lower than the upstream reach.

3.4.11 Discussion

The preceding parameters were all similar in reflecting the four major seasonal/hydrological events which occur in the study area: 1) salt water intrusion, 2) groundwater influence during winter, 3) freshet, and 4) precipitation.

Water movement and the intrusion of salt water into the river were discussed in Sections 3.1.1 and 3.1.2. The degree to which the salt wedge moves upstream is a function of both river flow and tidal amplitude, with the greatest penetration occurring during the low flow period in winter.

The parameters in this section show the above pattern clearly. The median values for each reach are similar from Hope downstream to Deas Island in the Main Arm and Mitchell Island in the North Arm, but seaward from these the median values for all parameters increase considerably (Table 3). It appears that the salt wedge frequently extends upstream to these reaches, but less often beyond.

The 90th percentile and maximum values for these parameters show salt water can occasionally move much further upstream, to New Westminster in the Main Arm and Queensborough (R4) in the North Arm. Two high chloride values (100 mg/L and 1 200 mg/L) were recorded near Port Mann (R2) suggesting that on rare occasions brackish water (the chloride values correspond to salinities of 1-2 ppt) can move further upstream than had previously been predicted (A. Ages, pers. comm.). There are no known discharges in the area of Port Mann which would contribute significantly to chloride levels in the river.

Seasonally, all parameters were at their highest concentrations during the late winter-early spring (December to March), then decreased through freshet. During the winter when most of the watershed of the Fraser is frozen, groundwater contributes a larger percentage of the water supply. This source is often high in dissolved ions and its presence is reflected in the winter maxima. During freshet, melting snow, which is low in dissolved ions, supplies most of the river water and the result is a dilution effect.

The seasonal effect of seawater intrusion is clearly demonstrated using the chloride data. Figure 15 for the Main Arm and Figure 16 for the North Arm represent the monthly means from 1970 to 1978 for the different reaches. Not only does the magnitude increase downstream, but also the frequency of occurrence of the higher values increases.

The random-pair statistic showed that Cannery Channel was higher in most dissolved ions compared to the main channel. This may be due to seawater entering the basin and becoming trapped due to flow restrictions. Values collected near the Pattullo Bridge were also higher than near the Queensborough bridge. The reasons for this are not clear, but it may have been associated with a former raw sewage outfall near Pattullo, which has now been directed to the Annacis STP. Studies should be considered to determine whether this anomaly still exists.

Rainfall can significantly influence the level of dissolved solids. Some low values for several parameters were recorded, which generally occurred during the late fall. The density of rainwater is relatively low and a layer of rainwater would float on the surface. This was observed in April, 1978, following a heavy rainfall (Bergerud and Alexander, in prep). Surface conductivities were less than 1 μS/cm and the pH was 7.0; both conductivity and pH went up as depth increased. Presumably any water sample collected at the surface during a rainfall would be quite low in dissolved ions.

3.4.12 Recommendations for Monitoring

All of the parameters in this section showed similar patterns of change occurring with season and between reaches. Background levels for most parameters are now known and none of these ions are considered critical when compared to various water quality criteria. For these reasons, a routine sampling strategy need only monitor one of these parameters as representative of the group. Specific conductivity is recommended because it can be measured easily in the field, and because depth profiles are easily determined.

Analyses for filterable residue and hardness are fairly time-consuming laboratory procedures, and yield no additional information over conductivity. Toxicity criteria often are influenced by water hardness. However, sufficient hardness data probably exist for use in the interpretation of toxicity information.

The individual ions (Cl, F, SO_4, Ca, Mg, K and Na) need not be monitored in a routine program, although special purpose studies may want to consider some of them. For example, a trend analysis on water quality parameters in the province suggests that sulphate may be a useful indicator for changing land-use patterns in watersheds (Clark, 1978 c). For reasons outlined in the previous section, it is recommended that samples be collected routinely, below 0.5 metres depth.

3.5 pH and Related Parameters

3.5.1 pH

The median pH value for most reaches ranged between 7.0 and 8.0 (Figure 17), and was comparable to levels along the length of the Fraser (7.7-8.2) and for most B.C. streams (median = 7.8). It should be noted that for this report pH measured in situ, is not distinguished from pH measured in the laboratory, though systematic differences have been noted previously (Clark et al., 1980).

Between reaches, there was an apparent increase of 0.3 in median values from New Westminster (R4) to Tilbury Island (R8). (It should be noted that this represents a two-fold increase in hydrogen ion concentration). The random-pair statistic indicated that the pH near Queensborough (R14) was significantly lower than at Pattullo Bridge (R3) which may be related to industrial discharges or storm water runoff from peat bogs in the North Arm. The statistic also showed Cannery Channel (R12) and the Annacis Island reach (R6) to be significantly lower than reaches immediately upstream, which again may be related to discharges in the area. There were no pronounced seasonal trends and no evidence of changes between 1970 and 1978.

A field survey team in April and August, 1978, tested some 70 sites in the main channels, sloughs and side-channels of the study area (Bergerud and Alexander, in prep). Generally pH ranged between 7.0 and 7.5 but values less than 6.0 were found in the bottom waters of Cannery Channel and in Deas, Tilbury and McDonald sloughs. These values were generally associated with higher conductivity and lower oxygen levels. Section 3.6.7 discusses the water quality of the sloughs and side channels in greater detail.

The lowest pH levels encountered in the river were measured during the April, 1978 survey, inside the south shore training wall opposite New Westminster. The pH ranged between 5.8 and 6.8 at several sites for all depths up to 10 metres. Along the north shore of the river and in the North Arm levels were significantly higher (7.1 to 7.5). Oxygen and temperature levels were not noticeably different from other sites but the oxidation-reduction potential was slightly higher.

The pH of several storm ditches near the New Westminster training wall where the low river pH was measured, was found to be low (about 5.9). Industrial discharges in the area include a number of sawmill and plywood operations, which discharge mainly wash or cooling water (median pH of 7.65 and a minimum pH of 7.0; Swain, in prep). The river sites were resampled in May and again in August, 1978, but the low values were not encountered. An intermittent acid discharge or spill from some unknown source may be responsible.

A number of lower pH values (below 6.0) were also found in bottom samples near a loading wharf at Wood Island (R18). High pH values, exceeding 10 units, have been measured along the shoreline near cleaning stations for some concrete industries (O. Langer, E.P.S., unpublished data).

Acid titrations of river samples from several sites were carried out in 1978 and 1979 (Krahn et al., in prep.). Both strong and weak acids (sulphuric and acetic) and strong and weak bases (sodium and ammonium hydroxide) were used. Figure 18 illustrates some of the results.

The titration curves indicate that the river is moderately well buffered against acid discharges, with about 5-10 x 10^{-5} equivalents per litre of both strong and weak acid required to lower the river pH to 6.0. However, the titration of Fraser River water with a strong and weak base suggest that the river is very poorly buffered against alkaline discharges. In fact, the Fraser is not much better than distilled water in its buffering capacity for bases (Krahn et al., in prep.).

Suggested pH criteria for the protection of aquatic life are generally between 6.0 and 8.5 (Clark, 1978 a). This range also corresponds to criteria suggested for the prevention of eye irritation during contact recreation. All but a few of the measurements in the study area were within these suggested limits, and in general pH does not appear to be a problem. However, some problems with respect to ammonia toxicity and alkaline discharges could exist, and will be discussed in Section 3.7.2.

Since some low values were encountered, and since pH is required in the calculation of chemical equilibria or in determining ammonia toxicity, it is recommended that in situ pH be included in any monitoring program.

3.5.2 Oxidation-Reduction Potential (ORP)

ORP (platinum reference) was measured during the oxygen survey and during two 24-hour sampling programs in April and October, 1977 (Alexander and Bergerud, in prep.). Median values ranged between +225 and +350 mV for the different reaches, indicating a well oxygenated system. The overall median was higher in the study area compared to most B.C. streams (+310 mV compared to +172 mV). These values correspond to an Eh of 0.4 to 0.6.

3.5.3 Alkalinity and Carbonate-Bicarbonate

Phenolphthalein alkalinity is present in significant amounts only when the pH exceeds 8.3. In the study area pH rarely was above 8.0 and as a consequence all phenolphthalein alkalinity measurements were at or below the detection limit of 0.5 mg/L. This implies that hydroxide alkalinity is nil and that carbonate alkalinity is very low.

Since the phenolphthalein alkalinity was very low, total alkalinity is an approximation of the amount of bicarbonate ion (HCO_3^-) in the water. Most measurements of total alkalinity were between 40 and 50 mg/L, slightly lower than the median of 60 mg/L for most B.C. streams. There were no differences between reaches, except that those near the mouth of the river had higher alkalinities due to the increased effects of marine water.

The random-pair statistic indicated that total alkalinity at both Pattullo Bridge (R3) and Oak Street (R17) was significantly lower than upstream (R25). A similar trend in suspended solids was noted (Section 3.3) and may be related to the calcium carbonate content of the water. Values at Queensborough (R14) were significantly lower than at Pattullo Bridge, but the reason for this is not clear.

Seasonal patterns were erratic; there was an indication in some reaches of higher values during the winter low flow, when dissolved ions were high, followed by a decrease during freshet. However, some higher values in freshet were also recorded.

The Environmental Protection Agency (EPA, 1972) recommendation that total alkalinity not exceed 20 mg/L, was met in the study area. Except for special-purpose investigations the measurement of alkalinity or of carbonate and bicarbonate ions is not recommended.

3.6 Dissolved Oxygen and Oxygen-Consuming Material

The dissolved oxygen content has a direct bearing on the ability of the river to support and sustain aquatic life. The prevailing dissolved oxygen levels will be discussed in this section, together with those elements which principally affect oxygen depletion. They include oil and grease, volatile residue (loss of weight after ashing), total organic carbon (TOC), five-day biochemical oxygen demand (BOD), chemical oxygen demand (COD), and dissolved oxygen.

3.6.1 Oil and Grease

"Oil and grease" measurements were restricted to the Main Arm (about 100 values); after 1973, measurements were made only at Tilbury Island (R8). There were some indications of higher values in the period 1970-1973 compared to those taken later, but this may be due to differences in methodology. Most of the measurements were between 2 and 5 mg/L (overall median was 3 mg/L) and the maximum was 10 mg/L. This compares with the median of 1 mg/L for most B.C. streams.

3.6.2 Volatile Residue

Some 450 measurements for volatile residue were taken in the Main Arm. All tests were done on the particulate fraction rather than on the whole sample.

A maximum of 35 mg/L was measured near Sand Heads, but most values were less than 10 mg/L. The overall median was 4 mg/L and there were no apparent trends between reaches. Levels appeared to be slightly higher than the median of 2 mg/L for most B.C. streams. Seasonal trends indicated a freshet maximum with lowest levels during the winter low flows, corresponding to the pattern of suspended solids (Section 3.3). There were no observable trends between 1970 and 1978.

3.6.3 Total Organic Carbon

Median values in the different reaches were low, ranging between 2 and 5 mg/L, with an overall median of 4 mg/L. This compares with the upstream reaches of the Fraser which had median TOC concentrations between 3 and 4 mg/L and with most B.C. streams (median 5 mg/L). There were no trends between reaches although some of the highest values were recorded near Annacis Island (presumably collected in the STP effluent plume). There was no significant difference ($p<0.05$) between all the data collected in the Main Arm and the North Arm; the overall mean for both was 4.2 mg/L.

There was no apparent seasonal pattern for TOC; high values occurred in freshet as well as low flow periods. There was no observable trend between 1970 and 1978 for any of the reaches or for the combined data. However, there was a slight, but significant ($p<0.001$) decrease (4.3 mg/L to 4.0 mg/L) in the North Arm between the period 1970 to 1974 and 1975 to 1978. A similar decrease also occurred in the Hope to Mission reach (R25) (5.4 mg/L to 5.3 mg/L) but there were no differences between the two periods in the Main Arm.

3.6.4 Biochemical Oxygen Demand

Two thirds of the BOD data were collected near Tilbury Island during 1976, and the data base for most years is limited. Many values were at or below the detection limit of 1 mg/L. The overall median was 2 mg/L and the maximum value 10 mg/L. There were no observable trends between 1970 and 1978.

3.6.5 Chemical Oxygen Demand

COD was measured only near Tilbury Island (R8) during 1976. Values ranged between 0 and 175 mg/L with a median of 20 mg/L. Twenty-one values were 50 mg/L or larger; these results are higher than some recent data (March, 1979) collected by the Waste Management Branch in the Main Arm, which showed that five out of six measurements were below the MDC of 10 mg/L (the other value was 12 mg/L). Data from upstream sites between Hope and Mission (R25) were also lower than those from Tilbury Island, with a range of 5 to 20 mg/L and a median of 12 mg/L.

Near Tilbury Island there was no obvious correlation between COD and the other parameters measured and no observable effect on dissolved oxygen levels. Values appeared to be higher during the winter, but this may be due, in part, to chloride interference which has a positive effect on the analysis. It is possible that the differences between the 1976 and 1979 values are due to different analytical techniques; the area should be re-investigated, especially in view of the fact that there is a chemical plant on Tilbury Island which discharges to the river.

3.6.6 Dissolved Oxygen

In the main river channels oxygen levels were high (Figure 19). The median concentrations for all reaches were above 9.5 mg/L and the 10th percentiles exceeded 7.0 mg/L. Most of these concentrations represent a saturation of 80 to 100 percent. A recent survey (April, August, and October, 1978) of some 70 sites in the river showed saturation levels in the main channels at or near 100% at all depths to 10 metres (Bergerud and Alexander, in prep.). However, low values were occasionally found in the bottom waters of some sloughs (see Section 3.6.7). Within the main river channels, oxygen levels were similar to the median of 10.8 mg/L for most B.C. streams.

There was a slight decrease of less than 1 mg/L in the median concentration between Annacis Island (R5) and Tilbury Island (R8), but levels increased again downstream. The random-pair statistic showed the reach downstream from the Annacis Island STP (R6) to be significantly lower than Tilbury reach. This is likely due to the fact that several of the samples at R6 were collected directly in the Annacis STP effluent plume.

A decrease of 2 mg/L in the median dissolved oxygen concentration between Queensborough (R14) and the North Arm Jetty (R19) was noted. This decreasing trend was found to be significant ($p<0.05$) using the random-pair statistic.

A comparison of all the data from 1970 to 1978 showed the North Arm to have significantly lower oxygen levels (t-test; $p<0.01$) compared with the Main Arm (mean values were 10.8 mg/L and 11.3 mg/L respectively) while both were significantly lower than upstream (Main Stem: $\bar{x} = 11.7$ mg/L).

Dissolved oxygen levels were highest during the winter months of January and February, when temperatures were lowest (oxygen is more soluble in cold water). Levels decreased during the spring to minima during July to September (Figure 20). There was no apparent trend between 1970 and 1978 for the combined data, or at any of the individual reaches. There were no trends indicated by the calculation of the 12-month running mean, with differences usually less than 1 mg/L and a maximum difference of only 1.3 mg/L. A comparison of all data collected between 1970 to 1974 and since the Annacis Island STP began operation (1975-1978), showed no statistical difference (t-test; $p<0.05$) between the two time periods, in either the Main Arm or the North Arm.

3.6.7 Sloughs

Three surveys in 1978 (April, August and October) investigated oxygen levels in many of the sloughs and back-channels of the study area (Bergerud and Alexander, in prep.). Most had oxygen levels exceeding 80% saturation, with concentrations generally greater than 8 mg/L.

There were a number of notable exceptions. Measurements taken within 2 metres of the bottom, in the central portion of Cannery Channel (R12), and at the heads of Deas Slough (Main Arm) and McDonald Slough (North Arm), fell below 5 mg/L in August and October. Deas Slough also had low values during April.

These low oxygen values appear to be related to pockets of more dense (saline) waters retained by depressions in the bottom. Usually conductivity was higher and pH and oxidation-reduction potential values were lower than levels in the river.

The Department of Fisheries and Oceans conducted monthly water quality surveys in and around Tilbury Slough and Deas Slough during 1976-1977. Reports on these data are in preparation, but their raw data have been included in this report.

In Tilbury Slough the median oxygen concentration was 6.9 mg/L but 9 out of 50 values were below 5 mg/L. These low values all occurred during the summer and were associated with higher total organic carbon and colour values.

Data from Deas Slough indicate that oxygen levels are low near the head of the slough, especially in the bottom waters. These results are similar to those found during the 1978 survey (cited earlier). Again, high total organic carbon and colour values were associated with the low oxygen levels.

The Westwater Research Centre has published data from Ladner Reach and Ladner Slough (Hall, in prep.). High levels in excess of 80% saturation were reported throughout most of the year although some summer values as low as 65% saturation were measured in bottom waters near the head of the slough. A similar trend of depressed, but not critically low oxygen levels was measured during the 1978 oxygen survey (Bergerud and Alexander, in prep.).

Oxygen measurements in Cannery Channel have been taken each summer from 1973 to 1978 (excluding 1975) by the Environmental Protection Service (Atwater et al., 1976 and unpublished). While most of the values exceeded 5 mg/L, occasional lower values were recorded, generally near the bottom. Percent saturation was usually better than 80%, but did drop to 23% on one occasion. The results were similar to those from the 1978 survey.

3.6.8 Discussion

The number of measurements for organic matter and oxygen-consuming parameters was not large but most of the values were near the detection limit. There were no indications of high organic matter content in any of the reaches in the main river channels. This observation is confirmed by the overall high oxygen levels in the river. Moreover, ambient levels are below those which will encourage the growth of slime forming bacteria.

Criteria for oxygen levels range from a minimum of 5 mg/L (EPA, 1976) to those suggested by Davis (1975). Ninety percent of all cxygen measurements exceeded the level B criteria of Davis (6-8 mg/L) in all reaches except at the North Arm Jetty (R19) and near the Iona Island STP (R20). Median oxygen concentrations for all reaches were close to or exceeded level A for salmonids (7.75-9.75 mg/L). In the main river channels, minimum values at each reach exceeded the 5 mg/L criterion.

Several reports and recent surveys by a number of government agencies have shown that oxygen levels in certain side-channels and sloughs do occasionally reach low levels, often below 5 mg/L. These low oxygen pockets are frequently near the bottom and characterized by correspondingly higher conductivities (except at Tilbury Slough), colour and organic content, and lower pH levels.

Deas and McDonald Sloughs are heavily utilized by the forest industries for the storage of log booms, and wood debris settling on the bottom represents a long-term oxygen demand. In addition, leachate from Burns Bog landfill drains into Crescent Slough, which in turn drains into the mouth of Deas Slough. Work is underway to divert the Burns Bog leachate to Annacis STP.

Considerable log-booming occurs at the mouth of Tilbury Slough but leachate from general land-use and agricultural activities probably is the major source of oxygen-consuming material. Similarly, organic material entering Ladner slough is likely from farmland and marsh drainage. In Cannery Channel the major source of organic material is from the fish-processing plants.

While the higher oxygen demand of the organic material draining into these sloughs certainly contributes to the lower oxygen levels, a major factor may still be the entrapment of saline water which had penetrated the sloughs during the intrusion of the salt wedge. The geography of these sloughs is such that they are poorly flushed and there is evidence that these pockets of saline waters may exist for a period of several weeks to months (high bottom conductivities in Deas Slough were measured during freshet at a time when the salt wedge rarely penetrates beyond Steveston). During this length of time, microbial activity would result in a considerable reduction in oxygen levels if there is little mixing with surrounding waters.

It should be noted that for Deas and MacDonald Sloughs, it is man-made obstructions which have restricted the river flow. Therefore it is possible to increase the flushing of these areas, thereby improving fish and wildlife habitat provided that other deleterious conditions would not result.

The river training proposal (Beak, in prep.) will likely create extensive areas of slack water behind the training walls, which may result in lower oxygen levels. Measurements behind existing walls do not suggest a problem, although oxygen levels are slightly lower than in the main channels (Bergerud and Alexander, in prep.).

3.6.9 Recommendations for Monitoring

Most measurements for organic and oxygen-consuming material did not show any regions of concern or significant trends. Data generally were erratic, in part due to the fact that most measurements were near the detection limits. None of these parameters are recommended for routine monitoring in the main reaches.

For programs measuring non-filterable residues the organic fraction (volatile residue) of these solids could be obtained at relatively little extra cost.

Dissolved oxygen monitoring should be continued, to follow the patterns established to date in the river. Periodic surveys of the sloughs and side-channels should also be included. A minimum frequency of monthly measurements is recommended to obtain reasonable seasonal patterns. Temperature, barometric pressure and conductivity should be measured simultaneously, in order to calculate percent saturation.

3.7 Nutrients

This section deals with the major nutrients—nitrogen, phosphorus and silica—required by aquatic plants. Nitrogen in the water can be present in the elemental form (N_2), in organic matter (e.g. amino acids and proteins) or as ammonia, nitrite or nitrate. In general, the breakdown of organic matter (ignoring some intermediate steps) results in production of ammonia, then nitrite, and finally nitrate. Each step is regulated by microbial activity, and the rates of conversion may vary from a few days to several months. Ammonia (and some organic nitrogenous compounds) are also excreted by some aquatic organisms.

Ammonia, nitrite and nitrate are all used by algae as nitrogen sources, with ammonia preferentially selected at concentrations greater than 0.02 mg/L-N (McCarthy, 1979). On the other hand, high concentrations of undissociated ammonia can be toxic to fish.

Phosphorus is usually reported as ortho phosphate (PO_4^{3-}) or as total phosphate; concentrations and loadings of phosphate are referred to in terms of 'P', not 'PO_4'. For total phosphate, the various forms of organic and inorganic phosphorus compounds are degraded by strong acid digestion to ortho-phosphate which is then analysed. Total phosphate measurements can be made on both filtered and unfiltered samples to determine the dissolved and particulate fractions. Ortho-phosphate is a reasonable approximation of biologically available phosphate.

3.7.1 Ammonia

In aqueous solutions, NH_3 combines with H_2O, forming NH_4OH, ammonium hydroxide. Ammonium hydroxide solutions partially dissociate, to ammonium and hydroxide ions, NH_4^+ and OH^- respectively. The extent of this dissociation is a function of pH, salinity (i.e., ionic strength) and temperature.

$$NH_3 + H_20 \rightarrow NH_4OH \rightleftharpoons NH_4^+ + OH^-$$

To avoid ambiguity, the terminology used for further discussion in this report will refer to NH_3 or NH_4OH as 'undissociated ammonia', to NH_4^+ as 'dissociated ammonia' or 'ammonium ion' and to the sum of undissociated and dissociated ammonia as 'ammonia' or 'total ammonia'.

Median values for ammonia were less than 0.05 mg/L-N for all reaches (Figure 21). Occasional high values (maximum 3.24 mg/L-N) were measured near Annacis and Tilbury Islands (R6 and R8) and these were apparently associated with the sewage effluent plume. In the same samples elevated levels of organic-nitrogen, total phosphate and coliform bacteria were noted. There were also a number of values greater than 0.1 mg/L in the lower reaches near Steveston Island (R9 to R13) which, along with higher coliform counts, may reflect the presence of either the Lulu Island or Annacis Island STP discharges.

Comparison of the median concentrations did not reveal any trends between the different reaches. However, the random-pair statistic did indicate that levels downstream from the Annacis discharge (R6) were significantly higher than those immediately upstream (R5). Sand Heads (R13) was also significantly higher than upstream (R11) or in Cannery Channel (R12). The reason for the higher levels at Sand Heads is not immediately apparent. It may be due to the presence of seawater, although levels of ammonia in marine waters are not typically higher than the concentrations measured in the study area (Table 10).

Median values in most reaches appeared to be slightly higher than those found between the headwaters of the river and Hope (ca 0.01 mg/L). The median for most B.C. streams is 0.015 mg/L, again slightly below the values measured in the study area.

Seasonal trends were not apparent within the individual reaches. Using the combined data for all reaches (R26) there is a pattern with maximum levels occurring during the winter months, decreasing through freshet to summer minima (Figure 22). The lower summer values are probably the combined result of dilution plus biological utilization, since minimum levels occur after the peak flow period. There was no observable trend between 1970 and 1978 in any of the individual reaches or with the combined data.

3.7.2 Ammonia Toxicity

While it is known that undissociated ammonia is more toxic than the ammonium ion, most analytical procedures report ammonia data as the sum of dissociated and undissociated ammonia ($NH_3 + NH_4^+$). However, if the pH, temperature and salinity are known, the concentration of undissociated ammonia can be calculated.

The equilbrium equations presented in Bower and Bidwell (1978), were used to calculate the amount of undissociated ammonia as a percentage of the total. Table 4 gives the actual concentrations of undissociated ammonia, for a range of total ammonia, pH and temperature values. The different values for each of the parameters approximate the 10th, 50th and 90th percentiles of the total data set from the study area. Salinity was assumed to be zero since that represents a worst-case situation. Note that an additional safety factor is inherent in this estimation, since ammonium may associate with metal ions, thus shifting the equilibrium further from the undissociated ammonia.

At the 90th percentile for all three parameters, the maximum amount of undissociated ammonia would be 0.004 mg/L-N, (less than 4% of the total ammonia), well below the water quality criterion of 0.01 to 0.02 mg/L-N (Inland Waters Directorate, 1972; EPA, 1972, 1976).

Ammonia in wastes from sewage treatment plants ranges between 8 and 25 mg/L-N, and averages about 12 mg/L-N. In these effluents the undissociated ammonia could reach 0.7 mg/L-N but would be rapidly diluted. The maximum undissociated ammonia value measured was 0.025 mg/L, directly over the outfall at high slack tide (B.C. Research, 1978). This implies some likelihood of fish toxicity in the effluent plume area, but only in those situations of low river dilution. At dilutions of greater than 15:1, no toxicity from undissociated ammonia is expected.

It is important to note that acute ammonia toxicity in the Fraser should not be a problem primarily because the river pH is usually below 8.0 and very rarely exceeds 8.5. Table 5 shows the concentration of undissociated ammonia for a series of pH levels (8.0-9.0) and assumed ammonia concentrations (0.1-1.5 mg/L- N). The dark line indicates the criterion level of 0.02 mg/L-N. Should ammonia concentrations approach the levels shown, the toxicity from this source would be a factor as pH reaches 8.5.

The data suggest an argument for particularly controlling alkaline discharges to the Fraser. While the river is moderately-to-well buffered against both weak and strong acids, it is very poorly buffered against either weak or strong bases. In fact the river is only slightly more buffered towards bases than distilled water (Section 3.5.1). An appropriate management strategy would be to eliminate all discharges to the river of wastes with high pH levels.

3.7.3 Nitrite-Nitrate

Nitrite (NO_2^-) was nearly always at or near the MDC of 0.005 mg/L-N. Nitrate (NO_3^-) values generally ranged between 0.03 mg/L-N and 0.18 mg/L-N (10th and 90th percentiles) with an overall median of 0.08 mg/L-N. Data are similar to the median concentration of 0.07 mg/L-N for most B.C. streams.

There were no apparent differences between reaches for nitrate (Figure 23), but the random-pair statistic indicated that Queensborough (R14) was significantly higher in nitrate than Pattullo Bridge (R3). The statistic also showed a trend of increasing concentrations downstream in the Main Arm, with the highest levels near Annacis Island and the mouth of the river. This trend would appear to be related to an increase in the amount of seawater present, which typically has higher nitrate concentrations (about 0.2 mg/L-N) than river water (Table 10). The sewage treatment plants are not likely a significant source, as primary treated sewage effluent is usually quite low in nitrate (most of the nitrogen is present as organic-N or ammonia-N). The residence time of the effluent in the river is expected to be much less than the time required for conversion of organic-N and ammonia to nitrate.

Like ammonia, nitrate levels were much higher during the low flow period of January to March, and decreased through freshet to late summer minima (Figure 24). There were no apparent trends between 1970 and 1978 at any of the reaches or for the combined data set (R26).

3.7.4 Organic Nitrogen

Data in this section include both organic and Kjeldahl-nitrogen. The Kjeldahl measurement includes both ammonia and organic nitrogen; however ammonia generally was low (<10%) in comparison to the organic fraction.

Median values for Kjeldahl-N generally ranged between 0.1 mg/L-N and 0.3 mg/L-N for the different reaches (Figure 25). The North Arm appeared to be slightly higher compared to the Main Arm and this proved to be statistically significant (t-test; $p < 0.05$). Mean values were 0.18 mg/L-N for the North Arm and 0.13 mg/L-N for the Main Arm, based on all the data collected in the two areas.

Median values for organic nitrogen near the Annacis STP did not appear to be higher than those at other nearby reaches. Several high values (maximum 5.03 mg/L-N), with correspondingly high coliform counts, were measured near Annacis and indicated the presence of the sewage effluent plume. The random-pair statistic showed values from the Queensborough reach (R14) to be significantly higher than at Pattullo bridge (R3). The reason for this is not apparent, but may be associated with the former raw sewage outfall from New Westminster near Pattullo Bridge at Braid Street. This sewage has now been diverted to the Annacis Island STP.

Data from the study area are comparable with those from the upper sections of the Fraser (0.1-0.3 mg/L-N) and with most B.C. streams, which have a median concentration of 0.14 mg/L-N (Table 10). The data from the study area were too variable to allow detection of any seasonal patterns or any trends between 1970 and 1978.

3.7.5 Ortho-Phosphate

There was no apparent trend for ortho-phosphate between most reaches in the study area (Figure 26). Median values generally ranged between 0.003 mg/L-P and 0.01 mg/L-P. These values may be slightly higher than levels in the Fraser upstream from Hope (0.002-0.005 mg/L-P), or from the median concentration of 0.005 mg/L-P for most B.C. streams. There was a suggestion of higher values near the mouth of the North and Main Arm, probably due to the increase in the amount of seawater present. Near the Annacis Island STP (R6) several high values (maximum 0.53 mg/L-P) were recorded and were associated with correspondingly higher organic carbon and coliform bacteria levels.

3.7.6 Total Phosphate

Total phosphate consists of dissolved and particulate material including organically bound phosphate and phosphate associated with sedimentary material. In the

Fraser River, total phosphate levels are generally 4 to 6 times higher than either ortho-phosphate or the total dissolved phosphate component, indicating that the bulk of phosphate is in the particulate form.

Median values for phosphate in the North Arm reaches ranged between 0.05 and 0.1 mg/L-P, and appear to be slightly higher than in the Main Arm (medians 0.04 to 0.08 mg/L-P). However, a comparison of all the data collected from the two arms did not show any significant difference (t-test; $p < 0.05$).

Total dissolved phosphate was infrequently measured. However, from the combined data (R26) the 10th, 50th and 90th percentiles were 0.005, 0.010 and 0.032 mg/L-P respectively, similar to that of ortho-phosphate (0.003, 0.007 and 0.037 mg/L).

In general, median values for total phosphate increase towards the mouth of both the North Arm and the Main Arm (Figure 27), reflecting the higher phosphate content of seawater (ca 0.6 mg/L-P compared to the upstream levels of about 0.03 mg/L-P). This trend of increasing levels downstream is supported by the random-pair statistic.

Total phosphate levels near the Annacis Island STP (R6) were significantly higher (random-pair statistic) when compared to the downstream reaches at R7 and R8. Several high phosphate levels near Annacis (maximum 0.9 mg/L-P) were reported and were associated with correspondingly high ammonia, organic nitrogen, and coliform bacteria levels. The samples were possibly collected in the effluent plume. The apparent increase in the median concentration of total phosphate near Tilbury Island is believed to be an artifact caused by a more intensive sampling program during freshet compared to other periods of the year.

Like turbidity, total phosphate levels increase between the headwaters and Hope (0.02 to 0.06 mg/L-P) then decrease until the effects of seawater are apparent. The Fraser River in general is much higher in total P than most B.C. streams (median 0.025 mg/L-P).

The data between 1970-1974 and 1975-1978 were compared to test for differences which may have been associated with the coming on line of the Annacis STP. There was no difference in the data collected between the two periods in the North Arm or in the Main Arm (t-test; $p<0.05$), nor was there any difference in levels between the periods for the data collected near Annacis Island (R6 and R7). However, one reach in the Main Stem (R3) and two in the North Arm (R14, R17) had significantly higher concentrations of total phosphate (0.077, 0.057, 0.059 mg/L-P respectively) during 1970-1974 compared to 1975-1978 (mean concentration for all three was 0.039 mg/L-P). It cannot be confirmed whether this observation was due to the diversion of sewage from the North Arm, Surrey and New Westminster water fronts to the Annacis Island STP.

Seasonally, there was a clear relationship between total phosphate and river flow. Phosphate levels increased 3 to 4-fold during freshet to maxima in May and June, while minimum values were generally measured during low flow in January to March (Figure 28). Like turbidity, the maximum concentration appeared to precede maximum flow, suggesting that the phosphate is associated with the sedimentary material which is resuspended during the initial increase in river discharge.

3.7.7 Reactive Silicate

Silicate was infrequently sampled in the study area. Median values ranged between 3 and 6 mg/L-Si and are similar to that of most B.C. streams (median of 6.2). Except for Queensborough (R14), which appeared lower than most reaches, there were no apparent trends.

Seasonal patterns were not clear, but there is a suggestion of higher values occurring during winter. This may be due to the increasing effect of groundwater supply to the river during low flow periods, and/or to the greater influence of seawater during this period.

Some industrial uses require silica levels to be below 10 mg/L-Si. This level has been exceeded only on a limited number of occasions, with a maximum of 13.4 mg/L-Si.

3.7.8 River Loadings

The discharge of municipal wastes to the Fraser River introduces the possibility of increasing the primary productivity in the river itself and/or in the Strait of Georgia. In fact, it has been suggested that the latter may be occurring (Stockner et al., 1979).

The annual loadings of nitrogen and phosphate entering the study area from upstream, were estimated. Kjeldahl-nitrogen (which includes ammonia), nitrate and nitrite were summed to estimate the total nitrogen (within a 95% confidence limit). Monthly flow data at Pattullo Bridge for low flow (10th percentile), high flow (90th percentile), plus two additional years (1967 and 1977) were used to estimate the total nutrient loading in the river. For 1967 and 1977, daily flows were used to calculate a 95% confidence limit to be used in estimating the overall variability of the loading calculations.

There was no indication of any trend between 1970 and 1978 for nitrogen and phosphate. Consequently, data collected from 1970 to 1978 at Pattullo Bridge were used to estimate the mean (95% confidence limits) monthly concentrations for NO_2^-/NO_3^-, Kjeldahl-N, total phosphate and ortho-phosphate. These were then used with the monthly flow data (10th and 90th percentiles, based on the years 1916-1976; see Section 3.1.1 and Table 1) to determine the annual nutrient loading for a low and high flow regime. In addition, average daily flows for 1967 and 1977 were used along with the nutrient data (combined data, 1970-1978) at Pattullo Bridge to estimate the mean (95% confidence limits) loading for those years. The data are presented in Table 6.

It should be made clear that these are very general estimates, and a great deal of uncertainty exists with the values. Variations in loading values are primarily due to changes in river flows, and to a lesser extent to variations in river concentrations. In addition, if flow is irregular, then a bias can result from regular monitoring (Kleiber and Erlebach, 1977). Other uncertainties include tidal effects, cross-sectional variability and variability with depth. The final values represent an estimate of the average loading, but instantaneous or short term loadings may differ substantially from the mean.

In a low flow year, the annual loading for total nitrogen at Pattullo Bridge is about 20 000 tonnes/annum (t/a) and in a high flow year, the loading is about 37 000 t/a. Total phosphate loadings varied between 5 000 and 9 000 t/a for a low and high flow year, respectively, while ortho-phosphate loadings ranged between 300 and 600 t/a, respectively.

Loading estimates (mean and 95% confidence limits) for 1967 were 32 000 ± 15 000 t/a total nitrogen, 8 000 ± 7 000 t/a total phosphate and 500 ± 300 t/a ortho-phosphate. In 1977, the loading estimates were 27 000 ± 11 000 t/a total nitrogen, 7 000 ± 5 000 t/a total phosphate and 400 ± 300 t/a ortho-phosphate. The decrease in 1977 is due to the lower flows that year compared to 1967.

3.7.9 Discharges of Nutrients

Table 7 shows the contribution of total nitrogen and total phosphate from domestic, industrial, landfill, storm sewer and surface run-off sources in the study area.

Loadings from the sewage treatment plants were based on twice monthly measurements during 1977 (coefficient of variation was about 20%) while industrial loadings for N and P were based on either actual effluent analyses or on Pollution Control Branch permit criteria if no data were available. Loadings from landfills are from Atwater (1980) while estimates for the storm sewers and surface runoff were obtained from Ferguson and Hall (1980).

For 1977, the estimated annual discharge from urban sources was about 5 300 t/a nitrogen and 900 t/a phosphate. Domestic wastes contributed about 70% of the nitrogen and 79% of the total phosphate discharged to the river, with most of the remainder coming from storm sewers or surface runoff. Nutrients discharged from industrial sources are considered minimal; landfill sources may have high ammonia concentrations but because of the low flows, the total loading is small.

Stockner et al., (1979) have estimated the domestic, industrial and storm sewer contributions of nitrogen from metropolitan Vancouver in 1977 to be 9 603, 1 680, and 453 t/a, respectively. The estimates in Table 7 are lower for municipal and industrial contributions (3 700 and 140 t/a) and higher for storm sewer contributions (1 100 t/a). Similarly, Stockner et al. (1979) estimated the amount of phosphate discharged into the Fraser to be 2 730 t/a which is three times higher than our estimate of 900 t/a. The differences may be attributable to the methods of calculating the loadings: Stockner's values appear to be based on 'typical' loadings derived from the literature, and adjusted to the population figures for Vancouver, whereas the figures in Table 7 are based upon effluent data from the study area.

Stockner et al. (1979) have reported a two to four fold increase in primary productivity in the Strait of Georgia between 1967 and 1977, and attributed it in part, to the increase in population and resultant discharges from the Lower Mainland of British Columbia, and to a change in the location of these discharge points from other waterways to the Fraser. Nitrogen has been specified by Stockner et al. (1979) and others (e.g., Antia et al., 1963) as the limiting nutrient for phytoplankton production in the Strait of Georgia; further discussion on eutrophication in the Strait will be limited to that nutrient.

Since there were no data available for 1967, the contribution of nitrogen from metropolitan Vancouver was estimated in the following manner. First, the domestic, industrial and storm sewer contributions were assumed to be proportional to the population increase over the ten years and so the values for 1977 were multiplied by 0.7 to determine the 1967 levels (Table 8). Secondly, changes in discharge locations, primarily the inputs to the Iona Island STP and the Annacis Island STP, were determined.

In 1967, about 50% of the present area serviced by Iona was connected to sewers discharging to Vancouver Harbour and Burrard Inlet (GVRD Engineers, pers. comm.). It was assumed that the area discharging from the Iona STP increased in proportion to the overall population change. The total loading for 1967 is estimated to be 1 400 t/a nitrogen of which 700 t/a was discharged to Sturgeon Banks through the Iona STP outfall. Annacis Island was not in operation in 1967 and 80% of the area now serviced by that plant discharged directly to the Fraser (GVRD Engineers, pers. comm.). As with Iona, it was assumed that the nitrogen discharged by those outfalls, which are now handled by the Annacis Island STP, was proportional to the overall population increase in the area. An estimate of 900 t/a for 1967 was made of which 700 t/a went into the Fraser River and 200 t/a went to other areas such as Burrard Inlet or Boundary Bay. It was also assumed that nitrogen loadings from other sources (landfills, industrial and storm water) were proportional to population changes, and these sources were estimated to be about 1 100 t/a.

Population growth for the Lower Mainland has been predicted to be about 2.9% per year (GVRD, 1975). Based on a 1977 figure of 1 515 000, the population will be about 3 000 000 in the year 2 000, and the total nitrogen discharged to the river and estuary will be about 10 600 t/a, assuming no change in present waste management strategies (Table 8).

