Fraser River Estuary Study Water Quality

Acute Toxicity of Effluents

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SUMMARY

This report presents a summary and analysis of all the bioassay data on discharges to the lower Fraser River, up to the end of 1978. The amount of data available is not large and the data are difficult to interpret due to variations in experimental methods, sampling techniques and calculation procedures.

Continuous flow bioassays, using juvenile salmon or trout, appear to be the most sensitive indicator of effluent toxicity. The data obtained on effluents are extrapolated to conditions in the river, using certain application factors. These calculations give a very approximate estimate of the possible effects of major effluents on fish in the river.

Primary treated effluents from the three main municipal treatment plants are moderately toxic to fish. The acute toxicity of the Iona effluent is not a major threat to aquatic life on Sturgeon Bank. However, the accumulation of heavy metals and other toxicants in benthic fauna indicates that effluent from Iona is having a detrimental effect on a localized area of Sturgeon Bank.

Projections indicate that the Annacis effluent does not generally affect fish outside the initial dilution zone. Certain criteria suggest that at the minimum recorded river flow and present effluent flows, sublethal effects from persistent and cumulative toxicants may be experienced. When the maximum effluent flow from the plant is reached, by about the year 2020, a small increase in the acute toxicity over present values could cause unsafe conditions for fish in the river. The control of industries discharging to the sewers and further treatment at the plant are ways of reducing effluent toxicity.

There is a need for more bioassay information on all discharges, including industrial discharges, and for the use of a uniform method to collect this information. More knowledge of which toxicants cause effluent toxicity is also required.

PREFACE

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

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

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

Since the water quality report was preliminary, a more detailed analysis of the information was undertaken by members of the water quality work group. As a result, eleven background technical reports, of which this report is one, are being published. The background reports are entitled as follows:

- Municipal Effluents.
- Industrial Effluents.
- Stormwater Discharges.
- Impact of Landfills.
- Acute Toxicity of Effluents.
- Trace Organic Constituents in Discharges.
- Toxic Organic Contaminants.
- Water Chemistry; 1970-1978.
- Microbial Water Quality; 1970-1977.
- Aquatic Biota and Sediments.
- Boundary Bay.

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

Five auxiliary reports are also being published in further support of the study. These cover the following subjects:

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

Copies of these reports will be available from the Ministry of Environment, Parliament Buildings, Victoria, British Columbia.

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

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TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

In recent years, acute toxicity bioassays have been conducted on some effluents which are discharged to the lower Fraser River and Estuary. Agencies involved in the collection of these data include the Environmental Protection Service (EPS), the International Pacific Salmon Fisheries Commission (IPSFC), the Department of Fisheries and Oceans (DFO) as well as B.C. Research and other consulting firms.

The purpose of this report was to compile, summarize, and analyze all of the available bioassay data on discharges to the lower Fraser River and Estuary, up to the end of 1978, with occasional data from 1979. Because many industries have ongoing programs to upgrade their discharges, data in this report will not reflect conditions which have changed after 1978.

This report is sectioned into the various sources of waste discharges which include municipal, forest, chemical and petroleum, food processing and miscellaneous categories. These basic categories have been used by the Pollution Control Board for presenting the provincial pollution control objectives for the various waste discharge types. A similar format has been used by the EPS for presenting federal regulations and guidelines.

Subsections of this report include pertinent information associated with specific discharges, discussions of the toxic components of the effluents and potential toxic effects in the receiving waters.

2. DEFINITION OF A BIOASSAY

In a bioassay, the toxicity of a given substance is determined by the reaction of a biological indicator to that substance. Toxicity bioassays generally fall into two classes of response according to the nature of the toxicant and organism tested. These are:

(1) Acute Toxicity - rapid response, usually lethal; and
(2) Chronic Toxicity - slow response, lethal or sublethal.

Acute toxicity data are normally presented as an LC50 or TLm. These two terms are synonymous and are defined as the concentration (% volume) of effluent causing 50% mortality of the test species over a specified time interval (normally 96 hours). Almost all the data compiled for this report were acute toxicity data.

In a static bioassay, several test organisms are introduced into a number of vessels, each containing effluents at a given dilution. The test solutions are usually left for 96 hours, although they can be replaced every 24 hours. Over 96 hours, the vessels are checked at predetermined time periods to measure accumulative mortality. The 96-h LC50 can be determined by graphical interpolation from the concentrations and mortality recorded. The 96-h LC50 is expressed as an effluent concentration by percent volume. Effluent samples for static bioassays can be collected in the form of grab samples or composite samples.

Continuous flow bioassays are conducted at the site on the effluent being discharged. Both effluent and dilution water are introduced to the test tanks at a continuous controlled rate to maintain a given concentration in each tank for 96 hours. The 96-h LC50 can be interpolated by the same method as used in a static bioassay.

In both continuous flow and static bioassays, tanks containing only dilution water and test organisms, but no effluent, are maintained as controls. These controls ensure that disease or toxicants in the dilution water are not the cause of mortality in the test tanks.

The sensitivity of the different types of tests are discussed in the following section of this report.

3. DATA INTERPRETATION

In this report some effluent toxicity data have been extrapolated to conditions in the lower Fraser River to obtain a flow proportioned relationship between effluent toxicity and potential toxicity in the river. The method is similar to the one used by Esvelt et al. (1973) to determine the potential toxic influence of municipal effluents in the San Francisco Bay area.

The toxicity emission rate (TER) is calculated by multiplying the effluent discharge rate by the toxicity concentration of the effluent (TCe) as follows:

$$TER = TCe \times \text{effluent discharge rate in } m^3/d$$

The TCe is defined as the reciprocal of the 96-hour LC50 and the units are toxic units (TU) described as:

$$TCe = \frac{100}{\text{96-hour LC50}}$$

This reciprocal provides a useful designation of toxicity concentration because it gives a numerical index increasing in magnitude with increasing toxicity.

By dividing the toxicity emission rate of an effluent by the flow in the river, a toxicity concentration for the effluent diluted by the river (TCr) can be calculated as follows:

$$TCr = \frac{TER}{\text{river flow in } m^3/d}$$

This value provides a flow proportioned estimate of potential toxicity in the river at a point where complete uniform mixing of the effluent and river has occurred. A TCr of 1.0 TU, for example, would indicate 50% mortality of the fish in the river.

The U.S. Technical Advisory Committee (1968) has recommended safe levels of 0.05-0.1 TU for non-persistent pollutants and 0.01-0.1 for persistent chemicals and pesticides. The National Academy of Sciences and National Academy of Engineering (1973) recommend factors of 0.05 for non-persistent and 0.01 for persistent toxicants. The "safe level" is defined as a "no effect" concentration, namely one that has no adverse sublethal or chronic effect on fish (Sprague, 1971). Toxic units, as described by Sprague

(1971), express concentration as a fraction of the incipient LC50. The incipient LC50 is defined as the concentration which is just acutely lethal to half the fish after indefinitely long exposure. According to Sprague (1969) if the incipient LC50 cannot be estimated, the 96-h LC50 is a useful and often equivalent substitute. The toxic units calculated in this report are based on the 96-h LC50.

The continuous flow bioassay data were used to extrapolate the sewage treatment plant effluent toxicity to the river situation. Studies conducted by Servizi et al., (1978) demonstrated that on-site continuous flow bioassays were more sensitive indicators of acute toxicity than static bioassays. Static bioassays using 24-hour composite samples normally reflect the effect of more stable toxicants, whereas continuous flow bioassays would be influenced by stable toxicants as well as by the effects of shock loading and volatile or unstable toxic compounds. Static bioassays, using a grab sample, may give more variable results than static tests with composite samples.

Continuous flow bioassays described in this report have involved the use of Fraser River water for dilution. As compared to dechlorinated tap water used in static tests, Fraser River dilution water in continuous flow tests provides a situation which would more closely parallel the results of in situ fish caging experiments. A continuous flow bioassay also provides a more controlled situation and reduces experimental variables which can interfere with in situ fish caging experiments. Therefore, the results of continuous flow bioassays are the best data available upon which to judge potential toxicity in the river.

The extreme minimum daily discharge of the Fraser River at the Port Mann pumping station for the years 1966 to 1972 was 5.65×10^7 m^3/day on March 16, 1969 (Inland Waters Directorate, 1977). The distribution of low flow below Port Mann was as follows:

North Arm - 6% of Total Flow	3.39×10^6 m^3/day
Middle Arm - 6% of Total Flow	3.39×10^6 m^3/day
Main Arm downstream from Canoe Pass - 83% of Total Flow.	4.69×10^7 m^3/day
Canoe Pass - 5% of Total Flow	2.82×10^6 m^3/day
Total Low Flow	5.65×10^7 m^3/day

To estimate the extreme potential toxic conditions in the river for certain effluent discharges, the appropriate low river flows listed above were used for the extrapolation of the acute toxicity data.

4. LIMITATIONS OF THE DATA

Salmonids (coho salmon, Oncorhynchus kisutch; sockeye salmon, Oncorhynchus nerka and rainbow trout, Salmo gairdneri) have been used as the test species for most of the acute toxicity bioassays because of the commercial and recreational importance of these fish. The Fraser River is a major migration route for juvenile and adult salmonids as well as a rearing area for these fish. As salmonids may not be the most sensitive organisms in the river, all discussions regarding toxicity must be limited to the test species used in the bioassays.

The extrapolation of effluent toxicity data to the river situation can only be considered an estimation of potential toxicity in the river. Several factors which may affect toxicity in the river, but could not be included in the extrapolation, are as follows:

(1) Multiple dosing of effluents caused by flow reversal from tidal action in the lower Fraser River, as well as additive effect of effluents.

(2) Degradation or decay rates of toxic effluent components in the river.

(3) First-flush toxicity from storm drains after extended dry periods.

(4) Synergistic or antagonistic effects of the various effluent components on aquatic biota.

(5) Absence of bioassay data from some potential toxicant sources such as log booming grounds, illegal discharges, run-off from river-side industries and contaminated groundwater.

The lack of data coupled with the variability and the complex interactions of the above factors in the receiving waters, makes all estimates very approximate. The variability of the results from the bioassay tests also increases the degree of uncertainty in any extrapolation. Any computations made in this respect should be considered as very approximate estimates of potential toxicity in the river and not as absolute values.

5. MUNICIPAL WASTE DISCHARGES TO THE STUDY AREA

Pollution Control Objectives for Municipal Type Waste Discharges in British Columbia (1975) specify 96-h LC50's of 100 and 75% $^{v}/v$ for Levels AA and BB, respectively. For specific discharges, these levels may be imposed on an "as required basis". The objectives require the effluent sample to be a grab sample obtained prior to chlorination. Although the test type is not specified, a static test is implied by the sampling method. The test procedure used is described in Standard Methods (1971).

Receiving water quality maintenance objectives for toxicity from municipal discharges specify no increase above background levels outside the initial dilution zone as measured in a 96-h LC50 static bioassay test. The initial dilution zone is described by the Pollution Control Objectives as follows:

(a) For point discharges in lakes, estuaries, and marine waters, the zone may extend up to 300 feet horizontally in all directions, but shall not exceed 25% of the width of the water body.

(b) For point discharges in rivers and streams the zone may extend up to 300 feet downstream from the discharge point, but shall not exceed 25% of the width of the river or stream.

(c) For multiple point discharges, such as multiport outfalls, the zone may extend up to 300 feet horizontally from all points of discharge but shall not exceed 25% of the width of the water body.

The initial dilution zone extends from the bed of the receiving water to the surface. The zone may not intrude on shellfish beds, restricted routes known to be followed by migrating salmon and trout, or on other significant biological resources or recreational areas.

5.1 Sewage Treatment Plants

There are three major sewage treatment plants within the study area. These are the Iona STP, the Lulu STP and the Annacis STP. These three primary treatment plants discharge over 97% of the municipal sewage in the study area. Bioassay data compiled for these plants are summarized in Table 1.

5.1.1 Toxic Components of Sewage Treatment Plant Effluent

Several known toxic compounds have been identified in municipal wastewater. These toxicants include un-ionized ammonia, cyanide, sulphides, chlorine, chloramines, phenols, anionic surfactants, heavy metals and a variety of organic compounds. The concentrations of these toxicants in sewage treatment plant effluent may vary and depend on the origin of the wastewater treated by the plant (i.e., industrial, residential, stormwater etc.).

The relative toxic influence of each of the toxic components of a mixture can be estimated by summing the toxic units of each component (Brown, 1968). Toxic units are calculated by dividing the actual concentration of a substance in solution by its 96-h LC50 concentration. According to this method, if the sum of the toxic units for the individual components is greater than 1.0, the mortality rate will be greater than 50% in the total effluent. Sprague (1969) has described several studies which support this theory of simple additive toxicity.

(a) Surfactants

Surfactants refer to the active ingredients of household and industrial detergents and are common in municipal effluent. The primary toxic ingredient is the anionic surfactant fraction normally measured as LAS (linear alkylate sulphonate), (Higgs, 1977). The National Academy of Science and the National Academy of Engineering (1973) recommend no concentration of LAS greater than 0.2 mg/L at any place or time for the protection of aquatic biota. Thatcher and Santner (1966) reported 96-h LC50's for LAS ranging from 3.3 to 6.4 mg/L for five species of fish.

(b) Un-ionized Ammonia

According to Higgs (1977) the common sources of ammonia in wastewater are:

(1) urine, which contains urea (H_2NCOH_2N) which in turn readily hydrolyzes to ammonia;

(2) organic matter containing protein and amino acids which decompose under bacterial action yielding ammonia;

(3) chemical plants and cleaning establishments which release ammonia to the sewer system;

(4) household cleaning agents.

Un-ionized ammonia has been widely accepted as the toxic fraction of ammonium hydroxide and its salts. In solution, the amount of un-ionized ammonia is mainly pH dependent and increases with increasing pH.

$$NH_4^+ + OH^- \rightleftharpoons NH_3 + H_2O$$

The U.S. Environmental Protection Agency (1976) states a maximum limit of 0.02 mg/L un-ionized ammonia for the protection of freshwater aquatic life. For marine situations, The National Academy of Science and National Academy of Engineering (1973) state that levels of un-ionized ammonia less than 0.01 mg/L present minimal risk to marine biota and levels greater than 0.4 mg/L constitute a hazard. Mayo et al., (1972) state that a concentration of 0.006 mg/L un-ionized ammonia may be considered the desirable upper level for extended fish exposure.

Baird et al., (1979) have demonstrated that aeration of test tanks with ambient air during a static bioassay can strip the carbon dioxide from the sample thus raising the pH. This procedure results in an increase in the un-ionized ammonia fraction and consequently increases the toxicity. Baird et al. (1979) suggest the use of low flow oxygen aeration to prevent the loss of carbon dioxide in the samples.

(c) Chlorine

Chlorine is frequently used as a disinfectant for municipal sewage to eliminate pathogenic bacteria. Chlorine toxicity to aquatic organisms is well documented in the literature (Brungs, 1973; Martens and Servizi, 1974; Morgan and Prince, 1977) and is related to the amount of residual chlorine remaining in the effluent after chlorination. Residual chlorine refers to the concentration of compounds containing active chlorine which remain after chlorination. These compounds may include chloramines (mono-, di- and tri-) and other chloro derivatives, as well as free available chlorine in the form of hypochlorous acid and hypochlorite ion (Brungs, 1973). At the three municipal plants free chlorine is unlikely to be present since the dosage is not usually high enough to consume all the ammonia in the effluents.

Although residual chlorine is quite innocuous to humans in the aqueous state, fish are especially sensitive to residual chlorine at very low concentrations. Servizi and Martens (1974) warned that conditions hazardous to salmon may occur when chlorine residuals equal or exceed the detection limit of 0.02 mg/L. The safe (no-effect) concentration of residual chlorine for most aquatic life is 0.002 mg/L (Brungs, 1973).

Residual chlorine can also combine with organics to form stable toxic compounds. Two of these compounds, 5-chlorouracil and 4-chlororesorcinol reduced hatching success of carp (Cyprinus carpis) eggs at concentrations of 1.0 mg/L (Gehrs et al., 1974). However, later tests suggested that these results were anomalous (Trabalka and Burch, 1978).