The total nitrogen loading to the Strait of Georgia is presented in Table 9. The estimates are made up of the discharges from metropolitan Vancouver (Table 8) plus river loadings measured at Pattullo Bridge (Table 6).

In 1967, the total nitrogen loading was estimated to be 34 700 $\pm$ 15 000 t/a. The contribution by effluents was about 8% (6-14%). Although the discharge of nitrogen from the various effluents nearly doubled in 1977 compared to 1967 (2 800 to 5 300 t/a) the total loading to the Strait of Georgia was less (32 100 $\pm$ 11 000 t/a), due to the lower river flow in 1977. In 1977 the contributions from effluents had increased to about 16% (12-25%) of the total, for an average annual increase of less than 10% between 1967 and 1977.

By the year 2000, if a low flow regime (i.e., 10th percentile) is encountered, the contribution by metropolitan Vancouver to the total nitrogen loading to the Strait of Georgia could be as high as 35% (if present waste treatment policies are maintained).

3.7.10 Discussion

Isolated high river values for ammonia, organic-nitrogen and total phosphate associated with effluents from the sewage treatment plants were found. However, there is no apparent overall trend in the river which can be attributed to changes in discharge patterns and particularly the consolidation of wastes to the Annacis Island STP. Neither nitrogen nor phosphate showed any significant difference between 1970-1974 and 1975-1978, the latter period corresponding to the operation of the Annacis Island STP. There was also no significant difference between the data collected in the Main Arm and those from the North Arm. Water quality near Annacis Island (R6 and R7) did not appear to change due to the sewage discharge except for isolated high values which were possibly for samples collected directly in the effluent plume. The increase in nitrate concentrations between 1967 and 1977 at Tilbury Island, reported by Stockner et al. (1979), was not apparent from the historical data now in EQUIS.

Total phosphate and organic carbon were significantly higher before 1975 than after, at two reaches in the North Arm (R14 and R17) and at Pattullo Bridge in the Main Stem (R3). This observation was not true of nitrogen. These results may reflect a reduction in nutrients entering the North Arm, but the data are not sufficiently precise to make a more definitive comment.

Compared to other rivers in British Columbia and North America, levels of nitrogen and ortho-phosphate in the Fraser appear to be about the same or lower (Table 10). Total phosphate levels are greater in the Fraser because of the high sediment load in the river.

In fresh waters phosphate is generally considered to be the limiting nutrient (see Schindler, 1974) and an increase in phosphate often results in an increase in primary productivity leading to eventual eutrophication. Levels of phosphate consistent with low productivity rivers are summarized by Vollenweider (1971), to be in the range of 0.002 - 0.23 mg/L; generally the Fraser is within these limits.

Much of the total phosphate in the river may not be biologically available since it is associated with the suspended sediments. Smith et al (1977) suggested that the contributon of apatite in the aquatic environment to the P-cycle would be important only under oligotrophic conditions. In Kamloops Lake, up to 80% of total P was apatite (St. John et al., 1976). Other factors which probably restrict algal growth in the lower Fraser River are the high seasonal turbidity, which limits the amount of available light, water fluctuations and substrate (for attached forms) and salinity changes. Generally, there have not been any public complaints of excess algal growth in the main river channels, and eutrophication problems are not anticipated. Nevertheless, Westwater Research have reported (Northcote, 1974) the common occurrence of the nuisance alga Cladapora glomeca (common to polluted waters) in the Lower Fraser, and also reported fairly high levels of total periphyton biomass and attached diatom cell densities. Westwater indicated that these facts may indicate incipient problems due to excessive nutrient addition to the Lower Fraser. It should also be noted that phosphate has been implicated in an increase in algal growth in the Thompson River below Kamloops Lake (Thompson River Task Force, 1975).

In the marine environment, nitrogen is generally considered to be the limiting nutrient for phytoplankton production (Antia et al., 1963; Thomas et al., 1974). Stockner et al. (1979) have reported a two to four-fold increase in annual primary productivity in the southern Strait of Georgia between 1967 and 1977. The increase has been attributed, in part, to the increase in nutrients, (particularly nitrogen) discharged to the river from metropolitan Vancouver. Loading estimates in this report have a degree of uncertainty associated with them but the data suggest that these discharges represent a small percentage of the total nitrogen loading in the river, increasing from 8 to 16% from 1967 to 1977.

Nitrogen in general, and the discharges from metropolitan Vancouver in particular, are not considered to be solely responsible for the reported increase in primary productivity, since the increase in total nitrogen to the Strait of Georgia from 1967 to 1977 appears to be so much less than any change in productivity. It is not known, however, how rapidly organic nitrogen from the STP is converted to ammonia and other usable forms of nitrogen; it is possible that organic-N is transported outside of the study area and even from the lower Strait of Georgia before nitrification occurs. It is not known whether nitrogen from sewage treatment plants is preferentially utilized compared to upstream forms of organic-N.

Under present waste management practices, the nitrogen discharged from metropolitan Vancouver by the year 2 000 could reach 35% of the total nitrogen in the river during a low flow year. The consequences of this to primary productivity in the estuary and the Strait of Georgia have not been resolved. At some point in the future, nutrient removal may have to be incorporated at the sewage treatment plants, if an increase is deemed detrimental (Stockner et al. (1979) have suggested that a benefit to the fisheries resource might be a result of an increase in nutrients). It should be pointed out, however, that conventional secondary treatment may not remove much more nitrogen than primary treatment alone. More advanced wastewater treatment would be required to remove significant amounts of nitrogen from the effluent.

Elutriate tests on sediments from the river banks suggest that phosphate and nitrogen might be released from resuspended bottom material, as a result of the river training project. However, this increase was estimated to be only eight percent and probably less, and would occur only during the duration of the project. The increase would be greatest during freshet when levels in the river are usually higher (Beak, in prep.). Problems due to nutrient enrichment, as a result of the river training project, are not anticipated.

3.7.11 Recommendations for Monitoring

The determination of nutrient levels in the Fraser, especially from upstream sources, is required, to determine future trends. Total nitrogen (ammonia, nitrate+nitrite, organic-N) and total phosphate (total dissolved-P and total particulate-P) are recommended.

3.8 Trace Metals

3.8.1 Introduction

Changing analytical techniques which improved the lower limits of detection have led to difficulties in comparing historical and current data. Frequently, the different detection limits for a particular metal would cover several orders of magnitude. The analyses for trace metals are generally covered by one of the following broad categories: (1) dissolved metal, or those metals in that portion of a water sample which passes through a 0.45 µm membrane filter; (2) total metal, or those metals in an unfiltered sample which are soluble after a reasonably harsh digestion with concentrated acid (but not necessarily a complete digestion to include mineral-bound metals) and (3) extractable metals, or metals in an unfiltered sample which are soluble after a less harsh digestion. None of these procedures will necessarily release all or even a predictable portion of mineral bound metals.

Besides these broad differences, a host of other methods exist, with differences in extraction times, strength of acids used, pretreatment of the sample and storage time before analysis. All are thought to play a part in affecting the analytical results.

The provincial Environmental Laboratory and the Inland Waters Directorate (IWD) Laboratory have performed most of the metal analyses. The provincial lab analyses for dissolved metals (filtered sample) and total metals, but the digestion procedure for total metals probably does not include mineral bound species. The IWD Laboratory measures for extractable metals, and the digestion treatment is not greatly different from that of the provincial lab. For the purposes of this study the analytical results from both laboratories have been considered equivalent.

The acute or lethal toxicity of contaminants, including trace metals, can be measured experimentally or in the field. However, it is much more difficult to detect the sublethal or chronic effects of metals on biota, particularly in their natural environment. An arbitrary safety factor, generally 10 to 100 times below acute toxicity levels, is frequently used to determine water quality criteria for aquatic life. Criteria cited in this report (Table 17) generally refer to levels which are considered safe for aquatic organisms and imply a margin of safety as mentioned above, but it cannot be stated with certainty that chronic effects will not occur even at these lower limits.

3.8.2 Cadmium

The major user of cadmium, resulting in discharges to the environment, is the electroplating industry, although releases also occur through its use in the manufacture of paint pigments, plastics and batteries. Most of the cadmium is discharged to the Fraser River through local sewage treatment plants.

A combined total of 837 measurements for dissolved and total cadmium have been made, of which only 62 were greater than the minimum detectable concentration

(MDC). MDC's ranged from 0.2 mg/L to 0.0001 mg/L, although most (90%) were 0.001 mg/L or smaller. Table 11 and Figure 29 show the distribution of the cadmium data.

Water quality criteria of 0.0002 mg/L for sensitive aquatic life (Reeder et al., 1979) and 0.004 mg/L for less sensitive organisms (Environmental Protection Agency, 1972) have been suggested (Table 17). Thirty-two values (3%) exceeded the most sensitive criterion but only two measurements were greater than 0.004 mg/L. The maximum value (0.13 mg/L, August, 1977) was measured near Annacis Island (R6). The same sample was high in dissolved zinc (0.09 mg/L) but nitrogen and coliform data suggest that sewage effluent was not present. Another possible source is a metal-finishing plant near Gunderson Slough (Swain, in prep).The next highest value (0.01 mg/L in May, 1976) was measured near Tilbury Island (R8). Again, other water quality data did not indicate the presence of sewage.

The percentage of measurable values (Table 12) suggests that cadmium was detectable more frequently in the Main Arm than in the North Arm, especially near Steveston Island (R11) and Cannery Channel (R12). There was no apparent difference in the frequency of measurable cadmium between the low flow and high flow periods.

3.8.3 Chromium

The most common forms of chromium in industrial wastes and in the environment are metallic chromium, trivalent chromium (Cr(III)) and hexavalent chromium (Cr(VI)). Although both trivalent and hexavalent chromium are toxic to aquatic life, the hexavalent form is more mobile in the environment, more easily taken up into biological tissues, and generally higher in toxicity than trivalent chromium.

Chromium is used mainly by the metallurgical industry for the production of alloy steels. Chromium compounds are also used for metal finishing and leather tanning, and in fungicides, wood preservatives, catalysts and oxidants. The major source of chromium release in the Lower Mainland is associated with the electroplating industry whose effluents often contain trivalent chromium. Most of the chromium entering the Fraser River is discharged via the municipal sewer system (Swain, in prep).

A total of 817 measurements have been made for both total and dissolved chromium, of which 656 (80%) were below the detection limit. A range of MDC's from 0.1 mg/L to 0.0001 mg/L was found although most (95%) were less than 0.005 mg/L (Table 11).

Figure 30 shows the distribution of the chromium data in the study area. A value of 0.04 mg/L has been suggested as safe for aquatic organisms (Reeder, et al., 1979; Table 17). Only two samples exceeded the criterion, each with a concentration of 0.07 mg/L. One was collected near Annacis Island (R5) and the other at Tilbury Island, both in May, 1976. While the Tilbury sample was also high in cadmium, neither measurement was associated with any indicators of sewage effluent.

The percentage of measurable values for total and dissolved chromium were similar for the North and Main Arms (Table 12). For individual reaches, the highest percentages were at Deas Island (R9), Steveston Island and Cannery Channel. There were no apparent differences between low and high flows.

The random-pair statistic indicated that both total and dissolved chromium were significantly higher at Steveston compared to Pattullo Bridge (R3), and total chromium at Steveston was higher than below Annacis Island (R7) or at Queensborough (R14).

3.8.4 Copper

Major sources of anthropogenic copper include wastes from the metal-plating industries, some wood-processing industries, petroleum refineries, metal works and foundries. Many of these industries now discharge to the municipal sewer systems. Significant concentrations of copper are also found in residential waste waters, resulting from corrosion of plumbing systems.

Copper was present in measurable amounts in approximately 75% of the 943 water samples collected from the Fraser River (Table 11). Detection limits ranged between 0.1 mg/L and 0.001 mg/L but some 90% were below 0.001 mg/L. Combined data for the study area (R26) are presented in Figures 31 and 32.

The median and 90th percentile of the entire data set for dissolved copper were 0.002 mg/L and 0.005 mg/L respectively; for total copper they were 0.005 mg/L and

0.05 mg/L respectively. The high 90th percentile for total copper was due to a large number of analyses with a MDC of 0.05 mg/L. The median concentration for both total and dissolved copper for most B.C. streams is 0.002 mg/L, similar to dissolved levels in the study area, but total copper in the Fraser may be slightly higher, probably as a result of the higher suspended sediment loading in the river from upstream sources of sediment.

Within the individual reaches, the median concentrations for dissolved and total copper were approximately 0.001 mg/L and 0.005 mg/L, respectively. There were no apparent trends between reaches. The random-pair statistic indicated a significant increase for dissolved copper downstream from the Annacis Island STP (R6) compared to the upstream reach (R5), and values at Sand Heads (R13) were higher than measurements collected in Cannery Channel (R12). Total copper appeared to be higher in some upstream reaches. Pattullo Bridge, Annacis Island (R7) and Queensborough were all significantly higher than Steveston, and values at Queensborough were higher than measurements near Oak Street (R17).

All of the data from the Main Stem (R25; R1-R3), the Main Arm (R4-R13) and the North Arm (R14-R19; R22) were combined to test for differences between the three areas; neither dissolved nor total copper were significantly different (t-test, $p<0.05$).

Most reaches had insufficient data to determine seasonal trends. However, when the data for all reaches were combined, total copper showed increasing levels corresponding to increasing flows during freshet (Figure 32). There was some indication that dissolved copper also increased at freshet but there were high winter (low flow) values as well. There was no apparent trend between the years 1970 and 1978. A comparison of the data collected in the Main Stem, Main Arm and North Arm between the periods 1970 to 1974 and 1975 to 1978 did not show any statistical difference (t-test, $p<0.05$). The 1975-1978 interval corresponds roughly to the period since operation of the Annacis Island STP.

Copper concentrations between 0.01 mg/L and 0.001 mg/L have been suggested as safe for aquatic organisms (Table 17), with the most recent review for Canadian waters (Reeder et al., 1979) suggesting a level of 0.005 mg/L. While 50% of the copper measurements (total and dissolved) exceeded the lowest criterion, only 10% exceeded 0.005 mg/L and 12 values were greater than 0.01 mg/L. Further discussion on metal toxicity is given in Section 3.9.4.

3.8.5 Iron

It has been estimated that as much as one-twentieth of the earth's crust consists of iron. Suspended sediment particles from the erosion of mineral bodies in the watershed are considered to be a major contributor of iron to the river. Other sources include the metal-plating industries, metal works and foundries, and the corrosion of domestic and storm drain piping and discarded metal.

About 50% of the samples analysed contained dissolved iron at concentrations above the detection limits. However these detection limits varied between 0.1 mg/L to 0.005 mg/L (Table 11 and Figure 33). All but two values were below 0.2 mg/L.

Most of the iron was associated with particulates. Total iron ranged between 0.01 mg/L and 19.5 mg/L with a median and 90th percentile of 1.0 mg/L and 3.4 mg/L respectively (Table 11; Figure 34). These values are higher than those for most B.C. streams, which have a median of 0.3 mg/L and a 90th percentile of 2.8 mg/L.

The apparent decrease in the median value for total iron from the upstream reaches (R1-R3) to the mouth of both the Main Arm and the North Arm (Figure 34) is possibly due to dilution and/or settling of the particulates. The random-pair statistic showed concentrations at Pattullo Bridge and Queensborough reaches to be significantly higher than at the Oak Street reach.

Because of the large number of values below the MDC's, no pattern could be found for dissolved iron. However, the random-pair statistic showed values at Oak Street to be significantly higher than at Pattullo Bridge, and values at both Sand Heads and Cannery Channel to be higher than at Steveston, suggesting an increase due to the influence of marine waters.

There was a definite seasonal pattern associated with total iron (Figure 35) with values increasing 4 to 5-fold during freshet. The pattern parallels that of turbidity and suspended solids. Dissolved iron did not show any consistent trends as high values were measured during freshet as well as in the winter low flows. There was no apparent change from 1970 to 1978 for total iron.

Iron concentrations of 0.01 mg/L to 0.3 mg/L have been suggested as criteria for some industrial users (see Clark, 1978 a). As more than half of the data for total iron exceeded the higher criterion the river water would require pretreatment for most uses. For the protection of aquatic life a level of 0.3-1.0 mg/L has been suggested (Table 17). This is presumably for dissolved iron, which never exceeded 0.56 mg/L in the study area, and was nearly always below 0.2 mg/L. With respect to total iron, the criteria do not appear to be appropriate, especially in view of the high natural levels in the river.

3.8.6 Lead

Industrial sources of lead include releases associated with the manufacture of batteries, printing pigments, photographic materials and paints. Significant amounts of lead are released to the atmosphere through automobile emissions. Lead from this source eventually enters the aquatic systems via urban runoff and storm sewers.

A combined total of 954 measurements were made for total and dissolved lead and 77% of these were below the detection limits which ranged between 0.3 mg/L and 0.0004 mg/L. Most of the measurable values were for total lead (161) compared with 38 for dissolved lead (Table 11 and Figure 36).

All but five of the analyses for dissolved and total lead were below 0.008 mg/L. The maximum measured value for dissolved lead was 0.2 mg/L, while the highest measured values for total lead were 0.02 mg/L, 0.023 mg/L, and 0.014 mg/L (all values were measured in the North or Middle Arms).

The percentage of detectable measurements (Table 12) was much higher in the North Arm compared to the Main Arm, especially at the reaches near Queensborough, Mitchell Island (R16) and Dinsmore Bridge (R22). Dissolved lead was more frequently detected during low flow, while total lead concentrations were greatest during high flow.

Levels of 0.01 to 0.05 mg/L have been suggested for preservation of aquatic life (Table 17). The lowest level was exceeded only four times in the study area.

3.8.7 Manganese

Manganese, like iron, is also found in some abundance in nature. The major industrial use is in the production of steel and cast iron, but other uses include the manufacture of dry cell batteries, glass, ceramics, paints and dyes. Manganese frequently appears in river systems from natural sources.

A combined total of 355 measurements were recorded for dissolved and total manganese, the latter comprising 80% of the analyses (Table 11 and Figure 37). Most of the values ranged between 0.01 mg/L and 0.1 mg/L with a median and 90th percentile of 0.035 mg/L and 0.09 mg/L respectively. The maximum value of 0.97 mg/L was obtained near the Oak Street Bridge in May, 1973. Values are similar to those from most B.C. streams (median = 0.3 mg/L).

The data were insufficient to determine any differences between reaches for either total or dissolved manganese. The random-pair statistic indicated higher levels nearer the mouth of both the Main Arm and North Arm compared with a number of upstream reaches, suggesting contributions from marine waters.

Levels of 0.01 to 0.1 mg/L for manganese have been suggested as safe for fish and aquatic life (Clark, 1978a). Over 90% of the measurements taken were below the most recent criterion of 0.1 mg/L (EPA, 1976), and dissolved manganese, which is the toxic form, never exceeded 0.04 mg/L. The criterion for irrigation purposes is 2.0 mg/L (Clark, 1978a).

3.8.8 Mercury

Possible sources of mercury relate to its use in electrical equipment, research and medical laboratories, dental amalgams, scientific instrumentation, paints, chemical industries, pharmaceutical industries, and some agricultural compounds. Most of the sources within the study area discharge to the municipal sewers. Upstream sources include cinnabar deposits in the Fraser watershed (John et al., 1975).

About 357 measurements have been made for total and dissolved mercury (Table 11). Of these, all but 46 were below the detection limit of 0.05 μg/L. The median and 90th percentile were both 0.05 μg/L due to the large number of samples below the MDC and 0.05 μg/L and 0.014 μg/L respectively, for total mercury (Figure 38).

A total of 23 values (14 in the North Arm) exceeded 0.1 μg/L, the maximum level which has been recommended for receiving waters (Reeder et al., 1979). The highest value was 0.4 μg/L, recorded in the Middle Arm. A value of 0.26 μg/L near Pattullo Bridge was associated with higher levels of cadmium, chromium, iron, lead and nickel.

Other samples collected the same day, while low in mercury, also had higher metal concentrations. Suspended solids were high and the metals were probably associated with the particulates.

The percentage of measurable values (Table 12) was higher for the North and Middle Arms, especially at Dinsmore Island and Mitchell Island (R16), compared to the Main Arm. Dissolved mercury was more frequently measured during low flow, while total mercury was more often detected at high flow.

A median value of 0.05 µg/L for total mercury has been suggested for the preservation of aquatic life (Table 17), and this is met in the study area. However, the maximum recommended concentration of 0.1 µg/L was exceeded 23 times.

3.8.9 Molybdenum

Molybdenum is almost exclusively used for metallurgical steel and alloy production. It may also be introduced to the atmosphere from the burning of fossil fuels.

Less than 100 measurements for molybdenum have been made. About 25% were below the detection limit of 0.0005 mg/L (Table 11). All but three values were below 0.002 mg/L and the maximum was 0.0075 mg/L (Figure 39). Most of the detectable measurements were for total molybdenum (Table 11). The greatest percentage was found in the Main Arm, especially near Steveston (R11).

Criteria of 0.005 mg/L and 0.01 mg/L or less have been suggested for irrigation uses (Clark, 1978 a). For fish, the metal is not considered acutely toxic (a 96-hour TL_{50} of 70 mg/L, fathead minnow in softwater, has been reported by McKee and Wolf, 1963). Levels of 0.01 mg/L have been suggested as safe for aquatic life (Table 17).

3.8.10 Nickel

Most nickel wastes are from metal-plating industries. Other potential sources include steelworks and foundries, printing and some food-processing industries.

Only 234 measurements have been made for dissolved and/or total nickel (Table 11). All but 22 were below the detection limit of 0.01 mg/L and the maximum recorded was 0.03 mg/L (Figure 40). Most of the detectable values were for total nickel, and the percentage of detectable levels was similar for both the North and Main Arms (Table 12) for low flow but lower in the North Arm for high flow. Dissolved nickel was more frequently detected in the Main Arm, especially near Steveston Island.

Nickel appears to be less toxic than most trace metals with criteria of 0.025 mg/L to 0.2 mg/L (Table 17); The lowest level was exceeded only once in the study area. Levels of 0.2 mg/L and 0.5 mg/L or less have been suggested for irrigation use (see Clark, 1978 a), much higher than values measured in the Fraser.

3.8.11 Zinc

Industrial sources of zinc include the metal-plating industries (galvanizing), zinc and brass metal works and some groundwood and newsprint operations. In addition, zinc is also found in stormwater runoff, especially in areas with galvanized gutters and stormdrain pipes.

Approximately 70% of the measurements for zinc were above the various detection limits (Table 11, Figure 41). Dissolved zinc had an overall median and 90th percentile of 0.005 mg/L and 0.017 mg/L respectively and median values for most reaches varied between 0.008 mg/L and 0.01 mg/L (Figure 42). These values are similar to the median of 0.006 mg/L for most B.C. streams. Total zinc was higher, with a median and 90th percentile of 0.008 mg/L and 0.03 mg/L respectively and median values for the reaches generally ranging between 0.008 mg/L and 0.04 mg/L (Figure 43). The median for most B.C. streams is less (0.005 mg/L).

The concentrations of total zinc at the Queensborough (R14) and Oak Street (R17) reaches were significantly higher than at Pattullo Bridge (R3). When all the data (1970-1978) were combined the North Arm had significantly higher levels of total zinc (t-test, $p<0.001$, mean = 0.014 mg/L) compared to the Main Stem (mean = 0.008 mg/L) or the Main Arm (mean = 0.009 mg/L).

Dissolved zinc levels near the Annacis Island STP (R5, R6) in the Main Arm were higher (random-pair statistic) than at Pattullo Bridge in the Main Stem or near Tilbury Island (R8). Sand Heads was also higher in dissolved zinc compared to Pattullo Bridge.

Seasonal patterns were erratic for most individual reaches. For the combined data, dissolved zinc did not show a consistent pattern; high values were associated with both high and low flows. The pattern for total zinc suggests the occurrence of higher levels during freshet (Figure 44). There was no indication of any trends between 1970 and 1978. A comparison of the data collected from 1970 to 1974 with data from 1975 to 1978 for the Main Stem, Main Arm and North Arm showed no significant difference (t-test, $p < 0.05$).

Levels of 0.005 mg/L to 0.01 mg/L have been suggested as safe for aquatic organisms (Table 17); the most recent Canadian criterion is 0.03 mg/L (Reeder et al., 1979). Less than 10% of the analyses exceeded 0.03 mg/L but approximately half the measurements exceeded the 0.005 mg/L criterion. Further discussion regarding the toxic effects of zinc is given in Section 3.9.4.

3.9 Discussion

3.9.1 Regional Patterns

There were no discernible differences in median concentrations between the reaches in the study area for most metals, mostly because a large number of the values were below the minimum detectable concentration.

Total iron appeared to decrease towards the mouth and the random-pair statistic indicated a number of the seaward reaches to be significantly lower than upstream. The statistic also showed total copper to be lower near the mouth of the river and total zinc to be higher. The decrease in iron and copper may be associated with a similar decrease in suspended solids as a result of dilution with less turbid marine waters and/or the settling out of particulates.

An increase in dissolved zinc and copper in the Strait of Georgia has been reported by Thomas and Grill (1977). The increase was attributed to desorption from suspended sediment as the river water mixes with seawater. Fletcher (1976) found that an increase in salinity was accompanied by a decrease in most dissolved metal concentrations, probably a result of dilution. However, copper didn't decrease, possibly due to desorption from sediments, similar to the results reported above. Other authors (e.g., Gaton, 1979) have found that some metals, such as copper, underwent sorptive processes in estuarine waters. The effects of seawater/river sediment mixtures on the nature of the metal "species" is not clear. Since the form (species) of the metal is important in assessing toxicity (see Section 3.9.4), research in this area should be encouraged.

The random-pair statistic indicated that the reach near the Annacis STP (R6) was significantly higher in copper compared to an upstream reach, reflecting the fact that 85% of the copper discharged to the study area enters via the municipal sewage system (Table 13). Despite the fact that most of the copper is discharged to the Main Arm, there were no statistical differences between the Main Arm, North Arm or the Main Stem. This may be due to the large dilution factors in the Main Arm or may simply be a result of the large variability in the data. Similarly, there were no differences between these three regions when the data from 1970 to 1974 were compared to 1975 to 1978 (the latter approximating the period since the Annacis Island STP began operation).

The median zinc concentration at several North Arm reaches appeared to be higher than upstream or in the Main Arm; the random-pair statistic for total zinc also indicated that this was the case. In addition, a comparison of all the data (1970 to 1978) from the Main Stem, Main Arm and the North Arm showed the North Arm to be significantly higher in total zinc compared to the other two areas. There were no significant differences between 1970 to 1974 and 1975 to 1978 for all the combined sites in either the Main Arm, North Arm or Main Stem.

For several of the trace metals, most of the measurements were below the detection limit. For these metals the frequency of when and where measurable values occurred was calculated.

Cadmium, molybdenum and dissolved nickel were more frequently detected in the Main Arm than in the North Arm, especially near Steveston Island and Cannery Channel. Overall, chromium was equally detected in the two arms, although it was most frequently detected near the Steveston Island reach (R11). The results are not surprising since the source of these metals is primarily the metal-finishing industries, which discharge to the municipal sewage system, and especially to the Lulu STP which has an outfall just upstream from Steveston. (Cain and Swain, 1980).

Lead was more frequently detected in the North Arm compared to the Main Arm. About equal quantities of lead are discharged from the municipal STP in the Main Arm and from industrial sources in the North Arm (Swain, in prep.). The much smaller flows in the North Arm could explain why lead was more frequently observed there in measurable concentrations.

While most measurements for mercury were below the detection limit, 23 values exceeded the recommended maximum, 14 of which occurred in the North and Middle Arms. Overall, mercury was more frequently detected in the North Arm than in the Main Arm, but the source of this mercury is not known. It has been observed (Clark, 1976) that the Fraser River basin has a higher frequency of measurable mercury compared to other B.C. rivers; it is known that several large ore deposits exist in the Fraser watershed (John et al., 1975). One of these areas is Pinchi Lake which eventually drains into the Nechako River, which is in turn, a tributary to the Fraser. Pinchi Lake was once the site of a mercury mine and very high levels of mercury in fish from Pinchi Lake have been reported (Reid and Morley, 1975). On the other hand, of the 120 analyses of samples collected between Pattullo Bridge and Hope, none exceeded 0.02 μg/L.

Mercury has been measured at all three sewage treatment plants, in the range of 0.2 to 0.5 μg/L (Garrett, 1980). Koch et al., (1977) have found mercury in some municipal sewers and potential sources may be research and medical institutions. The Iona Island STP has been implicated as a source of that mercury which appears to be accumulating in some biota on Sturgeon Banks (Stancil, in prep.). However, combined sewage overflows from Iona tributary sewers is not believed to be the only source of the high values in the North Arm.

All of the high mercury values were recorded prior to the diversion of the sewage from the North Arm, New Westminster and Surrey waterfronts to the Annacis Island STP, and it is possible that this sewage was one source of mercury. Since mercury is readily accumulated by aquatic organisms, and has been shown to be high in some Fraser River fish species (Northcote, 1974), it is recommended that the sources of mercury be located. Investigations should start at those potential sources which may have been previously discharging to the North Arm.

Zinc levels in the North Arm were higher than in other sections, possibly due to industrial discharges (Table 13), detailed by Swain (in prep.), but there were no apparent differences between other trace metal concentrations in the study area, and upstream, (R25). The levels of trace metals in the Fraser are lower than those reported for rivers in other industrialized areas, and are similar to other B.C. streams and more pristine rivers in North America (Table 14). Two exceptions are total iron and total copper, which were higher in the Fraser than most areas, probably because of the high sediment load in the river.

The Inland Waters Directorate undertook a study in 1977-78 to analyze for certain trace metals (copper, iron, lead, manganese, nickel and zinc) at several locations in the Fraser including Pattullo Bridge (R3), Tilbury Island (R8), Steveston Island (R13) and Oak Street bridge (R17). A report is in preparation, but some of the data are reproduced here for comparison with historical data. The IWD laboratory analyses for 'extractable metal', which is a weaker extraction procedure than the 'total metal' analysis performed by the provincial lab, but the techniques are considered comparable (see Section 3.8.1). Table 18 shows the results from the four sites compared with the median values for the study area. In general, there was good agreement, with the extractable metals having values between those for dissolved and total metals for the whole study area. An analysis of variance did not show any significant differences (mean values, $p<0.05$) between the four sites sampled by IWD.

Equilibrium calculations for mixing Fraser River and Strait of Georgia waters are presented in Clark and Drinnan (in prep.).

3.9.2 Loadings

The estimation of annual river loadings for metals is uncertain because of the poor data set, and because of the large variability in flow. As a consequence, the average values presented here (Table 15) might vary as much as 2-fold. However, it is useful to obtain some idea of the amount present in the river compared to that discharged into the study area. Only copper, iron and zinc data were used in the loading estimate because most of the remaining metals were generally undetectable in the water. Mean monthly concentrations at Pattullo Bridge were used to estimate the approximate annual loading, based on the combined data from 1970 to 1978 (R26).

A rough estimate of the average annual loading of total copper, total iron and total zinc from upstream sources is 420, 150 000 and 680 tonnes/annum, respectively. By comparison, an estimate of the amount discharged to the river (excluding the Iona STP) is 16 t/a, 749 t/a and 78 t/a, respectively. Even during low flow, and with the addition of

Iona Island, the contribution of copper, iron and zinc from all discharges would be less than 20% of the loading already in the river. It is not known what fraction of these metals are in a biologically reactive form.

Elutriation tests on sediments from the outer banks suggest that only a slight increase in metals (2 percent or less) would occur as a result of the resuspension of bottom material by the river training program (Beak, in prep.).

3.9.3 Seasonal and Tidal Patterns

Total copper, iron and zinc showed a clear relationship with river flow, with values increasing from winter low flow levels to a maximum during freshet. The pattern parallels that of suspended solids and turbidity, and indicates that the metals are associated with the particulates. Williams and Chan (1966) also found that total iron, which was highest during freshet, was generally deposited along the outer banks of the estuary.

The dissolved form of copper, iron and zinc did not show a clear seasonal pattern. High values were recorded in freshet as well as during low flow periods. The high winter values may be associated with the groundwater supply, which seems to be the case for other dissolved ions (see Section 3.4).

Because of the lack of data, and the large number of measurements below the detection limit, seasonal differences could not be determined for the remaining trace metals. However, the frequency of measurable values during low flow months (September to March) and high flow months (April to August) was determined. Cadmium, chromium, manganese and dissolved nickel did not show any differences between the two periods. This observation would suggest a consistent source and is in keeping with the premise that these metals are primarily from industrial sources that do not normally exhibit drastic seasonal patterns. Total lead, mercury and molybdenum all were more frequently detected during high flows, and may be associated with the higher sediment load.

Most of the historical data could not be used to discern tidal effects; however it is acknowledged that tides could have a considerable effect on water quality data. The Inland Waters Directorate has investigated the effect of the changing tide on trace metal concentrations. Several 24-hour series samplings were carried out and a report is in preparation (L. Churchland, IWD, in prep., Vancouver).

Extractable metal data from Steveston are presented (Figure 45) to illustrate IWD preliminary findings. Higher metal concentrations were associated with high suspended sediment values which reached a maximum (at Steveston) towards the end of an ebbing tide when river velocities were greatest. Salinity values were at their lowest level during this period. The differences in metal concentrations between low water and other stages of the tide were considerable (up to 8-fold at 1 metre above the bottom), and were measurable at the surface as well. The dominating factor was suspended solids which appeared to be eroded from the bottom as river velocity increased during the ebbing tide. Although this observation was noted at the other sites, it was not as marked as at Steveston.

Cross-sectional variability can be considerable, due to the changes in suspended sediment caused by varying flow patterns (L. Churchland, pers. comm.). Considerable variability in dissolved metal concentrations with time and depth was also reported by Fletcher (1976) but there were no systematic patterns to the changes. The results clearly show the need for considering tidal depth, and cross-sectional effects in the design of monitoring programs.

3.9.4 Toxicity

Table 16 lists the 10th, 50th and 90th percentile in the river for each of the trace metals as well as the level in receiving waters considered to be non-toxic for aquatic organisms. Boron was not represented since all measurements were below the detection limit. It should be pointed out that the criteria which are used to compare levels from the Fraser River are not lethal concentrations but actually employ a safety factor of 10 to 100 or more over toxic levels. While this does not guarantee protection from long-term, sub-lethal effects, the criteria were designed to approach that ideal. The exception is in the undiluted effluent plumes, especially the sewage treatment plants, where concentrations may approach acutely toxic levels.

For cadmium, chromium, lead and nickel even the 90th percentile was less than the minimum concentration considered to be acceptable for aquatic organisms. In fact, only a few values actually exceeded these levels and none were as high as published median lethal concentrations (96-hr LC_{50}) (Inland Waters Directorate, 1972; EPA, 1976). Based on available water quality information, there is no suggestion of a toxicity problem in the river due to these metals.

Manganese and molybdenum were generally detectable, but the median and 90th percentile concentrations in the river were well below the criteria suggested in Table 17, and maximum concentrations are below published LC_{50} values (EPA, 1976). Levels of these metals in the water column are not considered to be a problem.

Dissolved iron was frequently below the detection limit, and even the maximum value was below the suggested criterion of 1.0 mg/L. Total iron was always measurable, with values frequently exceeding the 1.0 mg/L criterion. However, since most of the iron is associated with the suspended matter from upstream erosion, it is not considered to be toxic.

The mercury criterion for aquatic life is a median of 0.05 μg/L or less, with no values to exceed 0.1 to 0.2 μg/L. In the study area the median mercury value was below the detection limit of 0.05 μg/L, but 23 measurements exceeded the recommended maximum. Potential sources were discussed in section 3.9.1.

Water quality criteria for copper of 0.003 mg/L and 0.01 mg/L have been reported. While 98% of the values were below 0.01 mg/L, 40% of the copper measurements exceeded 0.003 mg/L. None of the values (maximum was 0.11 mg/L) were as high as the 96-hour LC_{50} of 0.92 mg/L (Inland Waters Directorate, 1972).

Zinc concentrations of 0.005 to 0.01 mg/L have been suggested as safe for aquatic life. About half of the data exceeded the lowest level although the maximum zinc concentration (0.1 mg/L) was a factor of 10 below the 96-hour LC_{50} of 1.07 mg/L (Inland Waters Directorate, 1972).

There is some evidence that metal toxicity is synergistic (e.g., Sprague, 1964) although agreement is not unanimous (Spehar, et al., 1978). In order to estimate the potential toxicity of several metals in combination, the toxicity unit suggested by the Working Group on Water Quality Criteria (Inland Waters Directorate, 1972) was used. To avoid confusion with the term Toxic Unit used by Esvelt et al. (1973), the term "Maximum Safe Concentration" will be used here. This concentration is defined as the ratio between the river concentration of a particular toxicant (C_a) and the limit of this same toxicant which is considered to be safe for aquatic organisms (L_a). The latter is generally estimated by multiplying an appropriate LC_{50} with an application (safety) factor. Table 16 uses criteria which were considered to have a safety factor built in over acutely toxic levels. To determine the combined toxicity, the values for all toxicants are summed. The total should never exceed 1.0 in order to maintain safe conditions. The abbreviated equation is as follows:

$$\text{Maximum Safe Concentration} = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \dots \frac{C_a}{L_a} = 1.0$$

The maximum safe concentration was calculated for the lower Fraser using those metals for which the median and/or 90th percentile exceeded the MDC - namely chromium, copper, lead, mercury and zinc. Iron, manganese and molybdenum were not included since their effect on the index would be anomalous for calculations including total metal.

Calculations were based on appropriate water quality criteria described in the previous section on individual metals. These criteria, as has already been mentioned, attempt to take into account long term effects as well as acute toxicity, and generally employ a 0.01 or greater safety factor over the appropriate 96-hr LC_{50}. These criteria, along with the calculation of the Maximum Safe Concentration, are presented in Table 16.

Using the median concentration of all the metals, only copper and zinc contributed to the toxicity with a combined value of 0.28, below the criterion of 1.0. Using the 90th percentiles, a value of 1.99 was calculated, again with copper and zinc contributing over 90% of the potential toxicity. It should be emphasized that the value of 1.0 is not the lethal level, but the level at which some response action might be noted in the fish.

Hall et al. (1974) also calculated the toxicity index (maximum safe concentration as defined in this report) from several stations along the river below Hope. They used the median concentration for copper, lead and zinc and found the overall toxicity to be below 1.0, with lead contributing very little to the total.

The large number of values for copper and zinc which exceed some water quality criteria (see Section 3.8) and the value of 1.99, obtained for the maximum safe concentration, suggest a potential problem. However, there are a number of factors which provide some margin of safety. First, it is the dissolved form of the metal which is generally considered to be toxic (Demayo et al., 1978) whereas the calculations in Table 16 were based on "total" values. This probably provides an overestimate of what is biologically available, since in the Fraser River, copper and zinc are obviously associated with the particulate material, which would reduce their toxicity (Demayo et al., 1978). In the Fraser River, it is not known how much of the "total" metal is associated with particulates, but studies in the Yukon River (Gibbs, 1973) suggest that only 10 to 17% of the Mn and Cr, 2 to 7% of the Ni and Cu and less than 2% of the Co and Fe were in the ionic form.

3.10 Recommendations for Monitoring

The concentrations of most metals are generally too low to be effectively measured in the water; it is proposed that efforts be concentrated on effluent, sediment and biological analysis. The exceptions are copper, mercury and zinc.