According to Brungs (1973) most of the lethal effects of residual chlorine occur within 12 to 24 hours. Martens and Servizi (1974) found that residual chlorine in secondary treated effluent dissipates rapidly during the first 10 hours from 2.6 mg/L to 0.2 mg/L and then stabilizes for more than 50 hours. In primary effluent, residual chlorine disappeared in 13 hours (Martens and Servizi, 1975). Esvelt et al. (1973) found 25% of the original chlorine induced toxicity in chlorinated wastewater persisted after three days.

According to Brungs (1973) dechlorination with sodium bisulphite, sodium thiosulphate and sulfur dioxide greatly reduced or eliminated residual chlorine-induced toxicity. Martens and Servizi (1975) also found that dechlorination with sulfur dioxide removed chlorine induced acute toxicity from primary sewage. The sulfur dioxide residuals did not increase the mortality rate of sockeye or pink salmon in the primary sewage.

(d) Cyanide

Cyanide is sometimes found at toxic concentrations in municipal wastewater and mainly originates from sources which include metal finishing plants, electroplating industries and some chemical industries. The major toxic form of cyanide is hydrogen cyanide which is pH dependent, hence, as the pH decreases, toxicity increases. The toxicity of cyanide is also increased at elevated temperatures (McKee and Wolf, 1963).

The National Academy of Sciences and the National Academy of Engineering (1973) state that levels less than 0.005 mg/L present minimal environmental risk to freshwater and marine organisms whereas levels greater than 0.01 mg/L constitute a hazard to the marine environment. McKee and Wolf (1963) report that trout survived cyanide concentrations of 0.02 mg/L for 27 days but concentrations of 0.05 mg/L were lethal to trout in five to six days.

(e) Copper

Copper and copper salts are introduced to municipal wastewater from an extensive number of sources including the electroplating industry, domestic water supply pipes, textile industry, tanning, photography, engraving, insecticides, fungicides and many other industrial processes.

Several chemical and physical factors affect copper toxicity to fish including temperature, hardness, turbidity and carbon dioxide content (McKee and Wolf, 1963). According to Pagenkopf et al. (1974) the Cu^{++} ion is the chemical species that is most toxic to fishes and alkalinity is the major factor controlling Cu^{++} ion concentration. In municipal wastewater, the toxicity of copper may be reduced by binding with organics in the sewage.

For the protection of fish and aquatic life McKee and Wolf (1963) recommend dissolved copper concentrations of less than 0.02 mg/L for freshwater and less than 0.05 mg/L for sea water. Thurston et al. (1979) recommend a range of 0.005 to 0.015 mg/L.

(f) Phenol

Phenolic compounds can be introduced to municipal wastewaters from sources such as oil refineries, chemical plants and human and animal refuse. At sufficient concentrations, phenolic compounds may affect fish by direct toxic action or by imparting an unpleasant flavour to the fish flesh. For the protection of fish and aquatic life, McKee and Wolf (1963) recommend that concentrations of phenolic compounds not exceed 0.2 mg/L in fresh water. To protect against tainting of fish flesh, phenols should not exceed 0.01 mg/L (U.S. Environmental Protection Agency, 1976).

(g) Sulphides

Sulphides can be introduced to municipal wastewaters by industries such as tanneries, paper mills, chemical plants and gas works as well as by the anaerobic decomposition of organics in sewage. According to McKee and Wolf (1963) hydrogen sulphide and the HS^- ion are the major toxic chemical species. The toxicity of sulphides are pH dependent and toxicity increases with acidity. Doudoroff (1957) has reported inorganic sulphide concentrations of 0.5 to 1.0 mg/L to be fatal to trout. The U.S. EPA (1976) suggests that undissociated hydrogen sulphide should not exceed 0.02 mg/L to protect aquatic life.

5.2 Iona Island Sewage Treatment Plant

The Iona STP is a primary treatment facility servicing the City of Vancouver, Sea Island, the University Endowment Lands and part of the Municipality of Burnaby (Figure 1). The collection area covers approximately 144 km^2 and contains an estimated population of 460 000. The population is expected to increase to 640 000 by the year 2020.

The collection system is primarily a combined sanitary and stormwater system. On occasions, during large wet weather flows, the hydraulic capacity of the plant is exceeded and mixtures of sewage and stormwater, after screening, bypass the plant.

Treatment processes at Iona include prechlorination, mechanical screening, comminution, preaeration, sedimentation and sludge handling. From May to September inclusive, the final effluent is chlorinated. There are no dechlorination facilities at the plant. A more complete description of the Iona STP is presented by Cain and Swain (1980).

The final discharge is to a dredged channel which extends seaward, across Sturgeon Bank to the Strait of Georgia (Figure 2).

5.2.1 Comparison of Bioassay Monitoring Data With Provincial Objectives

Acute toxicity bioassays have been conducted monthly at the Iona STP by B.C. Research since April, 1978. The procedure used for these tests was a static bioassay conducted on a grab sample collected prior to chlorination. From a total of nine monthly bioassays from April to December, 1978, all the tests were non-toxic to rainbow trout at 100% effluent concentration (Table 1).

Effluent toxicity for the Iona STP corresponded to Level AA (96-h LC50 of 100% $^{v}/v$) of the "Pollution Control Objectives for Municipal Type Waste Discharges in British Columbia", (Pollution Control Board, 1975) 100% of the time.

5.2.2 Additional Acute Toxicity Studies Conducted at Iona STP

A series of 96-hour continuous flow bioassays, using sockeye salmon and primary sewage prior to chlorination, have been conducted at the Iona STP by Martens and Servizi (1976). Mean mortalities, for three to seven tests, were 37 and 88% of the test fish at 40 and 50% $^{v}/v$ primary sewage, respectively. Owing to the test procedures, a 96-h LC50, equal to 45% $^{v}/v$, could be calculated for only one bioassay, following Standard Methods. However, graphical interpolation of mean mortality data yielded 50% mortality at 42% $^{v}/v$ primary sewage, which was consistent with the LC50 calculated.

Two separate bioassay studies have been conducted by the EPS on the final effluent discharged from the Iona STP.

The first study was part of a one year program to relate wastewater characteristics to toxicity (Tanner et al. 1973). During 1971 and 1972, twenty static bioassays, each using a single grab sample, indicated that the final chlorinated effluent was only slightly toxic to coho salmon. The mean 96-h LC50 was 90.3% $^{v}/v$, and 74% of the tests were non-toxic at 100% effluent concentration. The bioassays were done according to the procedure described by Standard Methods (1971) for static bioassays, except that the effluent samples were preaerated. Preaeration of the effluent samples is not recommended when it will cause a reduction in the toxicity by accelerating the loss of volatile components. Therefore the results of these bioassays may underestimate the actual toxicity of the final effluent. The results may also be an underestimate because of high fish loading densities used in the bioassays. Sprague (1964) states that, for static tests, fish loadings expressed as two to three litres of solution/g of fish in each test tank are preferred, and not less than one litre/g is required to prevent toxicant depletion by the test fish. In the bioassays conducted by Tanner et al., (1973), the fish loading densities ranged between 0.05 to 1.1 litres/g. Therefore, toxicant depletion caused by preaerating the effluent samples as well as by high fish loading densities may have contributed to the high LC50 values that suggest low toxicity. The study demonstrated that the toxicity of the Iona effluent varied with climatic conditions. During wet weather periods stormwater and infiltration diluted the Iona effluent thus reducing toxicity.

The second study, conducted by Higgs (1977), found the final chlorinated effluent from Iona STP to be slightly more toxic than did Tanner et al, (1973). Although four static bioassays using 24-hour composite samples were conducted on the final chlorinated effluent, two of these tests were deleted in calculating the mean toxicity because they were not tested until two and three days after the samples were collected. Higgs (1977) suggests that these samples may not exhibit chlorine induced toxicity because Martens and Servizi (1975) found that chlorine disappeared in 13 hours from a sample of primary effluent. The two remaining bioassays exhibited 96-h LC50's of 44% $^{V}/v$ and 58.5% $^{V}/v$ with a mean 96-h LC50 of 51.2% $^{V}/v$ for rainbow trout. These values may also underestimate the toxicity of the final chlorinated effluent because volatile toxicants may have been lost during the time period between sample collection and testing. Bioassays conducted from composite samples are generally less sensitive indicators of acute toxicity than continuous flow bioassays for the reasons discussed in Section 3.