Total copper and total zinc often exceeded some water quality criteria, although it is stressed that this may not present a problem because much of the metal is associated with the sediment. However, samples should be collected and analyzed for the dissolved form, to give an indication of the toxicity potential, and the total form, to give an idea of the maximum limit of the biologically available concentration. The weight of the suspended materials in the sample should also be determined. The above are the recommendations of a recent review of the forms of metals in water by the Inland Waters Directorate (Demayo et al., 1978).

Mercury criteria were occasionally exceeded, but all sources of this metal have not been identified. For this reason, monitoring for total and dissolved mercury in the river as it enters the study area is recommended, to be done in concert with effluent analyses.

3.11 Miscellaneous Toxicants

3.11.1 Phenolic-Like Compounds

Phenolics are by-products of the petroleum and chemical industries and pulp and wood processing operations, while chlorinated phenolics (e.g., sodium pentachlorophenol) are sometimes used as wood preservatives. The test for "phenolic-like" compounds does not differentiate between the many substances which have phenol as part of their chemical structure. An auxiliary report to the Water Quality Work Group (Cain et al., 1980) discusses the various phenols more thoroughly and reports on the results from analyzing about 40 effluents for 50 phenolic compounds.

Phenolics were measured 336 times in the Main Arm, since 1970. The median value of all reaches was below 0.01 mg/L, ranging between 0.0075 mg/L and 0.008 mg/L. Only twenty-nine values exceeded 0.02 mg/L, with a maximum of 0.4 mg/L (Figure 46). The 10th, 50th and 90th percentile for most B.C. streams are 0.002 mg/L, 0.002 mg/L and 0.011 mg/L respectively, indicating that the receiving waters in the study area were higher in phenolics compared to most of the Province.

Tilbury Island (R8), which is downstream from the Dow Chemical Plant (PE 41), was slightly higher (0.008 mg/L) than most reaches and the plant may be affecting the river values slightly. The random-pair statistic also indicated that Tilbury was signficantly higher in phenol levels compared to the immediate upstream reach (R7). The random-pair test also showed higher phenols near the Annacis STP (R6) compared to the reaches upstream and downstream from the outfall. This result undoubtedly reflects the presence of the Annacis sewage effluent which can contain phenolic compounds in the order of 0.05 - 0.15 mg/L (Cain et al., 1980).

An additional 209 surface samples were taken by the Inland Waters Directorate in 1977 and 1978 (L. Churchland, pers. comm.). Sample sites were at Oak Street (R17), Steveston (R11), Tilbury Island (R8) and New Westminster (R3). All samples were below the detection limits of 0.005 mg/L or 0.001 mg/L.

Water quality criteria suggest that levels of phenolic compounds below 0.1 mg/L are not toxic but it should be noted that certain chlorinated phenolics can be quite toxic (Cain, et al., 1980). Fish tainting may occur at levels near 0.001 mg/L (EPA, 1976). Only two values exceeded the 0.1 mg/L criterion so a toxicity problem does not appear likely within the water column. Localized problems, associated with sediments seem likely and warrant further investigation. However, most measurements exceeded the 0.001 mg/L level for tainting of fish.

There have been no reports of problems with fish-tainting in the lower Fraser River (International Pacific Salmon Commission; WATDOC Search of newspaper reports). Tainting frequently occurs with pulp mills due to the phenolics associated with that process, but the survey of several industrial effluents did not suggest that those particular phenolics are present in large amounts (Cain et al., 1980).

Special studies may require the analyses for phenolic compounds, but it is not recommended as a routine parameter because of the low values encountered in the main flow of the river. Some further work near Tilbury Island should be considered to substantiate the apparently higher values in that reach.

3.11.2 Residual Chlorine

Chlorine gas is used for seasonal disinfection of sewage effluents in the study area. Residual chlorine (a mixture of hypochlorous acid, hypochlorite salts, and chloramines) can be quite toxic to aquatic organisms. In addition, it will react with organic substances to form various chlorinated organics which could have long term chronic effects on aquatic biota. Chlorinated organics are not measured with the chlorine residual tests, and are not degraded by dechlorination with reducing agents. They are not produced in high concentrations, and with the large dilution offered by the river, acute toxicity problems are not expected, although the sublethal impact of these compounds on biota is largely unknown.

Only 43 measurements have been made for residual chlorine, all from the Main Arm. All values were below the detection limit of 0.05 mg/L. A level of 0.002 mg/L for the protection of fish has been recommended (EPA, 1976) but this criterion is below the detection limit of conventional testing methods. Until improved field instrumentation becomes available to measure accurately residual chlorine, it is not recommended as a parameter for any receiving water monitoring, but should be retained as a parameter for effluent samples.

3.11.3 Cyanide

Cyanide is primarily used by the electroplating industries but can also be found in wastes from photographic processing and some petroleum industries.

A total of 155 background measurements have been made in the study area. All values were below the minimum detectable concentration, which in most cases was 0.01 mg/L. A few samples had a MDC of 0.1 mg/L. The highest value in the effluent at the Annacis Island STP was 0.014 mg/L.

The criterion for the protection of freshwater organisms is generally 0.005 mg/L (Reeder et al., 1979) and this probably has been met most of the time in the Fraser River. For this reason, cyanide is not recommended for further sampling on a routine basis.

3.11.4 Surfactants

Surfactants are a group of compounds that generally exhibit a foaming characteristic, and are a common constituent in household detergents. They are also known to contribute to fish toxicity.

Only 124 measurements have been made in the study area and these are mostly in the North Arm. All values were below 0.1 mg/L and most were less than 0.03 mg/L. Values in the Fraser were comparable to most B.C. streams (median = 0.03 mg/L).

The most sensitive criterion for the protection of aquatic life (0.5 mg/L; IWD, 1979) is greater than the maximum encountered. There have been no reports of undesirable foaming in the study area.

Surfactants are not a recommended parameter for any routine monitoring program.

3.11.5 Tannin and Lignin-Like Compounds (TLLC)

TLLC are released during the storage and processing of wood and can be found in the effluents of most wood industries. Leachate from hog-fuel in landfill operations is a common source. These compounds often impart undesirable colour to the water.

About 200 measurements have been made for TLLC. There was no apparent trend between reaches, and except for near the Port Mann Bridge (R2), median values were less than 0.6 mg/L. There were insufficient data to show any possible seasonal patterns, although a couple of reaches had lower values during the summer. Values were generally comparable to the rest of B.C. (median 0.3 mg/L).

The highest values, (median 0.95 mg/L; maximum 1.36 mg/L) were recorded in the vicinity of the Leeder municipal landfill. Drainage from this area may be the source of the high values, which are comparable to levels near the pulp mill of Prince George and

Quesnel (0.85 mg/L and 0.95 mg/L respectively; Clark, 1978c). Samples collected in a surface drainage ditch from the Leeder landfill averaged 35.8 mg/L (Atwater, 1980). The random-pair statistic could not be used in most reach comparisons because of the lack of data. However, the Queensborough reach (R14) was found to be significantly higher than at Pattullo Bridge (R3).

Tannin and lignin-like compounds are not recommended as a routine parameter since values generally were low. However, some special studies near landfills and areas of log-storage may be warranted to investigate local effects.

3.11.6 Sulphide

Sulphide is formed by bacterial reduction of sulphate under anaerobic conditions. It is considered extremely toxic to aquatic organisms.

Sulphide measurements were taken only near the North Arm Jetty (R19) and near Tilbury Island (R8) in the Main Arm. The North Arm values were all below the detection limit of 0.32 mg/L. At Tilbury, all but one value (0.11 mg/L) were at or below the MDC of 0.05 mg/L. These results are not surprising since oxygen levels are quite high in the river (see Section 3.6). However, higher sulphide values have been measured when the oxygen levels decrease, such as in the bottom waters of Deas and McDonald Sloughs.

The lowest criterion reported for protection of aquatic organisms is 0.002 mg/L (Reeder, et al., 1979), well below the detection limits of most labs. It is unlikely that sulphide will be present, other than on rare occasions, in the main river channels, but problems may exist in some sloughs.

Sulphide is not recommended for routine monitoring programs except for those sites where very low oxygen levels are expected.

3.11.7 Arsenic

Arsenic is often a product of the metallurgical and petroleum industries. It is quite toxic and is sometimes used in the production of pesticides. Only 91 values have been recorded in the study area and all but three were below the detection limit of 0.005 mg/L, with a maximum value of 0.01 mg/L. These are well below the level of 0.05 mg/L which has been suggested as safe for aquatic life (Reeder et al., 1979).

It is not recommended that arsenic be monitored in the main river flow of the study area on a routine basis. However, it should be considered for certain effluents since the accumulation of arsenic in some biota has been reported (Stancil, in prep.).

3.11.8 Asbestos

Three samples collected at Mission bridge by the Inland Waters Directorate, Vancouver, had values of 9.4×10^8, 9.0×10^9 and 1.2×10^9 fibres/L (as chrysolite) while samples from the Sumas River had 10^{10} to 10^{11} fibres/L. By comparison, asbestos in drinking water supplies range from a low in British Columbia of 10^7 to 10^8 fibres/L to 2×10^9 fibres/L in some systems in Newfoundland and Quebec (Environmental Health Directorate, 1979). The detection limit for fibres is approximately 1×10^6 fibres/L.

The effects of asbestos fibres on aquatic organisms is not known. Since the Fraser River is not used as drinking water, human health problems are not expected. Some additional sampling should be considered to see if the above values are representative.

3.11.9 Radioactive Elements

There were no data available on levels of radioactive material in the lower Fraser River. Levels are expected to be below the MDC since upstream and tributary sources in the Fraser Valley are very low (Radiation Protection Service, pers. comm.).

4. MONITORING PROGRAMS

4.1 General

Historically, the various agencies sampling in the study area have each chosen different sets of parameters for analysis, different sampling procedures and schedules, and different formats for storage and reporting the results. Clearly this is an inefficient and costly way to undertake monitoring. It is essential that future programs be organized in a co-ordinated fashion.

It is recommended that those agencies involved in sampling in the Fraser River frequently compare their field and laboratory procedures. Additionally, there should be centralized storage of all data and frequent (at least annually) review and reporting of this information. Since the results of most of the analyses collected to date in the Fraser River are presently stored in the EQUIS system, it seems reasonable to continue to do so.

It is recognized that agencies will continue to have site or program-specific interests in the river. These are considered additional to the general surveillance monitoring recommended in this report. However, these agencies should participate in any program involving the comparison of procedures, and ensure that their data are incorporated into the centralized data bank.

Monitoring programs have been recommended for municipal effluents (Cain and Swain, 1980), industrial effluents (Swain, in prep.), major storm sewers (Ferguson and Hall, 1979), aquatic biota and sediments (Stancil, in prep.) and microbial quality (Churchland, 1980). It should be noted that dissolved metal levels alone do not provide an adequate description of effluents, and therefore we recommend that total metals be measured in all relevant effluents.

It is important to note that all of these programs, along with those for receiving water, must be co-ordinated to provide effective, overall monitoring for the lower Fraser River, especially with respect to trace metal and nutrient loadings. This co-ordination could be provided by a committee similar to the Water Quality Work group, but the actual monitoring should be done by one or two agencies, such as the Waste Management Branch, Ministry of Environment, and/or the GVRD, who are already routinely sampling in the river.

The water chemistry monitoring program for the Fraser River should have three components: 1) routine surveillance; 2) intensive monitoring program every five years, and 3) special projects. These are discussed in greater detail below.

4.2 Routine River Surveillance Monitoring

4.2.1 General

Routine surveillance assumes a co-ordinated program for monitoring municipal and industrial effluents plus major storm sewers. The basic premise is that most toxicants are too dilute in the river to be effectively monitored. Measurements in the river will be limited to determining nutrient and metal (copper, mercury and zinc) loadings entering the study area from upstream sources.

The combined programs will allow the relative impact on the river of the various discharges, plus the total loading to the Strait of Georgia of selected parameters, to be determined.

In addition, long-term trends in water quality in the Fraser River, with respect to the above parameters, can be monitored.

A second aspect to the river surveillance program will examine conditions in selected sloughs and side-channels along the river, and at a number of main channel sites. Frequent field measurements (dissolved oxygen, pH, conductivity and temperature) should be taken to monitor general water quality, especially dissolved oxygen levels.

4.2.2 Parameters

Table 19 lists those parameters for which data exist in the study area. The parameters are divided into three categories: 1) recommended for routine programs, 2) recommended for special studies and 3) not recommended for further monitoring. The table can serve as a guide to those who are planning to do chemical analyses on Fraser River samples.

Routine monitoring should include the measurement for nutrients (total nitrogen, total phosphate, total dissolved phosphate, and reactive silicate), some trace metals (copper, mercury and zinc), non-filterable residue (or turbidity if field measurement is possible), specific conductivity, dissolved oxygen, pH, temperature and river flow/-direction. The basic objective is to determine the nutrient and metal loadings entering the study area, and ultimately the Strait of Georgia.

4.2.3 Sites

For the routine surveillance of nutrients and metals, it is proposed that only one location, near Pattullo Bridge, be monitored. Variability with depth and across the river should be checked initially to determine the number of samples to be included in the routine sampling program. The possible use of depth integration and compositing of cross-sectional samples should be determined from this initial program.

4.2.4 Frequency

Samples should be collected weekly during freshet (April to August, inclusive) and monthly during the remaining months.

4.2.5 Timing

Samples should be collected towards the end of an ebbing tide or at low slack tide, to ensure that water passing the Pattullo Bridge has originated from upstream. This is particularly important during the winter low flow months.

4.2.6 Sloughs and Side Channels

In order to monitor the general environmental condition of sloughs and sidechannels, especially with respect to dissolved oxygen levels, a field surveillance, similar to that reported in Bergerud and Alexander (in prep.) should be carried out at least four times each year. Suggested times are February, June, August and October. Conductivity, dissolved oxygen, pH, temperature and turbidity (if possible) should be measured throughout the water column.

4.3 Intensive Monitoring Program

A more comprehensive program entailing more sites and possibly additional parameters should be considered every five years. The details of the program would be based on the results of the routine surveillance monitoring and would be closely tied in with the biological and sediment program proposed for this same frequency (Stancil, in prep). Additional programs will be required for localized problems identified in the estuary.

4.4 Special Project Proposals

A number of data gaps have been identified which require a specialized study, but are not required at the present time to be a part of the routine monitoring program.

4.4.1 Dilution Studies at Annacis

The effluent plume from the Annacis Island STP is poorly delineated. Calculations for undissociated ammonia, one of the toxic contaminants in this plume, suggest that a minimum 15:1 dilution is required to reduce ammonia toxicity to acceptable levels. A study should be carried out to define the size of this dilution zone under differing tidal conditions.

4.4.2 COD and Phenol Survey Near Tilbury Island

Data suggest that these parameters may be higher near Tilbury Island than elsewhere in the river. A program should be undertaken to determine whether this difference exists and if so, to identify potential sources of these contaminants.

4.4.3 Nutrient Bioassays

While most of the total-N in the river originates from outside the study area, it is not known whether nitrogen from the STP's is preferentially utilized. It is therefore recommended that the effects of municipal sewage on primary productivity in the Strait of Georgia be examined.

4.4.4 Degradation Rates of Organic Nitrogen

Much of the nitrogen from upstream sources and from the STP's is organic in form. However, it is not known how long is required for the organic-N to degrade to ammonia and other inorganic forms which are utilized by phytoplankton. It may be that most of the nitrogen is carried beyond the Strait of Georgia before it can be utilized.

4.4.5 Primary Productivity Studies in the Strait of Georgia

Nutrients discharged to the river are expected to increase as the population increases. For this reason, and because there may be a potential impact on the estuary and the Strait of Georgia (Stockner, et al., 1979), it is recommended that the measurement of primary productivity be carried out in these above regions.

4.4.6 Contribution of Nutrients and Toxicants from Rainwater

Literature reviews indicate that a considerable amount of nitrogen may be entering the river and the Strait of Georgia via rainwater and particulate fallout. In addition, toxicants may be present. Chemical analyses of rainwater during several seasons should be undertaken, in conjunction with the stormwater program (Ferguson and Hall, 1979).

4.4.7 Speciation of Copper and Zinc in the Waters and Their Relative Toxicities

Data for total copper and total zinc indicate that a large number of values exceeded some water quality criteria. Therefore, the detailed chemistry of these metals should be determined, plus a better definition of the relative toxicity of the different metal species present in the Fraser River.

4.4.8 Inter-Lab Comparison of Various Guidelines for Metal Analyses

In view of the numerous analytical methodologies encountered in reviewing the metals data, it is essential that all agencies analyzing metals in the study area partake in regular inter-laboratory comparisons, including sampling procedures. The comparisons should be based on replicates collected from the Fraser River.

4.4.9 Distribution of Mercury Sources

Mercury, on a number of occasions, has exceeded recommended maxima in the water. The sources are unknown but may include upstream locations. Increased sampling in biota, sediments and river water should be done in concert with monitoring of the discharges in the study area.

4.4.10 Tannin and Lignin Levels Near Landfills

Several high TLLC values, similar to those near the Prince George pulpmills, were measured near the Leeder landfill. A short survey to determine the extent and overall impact of leachate discharges to the river should be considered.

5. SUMMARY AND CONCLUSIONS

5.1 Water Movement

Average flows in the Fraser River at Pattullo Bridge are estimated to range between a low of 900 m^3/s in February-March to a freshet maximum of 10 800 m^3/s in May-June.

At New Westminster, 85% of the river flows into the Main Arm and Annacis Channel and 15% into the North Arm. At Sea Island, about 45% of the flow in the North Arm enters the Middle Arm.

River velocity is greater during an ebb tide. On the flood tide, flow reversal at the surface occurs only during low flow (e.g., less than 1 000 m^3/s) and can be observed as far upstream as Pitt River. Estimated daily maximum velocities range from 0.5 m/s to over 2 m/s and are greatest near the mouth of the Main Arm.

A salt wedge moves along the river bottom during a flood tide and can penetrate as far as Annacis Island in the Main Arm during low river flows. During freshet the wedge does not move beyond Steveston. Because of the shallower depths, the penetration of the salt wedge in the North Arm does not extend as far upstream as it does in the Main Arm. However, chloride measurements indicate the occasional presence of salt water under low flow conditions along the entire North Arm and in the Main Arm and Main Stem as far upstream as the Port Mann Bridge.

Movement of water over Sturgeon Bank is a function of wind and tide. In general, water moves east and north-east on a flood tide and west or south-west on an ebb tide. Effluent from the Iona Sewage Treatment Plant generally moves seaward on an ebb and small flood tide, but presumably moves landward on a large flood tide. During freshet, effluent moving northward is unlikely to enter the North Arm but that possibility exists under low river flow and flood tide conditions.

The Annacis Island STP discharge undergoes an average dilution exceeding 400-fold, but dilution can be as low as 5-fold directly over the outfall diffusers at high slack tide. Effluent may travel upstream as far as Pattullo Bridge on a high flood tide. A theoretical average residence time in the river for effluent from Annacis Island is 1.7 days. Effluent from the Lulu Island STP discharged on a flood tide would move out to the estuary on the following ebb tide.

5.2 Temperature

Temperature values generally range between $4^{o}C$ and $17^{o}C$, depending on the season. The North Arm appears to be warmer on average than the Main Arm, but more data are required to confirm this conclusion.

5.3 Colour and Particulate Material

Values are lowest in February-March, increasing to maximum levels in freshet. The maxima precede peak flows suggesting that particulates are resuspended from the bottom during the initial stages of freshet. Monthly mean values for non-filterable residue range between 10 mg/L to over 150 mg/L, while true colour varies between 5 and 40 units.

Median concentrations of suspended particulates generally decrease downstream from the headwaters of the Fraser to the Lower Mainland. In the study area, the greatest decrease occurs at Deas Island in the Main Arm and Mitchell Island in the North Arm. The decrease may be due to a dilution and coagulation effect of marine waters, as dissolved solids increase significantly at these sites.

The contribution of particulates from the Annacis Island Sewage Treatment Plant is minimal, less than 2% of the total loading during low river flows. It should be noted, however, that particulates from the STP are largely organic, compared to the generally inert material present in the river.

5.4 Dissolved Materials

The effects of salt water are most prominent in the lower (seaward) reaches of the river. The area of greatest change in dissolved solids is near Deas Island and Mitchell Island.

Higher values for many dissolved ions occur during the low flow period, suggesting a greater contribution from groundwater sources. Values are lower during freshet due to dilution by the predominantly snow-melt nature of the water. During heavy rainfall, a surface layer can exist which is very low in dissolved ions.

Upstream from Deas Island in the Main Arm and Mitchell Island in the North Arm, water quality is generally suitable for irrigation purposes year round. During the summer (at high flow) concentrations of dissolved ions are probably suitable throughout the river except at the most seaward reaches.

5.5 pH and Buffering Capacity

pH generally ranges from 7 to 8 and this is within suggested criteria for aquatic life and recreational use.

Lower values (below 6.5) are occasionally found in zones of low oxygen. In addition, low pH values in one section of the river near New Westminster were detected (decreasing from 7-7.5 to 5.8-6.8 units) but the cause of the decrease is not known.

Titration curves indicate that the river is moderately buffered against acid discharges but very poorly buffered against alkaline discharges.

5.6 Oxygen-Consuming Materials and Dissolved Oxygen

Levels of oil and grease, volatile residues, total organic carbon, biochemical oxygen demand and chemical oxygen demand are very low in the river, often near the minimum detectable concentration for the test. Isolated higher values are found in the vicinity of the sewage effluent plume from Annacis Island.

Dissolved oxygen levels in the main river channels are high and generally in excess of 80% saturation even during the summer months. A slight decrease of less than 1 mg/L is sometimes apparent in the effluent plume found between Annacis Island and Tilbury Island, but levels increase again downstream.

Dissolved oxygen values in the North Arm are, on average, slightly lower than in the Main Arm (10.8 mg/L compared to 11.3 mg/L); this may possibly be due to the generally warmer waters in the North Arm. There is also a significant downstream decrease (ca 2 mg/L) along the North Arm from New Westminster to the mouth which may reflect the combination of higher industrial activity and low flows. However, oxygen levels in the North Arm are high with respect to criteria for maintaining aquatic life.

Many sloughs and side channels show a decrease in the oxygen concentration compared to levels in the main river channels. However, most levels supporting aquatic life are in excess of 65% saturation, and considered adequate for supporting aquatic life.

Low oxygen values (below 5 mg/L) are found in Cannery Channel and in Deas, Tilbury and MacDonald Sloughs. They occur near the bottom and in the case of Deas and MacDonald Sloughs, more frequently near the head of the inlets. Associated with the low oxygen values are higher levels of conductivity, colour and organic materials, and lower pH. The low oxygen values appear to be a result of trapped seawater in the bottom of these depressions which are poorly flushed. Microbial activity, probably enhanced by additional organic loading from log storage, hog fuel dumps and agricultural runoff, results in the decrease in dissolved oxygen.

Specific studies on the effects of low oxygen levels on fish in Deas Slough and Tilbury Slough are underway and should help to decide on rehabilitation and/or mitigation alternatives. It is recommended that a similar study on MacDonald Slough be considered.

5.7 Nutrients

Total ammonia is generally below 0.05 mg/L, but there are isolated high values near the Annacis Island STP outfall. The concentration of undissociated ammonia is nearly always below the toxicity criteria of 0.01 to 0.02 mg/L, even in the Annacis Island effluent plume. High ammonia levels in the effluent imply some likelihood of fish toxicity in the plume itself, but only in situations of low river dilution.

Dilutions exceeding 15:1 should be sufficient to alleviate ammonia toxicity. The controlling factor for undissociated ammonia is the river pH which rarely exceeds 8.5. However, if pH exceeds this value, undissociated ammonia is predicted to become of concern. For this reason, alkaline discharges should be avoided, especially considering the poor buffering capacity of the river.

Nitrite values are generally near or below the MDC of 0.005 mg/L. Nitrate ranges between 0.03 mg/L and 0.18 mg/L while Kjeldahl-nitrogen (organic-N plus ammonia) is slightly higher, 0.1 to 0.3 mg/L. Ortho-phosphate and total dissolved phosphate generally ranges between 0.003 and 0.06 mg/L, but total phosphate is much higher, 0.008-0.2 mg/L (i.e., 90th percentiles generally fall below 0.06 and 0.2 respectively for ortho and total phosphate). Total phosphate is associated with the suspended sediment in the river.

Levels of nitrogen and ortho-phosphate in the river are within levels for flowing waters known to be low to moderately productive. Total phosphate levels suggest a more productive system, but the biological availability of the particulate phosphate is not known. The Fraser is believed to be a light-limited system due to the high seasonal turbidity and there is no evidence of excess algal growth in the river (Stancil, in prep).

The total nitrogen loading in the river entering the study area is estimated to be between 20 000 and 37 000 t/a (mean values) for a low flow (10th percentile) and high flow (90th percentile) year, respectively. The mean loadings for 1967 and 1977 were estimated to be 32 000 ± 15 000 t/a and 27 000 ± 11 000 t/a, respectively. The decrease is a consequence of lower flows during 1977.

Mean total phosphate loadings in the river at Pattullo Bridge range between 5 000 and 9 000 t/a for a low flow and high flow year respectively, and 8 000 ± 7 000 t/a and 7 000 ± 5 000 t/a for 1967 and 1977.

Mean ortho-phosphate loadings for a low flow and high flow year are 300 and 600 t/a while a mean loading of 500 ± 300 tonnes/yr is estimated for 1967 and 400 ± 300 tonnes/yr for 1977.

The total nitrogen discharged from effluents into the study area is estimated to have been 5 000 t/a for 1977, of which 70% was from municipal wastes (STP's). An estimated 2 800 t/a was discharged to the study area in 1967 and a value of 11 000 t/a is predicted for the year 2 000, assuming no changes in present treatment policies.

The contribution of metropolitan Vancouver to the total nitrogen loading to the Strait of Georgia is estimated to have been 8% in 1967 and 16% in 1977, an average increase of less than 1% per year. By the year 2000, the contribution from all discharges to the total nitrogen loading in the river may reach 35% during a low flow year. The extent and consequence of this increase to overall changes in primary productivity, in the estuary or the Strait of Georgia, are not known.

Waste management practices do not appear to be causing a problem with respect to nutrient enrichment in the Strait of Georgia at the present time. Further increases in effluents discharged to the river may change this assessment but immediate treatment for nutrient removal is not considered urgent. Further studies on nutrient loadings to the Strait of Georgia and the possible impact on primary productivity are recommended.

5.8 Trace Metals

There are no apparent differences among reaches in the median concentration for most metals. Except for copper, iron and zinc, measurements are generally below the minimum detectable concentration.

Total copper and total iron are lower near the mouth of the river, while total zinc is higher. Cadmium, molybdenum and nickel are more frequently detectable in the Main Arm, especially near Steveston, and may reflect the presence of the Lulu Island STP.

Lead is more frequently detected in the North Arm. This may be due to the greater quantity of storm water discharged relative to river flow at that location. Mercury is also more frequently detected in the North Arm. The sources of mercury are not known and it is recommended that they be investigated.

There are no apparent changes in zinc concentrations that could be attributed to the Annacis Island STP. However, zinc levels in the North Arm are significantly higher on average compared to the Main Arm (0.014 mg/L compared to 0.009 mg/L) and this is probably due to industrial discharges, especially near Queensborough.

Copper, iron and zinc levels are much higher in the total form than in the dissolved form, and are clearly associated with the suspended sediment in the river. For these metals, the discharges to the river from metropolitan Vancouver are estimated to be less than 10% of the total from sources upstream.

Levels for several trace metals, including copper, iron and zinc, vary considerably with tidal changes, with highest values occurring during maximum ebb tide velocities. Suspended sediment are also highest during this period. It is recommended that tidal effects be considered in future monitoring programs.

For most metals, there is no known acute toxicity problem in the river, with levels at or below criteria suggested as safe for aquatic organisms. A significant portion of the total copper and zinc measurements exceeds some recommended criteria. However, it is not believed that this constitutes a toxicity risk, as most of the metal is associated with particulate material and probably not biologically active. It is recommended that the speciation of copper and zinc and their relative toxicities be investigated.

5.9 Miscellaneous Toxicants

Levels of arsenic, sulphide, surfactants, cyanide, phenolics, residual chlorine, and tannin and lignin compounds are very low and unlikely to cause acute toxicity in the receiving water. Toxic trace organics are known to be discharged to the environment; these are discussed by Garrett (1980).

It should be pointed out that while the levels for these contaminants are generally too low to be effectively measured in the water column, it does not guarantee that there would not be a significant impact on the estuary. Future studies should emphasize analysis of those compounds - not in the receiving waters, but in the discharges, biota and sediments.

6. RECOMMENDATIONS

These recommendations are based on factors dealing with the quality and chemistry of the water only, as reviewed in the preceding sections. They may be modified in light of conclusions from other reports by the Water Quality Group of the Fraser River Estuary Study, including the industrial and domestic discharges, storm sewers, and biological reports, or on technical and/or economic considerations. These aspects are addressed in the final Summary Report of the Water Quality Group.

6.1 It is recommended that a study of the water quality, particularly dissolved oxygen levels, of MacDonald Slough be undertaken to investigate the effects on aquatic biota.

6.2 It is recommended that the removal and avoidance of high alkaline (e.g. over pH 8.5) effluents be emphasized as a waste management strategy.

6.3 It is recommended that detailed studies on nutrient loadings to the Strait of Georgia be undertaken to determine the present and future degree of impact of municipal discharges on primary productivity in the Strait of Georgia.

6.4 It is recommended that a program be initiated to determine the source or sources of the high mercury values which were occasionally measured in the water.

6.5 It is recommended that source control be emphasized for the removal of toxicants from municipal effluent.

6.6 It is recommended that a review and comparison of methods for the analysis of trace metals be undertaken between the major laboratories analyzing samples in the study area.

6.7 It is recommended that the speciation of trace metals, and in particular copper and zinc, be investigated, including the possible toxic effects of the various chemical species, and those factors which cause changes in these species.

6.8 Special studies near Tilbury Island are recommended to determine whether levels for chemical oxygen demand and phenolics are higher in this reach than elsewhere in the river.

6.9 A restructured program for monitoring water quality in the lower Fraser River is recommended to provide a better information base on the impact of discharges in the study area. This will be co-ordinated with effluent, stormwater, biological and sediment monitoring. Details of the program are given in Section 4.

6.10 It is recommended that the data from the monitoring program be stored in the provincial data storage system, EQUIS. These data should be reviewed and reported on annually, by a single agency or committee.

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TABLE 1

10TH, 50TH AND 90TH PERCENTILES OF MONTHLY FLOWS (m^3/s) FOR THE FRASER RIVER, ESTIMATED FOR PATTULLO BRIDGE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
10th Percentile	1 000	900	900	1 100	4 200	7 200	5 100	3 400	2 300	1 800	1 400	1 200
50th Percentile	1 400	1 200	1 100	2 000	5 900	8 500	6 700	4 300	3 000	2 600	2 400	1 800
90th Percentile	1 900	1 800	1 600	3 100	7 700	10 800	9 300	5 700	3 900	3 700	3 500	2 600

The 10th, 50th and 90th percentiles for Fraser flow at Hope were calculated from the monthly means over the 60 year interval 1916-1976. Monthly means were calculated from available data for the Brunette, Chilliwack, Coquitlam, Harrison, Kanaka, Norrish, Pitt, Salmon, Silverdale, Silverhope, Stave, Sumas, Vedder, Wahleach, West, Whonnoch and Yorkson Rivers, and summed. The ratio of the total tributary flow to the monthly flow of the Fraser River at Hope was used to estimate the percentiles at Pattullo Bridge. Values are estimates only and do not take into account tidal effects.

TABLE 2

APPROXIMATE DILUTION OF ANNACIS EFFLUENT IN THE RIVER CALCULATED FROM DYE TEST RESULTS[1,2]

	Dye Study (B.C. Research, 1975)	Average Effluent Flow (m^3/s)		
		1977	1986	2021
No. of Risers in Use	1	9	18	18
Discharge Rate m^3/s	0.11	1.9	2.8	6.8
Dilution Near the Outfall For Release on Ebb Tide, Returning on Flood Tide	x 840	x 440	x 600	x 240
Dilution 140 m Upstream From the Outfall	x 530	x 280	x 380	x 160
Dilution Over the Outfall at High Slack Tide	x 5	x 3	x 4	x 1.5
Minimum Dilution at the Edge of the Initial Dilution Zone[3]	x 300	x 160	x 212	x 90

[1] From Singleton (1980).

[2] Approximate Dilution of Effluent = $\frac{\text{Dilution of Dye}}{\text{Effluent Flow/Dye Flow x No. of Risers}}$

[3] The initial dilution zone extends 100 m upstream and 100 m downstream from the outfall, and is 140 m wide (25% of river width).

TABLE 3

MEDIAN VALUES (RANGE) FOR DISSOLVED SOLIDS BETWEEN GROUPS OF REACHES AND COMPARISON WITH TYPICAL FRESHWATER AND MARINE MEDIAN VALUES

Parameter	Units	Main Arm		North Arm		B.C. Streams[1]	B.C. Marine[1]
		R25;R1-R9	R10-R13	R14-R16	R17-R19; R22		
Specific Conductivity	(µ S/cm)	99-150	1 400-6 925	99-110	800-29 000	168	36 500
Chloride	(mg/L)	<5-5	10-892	<5-5	10-6 000	1.2	14 025
Hardness	(mg/L)	46-56	115-375	42-59	172-1 109	67	4 750
Calcium-Total	(mg/L)	13-16	16-40	11	15	26.5	347
Magnesium-Total	(mg/L)	2-5	10-60	2-3	3-16	5.2	805
Sodium-Total	(mg/L)	1-3	6-662	2-16	115-1 900	3.8	7 650[2]

[1] From Clark (1978 b).
[2] Dissolved Sodium.

TABLE 4

RANGE OF UNDISSOCIATED AMMONIA LEVELS FOUND IN THE LOWER FRASER RIVER

Total Ammonia Concentration		0.01 mg/L-N[1]	0.02 mg/L-N[2]	0.1 mg/L-N[3]	Percent Un-Ionized Ammonia
pH	T (^{o}C)	Undissociated Ammonia Concentration			
	0[1]	8.8×10^{-6}	1.76×10^{-5}	8.8×10^{-5}	0.088
7.0[1]	10[2]	1.85×10^{-5}	5.71×10^{-5}	1.85×10^{-4}	0.185
	20[3]	3.90×10^{-5}	7.80×10^{-5}	3.90×10^{-4}	0.390
	0	2.78×10^{-5}	5.56×10^{-5}	2.78×10^{-4}	0.278
7.5[2]	10	5.84×10^{-5}	1.17×10^{-4}	5.84×10^{-4}	0.584
	20	1.22×10^{-4}	2.45×10^{-4}	1.22×10^{-3}	1.224
	0	8.73×10^{-5}	1.75×10^{-4}	8.73×10^{-4}	0.873
8.0[3]	10	1.82×10^{-4}	3.65×10^{-4}	1.82×10^{-3}	1.824
	20	3.77×10^{-4}	7.54×10^{-4}	3.77×10^{-3}	3.770

[1] Approximate 10th percentile for study area.
[2] Approximate 50th percentile for study area.
[3] Approximate 90th percentile for study area.

TABLE 5

LEVELS OF UNDISSOCIATED AMMONIA IN THE FRASER RIVER FOR TOTAL AMMONIA AND pH VALUES

Total Ammonia Concentration - mg/L-N		0.1	0.2	0.3	0.4	0.5	1.0	1.5	Percent Un-Ionized Ammonia
pH	T (°C)								
	0	0.001	0.002	0.003	0.003	0.004	0.009	0.013	0.87
8.0	10	0.002	0.004	0.005	0.007	0.009	0.018	0.027	1.82
	20	0.004	0.008	0.011	0.015	0.019	0.038	0.057	3.77
	0	0.003	0.005	0.008	0.011	0.014	0.027	0.041	2.71
8.5	10	0.006	0.011	0.017	0.022	0.028	0.055	0.083	5.55
	20	0.011	0.022	0.033	0.044	0.055	0.110	0.165	11.02
	0	0.008	0.016	0.024	0.032	0.040	0.081	0.121	8.10
9.0	10	0.016	0.031	0.047	0.063	0.078	0.157	0.235	15.67
	20	0.028	0.056	0.084	0.113	0.141	0.281	0.422	28.1

Line approximates the water quality criterion of 0.02 mg/L, undissociated ammonia.

TABLE 6

ANNUAL NUTRIENT LOADINGS ESTIMATED FOR THE FRASER RIVER AT PATTULLO BRIDGE

	Mean Annual River Flow (m^3/s)	Annual Loading (Tonnes/Annum)		
		Total-N	Total-P	Ortho-P
Low River Flow Regime (10th percentile)[1]	2 500	20 000	5 000	300
Median River Flow Regime (50th percentile)[1]	3 400	27 000	7 000	400
High River Flow Regime (90th percentile)[1]	4 600	37 000	9 000	600
1967	3 200	32 000 ± 15 000	8 000 ± 7 000	500 ± 300
1977	2 600	27 000 ± 11 000	7 000 ± 5 000	400 ± 300

[1] Based on mean monthly flows, 1916-1976, at Pattullo Bridge.

TABLE 7

SUMMARY OF SUSPENDED SOLIDS AND NUTRIENT DISCHARGES TO THE LOWER FRASER RIVER, 1977

Parameter	Source of contaminant	Loadings to the River (kg/day) Main Stem (R1-R3)	Main Arm (R4-R13)	North Arm (R14-R19)	Sturgeon Bank (Iona)	Total	Total Tonnes/Annum	Percent of Total
Flow (m^3/d)	Landfill Leachate[1]					14 000		1
	Industrial Discharges[2]	98 000	102 000	170 000		370 000		19
	Municipal Discharges[3]	6 000	198 000		387 000	591 000		30
	Tributaries[4]	5 000				5 000		1
	Storm Sewer Discharges[5]					970 000		50
	TOTAL					1 950 000		100%
Total Suspended Solids (kg/d)	Landfill Leachate[1]					4 700	1 700	4
	Industrial Discharges[2]	5 300	5 350	25 400		36 050	13 200	32
	Municipal Discharges[3]	460	12 800		18 500	31 700	11 600	30
	Tributaries[4]	240				240	90	1
	Storm Sewers Discharges[5]					39 000	14 200	36
	TOTAL					111 690	40 790	100%
Total Nitrogen (kg/d)	Landfill Leachate[1]					990	350	7
	Industrial Discharges[2]	4	210	40		254	90	2
	Municipal Discharges[3]	230	4 400		5 600	10 230	3 700	72
	Tributaries[4]	2				2	1	1
	Storm Sewer Discharges[5]					2 740	1 000	19
	TOTAL					14 216	5 140	100%

TABLE 7 (CONTINUED)

SUMMARY OF SUSPENDED SOLIDS AND NUTRIENT DISCHARGES TO THE LOWER FRASER RIVER, 1977

Parameter	Source of contaminant	Loadings to the River (kg/day) Main Stem (R1-R3)	Main Arm (R4-R13)	North Arm (R14-R19)	Sturgeon Bank (Iona)	Total	Total Tonnes/Annum	Percent of Total
Total Phosphate (kg/d)	Landfill Leachate[1]					1	0.4	1
	Industrial Discharges[2]	1	20	5		26	9	1
	Municipal Discharges[3]	50	840		1 020	1 910	700	81
	Tributaries[4]	1				1	0.4	1
	Storm Sewer Discharges[5]					410	150	17
	TOTAL					2 420	860	100%

1 Data from J. Atwater, Environmental Protection Service, Environment Canada. Estimates are for total discharge to the study area only.

2 Data from Technical Report on industrial effluents (Swain, in prep.).

3 Data from Technical Report on municipal effluents (Cain and Swain, in prep).

4 Estimated from EQUIS. Includes Brunette River.

5 Data and estimates from Technical Report on storm sewers. Includes dry and wet weather loadings (Ferguson and Hall, 1980).

TABLE 8

ESTIMATES OF THE TOTAL NITROGEN DISCHARGED TO THE FRASER RIVER AND ESTUARY IN 1967 AND 1977

	Loadings (Tonnes/Annum)		
	1967[1]	1977[1]	2000
Population	1 057 000	1 515 000	3 000 000
Total N: Iona STP	700[3]	2 000[2]	4 000
Total N: Annacis STP (or equivalent)	700[4]	1 300[2]	2 600
Other Domestic Waste	300	400[2]	800
Other Sources (Industrial, Leachate and Storm Water)	1 000	1 400[2]	3 200
Total Nitrogen from Effluents to Strait of Georgia			
a. total	2 700	5 100	10 600
b. rounded total	3 000	5 000	11 000

1. Nutrients discharged to the Fraser were assumed to increase at the same rate as population increase, which was estimated to be 1.43-fold from 1967 to 1977. Population figures from Stockner, et al., 1979.

2. Values from Table 7, this report, converted to tonnes/yr from kg/day.

3. Iona STP was receiving only 50% of the sewerage area covered in 1977 (GVRD Engineers). An additional 700 t/a were discharged to Vancouver Harbour/Burrard Inlet.

4. In 1967 the Annacis Island STP was not in operation. It is estimated that 80% of the nitrogen entering Annacis in 1977 were discharged directly to the Fraser River. The remainder (200 t/a) went to Burrard Inlet or Boundary Bay.

TABLE 9

TOTAL NITROGEN (ANNUAL LOADINGS) ENTERING THE STRAIT OF GEORGIA

	Nitrogen Loading (Mean and 95% Confidence Limits) 1967	1977	2000
River Loading (Tonnes/Annum)[1]	32 000 (17 000-47 000)	27 000 (16 000-38 000)	20 000
Effluent Discharges (Tonnes/Annum)[2]	2 700	5 100	10 600
Total (Tonnes/Annum)	34 700 (19 700-49 700)	32 100 (21 100-43 100)	30 600
Percent Contribution by Effluents	8% (6-14%)	16% (12-25%)	35%

1. From Table 4. For year 2000, low flow regime (10th percentile) was used.

2. Total nitrogen discharged from all sources. From Tables 7 and 8.

TABLE 10

COMPARISON OF NUTRIENT CONCENTRATIONS IN THE LOWER FRASER RIVER WITH OTHER NORTH AMERICAN RIVERS

Parameter		Columbia R.[1] (Mean)	St. Louis R.[2] (Mean)	Niagara R.[3] (Mean)	Williamette R.[4] (Mean)	Snohomish R.[5] (Mean)	B.C. Streams[6] (Median)	Fraser R.[7] (Median)	Marine[6] Waters (Median)
Ammonia-N	mg /L	0.042	0.129	0.035	0.19	0.060	0.015	0.018	0.01
Nitrate-N	mg /L		0.016	0.15	0.78	0.093	0.07	0.081	0.23
Organic-N	mg /L					0.135	0.14	0.140	0.05
Ortho-Phosphate	mg /L	0.03					0.005	0.007	0.046
Total Phosphate	mg /L	0.040	0.070	0.020	0.067	0.028	0.025	0.040	0.064

1 Water Investigations Branch (1979). Data downstream from a major metallurgical plant.
2 Wagner and Lemire (1976). Data downstream from a metropolitan area.
3 Chan (1977). River drains Great Lakes System and is considered polluted.
4 Rickert et al (1976). Three cities; secondary treatment.
5 U.S. Geological Service (1976). Moderate industrial activity.
6 Data from Clark (1978 b).
7 Median concentration for combined data in study area (R26).

TABLE 11

SUMMARY OF THE HISTORICAL TRACE ELEMENT DATA FOR THE COMBINED REACHES IN THE LOWER FRASER RIVER AND ESTUARY, COMPARING THE NUMBER OF NON-DETECTABLE MEASUREMENTS, DETECTION LIMITS AND TOTAL NUMBER OF ANALYSES

Parameter (EQUIS Code)	Detection Limit (mg/L)	No. of Non-Detectable Values		No. of Detectable Values		Total No. of Analyses	% of all values below MDC
		Dissolved	Total	Dissolved	Total		
Arsenic (251)	0.005	13	75	0	3	91	97%
Boron (252)	0.1	19	0	0	0	19	100%
Cadmium (253)	0.2	0	1	45	17	837	93%
	0.1	0	8				
	0.05	0	6				
	0.02	12	38				
	0.01	5	0				
	0.005	1	0				
	0.003	1	0				
	0.001	179	74				
	0.0005	301	103				
	0.0001	33	13				
Chromium (255)	0.1	9	33	68	93	817	80%
	0.07	3	0				
	0.05	0	8				
	0.01	0	6				
	0.009	0	1				
	0.005	316	131				
	0.002	57	0				
	0.001	49	0				
	0.0005	9	1				
	0.0004	7	0				
	0.0002	8	0				
	0.0001	18	0				

TABLE 11 (CONTINUED)

SUMMARY OF THE HISTORICAL TRACE ELEMENT DATA FOR THE COMBINED REACHES IN THE LOWER FRASER RIVER AND ESTUARY, COMPARING THE NUMBER OF NON-DETECTABLE MEASUREMENTS, DETECTION LIMITS AND TOTAL NUMBER OF ANALYSES

Parameter (EQUIS Code)	Detection Limit (mg/L)	No. of Non-Detectable Values		No. of Detectable Values		Total No. of Analyses	% of all values below MDC
		Dissolved	Total	Dissolved	Total		
Copper (256)	0.1	0	13	435	280	943	24%
	0.01	6	0				
	0.05	9	39				
	0.007	0	1				
	0.006	0	3				
	0.005	0	2				
	0.004	0	1				
	0.003	0	2				
	0.002	17	0				
	0.001	95	40				
Iron (257)	0.1	231	0	492	375	1 133	23%
	0.01	4	7				
	0.04	22	0				
	0.005	2	0				
Lead	0.3	0	8	732	222	954	77%
	0.2	7	6				
	0.03	1	0				
	0.02	2	0				
	0.005	108	10				
	0.003	1	10				
	0.002	71	0				
	0.001	338	136				
	0.0005	18	3				
	0.0004	13	0				
Manganese (260)	0.02	16	16	11	307	355	10%
	0.01	5	0				

TABLE 11 (CONTINUED)

SUMMARY OF THE HISTORICAL TRACE ELEMENT DATA FOR THE COMBINED REACHES IN THE LOWER FRASER RIVER AND ESTUARY, COMPARING THE NUMBER OF NON-DETECTABLE MEASUREMENTS, DETECTION LIMITS AND TOTAL NUMBER OF ANALYSES

Parameter (EQUIS Code)	Detection Limit (mg/L)	No. of Non-Detectable Values		No. of Detectable Values		Total No. of Analyses	% of all values below MDC
		Dissolved	Total	Dissolved	Total		
Mercury (261)	0.00005	173	135	14	35	357	86%
Molybdenum (262)	0.0005	0	24	11	62	97	25%
Nickel (263)	0.01	56	211	2	15	284	94%
Zinc (264)	0.05	0	8	383	259	927	31%
	0.03	0	8				
	0.02	8	40				
	0.01	5	0				
	0.005	104	77				
	0.001	4	13				
	0.003	5	0				
	0.0005	4	9				
Phenol	0.001				293	336	13%

TABLE 12

COMPARISON OF DETECTABLE MEASUREMENTS FOR TRACE METALS (DISSOLVED PLUS TOTAL) BETWEEN LOW AND HIGH FLOWS IN THE MAIN STEM PLUS MAIN ARM, AND THE NORTH ARM

	Metal	Main Arm Low Flow	Main Arm High Flow	Main Arm Total	North Arm Low Flow	North Arm High Flow	North Arm Total
Cadmium	No. Detectable	25	22	50	0	4	4
	Total No. Measured	377	245	622	63	71	134
	% Detectable	6.6%	9.0%	8.0%	0.0%	5.6%	3.0%
Chromium	No. Detectable	91	15	106	21	45	66
	Total No. Measured	435	45	480	61	269	330
	% Detectable	20.9%	33.3%	22.1%	34.4%	16.7%	20.0%
Lead	No. Detectable	63	60	123	29	38	67
	Total No. Measured	460	307	767	80	81	161
	% Detectable	13.7%	19.5%	16.0%	36.2%	46.9%	41.6%
Manganese	No. Detectable	144	117	261	65	70	135
	Total No. Measured	187	126	313	68	82	150
	% Detectable	77.0%	92.9%	83.4%	95.6%	85.4%	90.0%
Mercury	No. Detectable	11	9	20	12	13	26
	Total No. Measured	82	58	140	68	61	129
	% Detectable	13.4%	15.5%	14.3%	17.6%	21.3%	20.2%
Molybdenum	No. Detectable	23	18	41	9	14	23
	Total No. Measured	31	39	70	24	28	52
	% Detectable	74.2%	46.2%	58.6%	37.5%	50%	44.2%
Nickel	No. Detectable	2	7	9	2	2	4
	Total No. Measured	53	63	116	62	54	116
	% Detectable	3.8%	11.1%	7.8%	3.2%	3.7%	3.4%

TABLE 13

ESTIMATE OF THE DISCHARGE OF SELECTED TRACE METALS TO THE LOWER FRASER RIVER AND STURGEON BANKS

Parameter	Source	Loadings to the Estuary (kg/d) Main Stem (R1-R3)	Main Arm (R4-R13)	North Arm (R14-R19)	Sturgeon Bank (Iona)	Total	Loading Tonnes/Annum	Percent of Total
Copper	Landfill Leachate[1]					0.2	<0.1	1
	Industrial Discharges[2]		0.1	2.1		2.2	0.8	2.0
	Sewage Treatment Plants[3]		26.0		78.0	104	38.0	85
	Tributaries[4]	0.02				0.02	<0.1	1
	Storm Sewer Discharges[5]					15.0	5.5	12
	TOTAL					121.3	44.5	100%
Iron	Landfill Leachate[1]					135	49	4
	Industrial Discharges[2]		130	120		250	91	8
	Sewage Treatment Plants[3]		263		370	633	231	20
	Tributaries[4]	7.4				7.4	3	1
	Storm Sewer Discharges[5]					2 080	759	67
	TOTAL					3 105	1 133	100%
Lead	Landfill Leachate[1]					0.2	<0.1	1
	Industrial Discharges[2]		0.4	6.6		7.0	2.6	9
	Sewage Treatment Plants[3]		7.5		29.0	36.5	13.3	48
	Tributaries[4]	0.01				0.01	<0.1	1
	Storm Sewer Discharges[5]					32.6	11.9	42
	TOTAL					76.3	28.0	100%

TABLE 13 (CONTINUED)

ESTIMATE OF THE DISCHARGE OF SELECTED TRACE METALS TO THE LOWER FRASER RIVER AND STURGEON BANKS

Parameter	Source	Loadings to the Estuary (kg/d) Main Stem (R1-R3)	Main Arm (R4-R13)	North Arm (R14-R19)	Sturgeon Bank (Iona)	Total	Loading Tonnes/Annum	Percent of Total
Nickel	Landfill Leachate[1]					0.4	<0.1	1
	Industrial Discharges[2]			0.3		0.3	0.1	1
	Sewage Treatment Plants[3]		15.7		29.0	44.7	16.3	73
	Tributaries[4]	0.1				0.1	<0.1	1
	Storm Sewer Discharges[5]					15.4	5.6	25
	TOTAL					60.9	22.2	100%
Zinc	Landfill Leachate[1]					5.3	1.9	2
	Industrial Discharges[2]		0.2	143		143.2	52.3	54
	Sewage Treatment Plants[3]		43		44.0	87.0	31.8	33
	Tributaries[4]	0.04				0.1	<0.1	1
	Storm Sewer Discharges[5]					29.0	10.6	11
	TOTAL					264.6	96.6	100%

1 Data from J. Atwater, Environmental Protection Service, Environment Canada.
2 Data from Technical Report on industrial effluents (Swain, in prep.).
3 Data from Technical Report on municipal effluents (Cain and Swain, 1980).
4 Estimated from EQUIS. Includes Brunette River.
5 Data and estimates from Technical Reports on storm sewers. Includes dry and wet weather loadings (Ferguson and Hall, 1980).

TABLE 14

COMPARISON OF METAL LEVELS (MEANS) FROM NORTH AMERICAN RIVERS WITH THE FRASER RIVER

		U.S. Waters[1]								
		Low Range	High Range	Mean	Columbia[2] R., B.C. (Mean)	St. Louis[3] R. (Mean)	Niagara[4] R. (Mean)	Snohomish[5] R. (Mean)	B.C.[6] (Median)	Fraser[7] River (Median)
Cadmium	(mg/L)	0.001	0.120	0.0095	0.0006	0.0005	0.001	0.0075	0.0005	0.0007
Chromium	"								0.005	0.005
Copper	"	0.001	0.280	0.015	0.003	0.0021	0.0047	0.001	0.002	0.005
Iron	"	0.001	4.60	0.052					0.3	1.0
Lead	"	0.002	0.140	0.023					0.001	0.002
Manganese	"	0.003	3.23	0.058					0.03	0.050
Mercury	"	0.0001	2.005	-	0.00005		0.0005	0.0075	0.00005	0.00005
Molybdenum	"								0.0009	0.0007
Nickel	"								0.01	0.01
Zinc	"	0.002	1.18	0.064	0.009	0.0063	0.0078		0.005	0.008

1 Low range, high range and mean values for trace metals, summarized for a number of U.S. rivers. Data from Kopp and Kroner (1968) as summarized and reported by Hall et al. (1974).
2 Water Investigations Branch (1979).
3 Wagner and Lemire (1976). Data downstream from a metropolitan area.
4 Chan (1977). River drains Great Lakes System and is considered polluted.
5 U.S. Geological Service (1976). Moderate industrial activity.
6 Data from Clark (1978 b).
7 Median concentration for combined data in study area (R 26).

TABLE 15

ESTIMATE OF THE TOTAL COPPER, TOTAL IRON AND TOTAL ZINC LOADINGS[1] IN THE FRASER RIVER AT PATTULLO BRIDGE

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total (Tonnes/Annum)
Copper (Tonnes/Mo)	13.0	8.8	5.8	28.8	47.2	154	71.7	34.4	15.4	13.7	18.6	4.79	420
Iron (Tonnes/Mo)	6 329	590	868	7 592	12 757	59 486	32 253	14 903	6 179	4 780	6 195	1 630	150 000
Zinc (Tonnes/Mo)	18.6	13.3	20.2	31.4	142	176	89.6	57.3	38.6	34.1	31.0	24.0	680

[1] Based on median (50th percentile) flows and concentration.

TABLE 16

COMPARISON OF TRACE METAL LEVELS IN THE LOWER FRASER RIVER WITH WATER QUALITY CRITERIA AND THE CALCULATION OF THE MAXIMUM SAFE CONCENTRATION

Parameter	River Concentration (Percentiles; mg/L)[1]		Water Quality Objectives (mg/L)[2]	Maximum Safe Concentration[3]
		C_a	L_a	C_a/L_a
Cadmium	10th	MDC	Not Detectable	
	50th	MDC		
	90th	MDC		
Chromium	10th	MDC		
	50th	MDC	0.05	
	90th	0.0051		0.10
Copper	10th	MDC		
	50th	0.0020	0.005	0.2
	90th	0.0633		1.1
Lead	10th	MDC		
	50th	MDC	0.03	
	90th	0.002		0.07
Mercury	10th	MDC		
	50th	MDC	0.0005	
	90th	0.000053		0.12
Nickel	10th	MDC		
	50th	MDC	0.1	
	90th	MDC		
Zinc	10th	MDC		
	50th	0.0039	0.03	0.08
	90th	0.020		0.60
				Total
				50th Percentile: 0.28
				90th Percentile: 1.99

[1] Total plus dissolved metal data. Percentiles estimated from cumulative frequency curves. Iron, manganese and molybdenum not included for calculation.

[2] See Table 17. Most common or most recent criteria were used.

[3] MSC = River concentration criteria. See text, Section 3.9.4.

TABLE 17

A COMPARISON OF PUBLISHED WATER CRITERIA FOR AQUATIC LIFE

Toxicant	Units	EPA (1972)	EPA (1976)	Am. Fish. Soc. (1979)	IWD (1972)	McNeely (1979)	Reeder et al (1979)
Arsenic	mg /L	0.1		0.05	0.05		
Cadmium	mg /L	0.004	0.0004		0.005		
Chlorine-Res.	mg /L	0.003	0.002				
Chromium	mg /L	0.05	0.1	0.3 x LC_{50} or 0.05	0.05	0.05	0.04
Copper	mg /L	0.002	0.1 x LC_{50} =0.002		0.01	0.005	0.005
Cyanide	mg /L		(young salmonids) 0.005			0.005	0.005
Iron (Diss.)	mg /L	0.03	1.0		0.3	0.3	
Lead	mg /L	0.03	0.01 x LC_{50} =0.01 x 1.0=0.01 (rainbow)	0.025	0.05	0.01	0.01
Manganese	mg /L	0.05				0.02	
Mercury	µg /L	0.05	0.05	0.05	0.1	0.05	0.1
Molybdenum	mg /L	2.7				0.01	
Nickel	mg /L	0.2	0.1			0.025	
Sulfide	mg /L	0.002	0.002			0.002	
Zinc	mg /L	0.005 x LC_{50} =1 x 0.005=0.005 (salmonids)	0.01 x LC_{50} =0.01 x 1=0.01 (salmonids)	0.05	0.007	0.05	0.03

TABLE 18

COMPARISON OF "EXTRACTABLE" TRACE METAL DATA (MEAN VALUES) COLLECTED BY INLAND WATERS DIRECTORATE (1977-1978) WITH MEDIAN CONCENTRATIONS FOR "DISSOLVED" AND "TOTAL" TRACE METALS FOR COMBINED DATA IN THE STUDY AREA (R26)

Parameter	New Westminster (R3)	Tilbury Is. (R8)	Steveston (R11)	Oak Street (R17)	Combined Study Area (R26)	
	Extr.	Extr.	Extr.	Extr.	Diss.	Total
Copper	0.005	0.004	0.004	0.003	0.002	0.005
Iron	0.766	0.641	0.517	0.691	0.010	1.000
Lead	0.001	0.001	0.001	0.002	0.001	0.002
Manganese	0.060	0.048	0.050	0.048	0.008	0.050
Nickel	0.003	0.003	0.003	0.002	0.010	0.010
Zinc	0.004	0.003	0.004	0.004	0.005	0.008

TABLE 19

LIST OF PARAMETERS RECOMMENDED FOR RECEIVING WATER MONITORING

Parameter	EQUIS Test Code	Recommended For Routine Monitoring	Special Studies Only	Not Recommended	Comments
Apparent Colour	001			✓	
True Colour	002		✓		see TAC colour
Oil and Grease	003			✓	
pH	004	✓			
Total Residue	005			✓	
Total Fixed Residue	006			✓	
Filterable Residue	007			✓	
Non-Filterable Residue	008	✓			if metals, required
Fixed Non-Filterable Residue	009		✓		
Non-Filterable Residue Vol.	010		✓		calculation-best method for estimating organic fraction
Specific Conductivity	011	✓			
Temperature - Sample	013	✓			
Dissolved Oxygen	014	✓			
Turbidity	015		✓		prefer non-filterable residue—turbidity affected by stain
Chlorine Residual	016			✓	
Extinction Depth	019			✓	
Air Temperature	020		✓		
Water Level/Flow Direction	021	✓			field note should record
Dissolved Gases	022		✓		
TAC Colour	024		✓		preferred test for colour measurements
Oxidation-Reduction Pot.	039		✓		

TABLE 19 (CONTINUED)

LIST OF PARAMETERS RECOMMENDED FOR RECEIVING WATER MONITORING

Parameter	EQUIS Test Code	Recommended For Routine Monitoring	Special Studies Only	Not Recommended	Comments
Phen. Alkalinity	101		✓		important if pH >8.3; prefer acid/base titration curve
Total Alkalinity	102		✓		prefer acid/base titration curves
Total Organic Carbon	103			✓	prefer test 008 with 009
Chloride	104			✓	test 011 should be adequate
Cyanide	105			✓	no record of it being present
Fluoride	106			✓	test 011
Hardness	107		✓		test 011 preferred-positive correlations for Fraser with conductivity
Ammonia-N	108		✓		measure if pH >8.5
Nitrite/Nitrate-N	109	✓			use with Kjeldahl to calculate total
Nitrate-N	110			✓	combined analysis (109) is sufficient
Nitrite-N	111			✓	" " " " "
Organic Nitrogen-N	112			✓	
Kjeldahl Nitrogen-N	113	✓			includes ammonia plus organic nitrogen
Total Nitrogen-N	114	✓			calculation
Biological Oxygen Demand	115			✓	
Chemical Oxygen Demand	116		✓		
Phenolic-like Compounds	117		✓		
Ortho-Phosphate (PO_4)	118		✓		
Total Phosphate	119T	✓			
Total Dissolved Phosphate	119D	✓			usually the same or close to ortho-phosphate
Silica	120	✓			required for diatom productivity analysis-few data
Sulphate	121		✓		test 011 sufficient
Surfactants	122			✓	
Tannin and Lignin	123		✓		
Inorganic Carbon	124			✓	
Sulphide	125		✓		rarely present except in anoxic waters

TABLE 19 (CONTINUED)

LIST OF PARAMETERS RECOMMENDED FOR RECEIVING WATER MONITORING

Parameter	EQUIS Test Code	Recommended For Routine Monitoring	Special Studies Only	Not Recommended	Comments
Free CO_2	126			✓	
Salinity	130	✓			can be used instead of specific conductivity, if appropriate (i.e., saline water)
Chlorophyll-A	143		✓		good routine measure of phytoplankton biomass
Arsenic-Dissolved	251D			✓	no problem historically
Arsenic-Total	251D			✓	no problem historically
Boron-Dissolved	252D			✓	
Cadmium-Dissolved	253D			✓	see note 1 below
Cadmium-Total	253T		✓		see note 1
Calcium-Dissolved	254D			✓	test 011 sufficient
Calcium-Total	254T		✓		"
Chromium-Dissolved	255D			✓	see note 1
Chromium-Total	255T		✓		"
Copper-Dissolved	256D			✓	"
Copper-Total	256T	✓			Loadings into study area recommended
Iron-Dissolved	257D			✓	see note 1
Iron-Total	257T		✓		"
Lead-Dissolved	258D			✓	"
Lead-Total	258T		✓		"
Magnesium-Dissolved	259D			✓	test 011 sufficient
Magnesium-Total	259T			✓	"
Manganese-Dissolved	260D			✓	see note 1
Manganese-Total	260T		✓		"
Mercury-Dissolved	261D			✓	"
Mercury-Total	261T	✓			sources need to be determined
Molybdenum-Dissolved	262D			✓	see note 1
Molybdenum-Total	262T		✓		"

TABLE 19 (CONTINUED)

LIST OF PARAMETERS RECOMMENDED FOR RECEIVING WATER MONITORING

Parameter	EQUIS Test Code	Recommended For Routine Monitoring	Special Studies Only	Not Recommended	Comments
Nickel-Dissolved	263D			✓	see note 1
Nickel-Total	263T		✓		"
Potassium-Dissolved	264D			✓	test 011 sufficient
Potassium-Total	264T			✓	"
Sodium-Dissolved	265D			✓	"
Sodium-Total	265T			✓	"
Zinc-Dissolved	266D			✓	see note 1
Zinc-Total	266T	✓			loadings into study area recommended
Radionucleotides	-			✓	
Asbestos	-			✓	

Note:

1. Most metals except for copper, iron and zinc were rarely detectable in the river, and routine analysis is not recommended. If data are required, total is preferred to dissolved.

FIGURE I

LOCATION OF REACHES INTO WHICH SAMPLING SITES ARE GROUPED

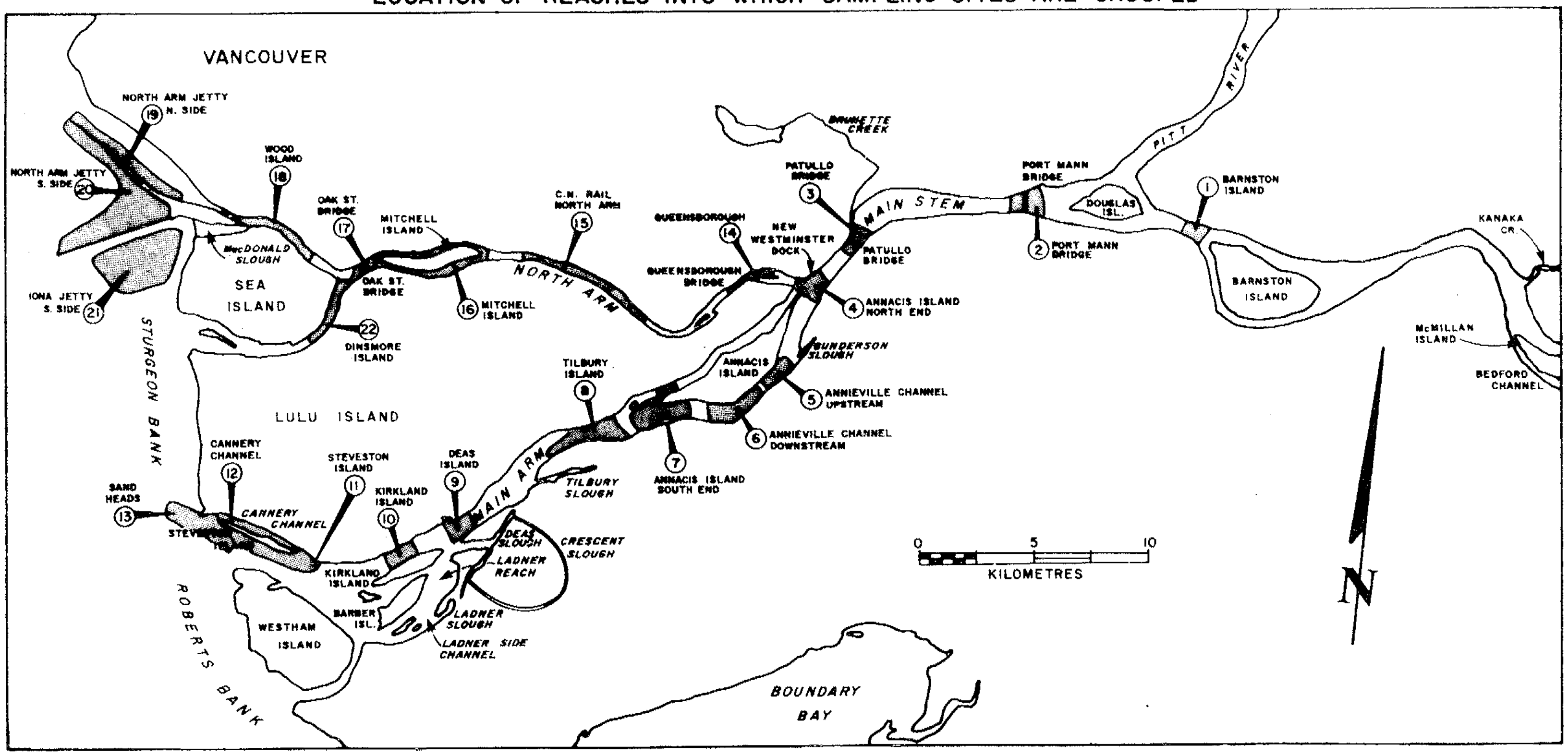


FIGURE 2

ESTIMATED DAILY MAXIMA OF CURRENTS FOR LOW, MODERATE AND HIGH RIVER DISCHARGES AT VARIOUS LOCATIONS IN THE LOWER FRASER RIVER

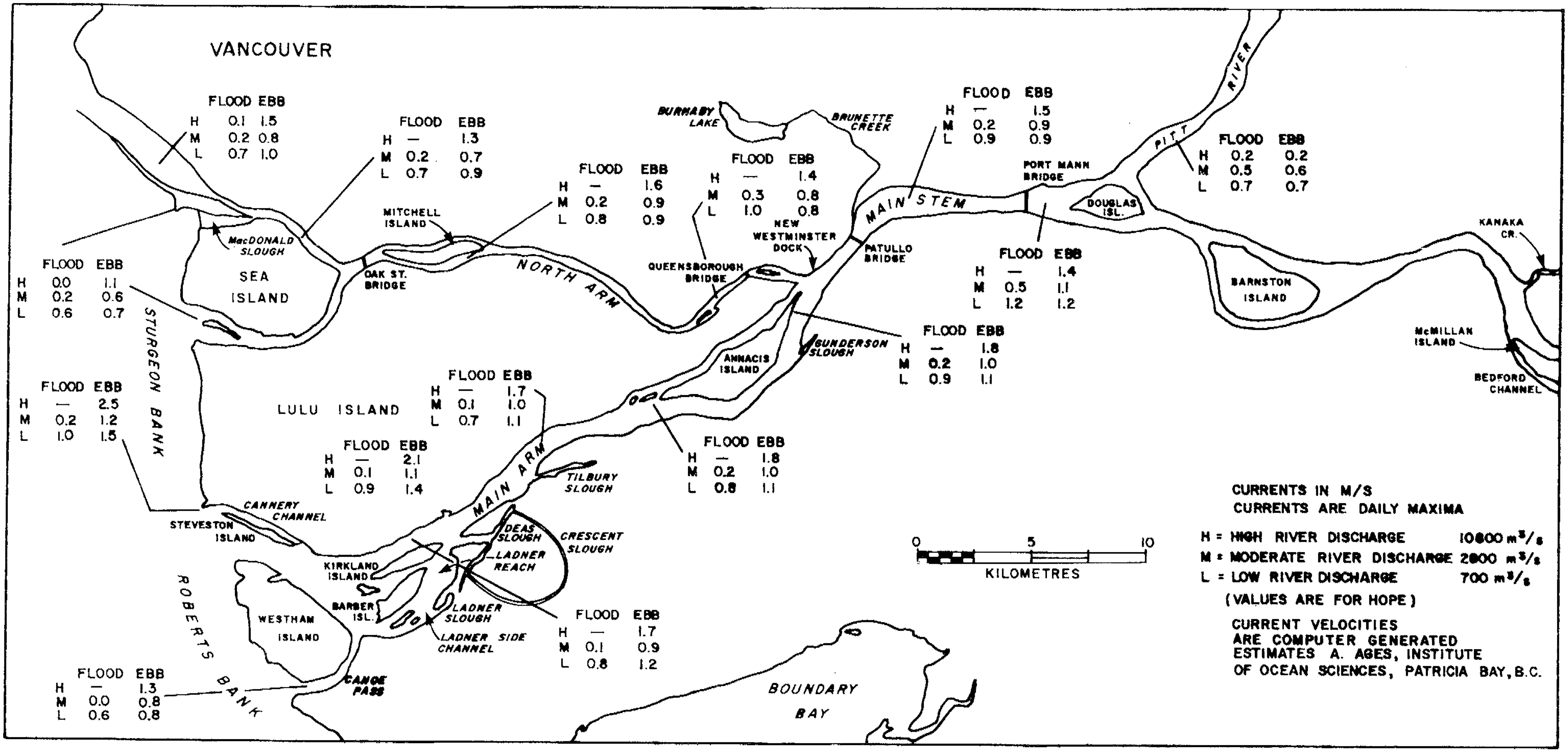


FIGURE 3

TIME SERIES OF SALINITIES AND CURRENTS, BUOY S 21

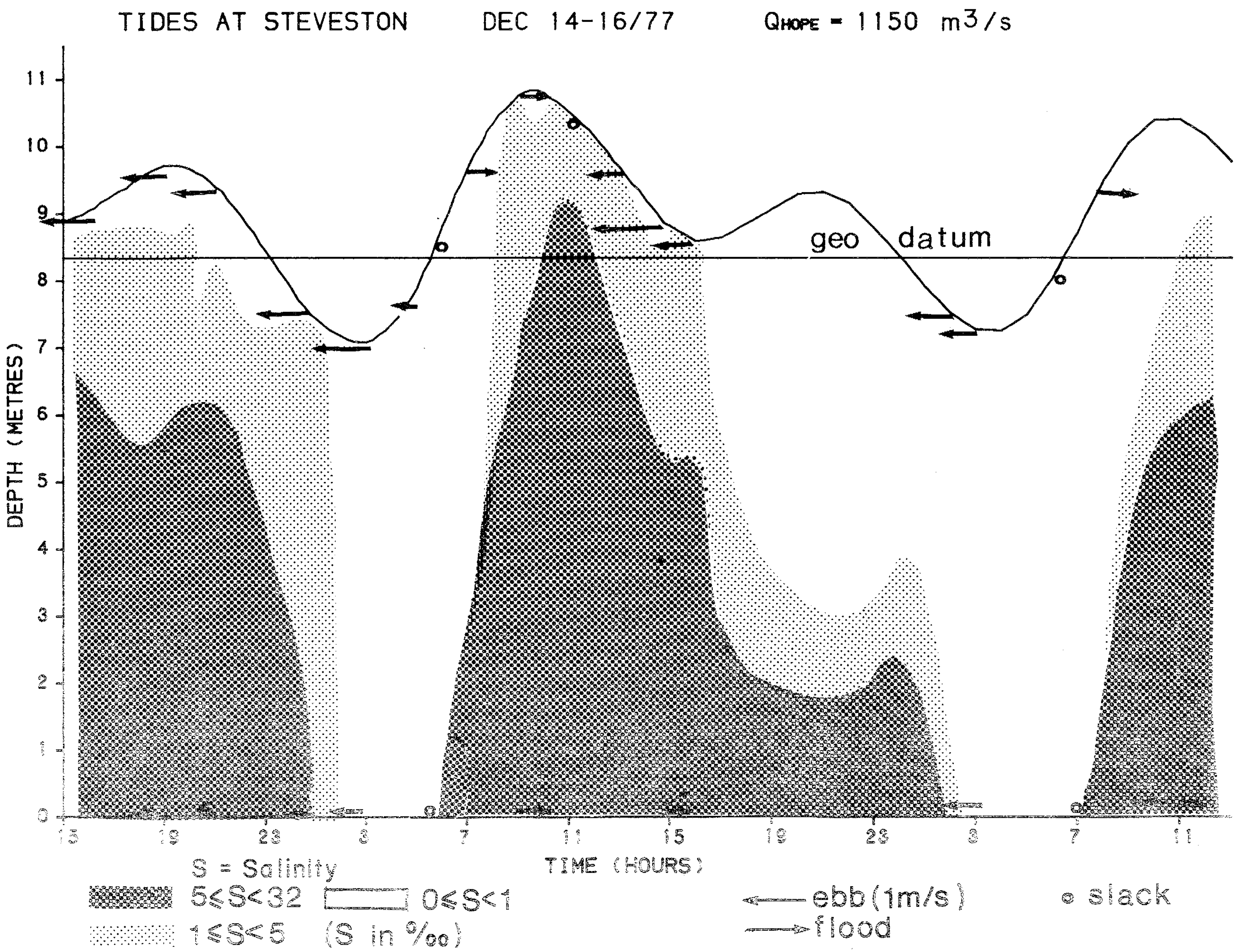


FIGURE 4

SEASONAL CHANGES (MONTHLY MEANS) IN TEMPERATURE FOR COMBINED DATA IN THE LOWER FRASER RIVER

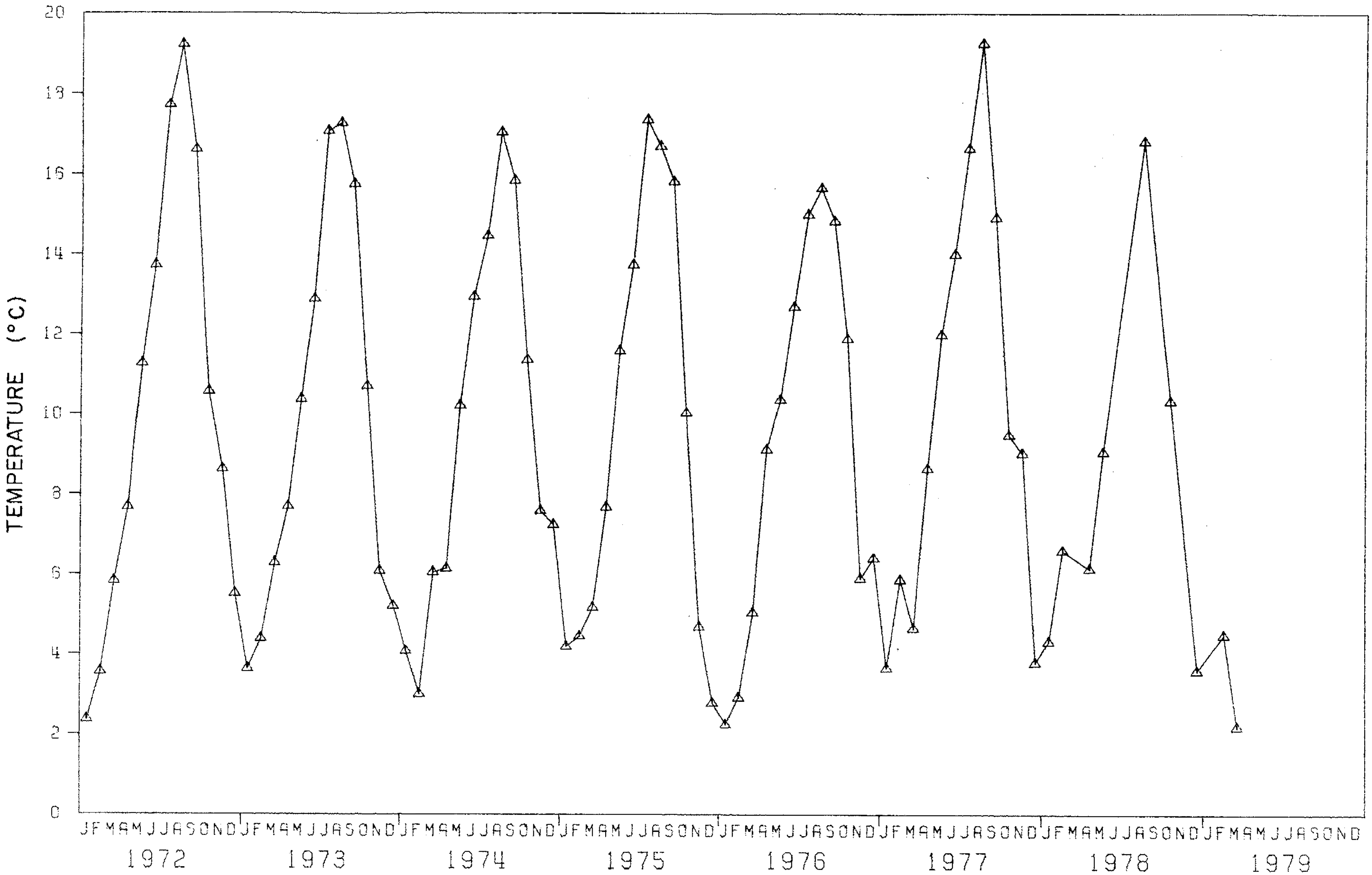


FIGURE 5

SUMMARY OF TEMPERATURE DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

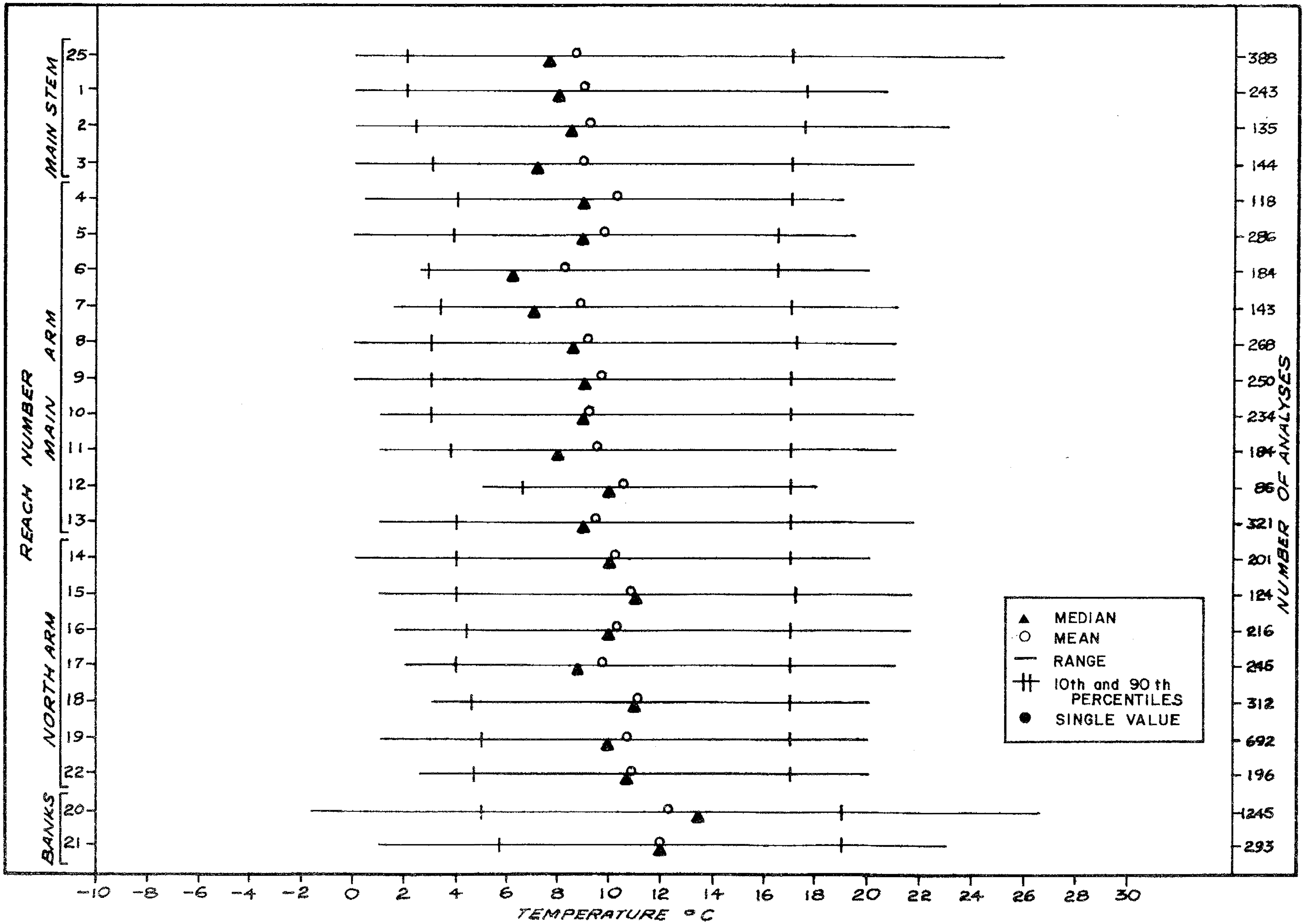


FIGURE 6

SUMMARY OF APPARENT COLOUR DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