For the reasons given above, the static bioassay results from Iona STP may not be representative of the actual acute toxicity of the final chlorinated effluent. The variable results from the EPS tests indicate the possibility that some toxicants are being missed in the static bioassays. The data reported by the IPSFC and B.C. Research describe the acute toxicity of the primary effluent prior to chlorination hence, any chlorine induced toxicity in the final effluent would not be included in the results.

5.2.3 Toxic Components of Iona STP Effluent

Higgs (1977) performed chemical analyses of the Iona STP effluent in an attempt to determine the major causes of acute toxicity. The author concluded that the un-ionized ammonia levels (mean = 0.025 mg/l) in the effluent could have contributed marginally to acute toxicity. Anionic surfactants, measured as LAS, were also found at concentrations which could have contributed to effluent toxicity.

Martens and Servizi (1976) reported that filtered copper and anionic surfactants in Iona STP effluent were associated with major values of toxic units. However, the sum of the calculated toxic units (described in Section 5.1.1) for these components (1.18 TU equivalent to a 96-h LC50 of 85% $^{V}/v$) did not account for all the acute toxicity determined from the actual bioassays (40 to 45% $^{V}/v$). The authors suggested that the toxic role of copper may be overestimated and that substances in addition to those measured may have contributed to the acute toxicity of the effluent.

Tanner et al. (1973) did not recommend a direct correlation between the bioassay results and the effluent component concentrations for their study because of different sampling times.

Concentrations of several effluent components measured at the Iona STP are compared with lethal, avoidance and safe concentrations compiled from several literature sources (Table 2). Concentrations of effluent components measured at Lulu and Annacis STP's are also included in Table 2 for comparison. The high concentrations of total residual chlorine in the Iona effluent reflect the absence of dechlorination facilities at the plant.

5.2.4 Toxic Effects in the Estuary

The Iona STP discharges to the Strait of Georgia via a dredged channel across Sturgeon Bank. On a flood tide, backwash of the effluent into the North Arm of the Fraser River is prevented by the Iona Jetty which parallels the outfall channel on the north side (Figure 2). Effluent flow is generally restricted to the outfall channel during low tide but dispersion over Sturgeon Bank occurs during rising tides. Effluent movement beyond the Jetty is predominantly northward, except during freshet, when it is carried westward by large North Arm flows.

Drogue studies by B.C. Research (1973) revealed that wind and tides are major factors in effluent dispersal. The analysis of 1972 wind data indicated that effluent moved along the south face of the Iona Jetty 55% of the time.

Toxicity emission rates have been calculated for the Iona STP for present and future discharge rates and are presented in Table 1. These values are included for comparison with other discharges to the study area. Extrapolation of these data to the receiving waters was not possible by the method described in Section 3 because of unknown dilutions available in the marine situation.

In situ bioassays have been conducted in the effluent channel. After 96 hours of exposure, mortality of the bivalve Macoma balthica, a type of clam, ranged from 100% at the outfall to 37% at a site midway along the length of the outfall channel (McGreer and Vigers, 1979). Caged chinook salmon, Oncorhynchus tshawytscha, at a site adjacent to the outfall, died within 24 hours and those placed at the seaward end of the effluent channel died within 96 hours (Fisheries and Marine Service, 1976 unpublished). According to Harbo (personal comm.) the results of the caging experiment at the seaward end of the channel were somewhat inconclusive due to storm conditions which interfered with the test.

McGreer (1980) conducted in situ bioassays in the effluent channel using the bivalve Macoma balthica. No mortalities occurred after 7 days of exposure. The difference between these results and those reported above is probably due to experimental factors. In any case, pollution in the channel is such that these bivalves do not normally live there (Stancil, 1980). Laboratory 24-hour replacement bioassays by McGreer (1980) also indicated that chlorinated and chlorinated/dechlorinated Iona STP effluent was not acutely toxic to M. balthica at 100% effluent concentration. Furthermore, additional observations of feeding and burrowing behaviour during the laboratory bioassays did not reveal any sublethal stress.

Stancil (1980) has reviewed the impact of the Iona STP effluent on the aquatic biota of Sturgeon Bank. The author concluded that the Iona STP effluent has a definite impact on the biota. Low oxygen levels caused by high oxygen demand of the effluent, and siltation from suspended particulates, have resulted in the reduction in the number of invertebrates immediately adjacent to the outfall. In a zone of eutrophication, seaward from the outfall, the invertebrate population is characterized by high numbers of a few species.

McGreer (1980) has reported that the concentrations of metals (copper, mercury and zinc) in the tissues of Macoma balthica are higher near the Iona outfall and that levels decrease with increasing distance from the outfall.

Tissue analyses of other benthic fauna collected from Sturgeon and Roberts Banks have indicated the bioaccumulation of heavy metals. McGreer and Vigers (1979) reported that mercury levels in the muscle tissue of large crabs (Cancer magister), flounders (Platichthys stellatus) and clams (Macoma balthica) collected from Sturgeon Bank, approached the Food and Drug Directorate maximum limit of 0.5 μg/g wet weight. Arsenic exceeded the guideline of 5.0 μg/g wet weight in tissue samples of both crabs and flounders.

5.2.5 Summary and Conclusions

The Iona STP effluent is moderately toxic to fish as measured by 96-h LC50's which ranged from 42 to more than 100% $^v/v$. Test procedures, chlorination and storm water dilution appear to be responsible for the range of toxicity measured in the effluent. Continuous flow bioassays were the most sensitive indicators of acute toxicity followed by static bioassays conducted on 24-hour composite effluent samples. Static bioassays conducted on grab samples of effluent were the least sensitive. During wet weather periods, stormwater diluted the effluent and reduced toxicity.

Toxic components of the Iona STP effluent include un-ionized ammonia, anionic surfactants and possibly copper. Other substances not measured may also have contributed to the acute toxicity of the effluent.

Acute toxicity does not appear to be a major threat to aquatic organisms on Sturgeon Bank except for the immediate area of the Iona outfall and occasionally in the effluent channel. However, the high levels of some heavy metals bioaccumulated by certain benthic fauna indicate that the effluent is having a detrimental effect on a localized area of Sturgeon Bank. Also, low oxygen levels around the outfall, caused by high BOD, have had an adverse effect on invertebrates.

5.3 Lulu Island Sewage Treatment Plant

The Lulu STP is a primary treatment facility and treats domestic sewage and industrial wastewater collected from the Municipality of Richmond.

The collection area for the Lulu STP covers 53 km^2 with a present population of about 80 000. The population of this area is expected to increase to 141 000 by the year 2021.

Treatment processes at the Lulu STP include prechlorination, comminution, preaeration, sedimentation and sludge incineration. The effluent is chlorinated and dechlorinated during the summer months from May to September, inclusive. A more complete description of the Lulu STP is presented by Cain and Swain (1980).

The final discharge is to the Main Arm of the Fraser River approximately one kilometre upstream from Steveston Island (Figure 1).

5.3.1 Comparison of Bioassay Monitoring Data With Provincial Objectives.

Acute toxicity tests have been conducted monthly by B.C. Research since April, 1978. The procedure used was a static bioassay conducted on a grab sample of unchlorinated or dechlorinated effluent. From a total of 9 monthly bioassays from April to December, 1978, all the tests were toxic to rainbow trout with an average 96-h LC50 of 65% ^{V}/v and a range of 40.7 to 84.4% ^{V}/v. The effluent toxicity exceeded Level BB (96-h LC50 of 75% ^{V}/v) of the "Pollution Control Objectives for Municipal Type Waste Discharges in British Columbia" (Pollution Control Board, 1975), 75% of the time. Data are summarized in Table 1 and a graphical comparison with the provincial objectives is presented in Figure 3.

5.3.2 Additional Acute Toxicity Studies Conducted at Lulu STP

Two extensive bioassay studies were conducted by the IPSFC to assess the toxicity of chlorinated effluent (Martens and Servizi, 1974) and dechlorinated effluent (Martens and Servizi, 1975) at the Lulu STP.

The objective of the first study (Martens and Servizi, 1974) was to determine if sewage could be adequately disinfected by chlorination without increasing the toxicity of the final effluent to fish. "Adequate disinfection" was described as resulting in a MPN of less than 10 000 coliform bacteria per 100 mL of sewage. The authors concluded that adequate disinfection of the sewage with chlorine was not possible without increasing the toxicity of the effluent. The 96-h LC50 of the primary sewage was between 10 and 25% ^{V}/v as measured in 15 continuous flow bioassays using sockeye salmon. When chlorinated, the toxicity of the sewage was substantially increased if a chlorine residual was detectable (over 0.02 mg/L).

The objective of the second study (Martens and Servizi, 1975) was to evaluate the effectiveness of sulphur dioxide for the removal of chlorine and chlorine induced toxicity. Results of the study indicated that dechlorination with sulphur dioxide eliminated chlorine induced toxicity but did not substantially reduce the initial toxicity of the primary effluent. Six continuous flow bioassays of dechlorinated effluent gave an average 96-h LC50 of approximately 25% ^{V}/v. Mortalities occurred at 17% ^{V}/v in one case but no mortalities were noted at 10% ^{V}/v.

Martens and Servizi (1975) also conducted separate bioassays to determine if residual sulphur dioxide could be harmful to fish. Sulphur dioxide-induced toxicity has been shown to occur in trout exposed to a concentration of 5.0 mg/L (McKee and Wolf, 1963). The maximum delivery rate of sulphur dioxide at the Lulu STP resulted in an average residual of 2.2 mg/L and did not affect sockeye or pink salmon after 96 hours of exposure. Cairns and Conn (1979) reported that 10 mg/L of sodium sulphite was not lethal to rainbow trout in treated municipal sewage.

5.3.3 Toxic Components of Lulu STP Effluent

The Lulu STP effluent may be atypical of municipal sewage because about two percent of the influent is composed of electroplating plant process water which contains variable concentrations of cyanide and heavy metals.

Martens and Servizi (1974) concluded that un-ionized ammonia, cadmium, copper and possibly iron contributed to the acute toxicity of the Lulu STP effluent. Cyanide and surfactants also were indicated as toxic components, based on the results of the second study at the Lulu STP (Martens and Servizi, 1975).

Although un-ionized ammonia concentrations in Lulu STP effluent did not reach the lethal levels of 0.2 to 0.9 mg/L reported by Esvelt et al. (1971), concentrations were similar to those found in San Francisco primary sewages, where acute toxicity was correlated with ammonia nitrogen concentrations. Thus, in view of this similarity, Martens and Servizi (1974) concluded that ammonia may have contributed to the acute toxicity of the Lulu STP effluent.

Martens and Servizi (1974) found that the anionic surfactant concentration in Lulu STP effluent was below the acutely toxic level of 2 to 6 mg/L reported by Esvelt et al. (1971). However, during a later bioassay study at Lulu STP (Martens and Servizi, 1975), anionic surfactant concentrations which averaged 4.47 mg/L and ranged from 2.2 to 8.8 mg/L, were within the toxic levels reported by Esvelt et al. (1971). Martens and Servizi (1975) concluded that anionic surfactants contributed to the acute toxicity of the Lulu STP effluent.

Martens and Servizi (1975) found cyanide concentrations in the Lulu STP effluent to average 0.11 mg/L and to range from less than 0.03 to 0.36 mg/L. McKee and

Wolf (1963) reported that 0.05 mg/L cyanide was toxic to trout in five to six days. Martens and Servizi (1975) concluded that the average concentration of cyanide probably contributed to the acute toxicity of the effluent.

Nitrite concentrations ranged from 0.005 to 0.08 mg/L in the effluent. These levels were below the LC50 value of 0.23 mg/L reported by Brown and McLeay (1974). Martens and Servizi (1975) concluded that nitrite did not contribute to the acute toxicity of this effluent but may indirectly affect fish toxicity by increasing blood methemoglobin. Brown and McLeay (1974) reported that sublethal concentrations of nitrite may reduce the tolerance of fish to other toxicants by causing a reduction in blood hemoglobin and forming methemoglobin.

Concentrations of several effluent components measured at the Lulu STP are compared with lethal, avoidance and safe concentrations compiled from the literature (Table 2). Concentrations of effluent components measured at Iona and Annacis STP's are also included in Table 2 for comparison. The concentrations of dissolved copper, dissolved zinc, dissolved lead, dissolved chromium and cyanide in the Lulu STP effluent are indicative of the high concentrations in metal industry wastewaters discharged to the plant.

5.3.4 Dilution of Effluent in the Estuary

Despite weaknesses in the application of bioassay results, simple extrapolations were attempted to obtain an approximate estimate of potential toxic effects in the river. A flow proportioned toxicity index was calculated for the Lulu STP effluent in the Main Arm following the method described in Section 3. This calculation assumes the simultaneous occurrence of the following extreme conditions:

(1) The maximum acute toxicity value of the effluent (96-h LC50 of 17% $^{v}/v$) measured by Martens and Servizi (1975);

(2) The maximum allowable daily discharge rate for the Lulu STP (132 000 m^3/day) specified in the Pollution Control Branch permit (PE-233), which could be reached in the year 2021; and

(3) The extreme minimum daily river flow ($4.69 \times 10^7 m^3$/day) calculated for the Main Arm (Section 3).

For the above conditions, a TCr of 0.016 toxic units was calculated for the Lulu STP effluent in the river. This value is within the safe level of 0.01 to 0.1 toxic units for persistent chemicals and pesticides recommended by the U.S. National Technical Advisory Committee (1968), although it exceeds the safe level of 0.01 toxic units for persistent toxicants recommended by the National Academy of Sciences and National Academy of Engineering (1973). The calculated TCr is a very approximate estimate of potential toxicity in the river assuming uniform dilution of the effluent. Values higher than the one calculated may be encountered in the initial dilution zone. Other factors which may affect the dilution and toxicity of the effluent in the river are listed in Section 4.

The Annacis STP also discharges to the Main Arm, approximately 18 km upstream from the Lulu STP outfall. A maximum TCr of 0.07 toxic units was calculated for the Annacis effluent in the river (Section 5.4.4). If the effluent toxicity of Annacis and Lulu STP's can be considered additive, a combined maximum TCr of 0.086 toxic units could occur at minimum river flow and at maximum permitted effluent discharge rates projected for the year 2021. This value would still be within the safe level recommended by the U.S. National Technical Advisory Committee (1968), although it would exceed the safe level for non-persistent contaminants (0.05 toxic units) recommended by the National Academy of Sciences and National Academy of Engineering (1973).

Knowledge of toxicants, toxicant behaviour and decay rates in the river is minimal, therefore the calculated TCr values can only be considered very approximate estimates.

The above calculations are based on the assumption that the Lulu STP effluent mixes completely with the lower Fraser River before entering the Strait of Georgia. In reality, considering the proximity of the outfall to the Strait of Georgia, the effluent would probably tend to flow seaward in concentrated streams during ebb tides. The calculated values would therefore be an underestimate in this effluent plume and an overestimate in areas outside the plume. During flood and slack tides, flow reversal occurs which may result in poor dilution and multiple dosing of the effluent. These conditions would not be expected to persist for more than 12 hours. According to B.C. Research (1972) effluent discharged from the Lulu STP moves seaward onto Sturgeon Bank on the following ebb tide.

5.3.5 Summary and Conclusions

The Lulu STP effluent is moderately toxic to fish as measured by 96-h LC50's, which ranged from 17 to 85% $^{v}/v$ depending on the test procedure. Continuous flow tests conducted by the IPSFC were more sensitive indicators of toxicity than the static bioassays conducted by B.C. Research.

Toxic components of the Lulu STP effluent include un-ionized ammonia, cadmium, copper, cyanide, surfactants and possibly iron and nitrite.

Extrapolation of the acute toxicity data to the river situation indicated generally safe conditions for fish outside the initial dilution zone. At maximum effluent flow, to be reached in the year 2020, and at the very minimum river flow, sublethal effects on fish may occur outside the initial dilution zone. In the initial dilution zone, multiple dosing and combined toxic effects of other discharges to the Main Arm may result in conditions which are unsafe for fish under certain effluent and river flow conditions.

5.4 Annacis Island Sewage Treatment Plant

The Annacis STP is a primary treatment facility and treats domestic and industrial effluent from Coquitlam, Port Coquitlam, Delta, Langley City, New Westminster, Surrey, White Rock, Port Moody, Burnaby and a small part of Vancouver (Figure 1). Some stormwater is collected with the municipal effluent.