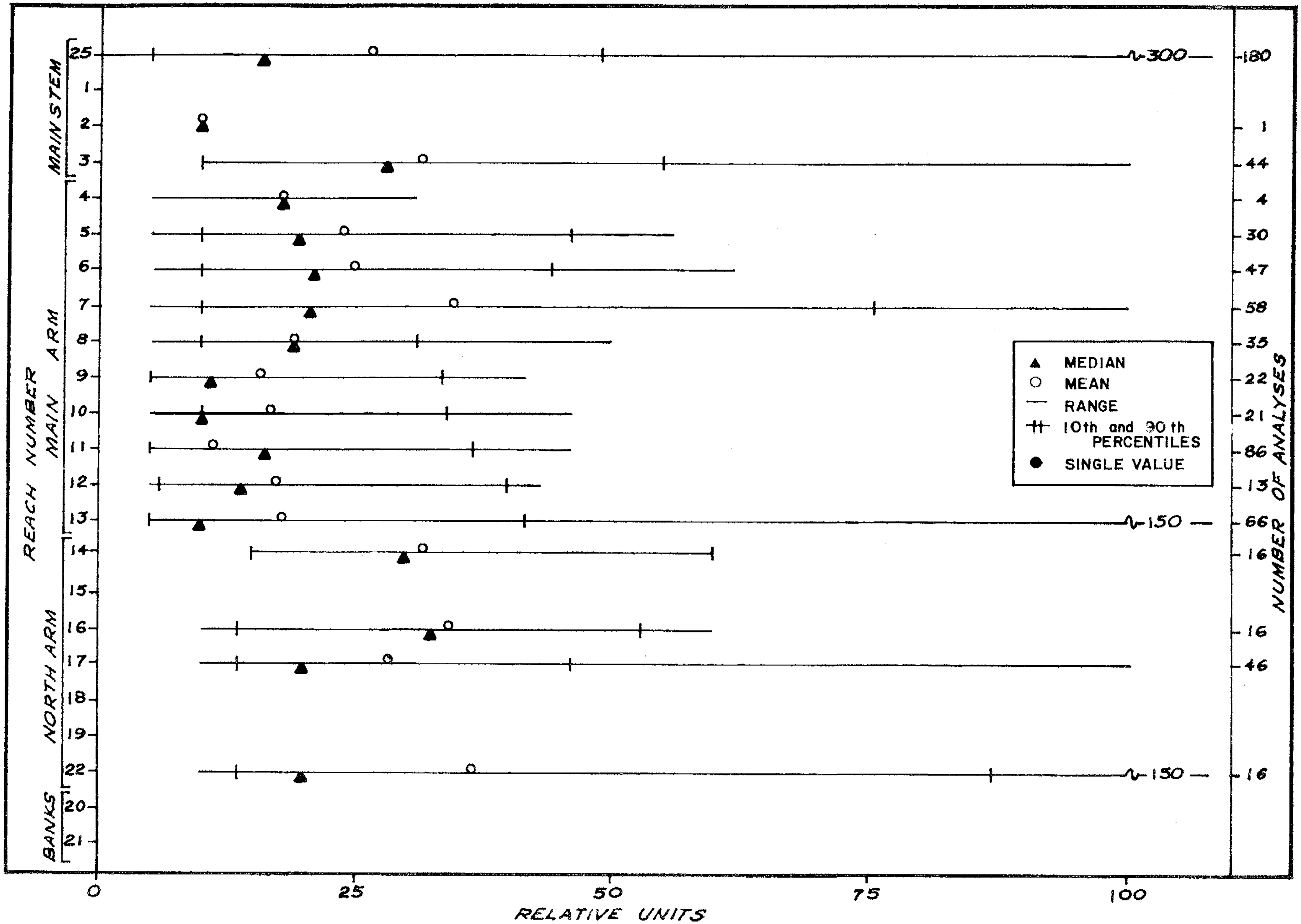


FIGURE 7

SUMMARY OF NON-FILTERABLE RESIDUE DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

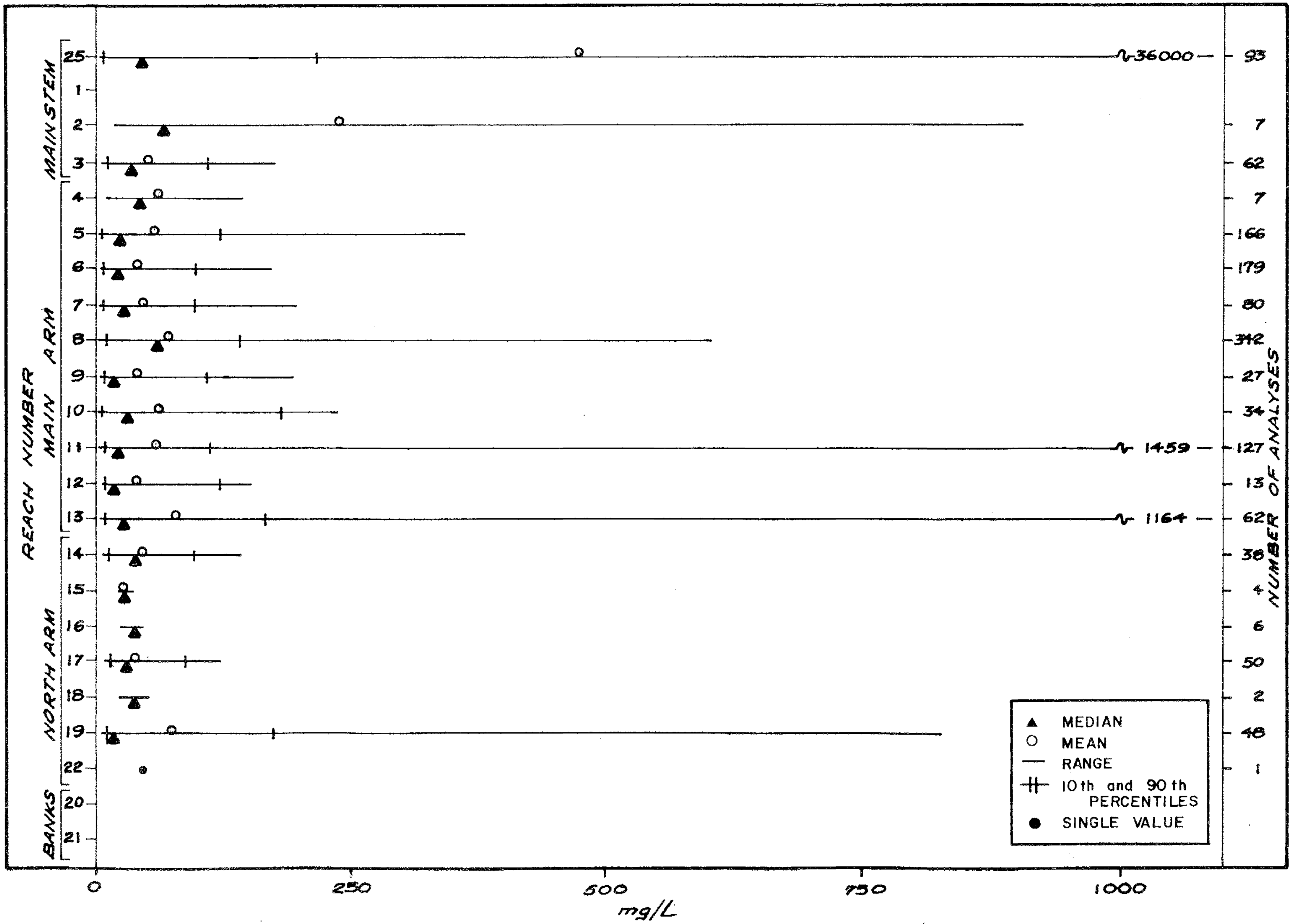


FIGURE 8

SEASONAL CHANGES (MONTHLY MEANS) IN NON-FILTERABLE RESIDUE FOR COMBINED DATA IN THE LOWER FRASER RIVER

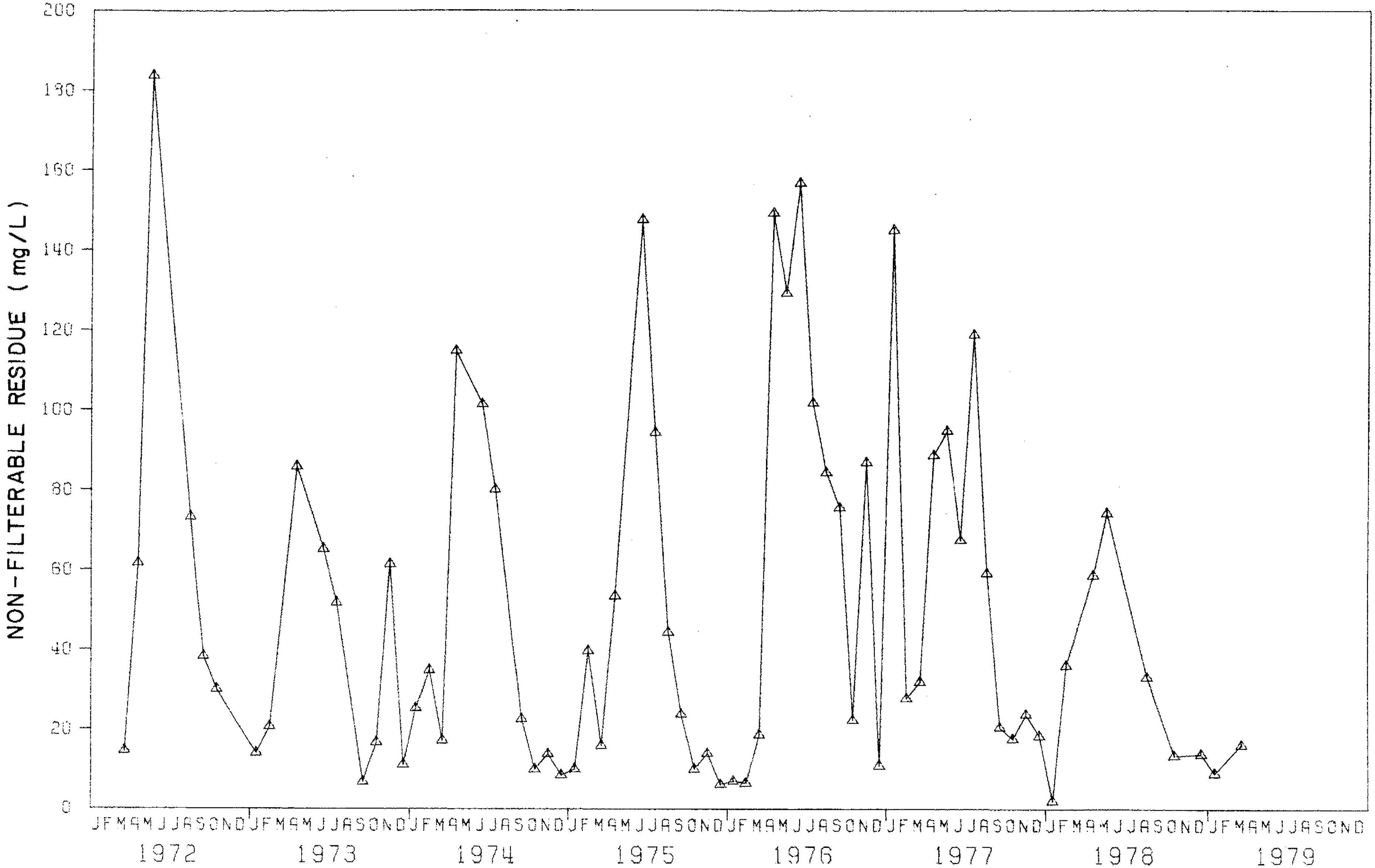


FIGURE 9

SUMMARY OF TURBIDITY DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

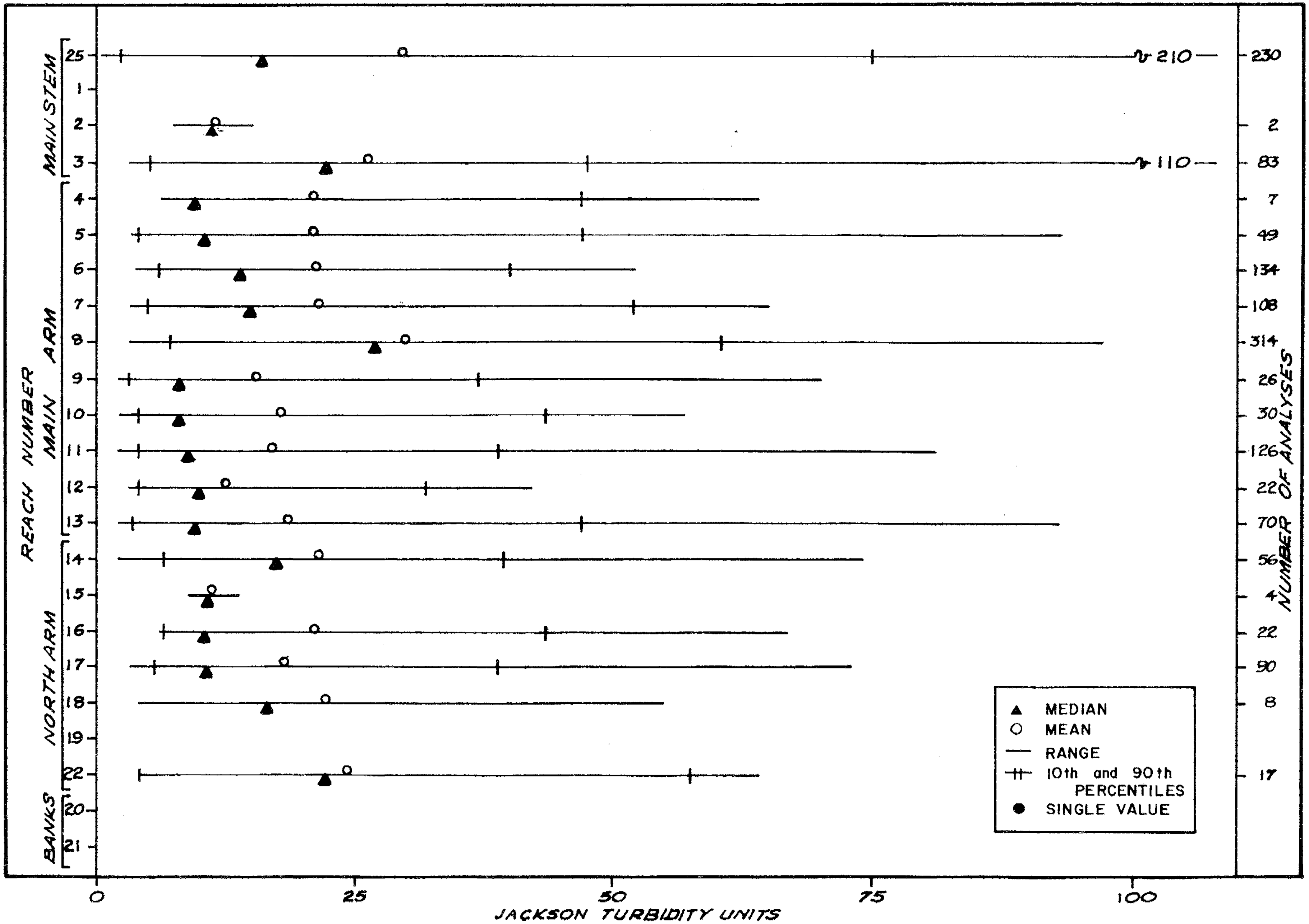


FIGURE 10

SEASONAL CHANGES (MONTHLY MEANS) IN TURBIDITY FOR COMBINED DATA IN THE LOWER FRASER RIVER

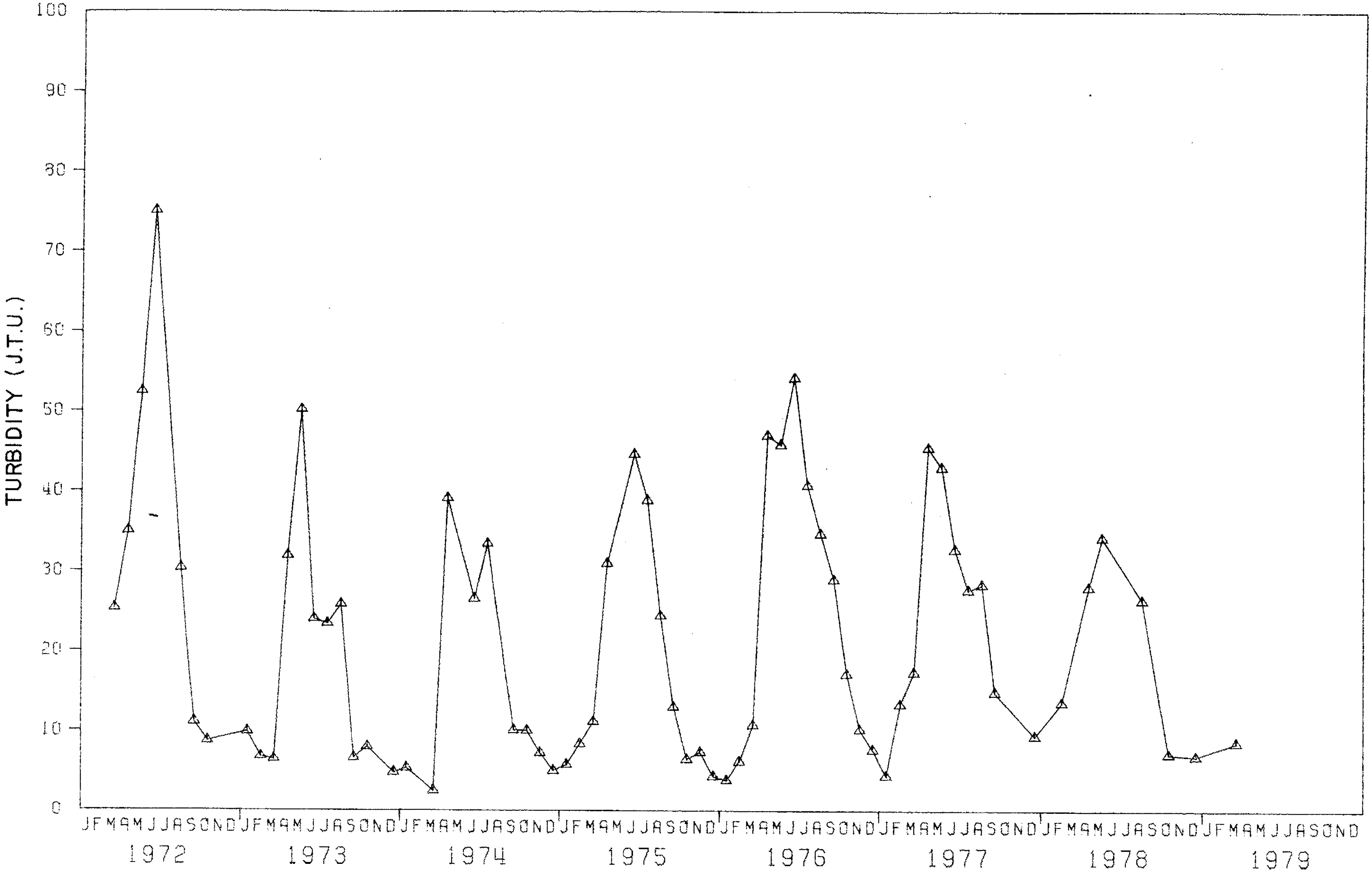


FIGURE II

SUMMARY OF FILTERABLE RESIDUE DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

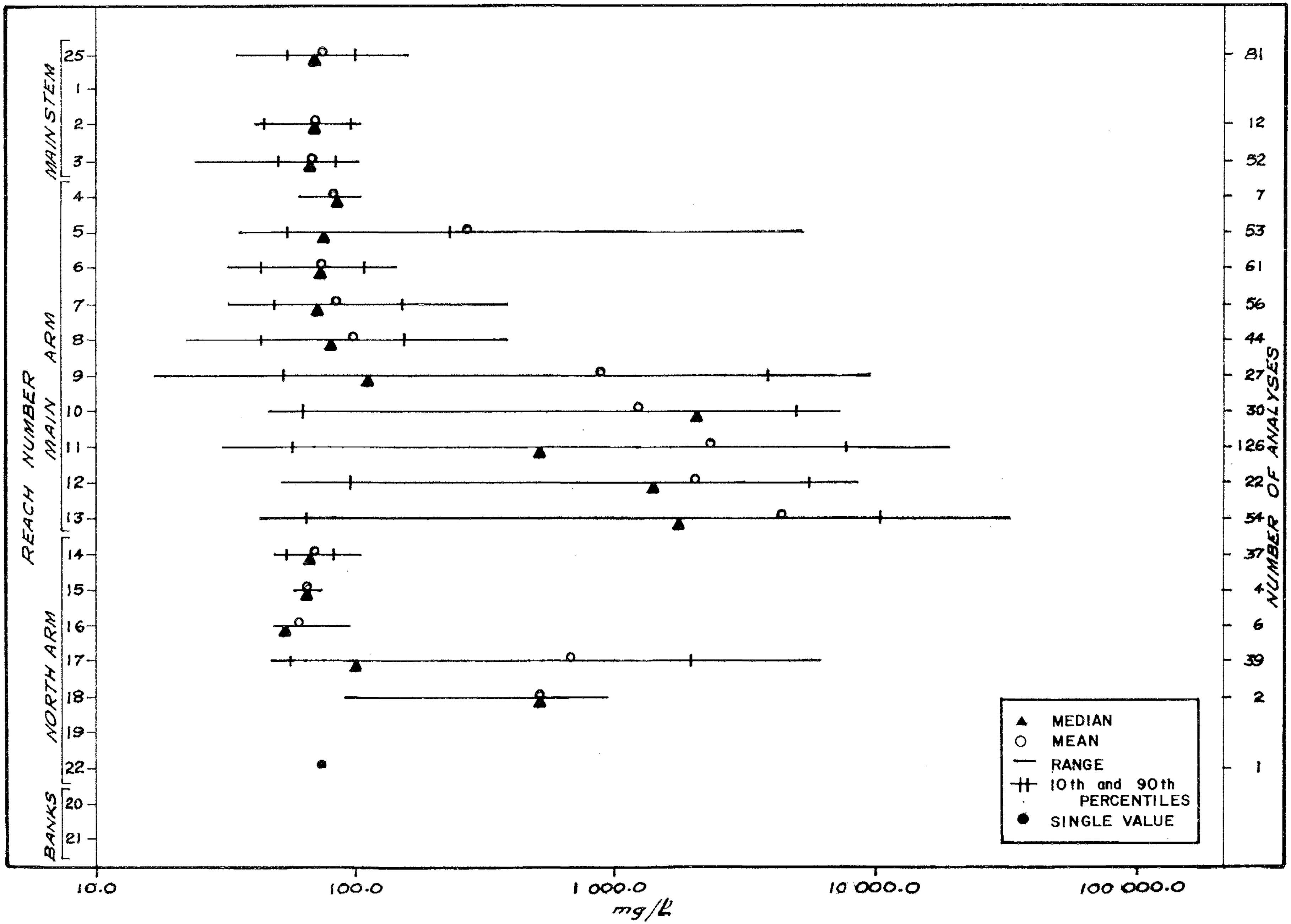


FIGURE 12

SUMMARY OF SPECIFIC CONDUCTIVITY DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

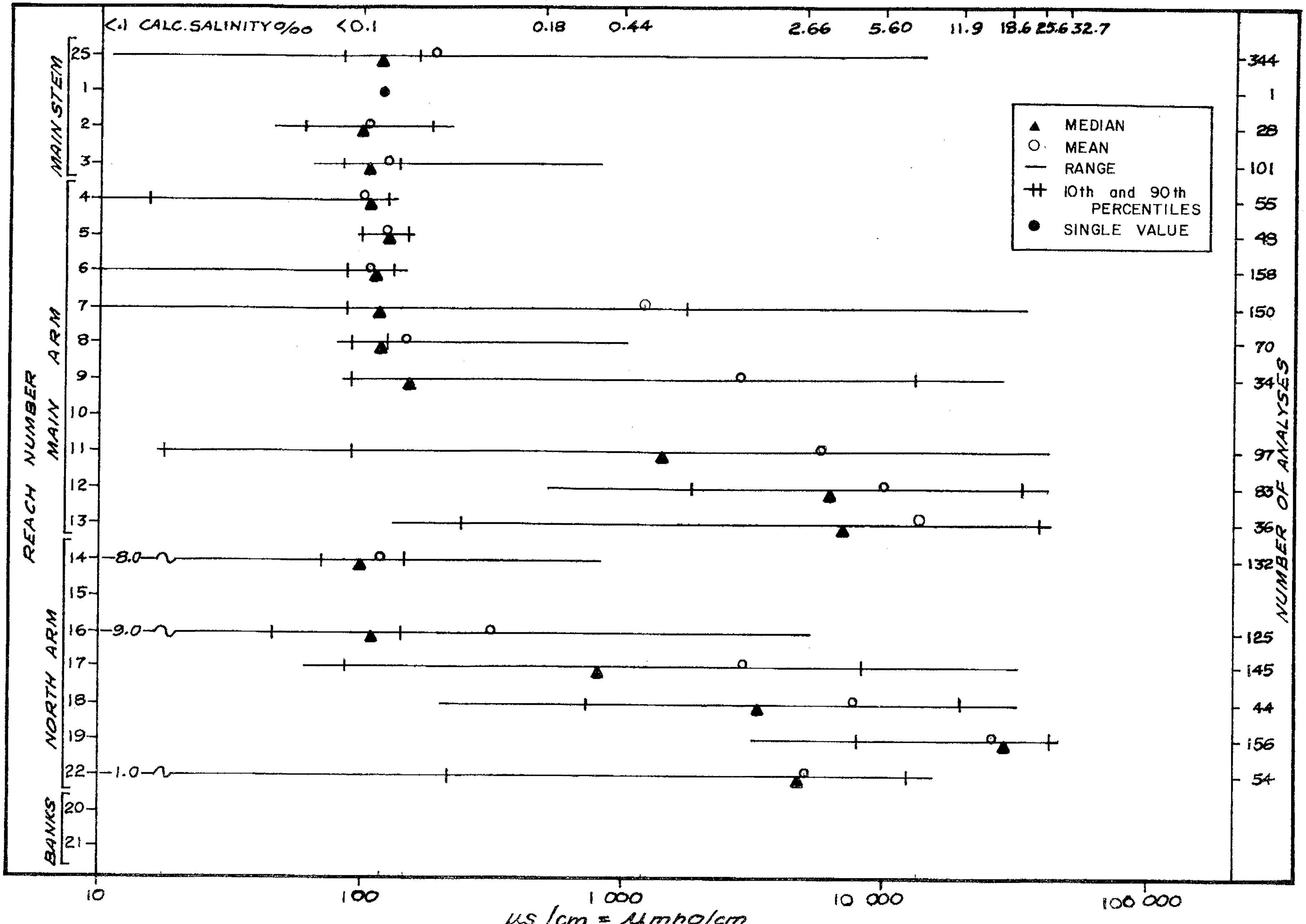


FIGURE 13

SUMMARY OF CHLORIDE DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

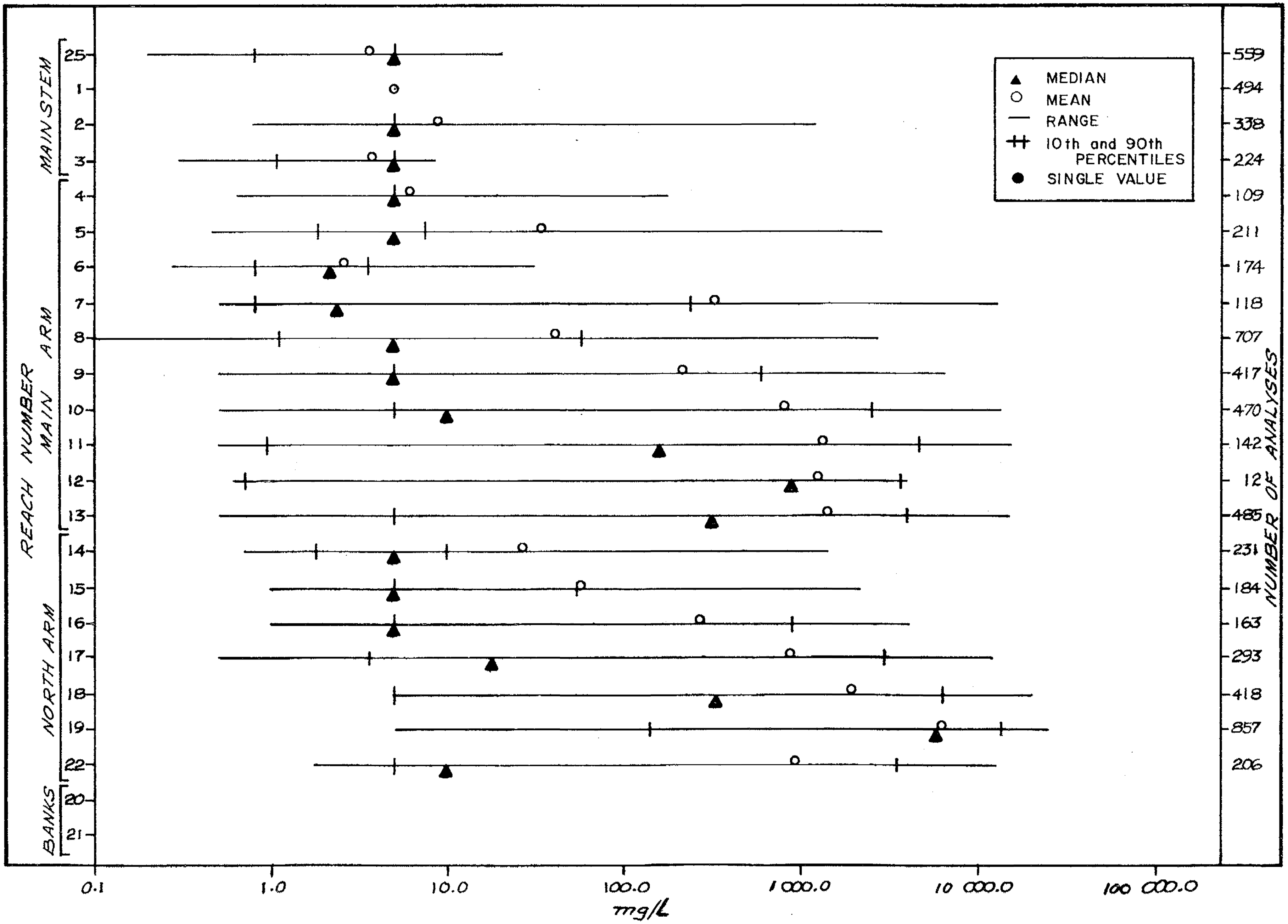


FIGURE 14

SEASONAL CHANGES (MONTHLY MEANS) IN CHLORIDE FOR COMBINED DATA IN THE LOWER FRASER RIVER

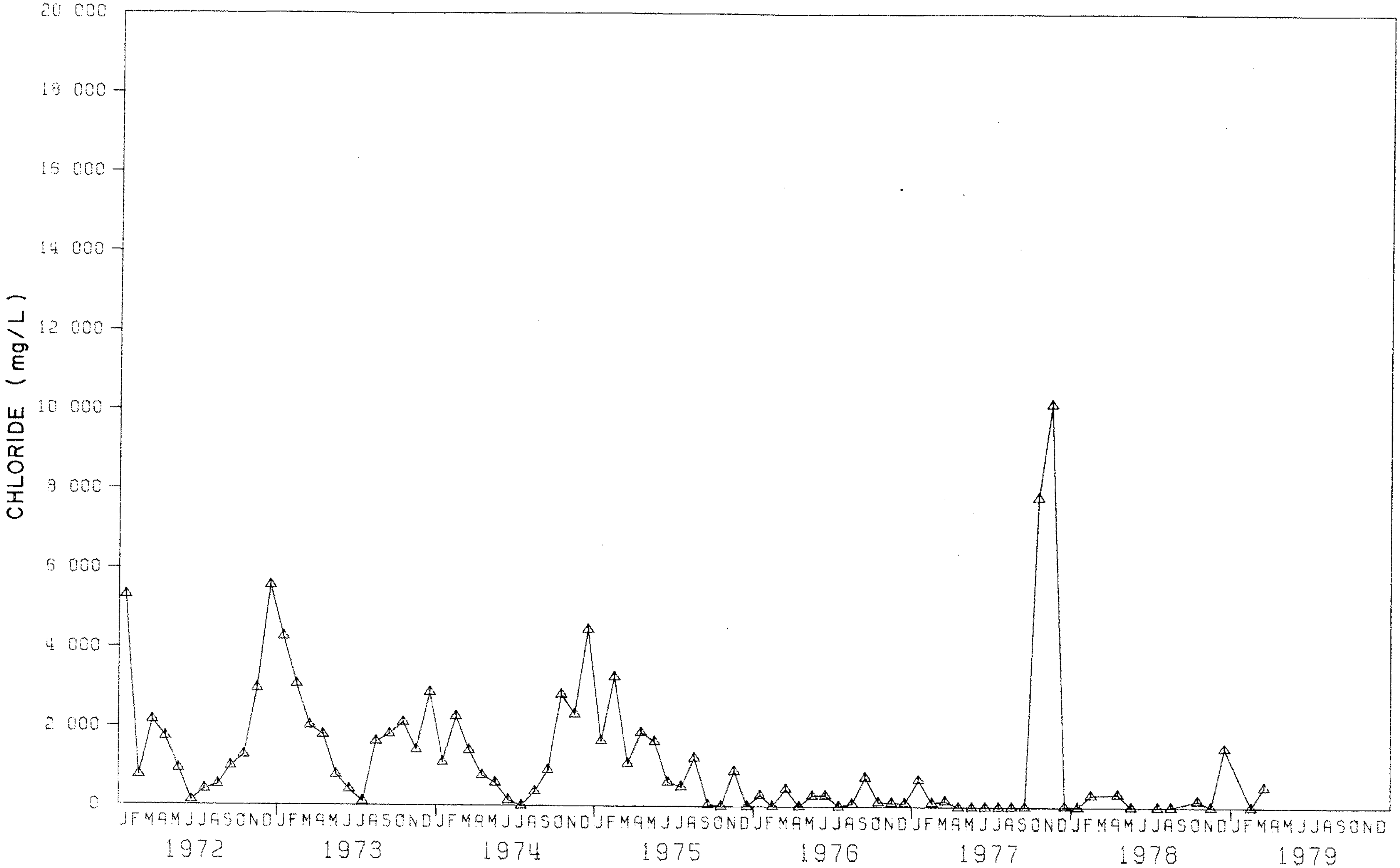


FIGURE 15. CHANGES IN MONTHLY CHLORIDE LEVELS : MAIN ARM.

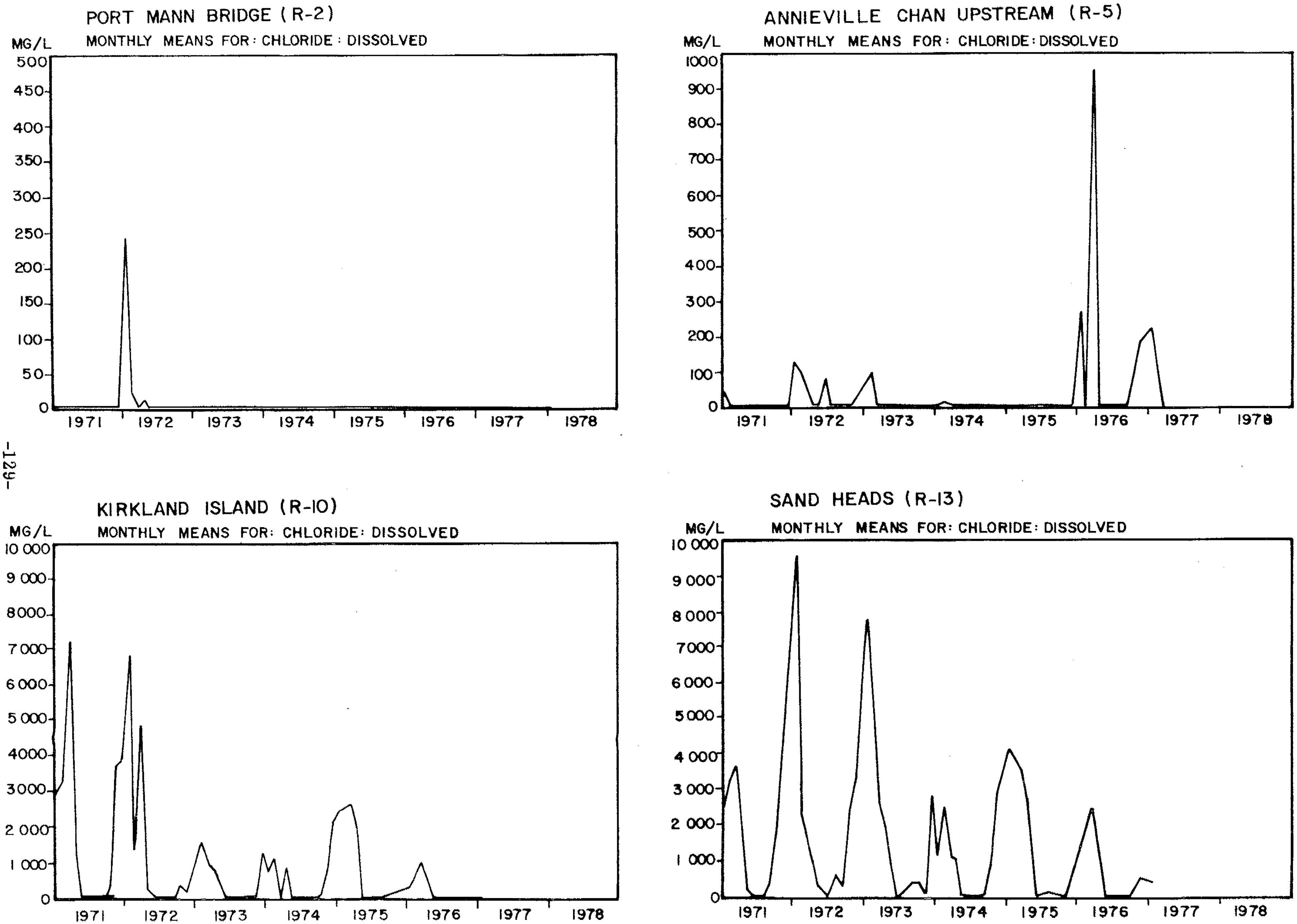


FIGURE 16 CHANGES IN MONTHLY CHLORIDE LEVELS: NORTH ARM

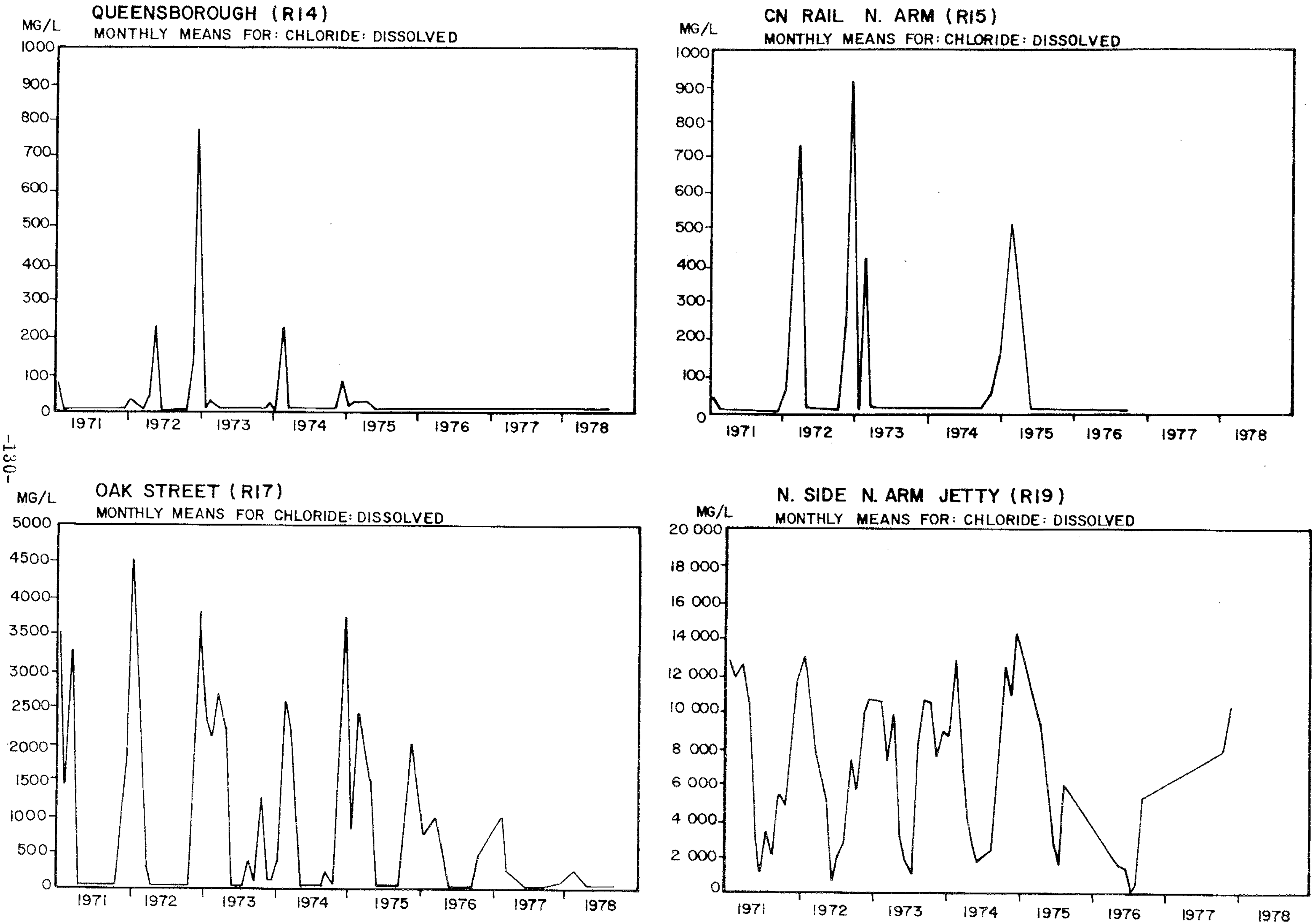


FIGURE 17

SUMMARY OF pH DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

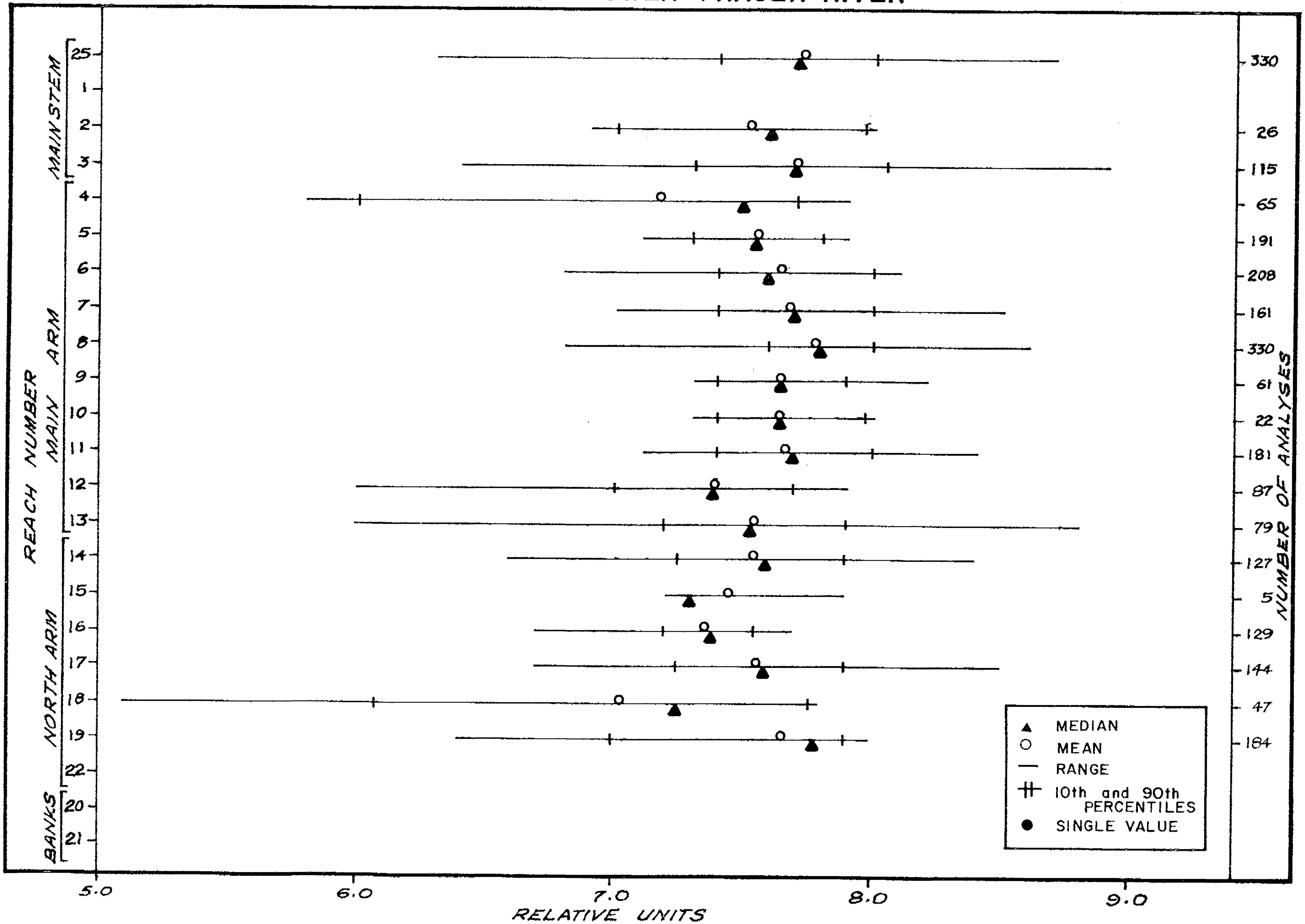


FIGURE 18

AVERAGE TITRATION CURVES OF THREE RIVER SAMPLES COLLECTED IN MAY AND JUNE, 1979 NEAR NEW WESTMINSTER (REACH 4)

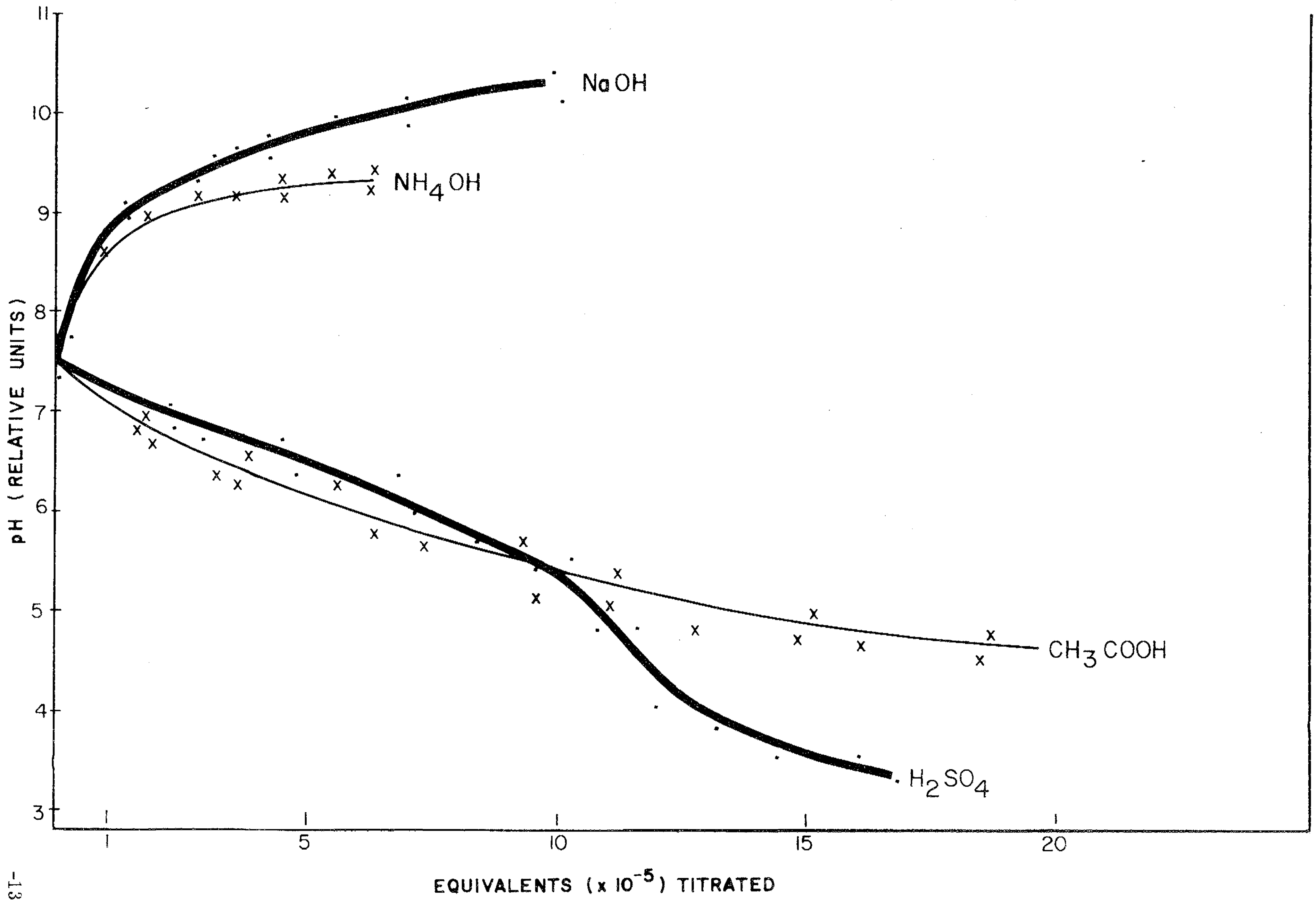


FIGURE 19

SUMMARY OF DISSOLVED OXYGEN DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

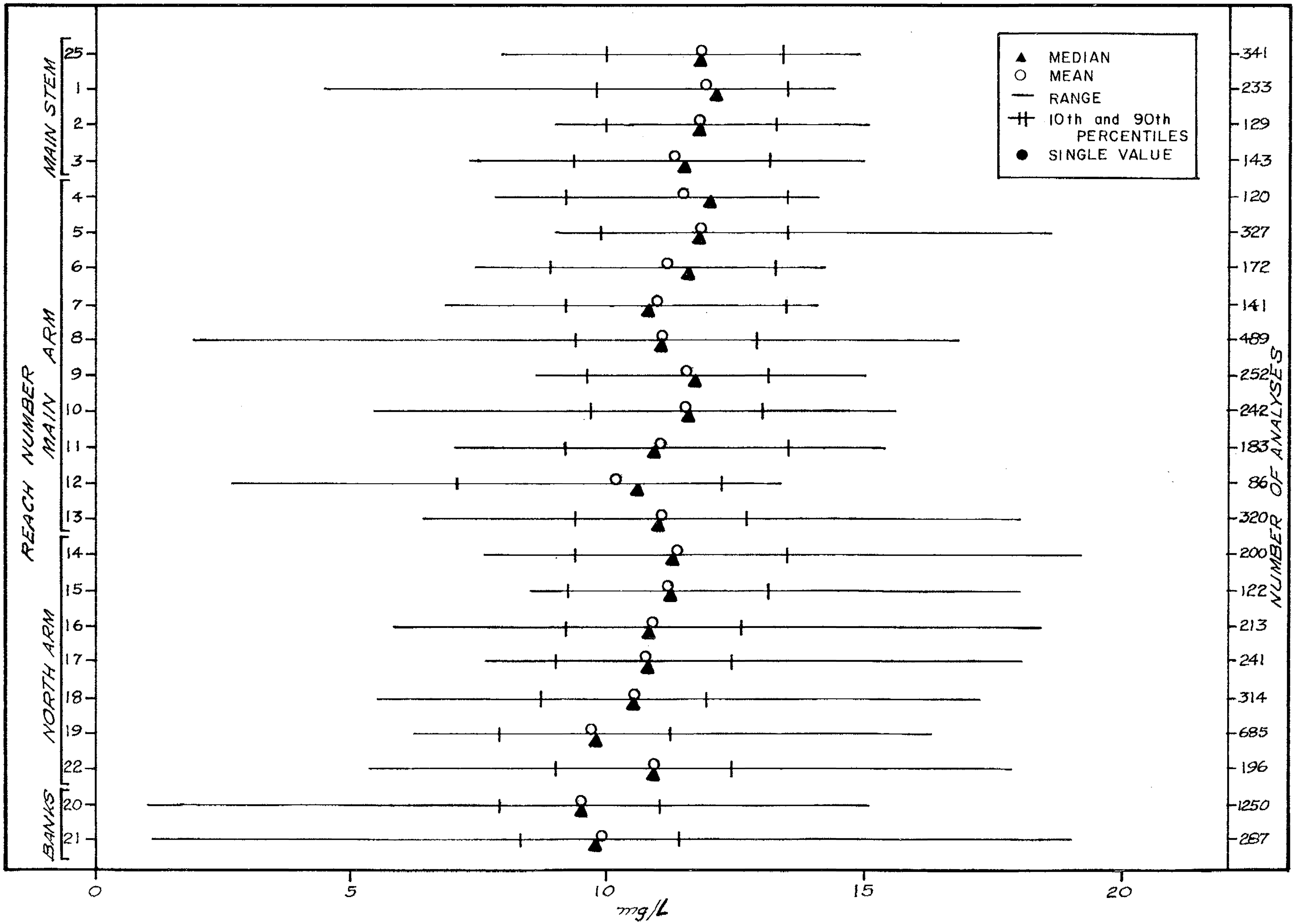


FIGURE 20

SEASONAL CHANGES (MONTHLY MEANS) IN DISSOLVED OXYGEN FOR COMBINED DATA IN THE LOWER FRASER RIVER

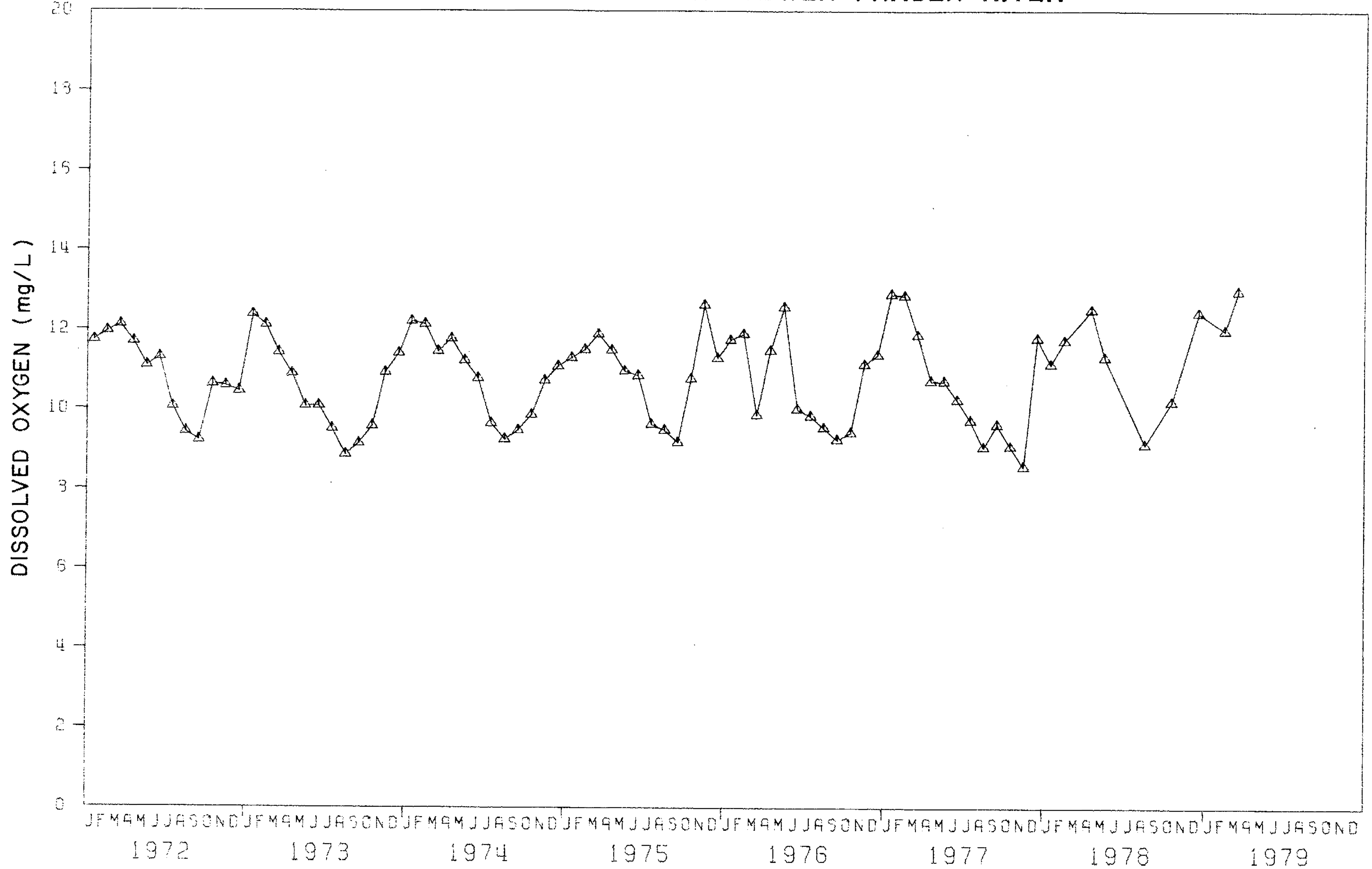


FIGURE 21

SUMMARY OF AMMONIA DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

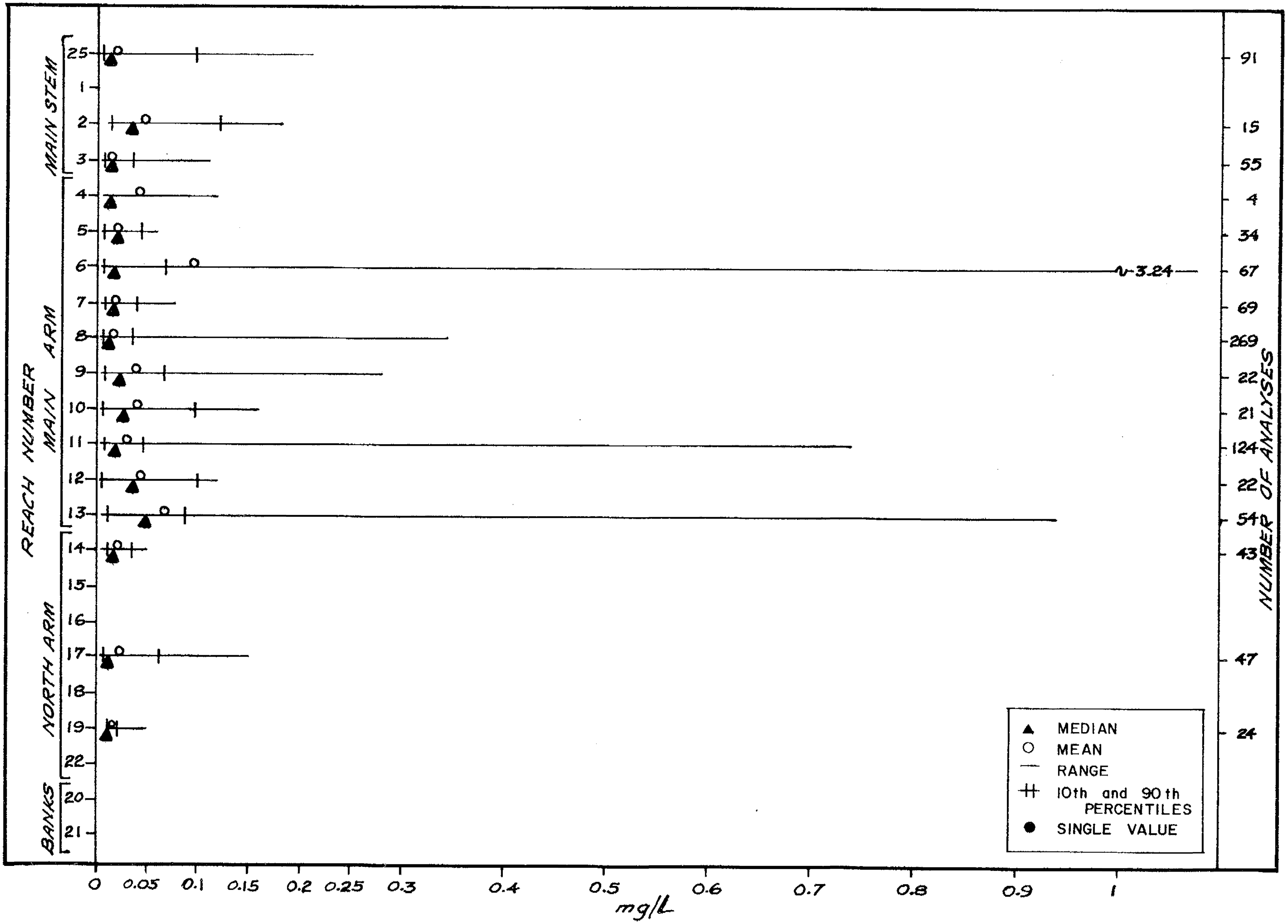


FIGURE 22

SEASONAL CHANGES (MONTHLY MEANS) IN AMMONIA FOR COMBINED DATA IN THE LOWER FRASER RIVER

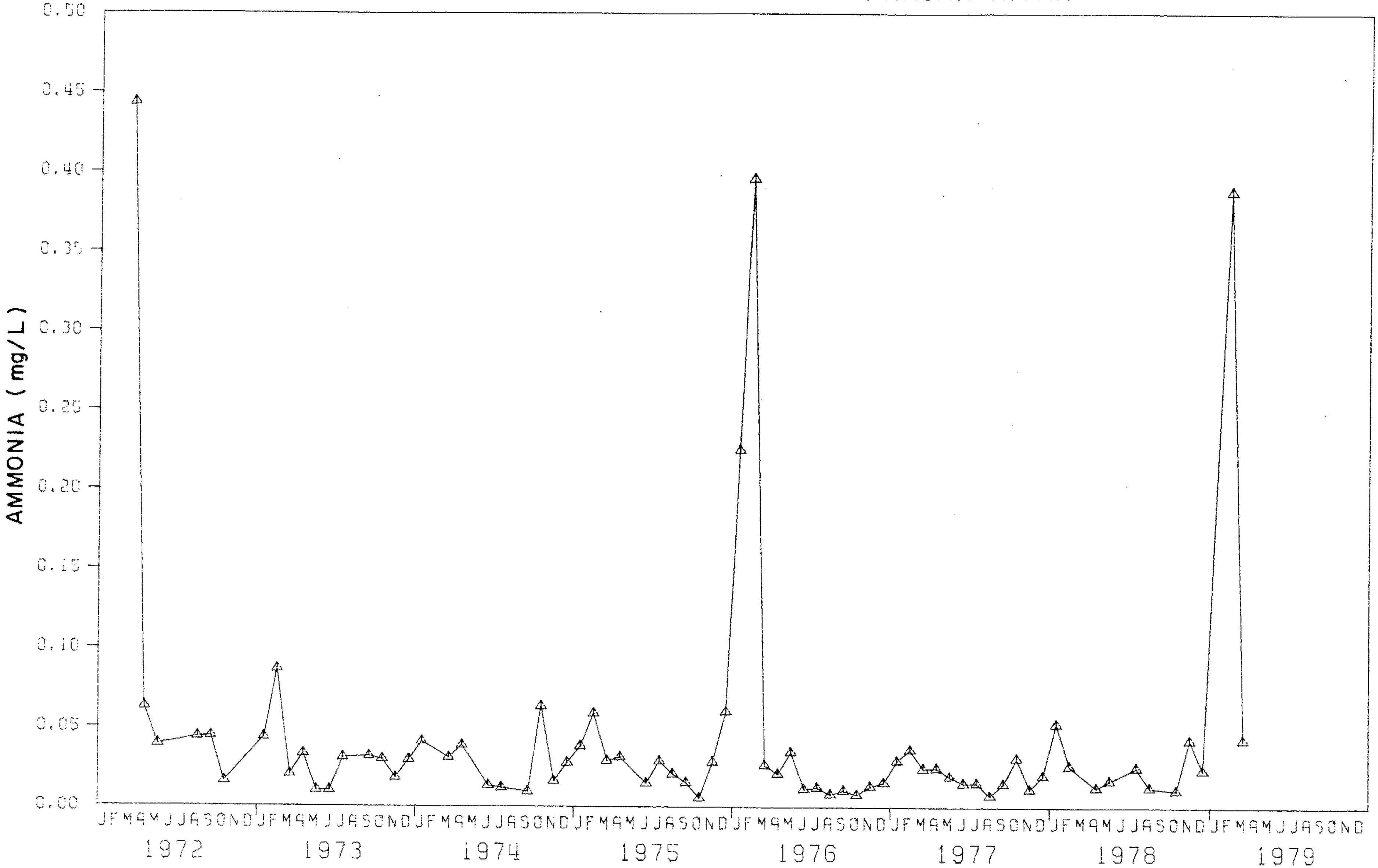


FIGURE 23

SUMMARY OF NITRATE DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

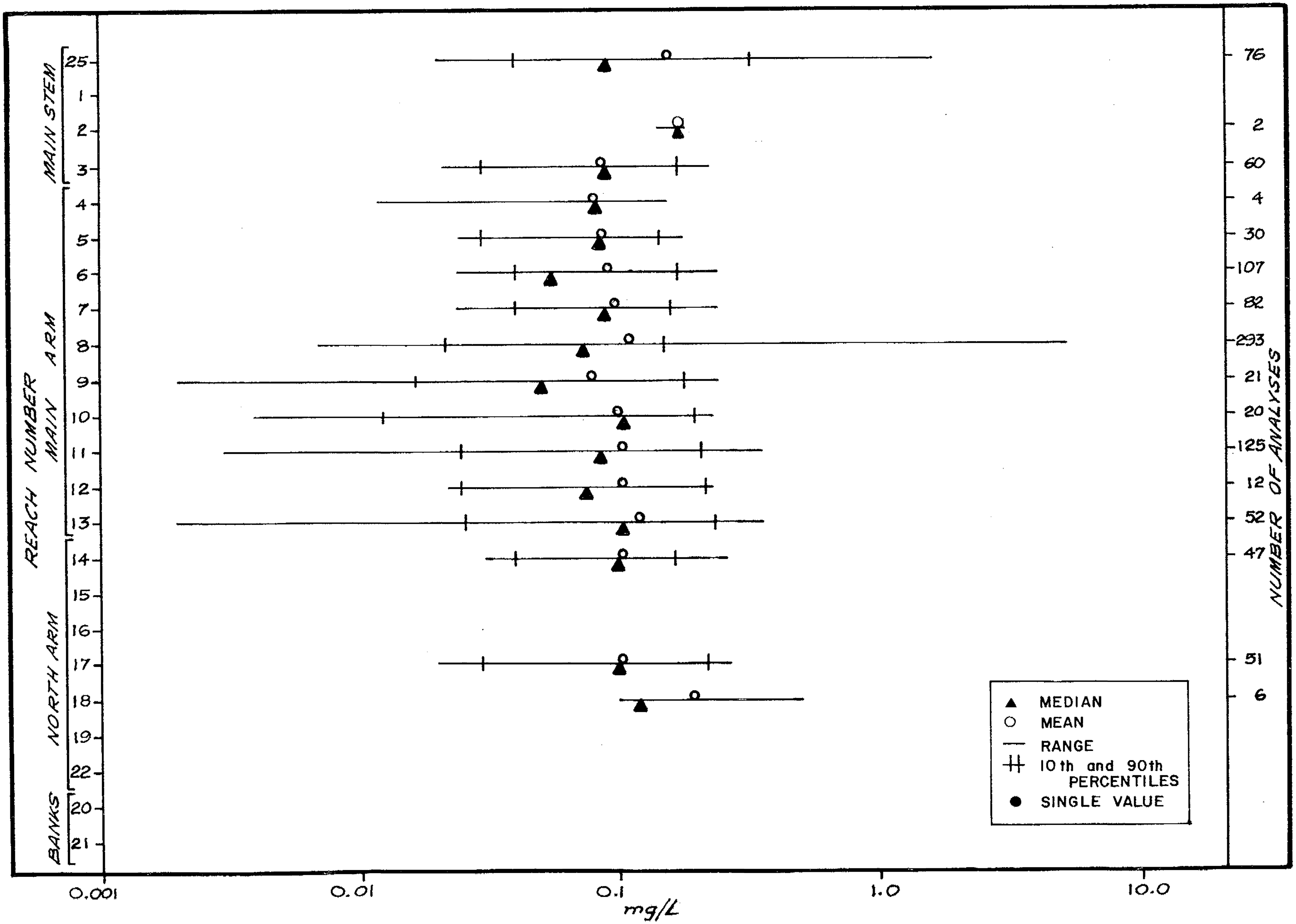


FIGURE 24
SEASONAL CHANGES (MONTHLY MEANS) IN NITRATE
FOR COMBINED DATA IN THE LOWER FRASER RIVER

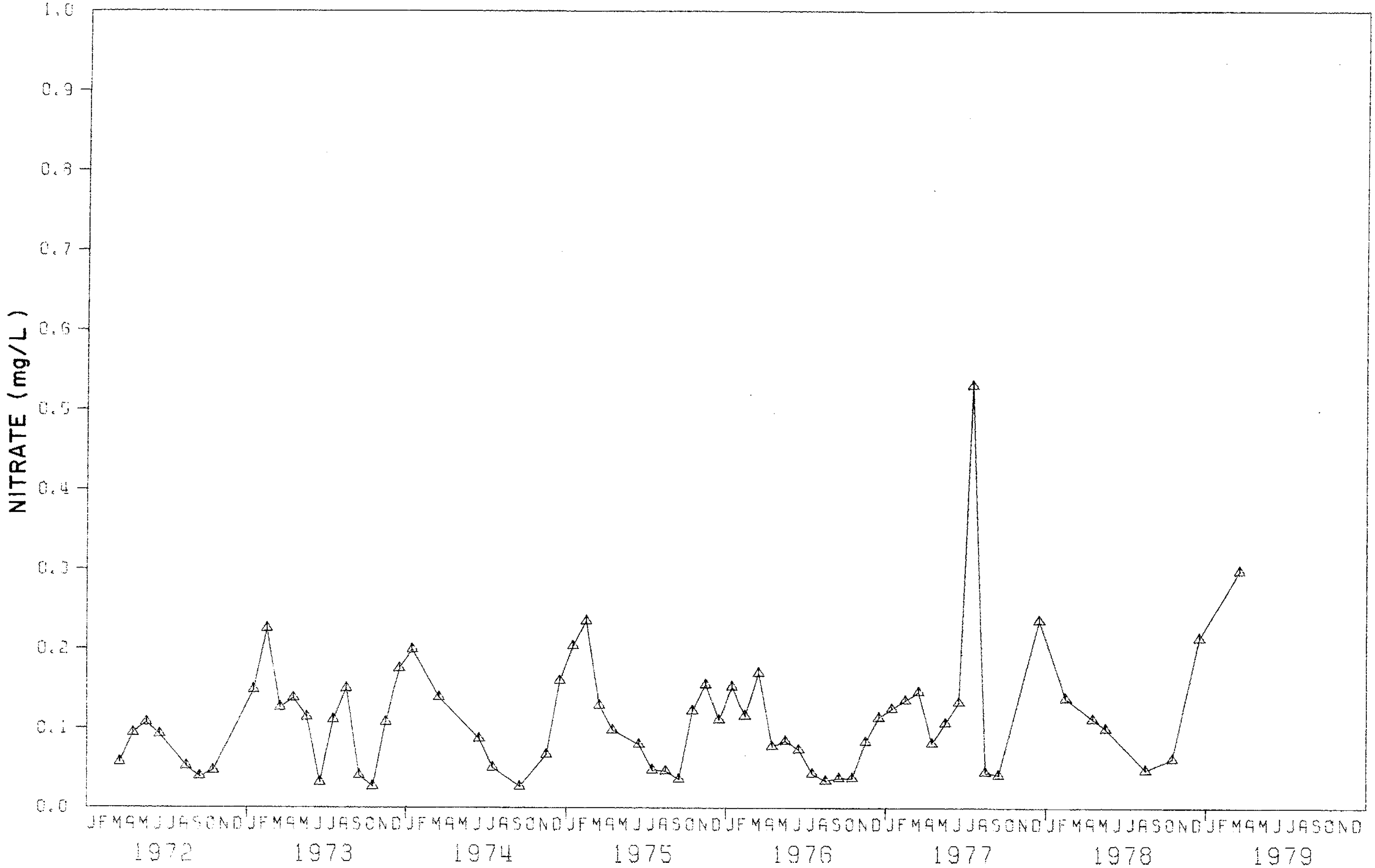


FIGURE 25

SUMMARY OF KJELDAHL-NITROGEN DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

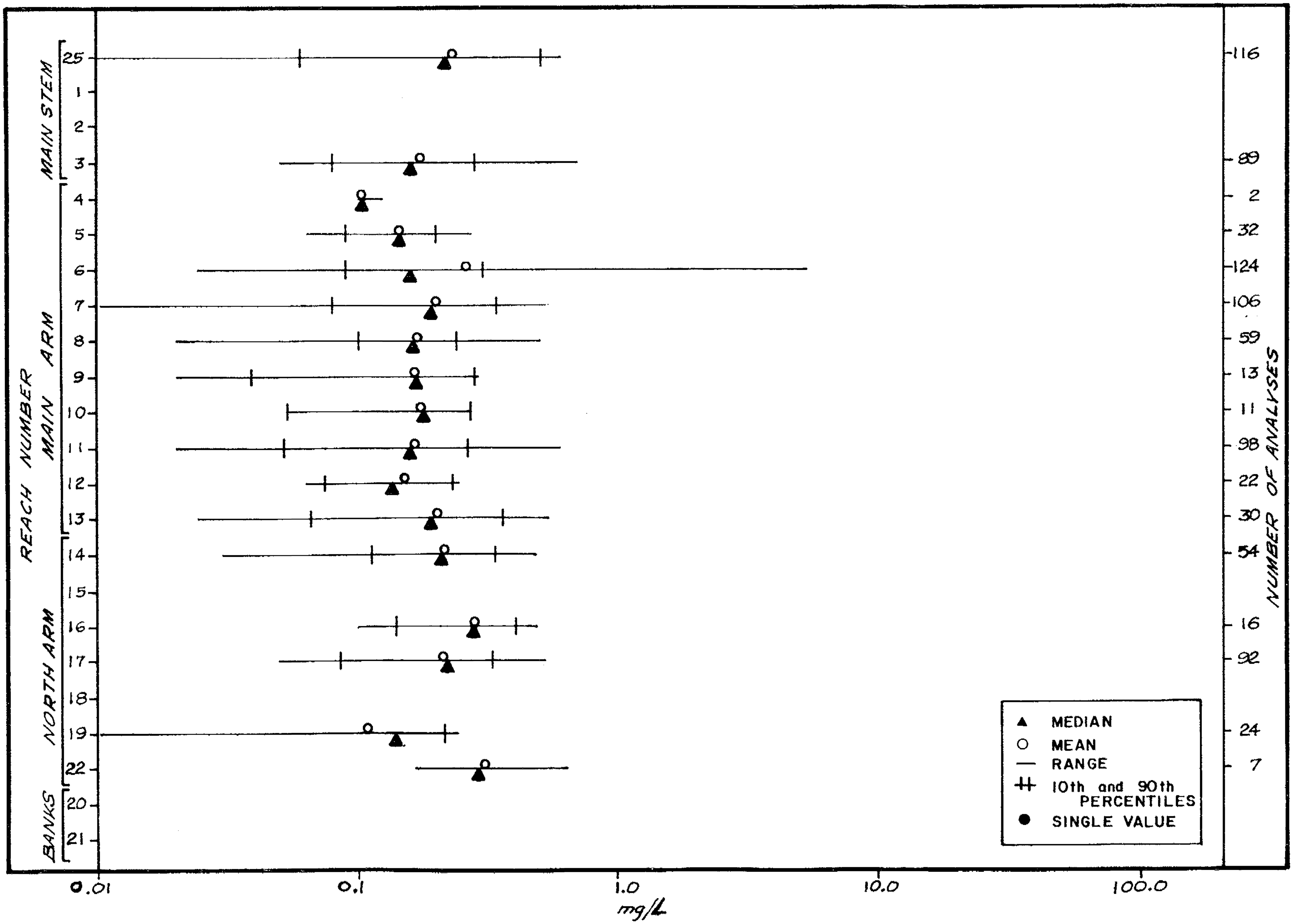


FIGURE 26

SUMMARY OF ORTHO-PHOSPHATE DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