The collection area for the Annacis STP covers about 460 km^2 with a present population of about 370 000. The population of this area is expected to increase to approximately 490 000 by 1986 and to 1 200 000 by 2021.

Treatment processes at Annacis include prechlorination, mechanical screening, preaeration, sedimentation and sludge handling. The effluent is chlorinated and dechlorinated during the summer months from May to September, inclusive. A more complete description of the Annacis STP is presented by Cain and Swain (1980). The final discharge is to the Main Arm of the Fraser River via a submerged diffuser system.

The Annacis STP began operations in May, 1975 and several municipal wastewaters, which previously discharged directly to the North Arm, New Westminster Harbour, Burrard Inlet, Boundary Bay and the Pitt River, were diverted to the plant after this date. These diversions were the result of policies established by the Pollution Control Board in 1968. These policies are discussed in Section 6.

5.4.1 Comparison of Bioassay Monitoring Data With Provincial Objectives

Acute toxicity tests have been conducted monthly by B.C. Research since December, 1976. The procedure used for these tests was a static bioassay conducted from a grab sample of unchlorinated or dechlorinated effluent. The test species used was rainbow trout. A total of 25 monthly bioassays gave an average 96-h LC50 of 88% $^{v}/v$ with values ranging from 43 to more than 100% $^{v}/v$. The effluent toxicity corresponded to Level AA (96-h LC50 of 100% $^{v}/v$) of the "Pollution Control Objectives for the Municipal Type Waste Discharges in British Columbia", (Pollution Control Board, 1975) 48% of the time and was better than Level BB (96-h LC50 of 75% $^{v}/v$) 72% of the time. These data are summarized in Table 1 and a graphical comparison with the provincial objectives is presented in Figure 4.

5.4.2 Additional Acute Toxicity Studies Conducted at Annacis STP

Additional acute toxicity studies have been conducted at the Annacis STP by the EPS (Higgs, 1977) and the IPSFC (Servizi et al. 1978 and Environment Canada, 1979).

Higgs (1977) conducted four static bioassays on the dechlorinated effluent using 24-hour composite samples. Three bioassays gave an average 96-h LC50 ot 68% $^{v}/v$ to rainbow trout, with values ranging from 51 to 78% $^{v}/v$. One test result was excluded from the mean as it may have been invalid due to control mortalities.

Servizi et al. (1978) also conducted static bioassays from 24-hour composite samples on the dechlorinated effluent but used sockeye salmon as the test species. A total of 72 individual test concentrations gave an average 96-h LC50 of 38% $^{v}/v$. Mortalities were 100% at a concentration of 65% $^{v}/v$ but no mortalities were reported at 10% $^{v}/v$.

The reasons for the different results obtained by Higgs (1977) and Servizi et al. (1978) were not known but the fish used were different (rainbow trout vs sockeye salmon) and the effluent samples collected by Higgs (1977) were aerated 18 to 23 hours prior to testing. Aeration may have resulted in stripping some of the toxic components from the effluent.

Servizi et al. (1978) also conducted continuous flow bioassays with sockeye salmon on the dechlorinated effluent. A total of 104 individual test concentrations resulted in an average 96-h LC50 of 26% $^{v}/v$. Mortalities were 100% at a concentration of 65% $^{v}/v$ but no mortalities were reported at 10% $^{v}/v$. During dry weather flow the 96-h LC50 was 17% $^{v}/v$ whereas during wet weather flow the 96-h LC50 was 33% $^{v}/v$ for continuous flow bioassays. Dilution by stormwater was suggested as the cause for lower toxicity during wet weather flow conditions. When five continuous flow bioassays were conducted in autumn 1979, the average 96-h LC50 was 24% $^{v}/v$ (Environment Canada, 1979).

5.4.3 Toxic Components of the Annacis STP Effluent

Higgs (1977) reported that un-ionized ammonia and anionic surfactants contributed to the acute toxicity of the Annacis STP dechlorinated effluent. Un-ionized ammonia concentrations ranged from 0.034 to 0.046 mg/L in the dechlorinated effluent. A level of 0.025 mg/L un-ionized ammonia has been stated as the maximum that fish can tolerate (Dept. of the Environment, 1973) whereas lethal levels reported by Esvelt et al. (1973) were 0.2 to 0.9 mg/L. Thus, un-ionized ammonia may have contributed to the acute toxicity of the dechlorinated effluent at Annacis STP.

Anionic surfactant levels in the dechlorinated effluent, measured as linear alkylate sulphonate (LAS), ranged from 3.5 to 4.2 mg/L (Higgs, 1977). Thatcher and Santner (1966) found 96-h LC50 values for LAS of 3.3 to 6.4 mg/L for five species of fish. Thus, at times, anionic surfactant concentrations were within acutely toxic levels.

According to Servizi et al. (1978) calculations indicated that anionic surfactants, un-ionized ammonia, cyanide, nitrite and heavy metals failed to account for all the acute toxicity measured in the effluent. The relative toxic influence of each toxic component of the effluent was estimated by the method described in Section 5.1.1.

Calculation of toxic units attributed 0.8 toxic units to anionic surfactants and 0.3 toxic units to cyanide. Certain components including copper, un-ionized ammonia and nitrite were excluded from the summation of the toxic components because:

(1) alkalinity and binding with organics may have been antagonistic to copper toxicity; and

(2) these components were present at less than the 0.2 toxic unit criterion recommended for estimating the combined effects of toxicants.

The summation of the toxic units for the anionic surfactants and cyanide (1.1 TU equivalent to a 96-h LC50 of 91% $^{v}/v$) indicated less toxicity than was actually measured (17 to 33% $^{v}/v$). Thus, Servizi et al. (1978) concluded that substances other than those measured may have contributed to the acute toxicity of the Annacis STP effluent.

Concentrations of several effluent components measured at the Annacis STP are compared with lethal, avoidance and safe concentrations compiled from several literature sources (Table 2). Concentrations of effluent components measured at the Iona and Lulu STP's are also included in Table 2 for comparison.

5.4.4 Dilution of Effluent in the Estuary

The final discharge of the Annacis STP effluent is to the Main Arm of the Fraser River through three submerged outfall pipes, each equipped with six risers. During the first 21 months of operation, effluent was discharged from a single terminal riser. Nine risers from a total of eighteen are presently in use to assist in the dispersal of effluent.

Western Canada Hydraulic Laboratories Ltd. has estimated complete mixing of the effluent and river to occur approximately 6100 metres downstream from the outfall at a river velocity of 0.3 m/s (B.C. Research, 1978). Although complete lateral mixing may occur at this point, tidal influence would probably result in the oscillatory progression of effluent "clouds" down the river. Associated Engineering (1977) estimated the average residence time of Annacis effluent in the river to be 1.7 days, assuming a low river flow of 1000 m^3/s at Hope.

The dilution of the Annacis STP effluent in the river was considered in two ways, using the following information:

- B.C. Research (1975) dispersion test with dye released from a single terminal riser at a known rate. This test enabled the calculation of minimum effluent dilutions in the river during unfavourable mixing conditions.

- The TCr for Annacis effluent in the river, calculated to obtain an estimation of potential toxicity during uniform dispersion. The method for this extrapolation is described in Section 3 and the limitations of the data are described in Section 4.

(a) Minimum Effluent Dilution, Using Results of the Dispersion Test

B.C. Research (1975) conducted a dye study in the river to obtain information on dispersal and dilution patterns of the Annacis STP effluent. A time period was chosen whereby tidal conditions and a low river flow (790 m^3/s at Hope) were expected to simulate unfavourable mixing conditions in the river.

Dye was released to the river from a single terminal riser at a rate of 0.11 m^3/s for 5.5 hours and the dye concentration was measured at various points in the river during a tidal cycle. These data were then used to calculate the approximate dilution of effluent discharged from 1 to 18 risers for different tidal conditions and for various effluent flows as follows:

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

The calculated effluent dilution factors are presented in Table 3 with the corresponding discharge rates for the Annacis STP. The effluent dilution values estimated for the year 2021 were multiplied by a factor of 18 as it was assumed that all 18 risers would be in operation when the Annacis STP approaches the maximum permitted discharge rate. The effluent dilution factors presented in Table 3 may be overestimated in some cases because effluent discharged from the risers may overlap. In general, the dye study indicated uneven mixing and surface pooling in the initial dilution zone during high slack tide.