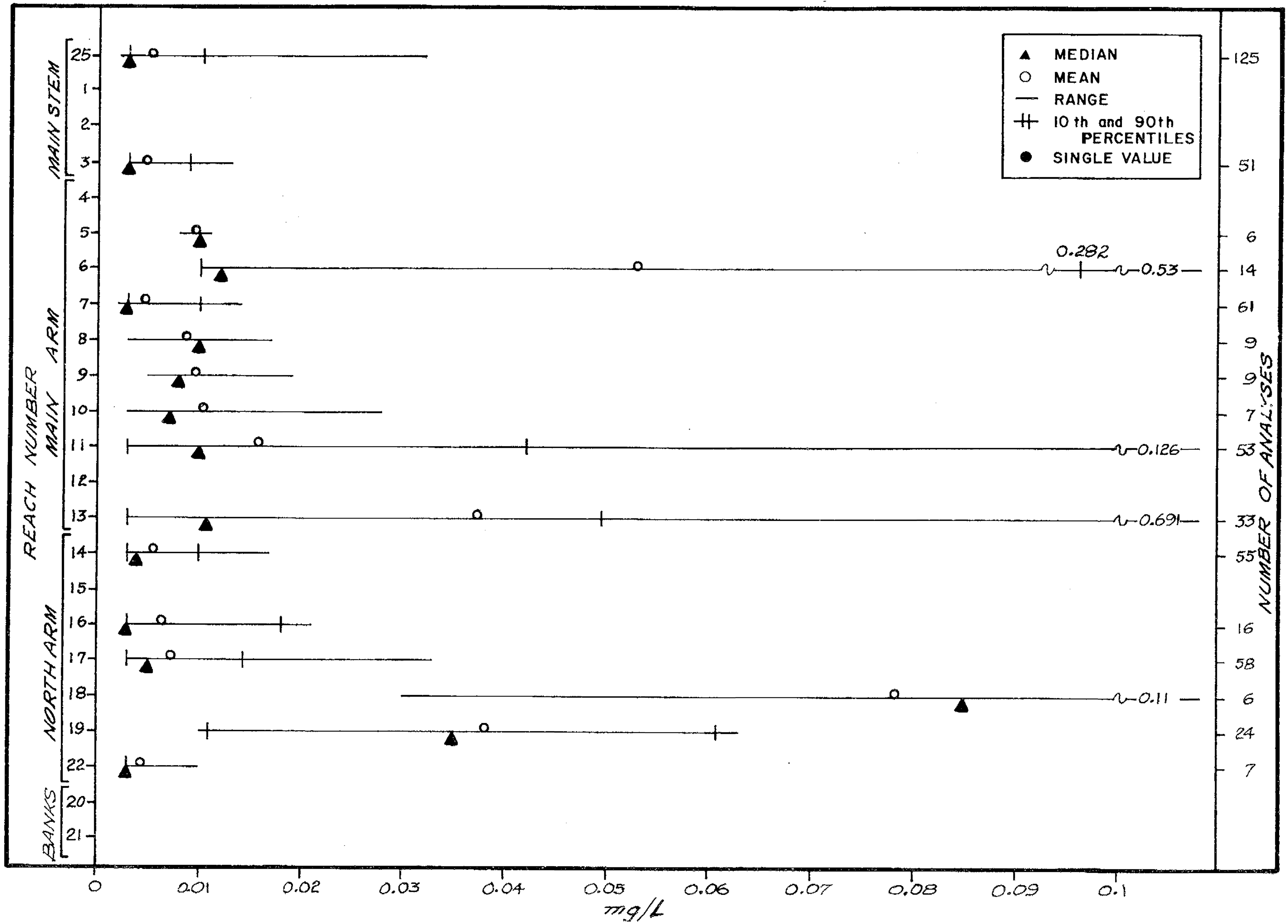


FIGURE 27

SUMMARY OF TOTAL PHOSPHATE DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

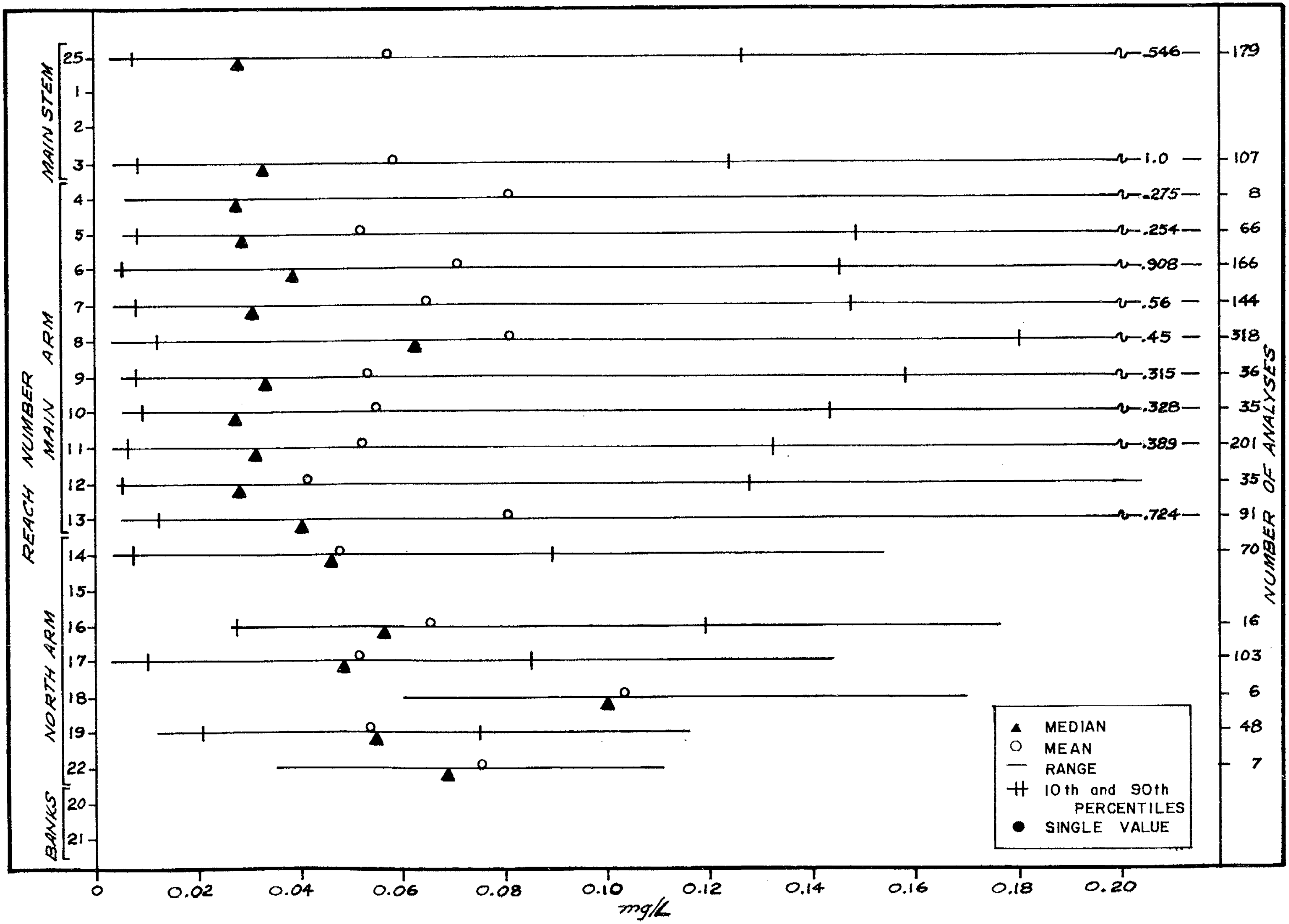


FIGURE 28

SEASONAL CHANGES (MONTHLY MEANS) IN TOTAL PHOSPHATE FOR COMBINED DATA IN THE LOWER FRASER RIVER

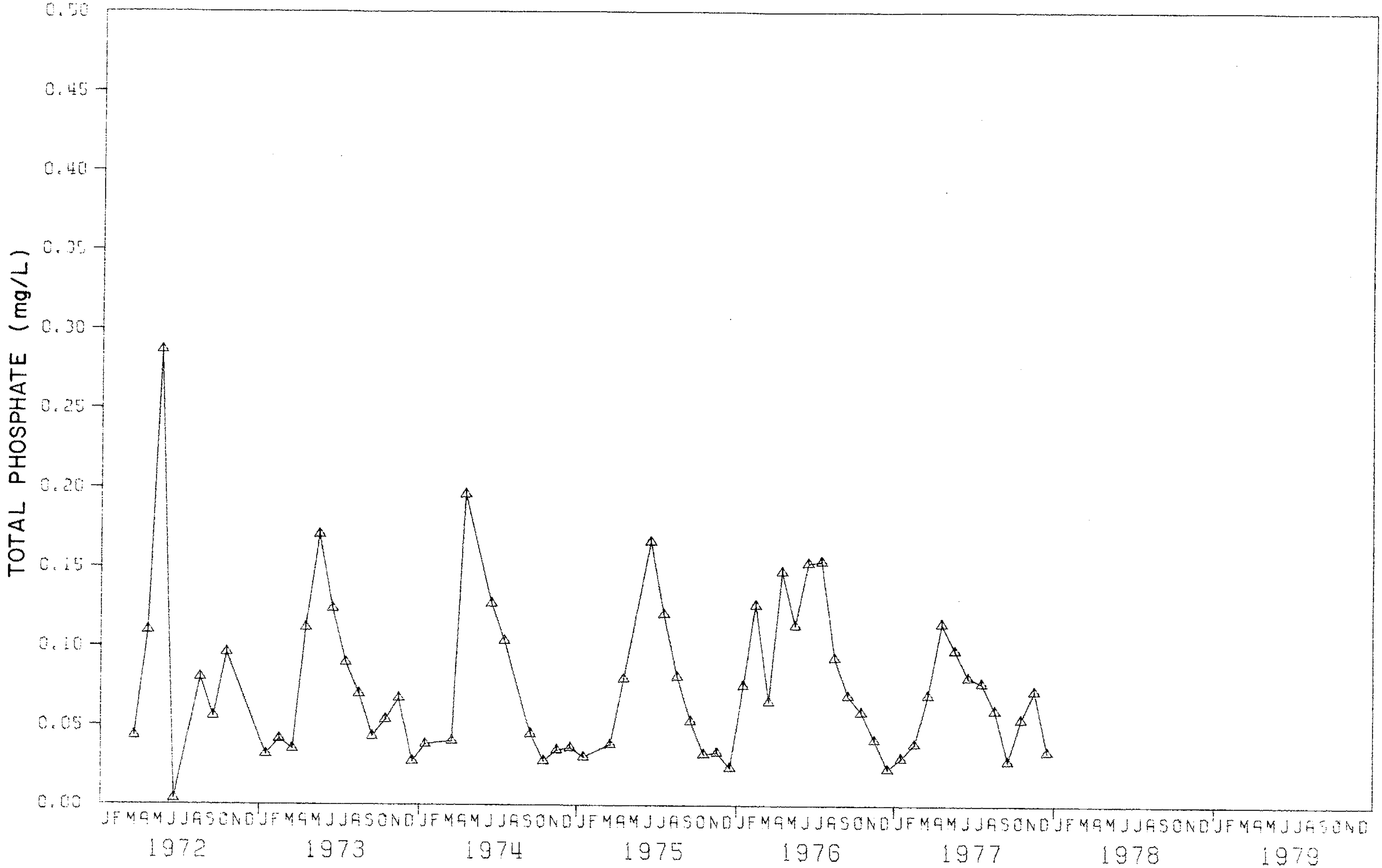


FIGURE 29

TOTAL AND DISSOLVED CADMIUM; LOWER FRASER RIVER

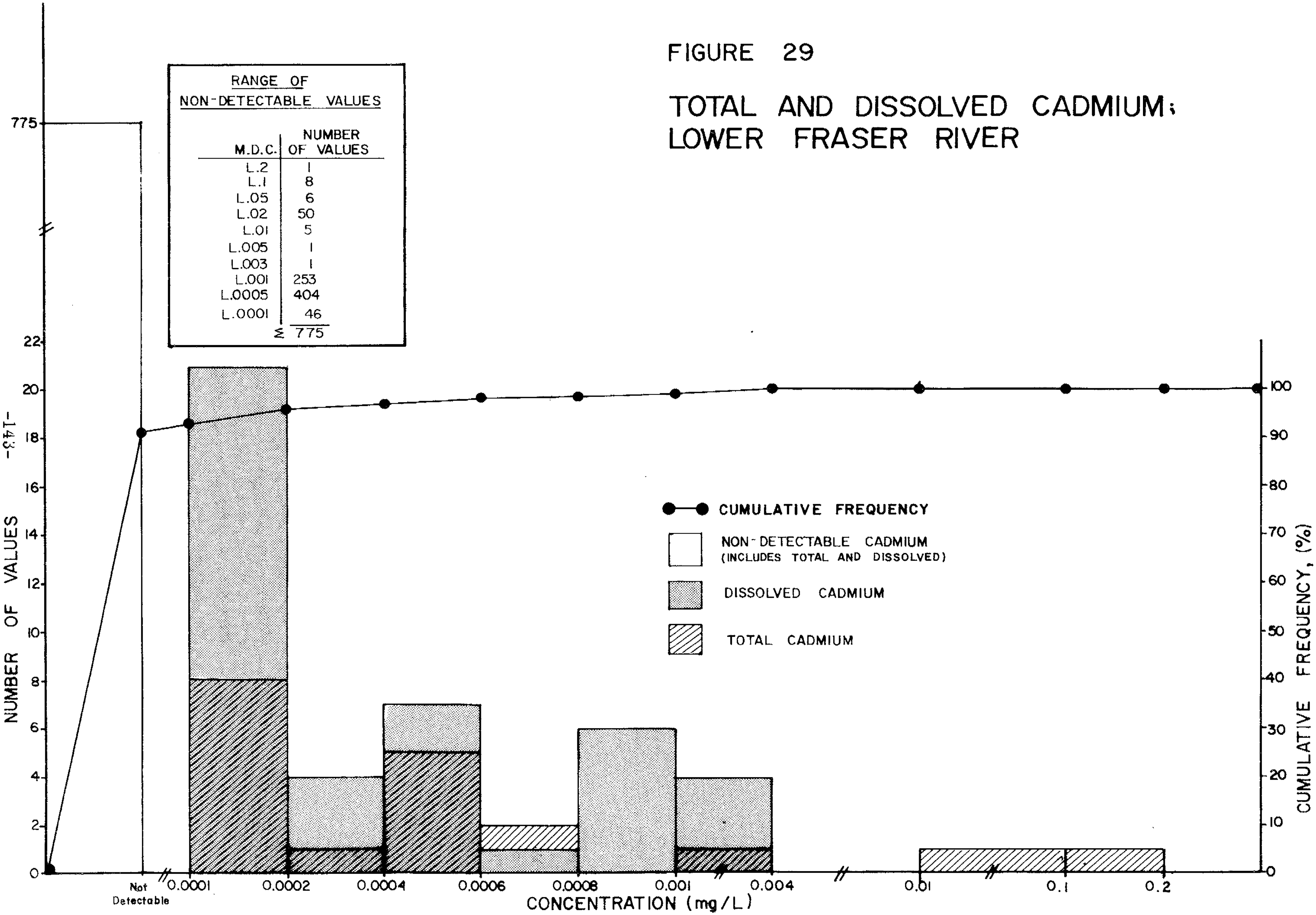


FIGURE 30

TOTAL AND DISSOLVED CHROMIUM; LOWER FRASER RIVER

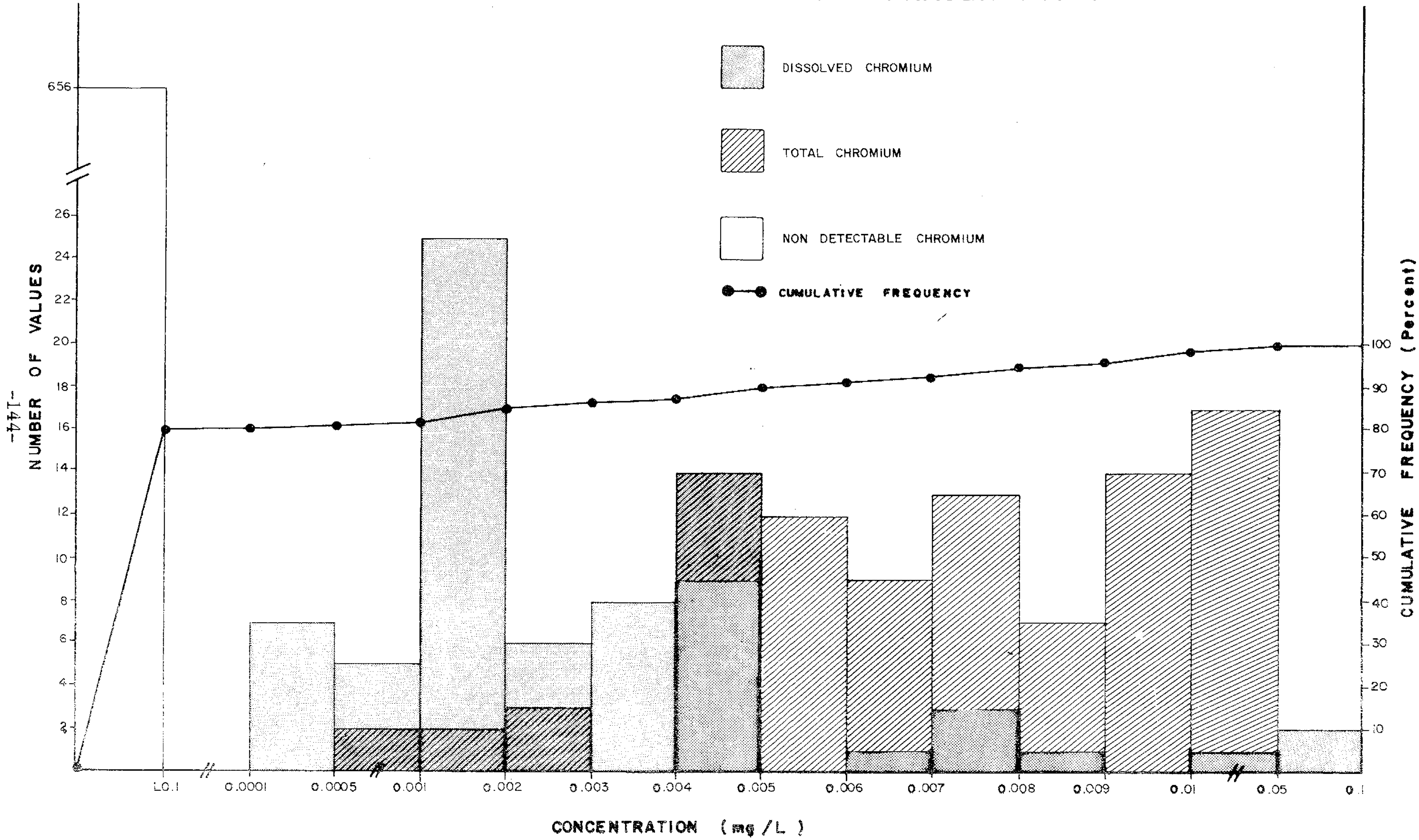


FIGURE 31

TOTAL AND DISSOLVED COPPER; LOWER FRASER RIVER

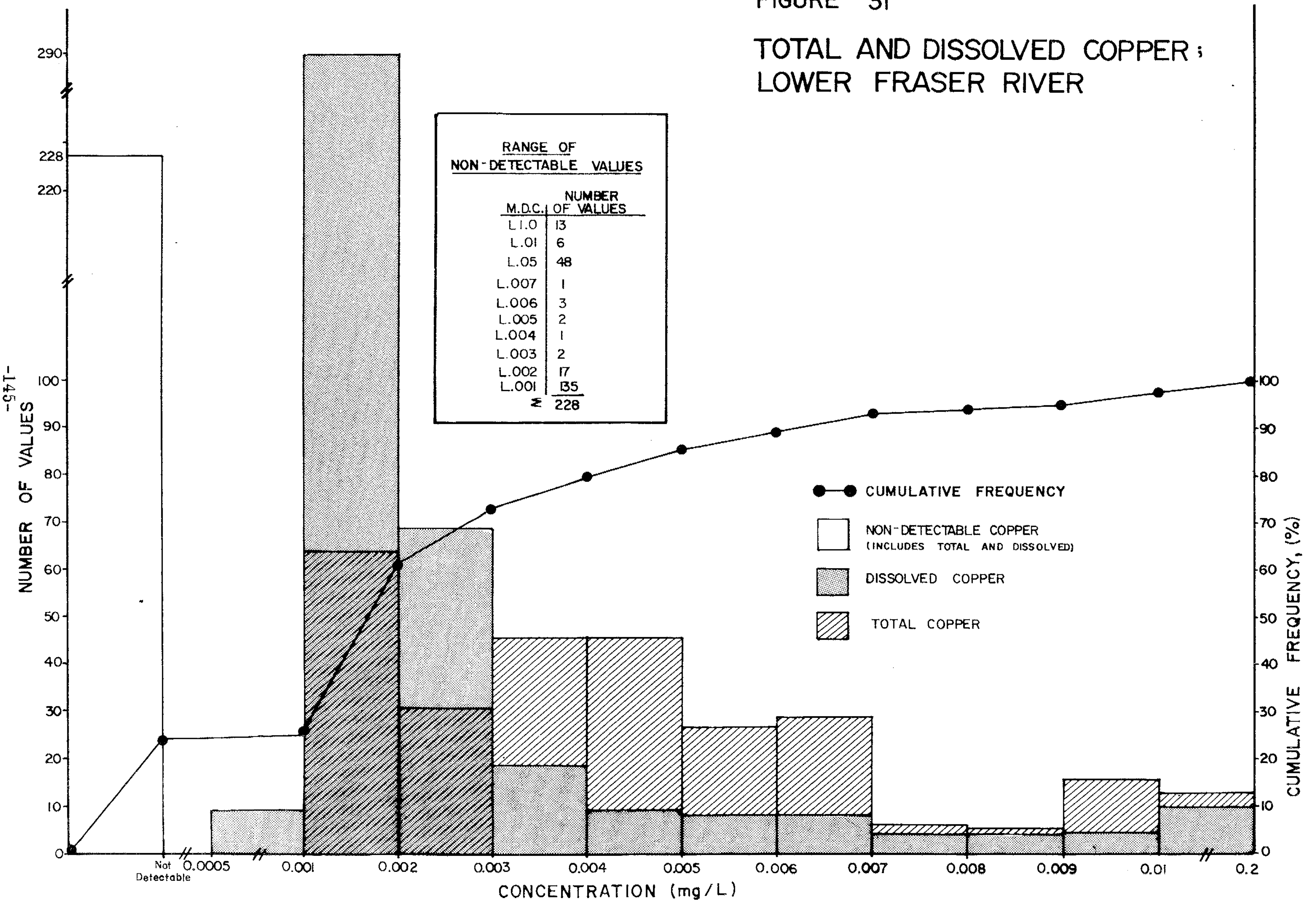


FIGURE 32

SEASONAL CHANGES (MONTHLY MEANS) IN TOTAL COPPER FOR COMBINED DATA IN THE LOWER FRASER RIVER

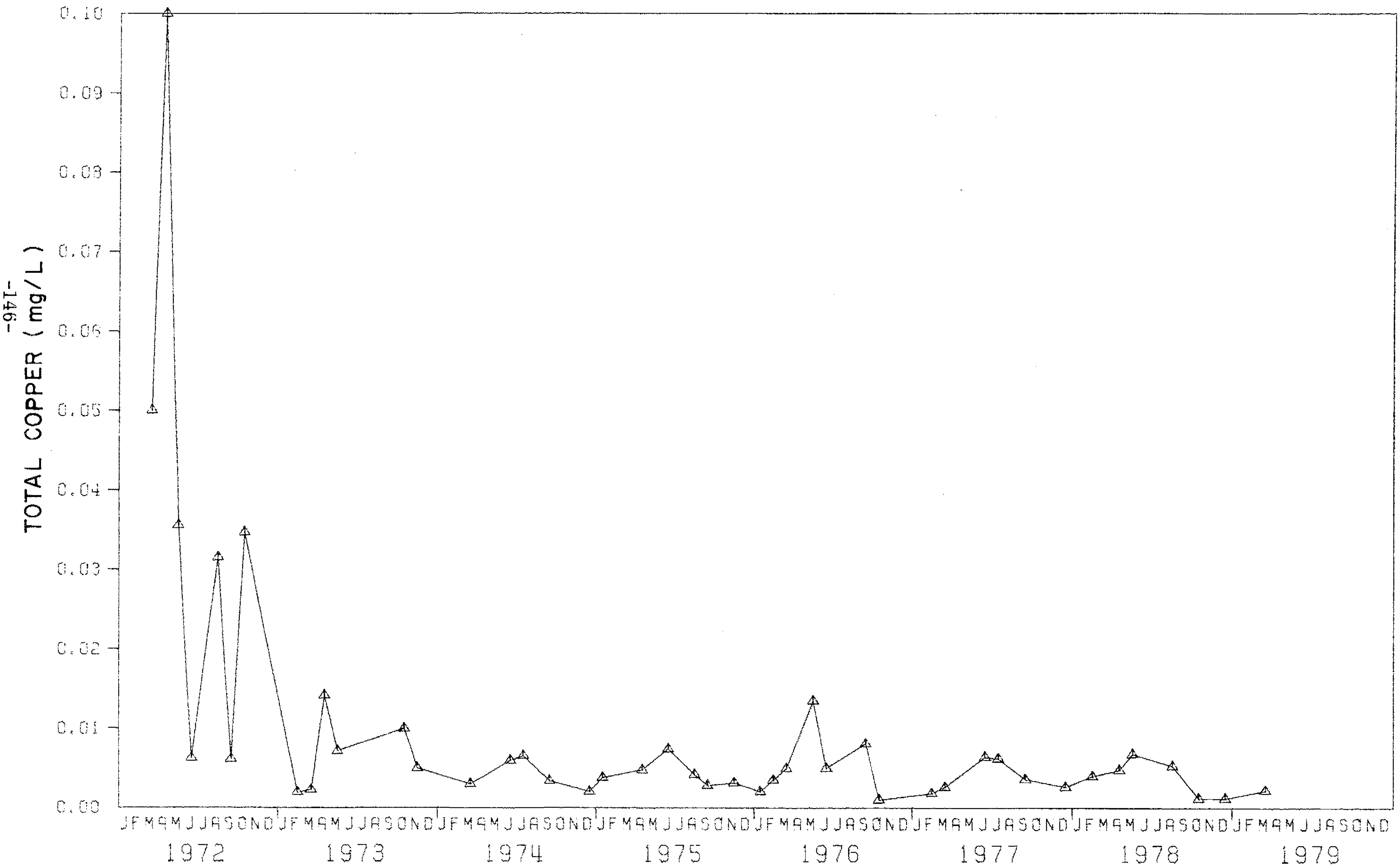


FIGURE 33

TOTAL AND DISSOLVED IRON ; LOWER FRASER RIVER

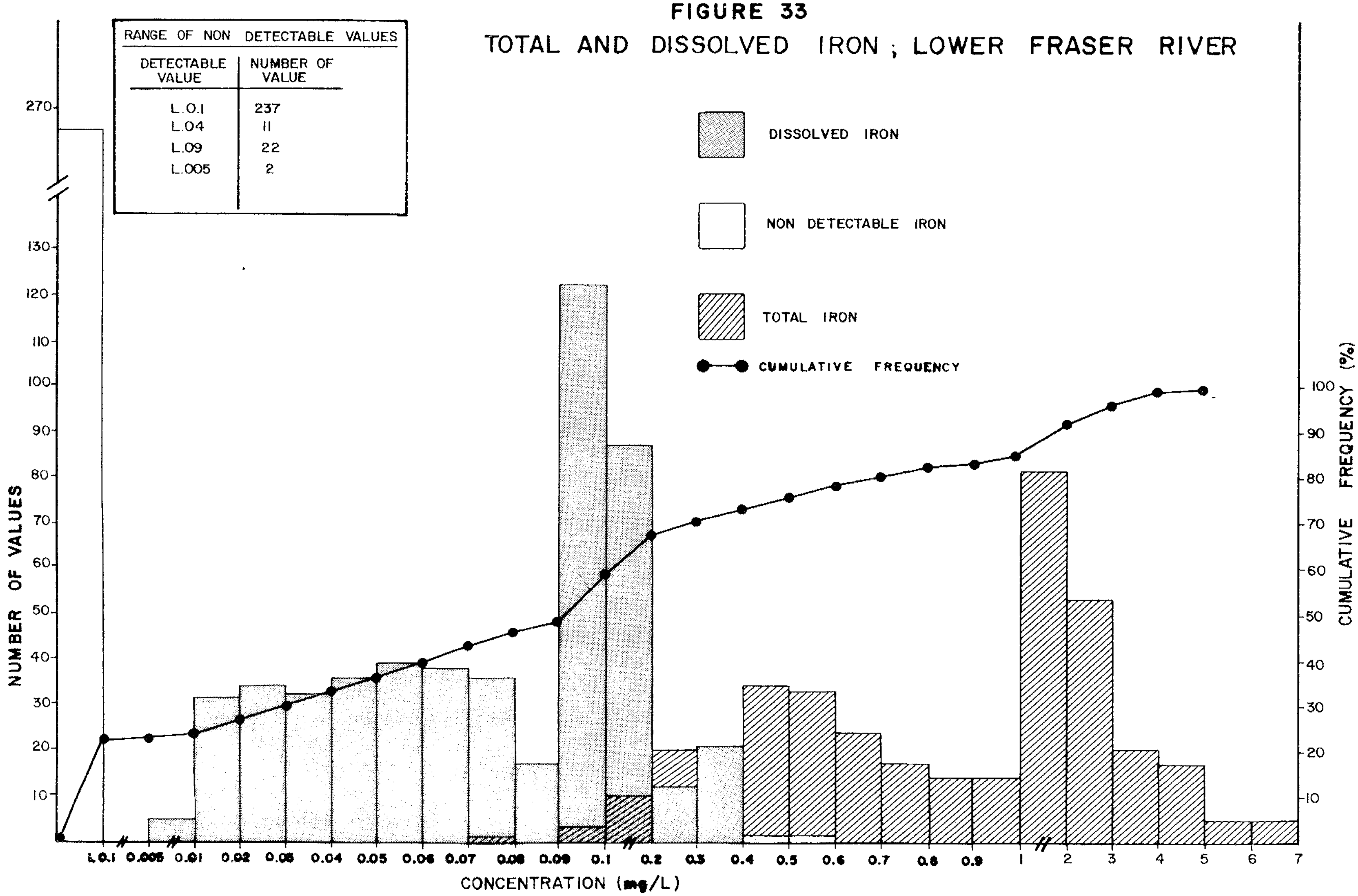


FIGURE 34

SUMMARY OF TOTAL IRON DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

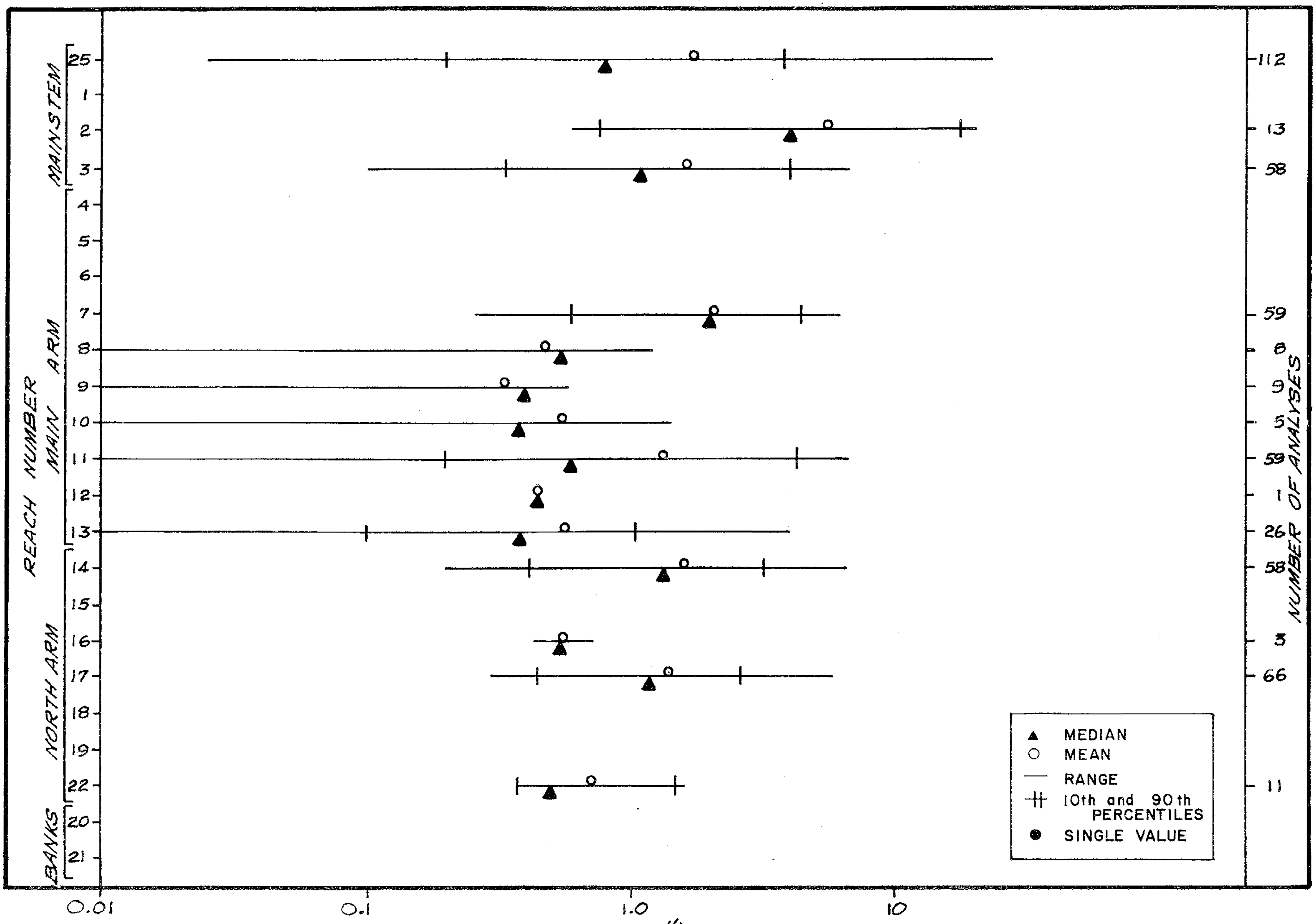


FIGURE 35

SEASONAL CHANGES (MONTHLY MEANS) IN TOTAL IRON FOR COMBINED DATA IN THE LOWER FRASER RIVER

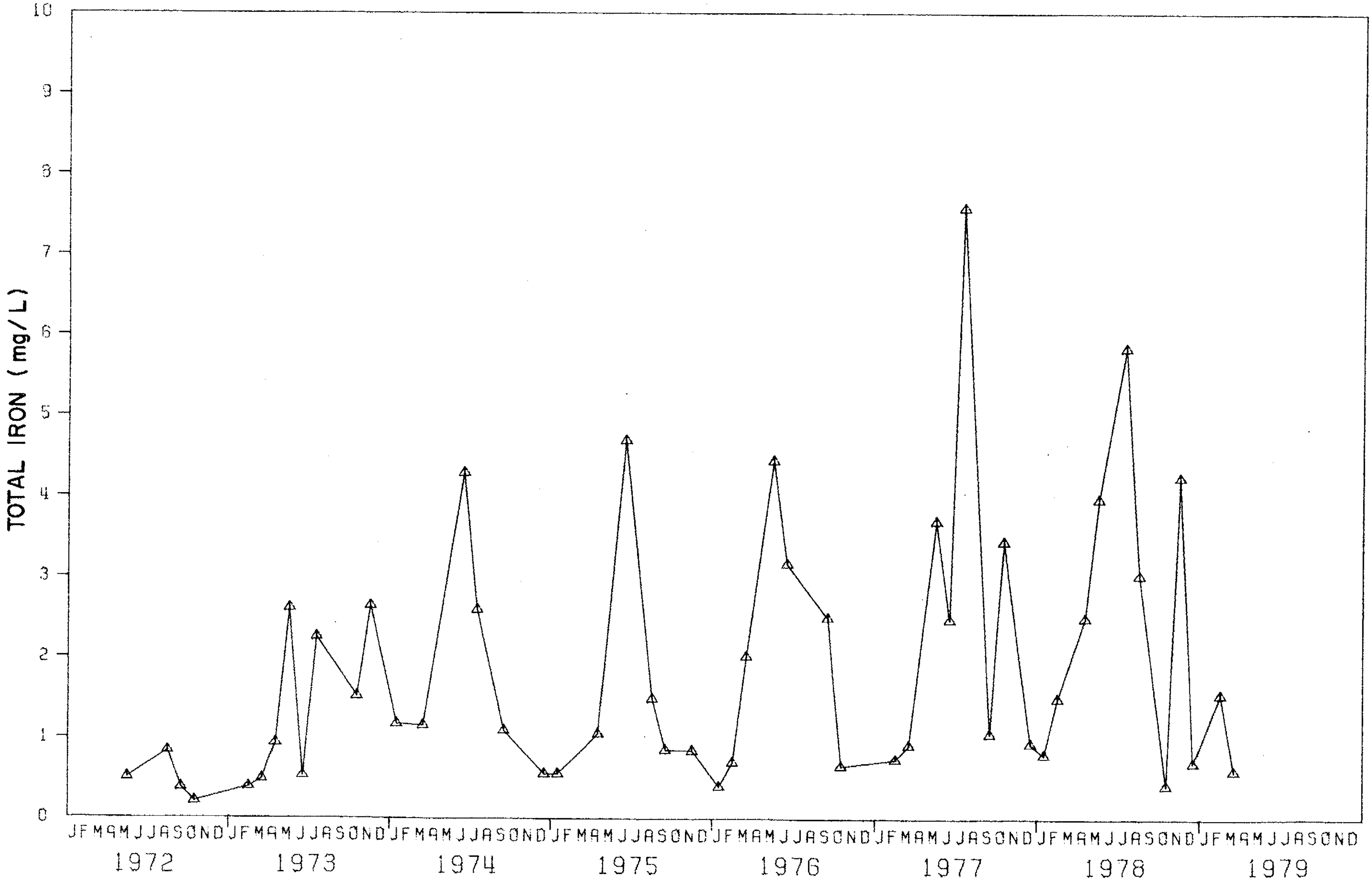
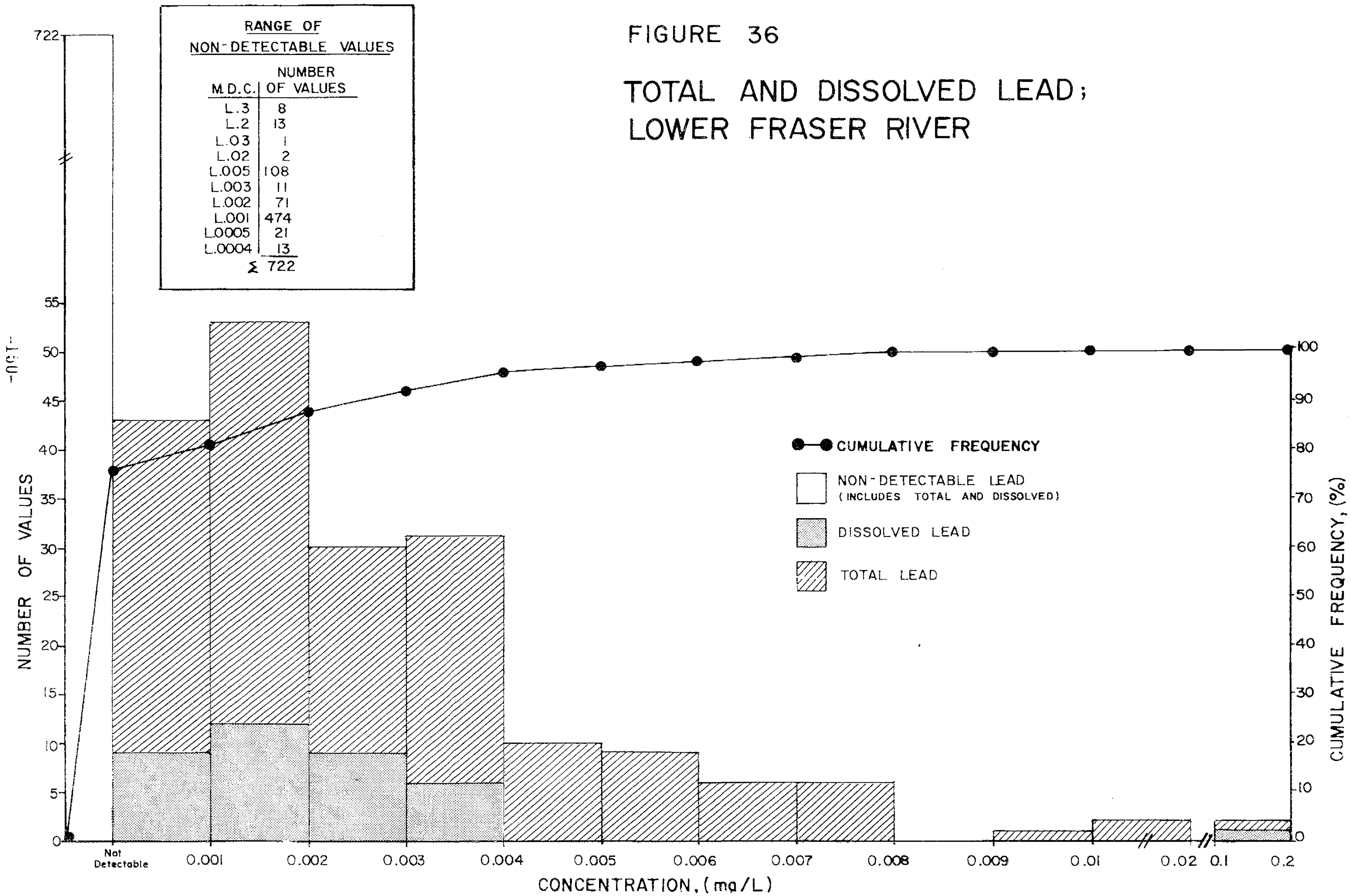


FIGURE 36

TOTAL AND DISSOLVED LEAD; LOWER FRASER RIVER



RANGE OF NON-DETECTABLE VALUES

M.D.C.	NUMBER OF VALUES
L.3	8
L.2	13
L.03	1
L.02	2
L.005	108
L.003	11
L.002	71
L.001	474
L.0005	21
L.0004	13
	Σ 722

FIGURE 37

TOTAL AND DISSOLVED MANGANESE; LOWER FRASER RIVER

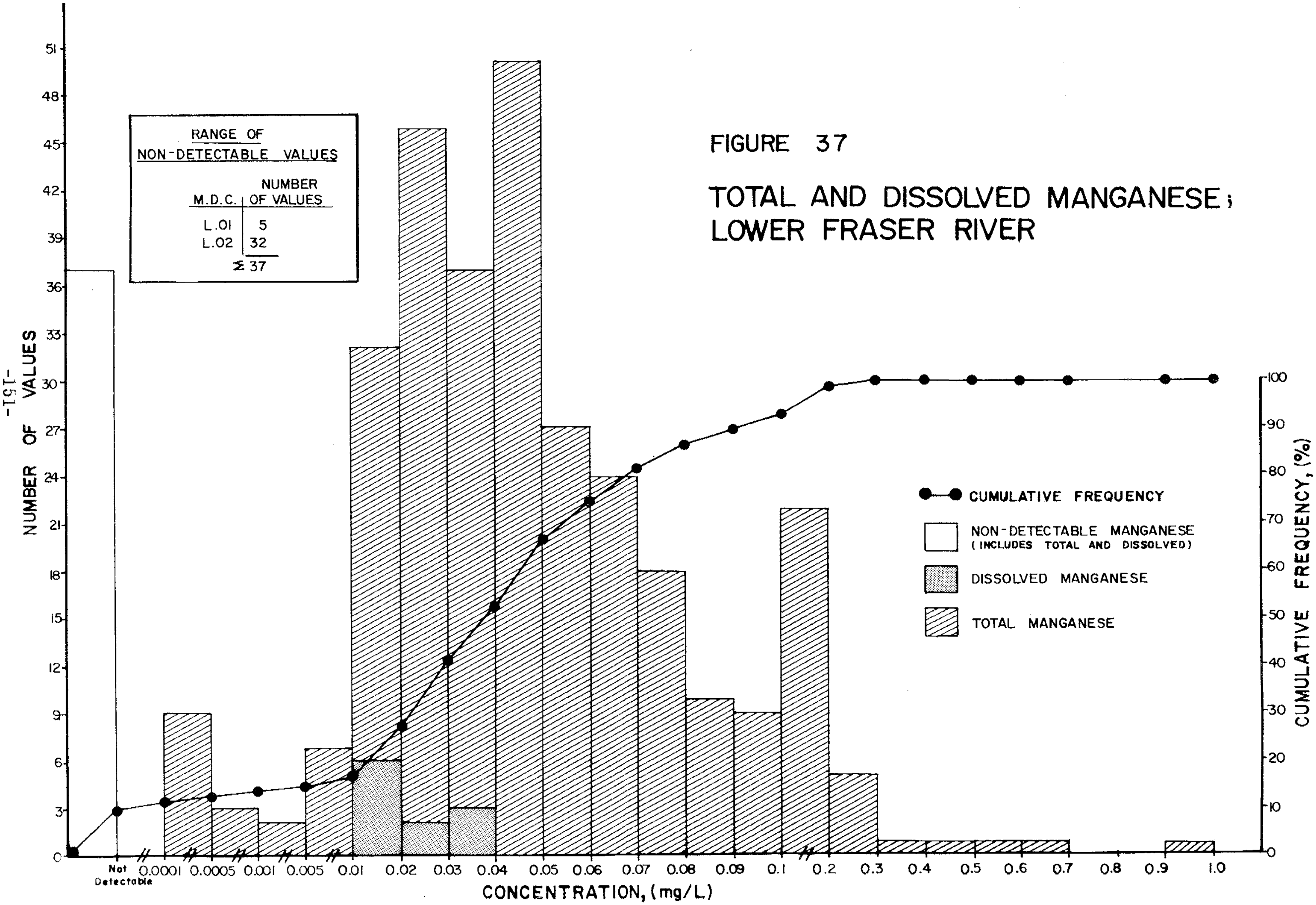


FIGURE 38

TOTAL AND DISSOLVED MERCURY; LOWER FRASER RIVER

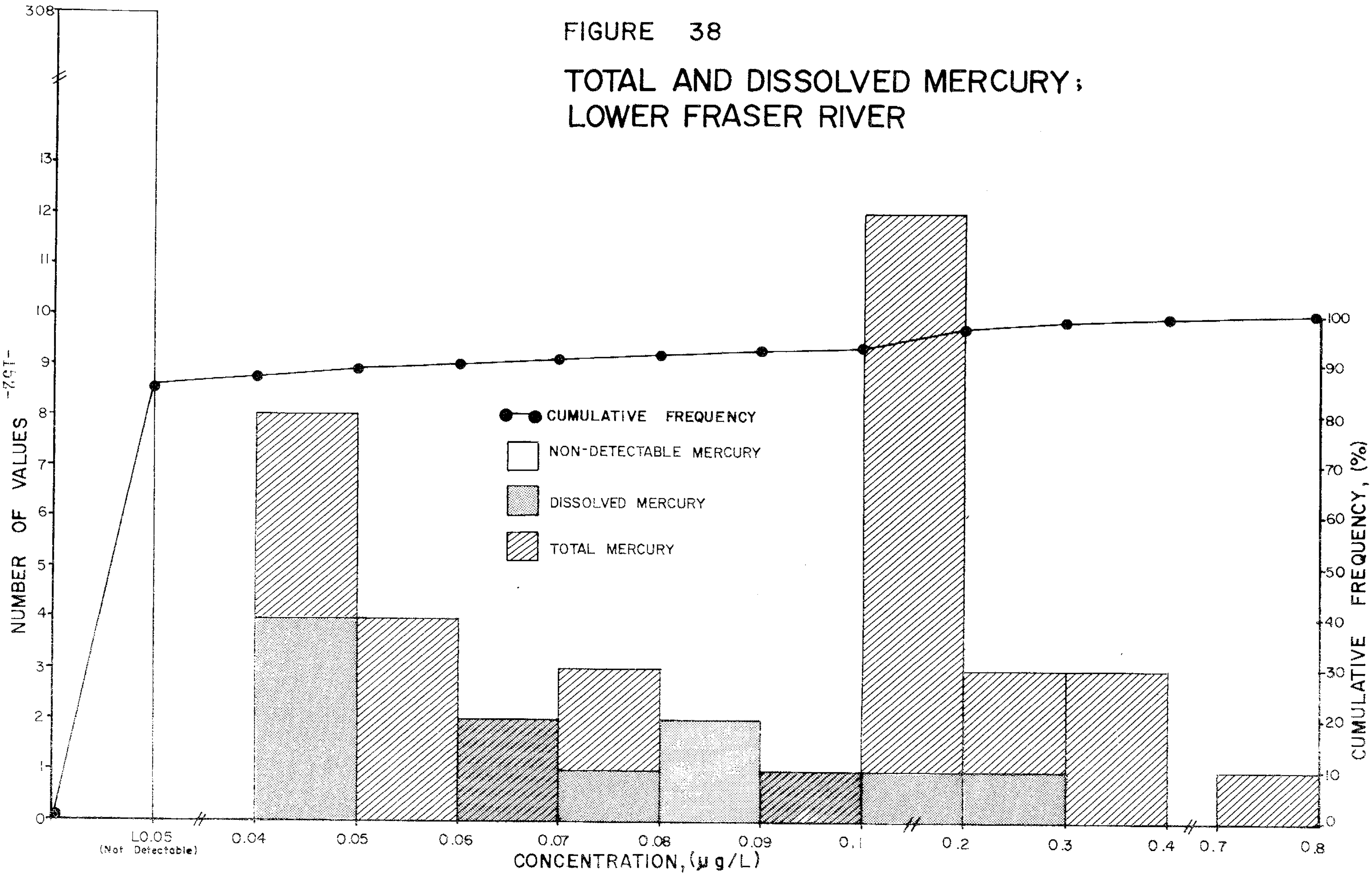


FIGURE 39

TOTAL AND DISSOLVED MOLYBDENUM; LOWER FRASER RIVER

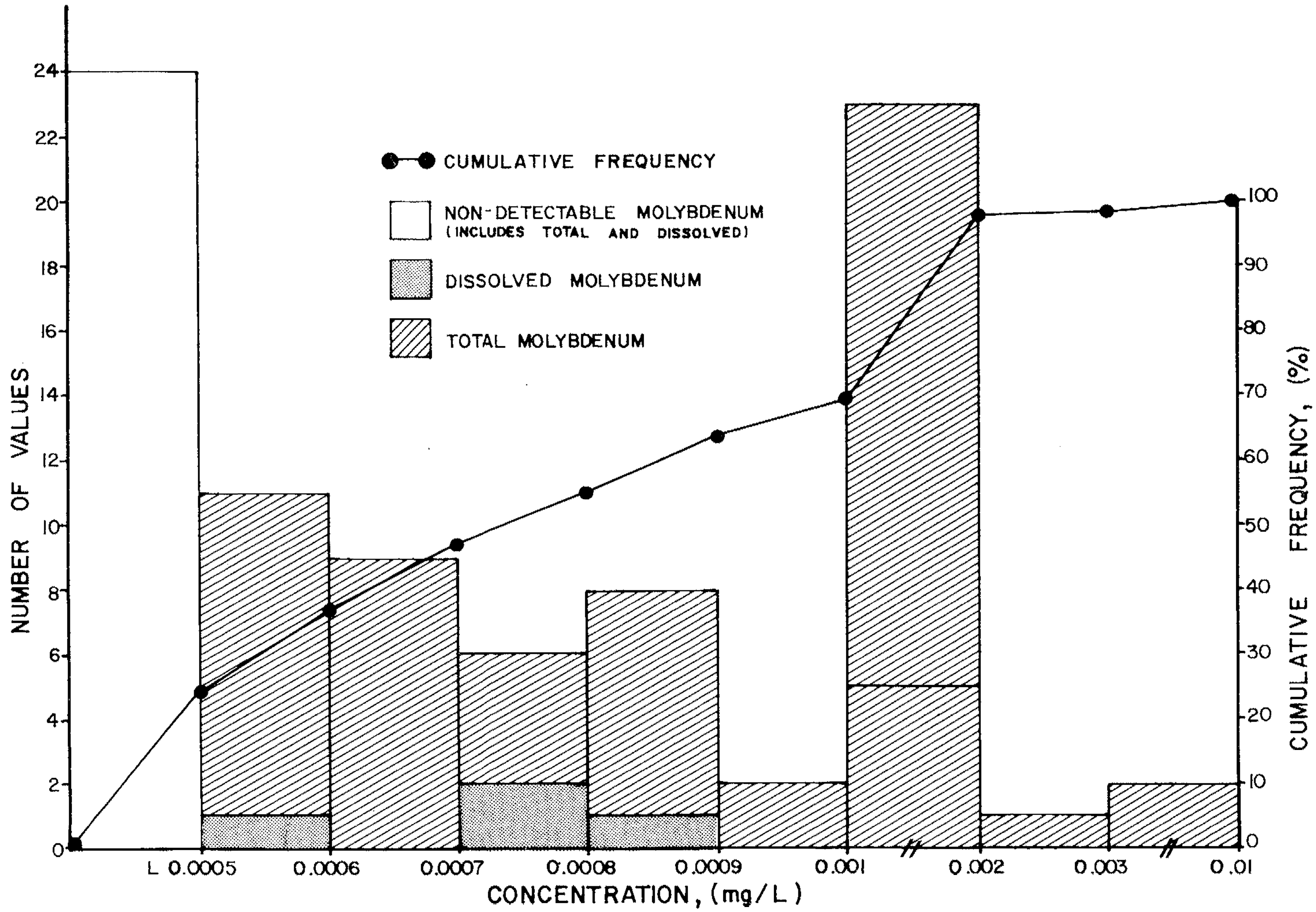
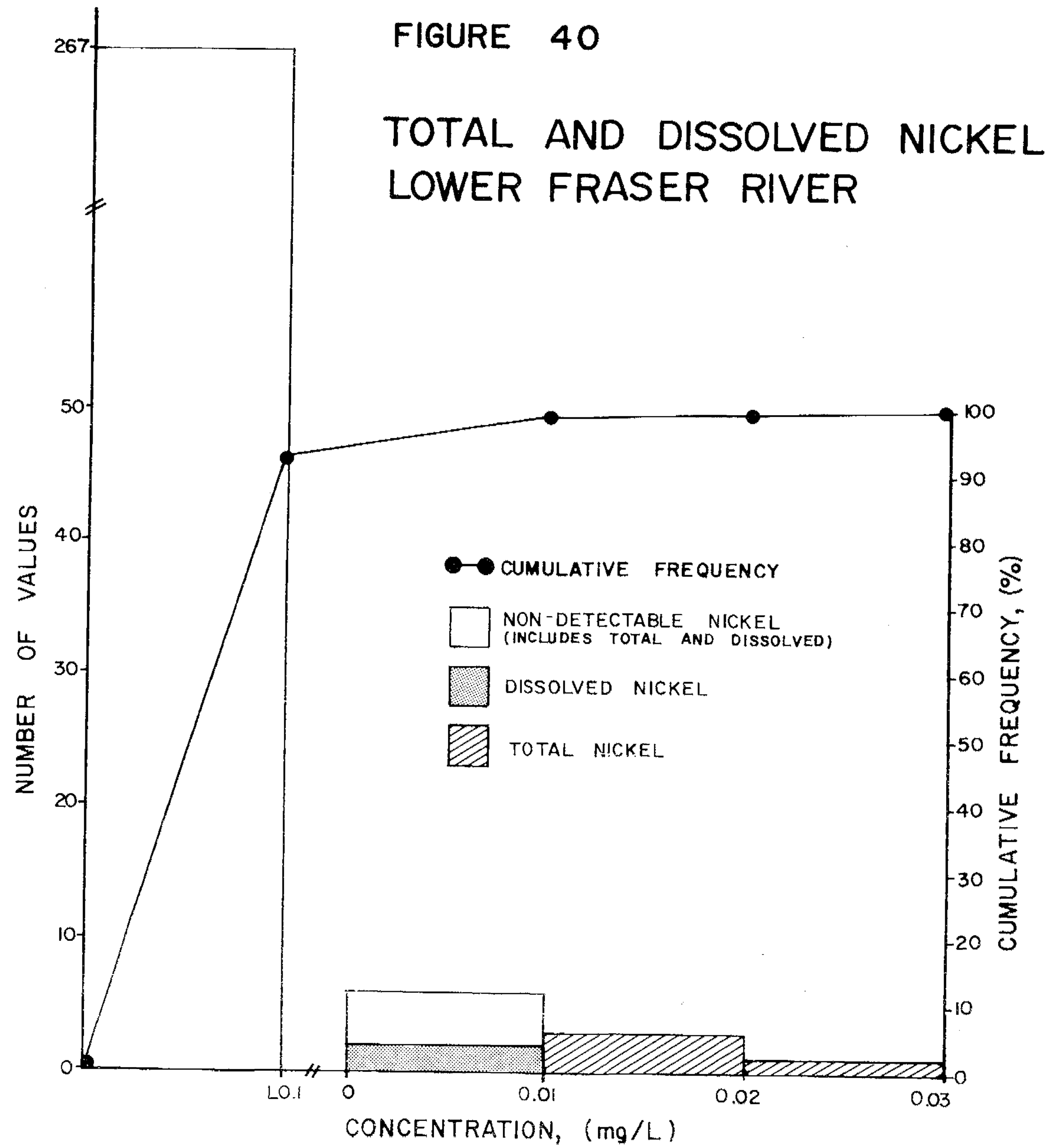


FIGURE 40

TOTAL AND DISSOLVED NICKEL; LOWER FRASER RIVER



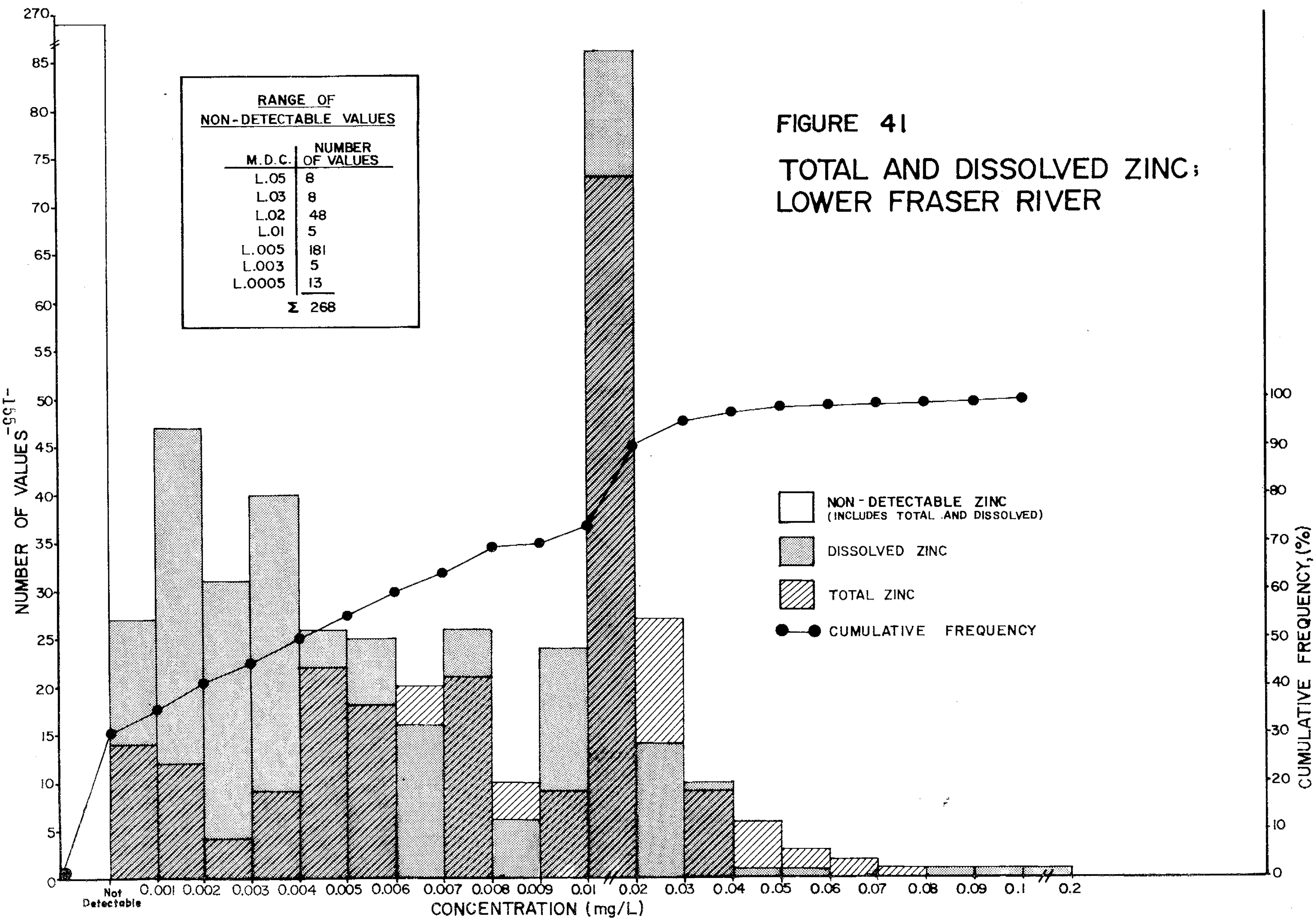


FIGURE 41
TOTAL AND DISSOLVED ZINC;
LOWER FRASER RIVER

FIGURE 42
SUMMARY OF DISSOLVED ZINC DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

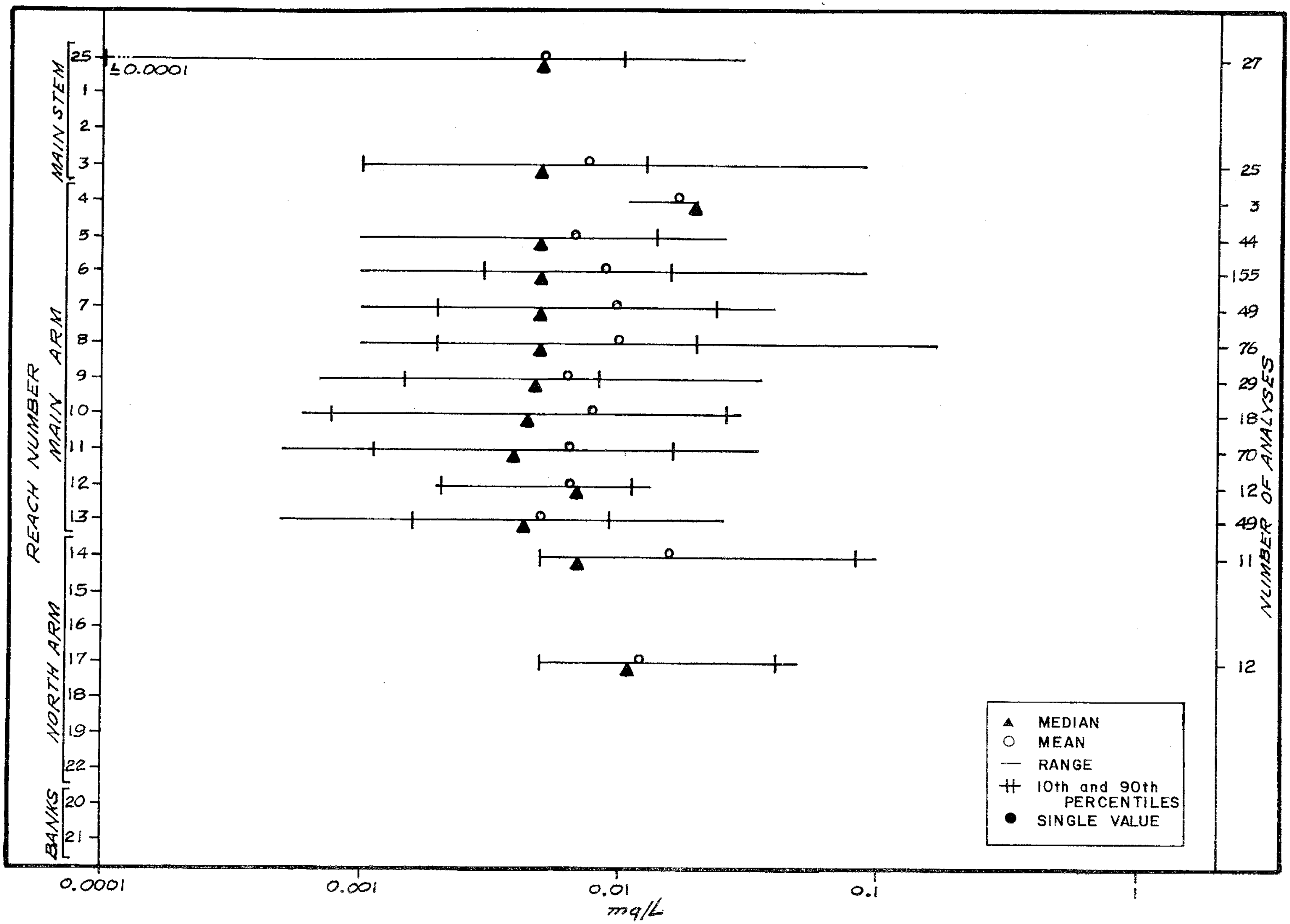


FIGURE 43
SUMMARY OF TOTAL ZINC DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER

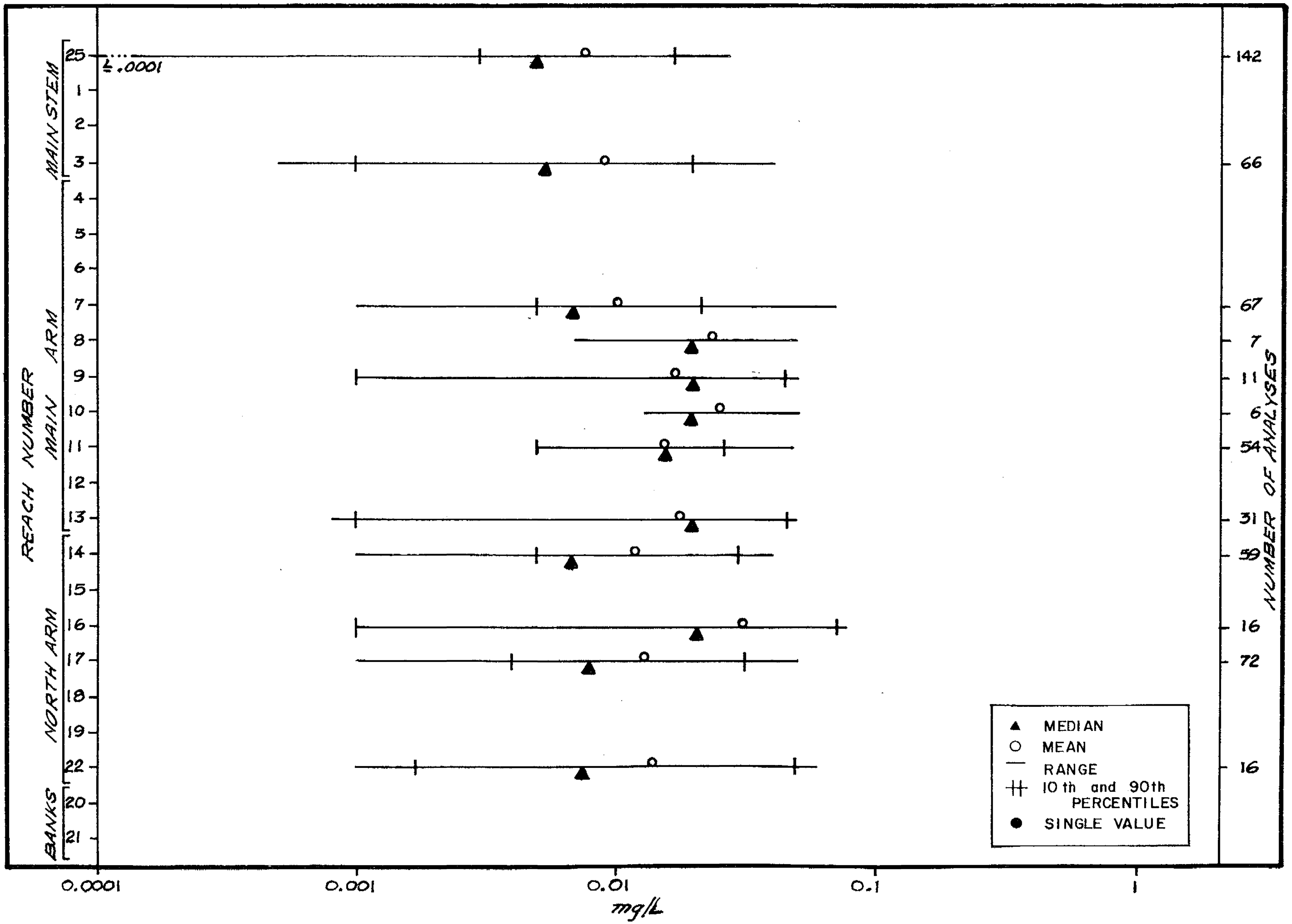


FIGURE 44
SEASONAL CHANGES (MONTHLY MEANS) IN TOTAL ZINC
FOR COMBINED DATA IN THE LOWER FRASER RIVER

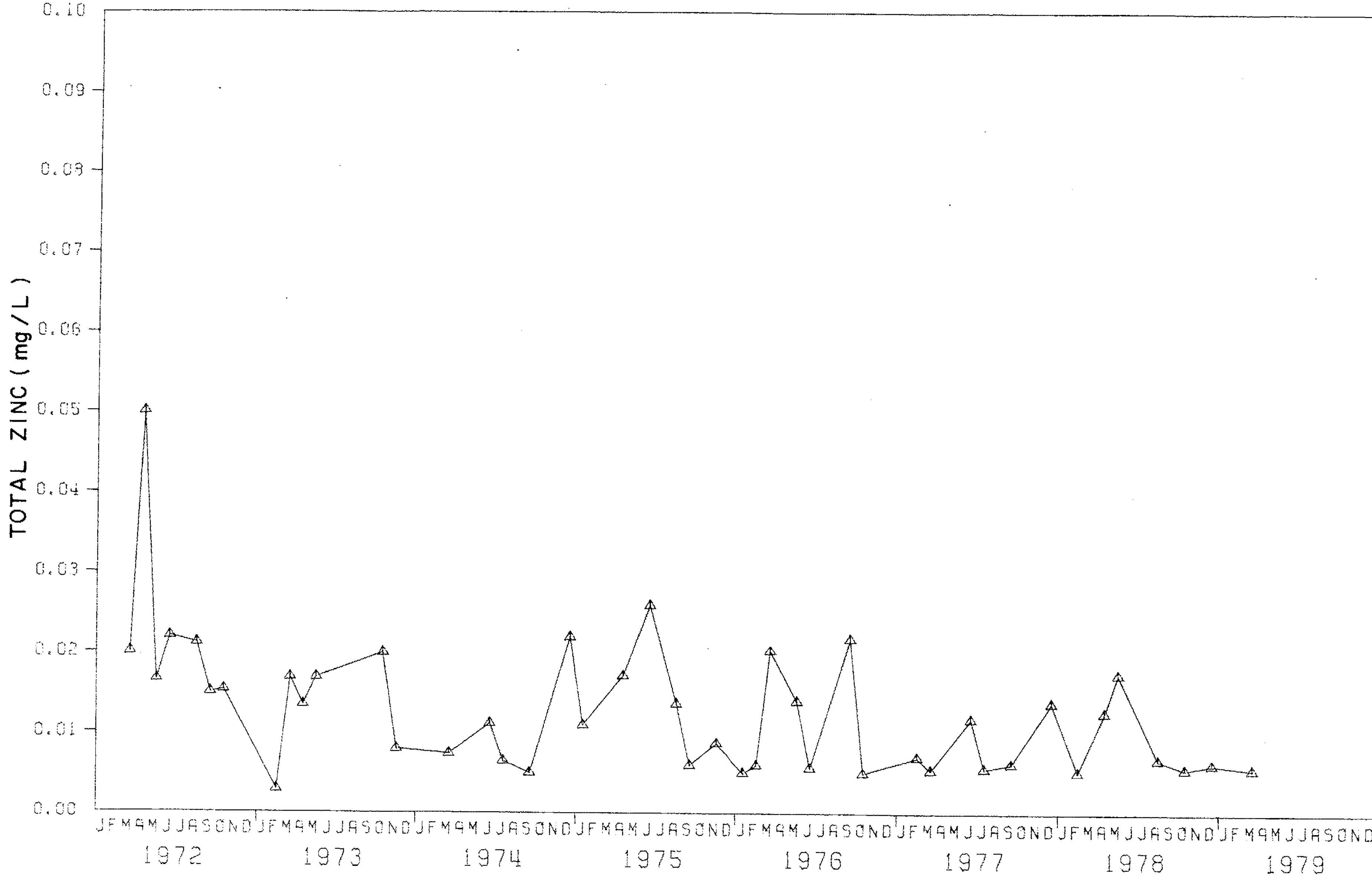


FIGURE 45

CHANGES IN CONCENTRATIONS OF EXTRACTABLE METALS, SUSPENDED SOLIDS AND VELOCITY, DURING A TIDAL CYCLE NEAR STEVESTON ISLAND (R11), OCTOBER, 1977.

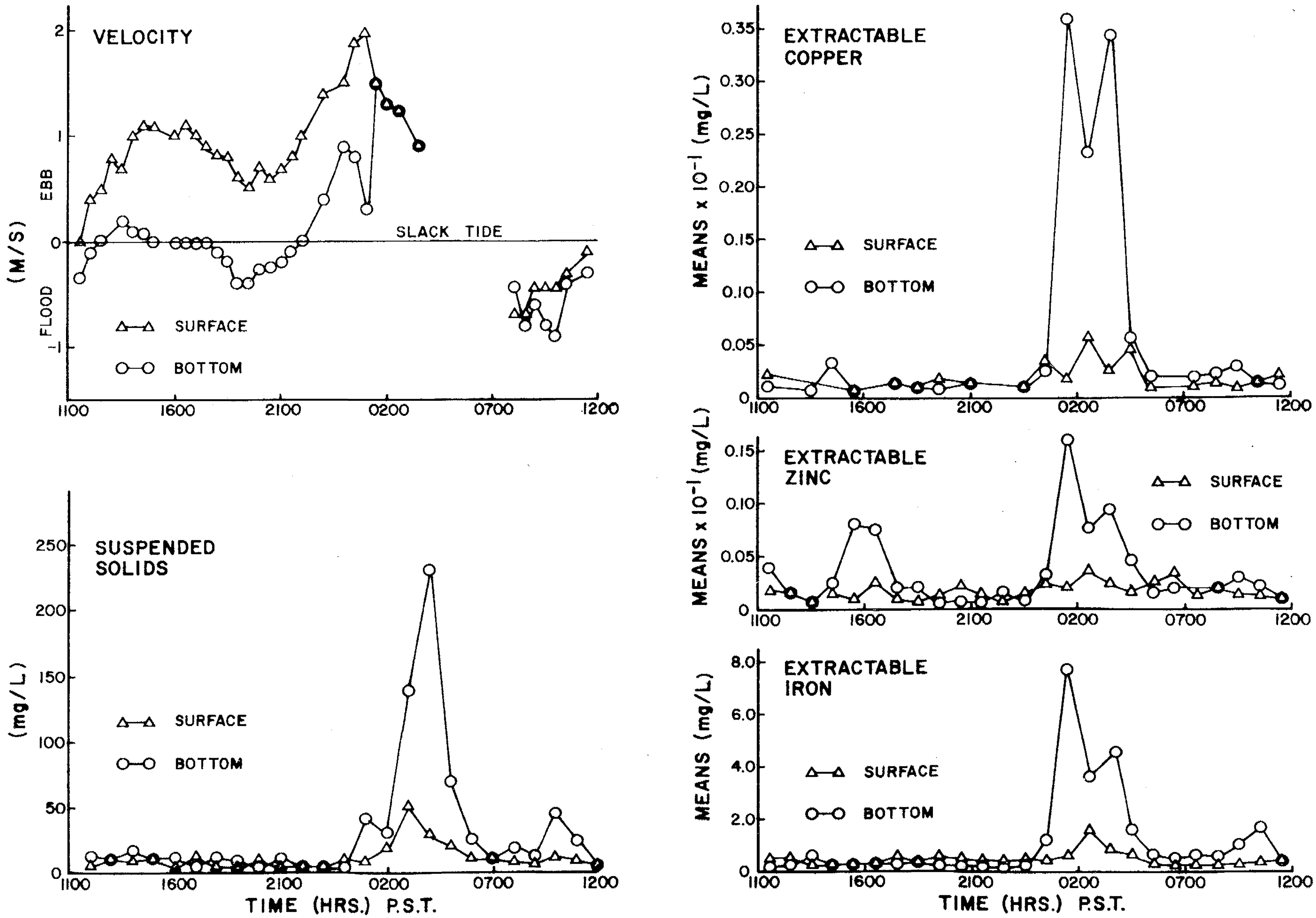


FIGURE 46

SUMMARY OF PHENOLICS DATA FOR THE LOWER FRASER RIVER