B.C. Research (1978) has estimated that a five to six fold dilution would be sufficient to dilute Annacis STP to non-acutely toxic levels in the river. These dilution factors only apply to acute toxicity and do not consider sublethal or chronic effects which may occur at lower concentrations. The effluent dilution factors presented in Table 3 indicate that non-acutely toxic conditions occur in the river except near the outfall during high slack tide. However, the duration of high slack tide is less than one hour and it is assumed that the effluent would be diluted beyond acutely toxic levels on the following ebb tide.

(b) Minimum Effluent Dilution During Uniform Dispersion

Flow proportioned toxicity indices were calculated for the Annacis STP effluent in the Fraser River following the method described in Section 3 of this report. Extrapolation of the effluent toxicity data to the river is based on the following extreme conditions:

(1) the maximum acute toxicity value of the effluent (96-h LC50 of 17%) measured by Servizi et al. (1978).

(2) the minimum recorded flow for the Main Arm (4.97×10^7 m^3/day) calculated from the distribution of flows below Port Mann which are presented in Section 3.

The effluent discharge rates chosen to assess potential toxicity in the river are:

(1) The daily average discharge rate of 163 000 m^3/day for 1977.

(2) The average of the maximum daily discharge rates for March and April, 1977 which was 216 000 m^3/day. (The rationale for choosing these two particular months was to isolate the most sensitive time period with respect to juvenile fish migration which also coincides with periods of extreme low flows in the river as shown in Figure 5).

(3) A discharge rate of 244 000 m^3/day projected for the year 1986.

(4) The maximum allowable daily discharge rate of 586 000 m^3/day specified in the Pollution Control Branch Permit (PE-387) for Annacis. This discharge rate reflects a projected figure for the year 2021.

The TCr calculated for each of the effluent discharge rates shown above are 0.02 TU, 0.03 TU, 0.03 TU and 0.07 TU, respectively. These values are within the safe levels of 0.01 to 0.1 TU for persistent toxicants recommended by the U.S. National Technical Advisory committee (1968), although they exceed the safe level of 0.01 TU for cumulative toxicants recommended by the National Academy of Sciences and the National Academy of Engineering (1973). The safe level of 0.05 TU for non-cumulative toxicants, also recommended by these Academies, is exceeded by the fourth flow condition.

The calculated TCr values for the Annacis STP effluent assume total uniform mixing with the river and are for a hypothetical situation whereby extreme conditions occur simultaneously. Although these values are very approximate and cannot include certain limitations described in Section 4, they do provide an estimate of potential toxicity in the river. Concentrations exceeding the safe levels could occur in localized areas of the outfall before complete mixing of the effluent and river as was indicated by the dye study.

A graph was plotted to show the relationship between effluent toxicity and potential toxicity in the river (Figure 6). The asymptotic curve warns that during minimum river flow and a simultaneous maximum effluent discharge, a small increase in the effluent toxicity above present levels could result in conditions in the river which are unsafe for fish, by the year 2020.

5.4.5 Summary and Conclusions

The Annacis STP effluent is moderately toxic to fish as measured by 96-h LC50's, which ranged from 17 to over 100% $^v/v$, depending on the test procedure. Continuous flow tests using sockeye salmon were the most sensitive indicators of acute toxicity followed by static bioassays conducted on rainbow trout with 24-hour composite effluent samples. Static bioassays conducted on rainbow trout with grab samples of effluent were usually the least sensitive tests. Also, during wet weather periods, stormwater diluted the effluent and reduced toxicity.

Toxic components of the Annacis effluent have been suggested to include anionic surfactants, cyanide and possibly un-ionized ammonia. Other toxicants measured, including nitrite and copper, were below criteria levels for toxicity. Substances other than those measured may have contributed to the acute toxicity of the effluent.

Extrapolation of acute toxicity data to the river situation for present effluent discharge rates indicates safe conditions for fish outside the initial dilution zone, although some criteria suggest that, at minimum recorded low, persistent and cumulative toxicants may cause sublethal effects. However, multiple dosing of effluent, confirmed by dye tests, indicates that conditions unsafe for fish may occur at times in the immediate area of the outfall.

When the maximum effluent discharge rate, projected for 2021, coincides with low river flow, a small increase in effluent toxicity above present levels could result in conditions in the river which are unsafe for fish.

Present trends of consolidating industrial wastewaters and landfill leachates with domestic sewage is expected to increase the toxicity of Annacis effluent unless source control is practiced or more advanced treatment facilities are installed at Annacis.

5.4.6 Recommendations for Lulu, Iona and Annacis STP's

In view of the large volumes of toxic industrial wastewaters being diverted to the municipal sewers and their effect on effluent toxicity at the sewage treatment plants, further control measures are recommended to reduce toxicant levels at the plants. Options to reduce toxicant levels include source control at the industries (discussed in Section 6.7) and further treatment at the sewage treatment plants (discussed in Section 5.5).

To assess potential toxic effects in the river and estuary, on-site continuous flow bioassays should be conducted at the sewage treatment plants twice a year. These tests should employ receiving water for the dilution of test samples rather than dechlorinated tap water. To evaluate sublethal or chronic effects, the tests might be adapted to incorporate sublethal response tests such as the "corticosteroid" stress response described in Section 5.6.4. Although in situ bioassays using caged fish placed in the initial dilution zone at potential problem areas may provide valuable information, these tests are not always practical and in many cases are difficult to assess because of the numerous uncontrolled variables present during the experiment.

Monitoring of acute toxicity by static bioassays should be maintained at the sewage treatment plants on a regular monthly basis.

Further identification of toxic components in sewage treatment plant effluent will assist in making decisions on further treatment.

Dye studies at the Iona STP during unfavourable mixing conditions may provide information on the dispersion and dilution patterns over Sturgeon Bank.

Knowledge of toxicant behaviour and decay rates in the river are minimal. More information is required on these factors before accurate estimates of toxic effects in the river can be predicted.

5.5 Sewage Treatment Options Related to Toxicity

Based on the concern that the effluent toxicity will increase at the sewage treatment plants, comparison of several sewage treatment methods and related toxicity would provide valuable information for future decisions.

A comparison of treatment methods and related toxicity has been conducted at sewage treatment plants located in the San Francisco area (Esvelt et al. 1973). The relative toxicities of the various effluents are presented in Figure 7 for comparison. Although some idea of acute toxicity reduction by further treatment can be obtained from this study, direct comparisons are not advised as the composition of sewage will vary from plant to plant.

The results reported by Esvelt et al. (1973) indicate that treatment by aerobic biological treatment, such as activated sludge operated at conventional loading rates, was the single, most effective method for toxicity removal. Treatment by chemical precipitation with ammonia removal, plus activated carbon adsorption was comparable to activated sludge treatment for toxicity removal. Both treatment processes reduced acute toxicity by about 75% as compared to primary treatment (Figure 7).

Chemical treatment has generally proven to be more effective in the removal of cumulative toxicants whereas biological treatment has demonstrated more effectiveness in the removal of biodegradable pollutants. According to Westwater (1976) effluent toxicity from ammonia and surfactants is likely to be rapidly reduced by degradation in the Fraser River, therefore a greater emphasis should be placed on the removal of cumulative toxicants.

One alternative or supplement to chemical treatment for the removal of cumulative toxicants (i.e., heavy metals) would be the implementation of an industrial source control program which is discussed in Section 6.5.

5.6 Municipal Landfills

Several large landfills in the study area are located adjacent to the Fraser River (Figure 8). Leachates from these sites reach the river by means of surface drainage and possibly through the groundwater. The major active landfill sites are Burns Bog, Richmond, Braid Street and Port Mann landfills. Four large closed landfill sites in the study area include the Kerr Road, Stride Avenue, Leeder and Terra Nova landfills. There are also several other small municipal landfills and refuse dumps and about 35 woodwaste landfill sites in the study area. Detailed information on the geology, leachate analysis, filling operations and environmental impact of the landfills is presented by Atwater (1980).

Limited toxicity data were available for landfill leachates. Most of the data were from scattered observations, however, these data indicated that the leachate was often acutely toxic to fish. The available bioassay data are summarized in Table 4.

5.6.1 Toxic Components of Municipal Landfill Leachates

Leachate components have not been successfully correlated to acute toxicity. Atwater (1980) states that the isolation of any single cause of toxicity in municipal leachates is difficult due to the complex nature of the mixtures.

Lysimeter studies have been conducted by recycling water through municipal refuse (Cameron, 1975). This simulated leachate was extremely toxic to rainbow trout with 96-h LC50's which ranged from 0.062 to 0.70% $^{v}/v$. A poor correlation between contaminant concentrations and toxicity was noted except for iron. It was considered doubtful that iron alone could account for all the toxicity measured in the samples.

E.V.S. Consultants (1976) could not find a significant correlation between acute toxicity and leachate components originating from the Richmond landfill. Although total dissolved iron, sulphide and ammonia were found to correspond with acute toxicity, the concentrations of these contaminants were not considered sufficient to account for all the toxicity measured. Resin and fatty acids were not included in the analyses but were suggested to have contributed to toxicity. Soper and McAlpine (1977) suggest that synergistic effects between the leachate components may account for some of the toxicity at the Richmond landfill.

5.6.2 Major Closed Landfills

The toxicity of leachate from municipal refuse has been shown to persist for up to 13 years after the closure of a landfill.

The Kerr Road landfill, located in Vancouver on the North Arm has been closed since 1966. The contaminant concentrations of the leachate have shown a significant decrease since the closure (Atwater, 1980). However, two bioassays conducted on the leachate in 1979 gave evidence that the leachate was still toxic to fish. One bioassay conducted on January 2, 1979 showed that the leachate was lethal to 50% of the rainbow trout at 100% concentration in 34 minutes. A second bioassay on February 16, 1979 gave a 96-h LC50 of 24% $^{v}/v$ to rainbow trout.

The Stride Avenue landfill in Burnaby has been closed since 1969. Two bioassays conducted on the leachate on January 26, 1979 and March 24, 1979 showed toxicity to rainbow trout with 96-h LC50's of 90 and 56% $^{v}/v$, respectively. One sample collected on February 27, 1979 was not toxic to rainbow trout at 100% concentration.

The Terra Nova landfill in Coquitlam was closed to municipal refuse dumping in September, 1975 but the site is still used for the storage of hog fuel. No bioassay data were available for leachate emanating from this site.

5.6.3 Major Active Landfills

The four major active landfills, which include Richmond, Burns Bog, Braid Street and Port Mann landfills, produce acutely toxic leachate which drains to the Fraser River and tributaries. The available bioassay data for the leachate from these landfills are summarized in Table 4.

Burns Bog landfill, located in Delta, was found to discharge the most toxic leachate of the five major active landfills. Three samples from a ditch contaminated with leachate gave 96-h LC50's of 6.5 to 18% $^{v}/v$ for rainbow trout and one sample from a standing pool of leachate within the landfill site gave a 96-h LC50 of 7% $^{v}/v$. One bioassay has been conducted on a sample of the receiving water from Crescent Slough and was not acutely toxic to rainbow trout after 96 hours.

Two static bioassays have been conducted on samples collected from a ditch contaminated with Braid Street landfill leachate. These tests gave 96-h LC50's of 24 and 36.5% $^{v}/v$ for rainbow trout.

Three bioassays conducted on samples of leachate entering the Fraser River from the Port Mann landfill in Surrey gave an average 96-h LC50 of 43.3% $^{v}/v$ for rainbow trout, with values ranging from 38 to 50% $^{v}/v$.

Richmond landfill leachate was normally in the acutely toxic range of 30 to 50% $^{v}/v$ as measured by 96-h LC50's. Soper and McAlpine (1977), in an assessment study of the Richmond landfill, considered the leachate to be environmentally unacceptable by Provincial standards. The "Pollution Control Objectives for Municipal type Wastes Discharges in British Columbia" (Pollution Control Board, 1975) specify 96-h LC50's of 100 and 75% $^{v}/v$ for levels AA and BB, respectively. If these objective levels, as quoted for municipal type effluents, are applicable to landfill leachates, then Level BB was exceeded about 92% of the time. At the present time, however, it would appear that the Receiving Water Quality Maintenance Objectives as given in Table 5-3 of the "Pollution Control Objectives for Municipal Type Waste Discharges in B.C." (Pollution Control board, 1975) are the only criteria for leachate toxicity which are considered applicable. These objectives specify no increase above background for toxicity of receiving waters as measured in a 96-h LC50 static bioassay test.

5.6.4 Impact of Municipal Landfill Leachate in the River/Estuary

Up to 1978, toxicity data collected from municipal landfill leachates were inadequate to assess the impact on aquatic biota in the river and estuary.

Soper and McAlpine (1977) recommended further toxicity studies to determine the impact of leachate discharges on aquatic biota. The "corticosteroid" stress response bioassay developed by Donaldson and Dye (1975) was also suggested for determining the sublethal concentrations of landfill leachates. Donaldson and Dye (1975) indicate that this technique may be of use for the rapid evaluation of effluents containing heavy metals, or those containing a mixture of toxicants.

Continuous flow bioassays, using receiving water for dilution of the test samples, would provide information on the toxicity of municipal landfill leachates in the river.

5.6.5 Diversion of Leachate to the GVS & DD Sewerage System

In recent years there has been a trend to divert the leachate from some of the major active landfills to the GVS & DD sewerage systems. Leachate from the Braid Street landfill, which originally drained into the Brunette River, was diverted to the Annacis STP in April, 1976. Leachate from the Port Mann landfill was diverted to Annacis in the first half of 1980, and leachate from Burns Bog should be flowing to Annacis by the end of 1980. Atwater (1980) concluded that the toxicity of the Annacis STP effluent is bound to increase, mainly due to an expected 12% increase in ammonia loadings from the landfills and the high alkalinity associated with the leachates.

5.6.6 Summary and Conclusions

Leachate samples collected from municipal landfills in the study area were usually toxic to fish and their toxicity ranged from 6.5 to more than 100% $^{v}/v$ as measured in 96-h LC50 static bioassays.

Toxic components of municipal landfill leachates include iron, ammonia, sulphide and possibly resin and fatty acids. Other substances may also contribute to the toxicity. However, the complex nature of the leachates has prevented meaningful correlations.

The acute toxicity of municipal landfill leachate has been shown to persist for up to 13 years after the closure of a landfill.

The impact of municipal landfill leachate on aquatic biota in the river and estuary cannot be determined because of insufficient data.

Leachate from Port Mann and Burns Bog landfills are to be diverted to the Annacis STP. The high ammonia concentrations coupled with the high alkalinity of the leachate, is expected to increase the toxicity of the Annacis effluent.

5.7 Woodwaste Landfills

An estimated total of 2 708 000 m^3 of woodwastes was landfilled in the lower Fraser Valley in 1977. An aerial survey in the same year identified 31 woodwaste landfills on the foreshore of the Fraser River containing an estimated 4 350 000 m^3 of woodwaste (Atwater, 1980).

5.7.1 Toxic Components of Woodwaste Leachate

Leachate contaminant concentrations from woodwastes are almost entirely dependent on the water soluble fraction of the wood extracts which include lignins, resin acids and phenolic compounds. Atwater (1980) reported that the toxicity of woodwaste leachate has been attributed to resin acids by one researcher, and to tropolones by other researchers working mainly with Western Red Cedar. Tropolones were reported to represent 5% of the water soluble fraction from cedar. Cameron (1975) found no correlation between toxicity and contaminant concentrations for simulated wood waste landfill leachates collected from lysimeters.

These woodwaste leachates were generally less toxic than the simulated municipal refuse leachates collected from lysimeters. Static bioassays conducted on leachate from the woodwaste lysimeters gave 96-h LC50's for rainbow trout which ranged from 0.48 to 4.0% $^{v}/v$ with no pH adjustment.

5.7.2 Impact of Woodwaste Leachate in the River/Estuary

When given adequate dilution, leachates emanating from woodwaste landfills are considered to have a lower environmental impact than leachates from municipal refuse landfills. The attenuation of leachate toxicity from woodwaste landfills generally occurs more rapidly than from municipal refuse landfills (Econotech, 1979). Atwater (1980) estimated that the leachate from woodwaste landfills would attenuate to non-toxic levels after the landfill had been exposed for three years to the weather. Also, Cameron (1975) found the toxicity of woodwaste leachates to be significantly less than that of municipal refuse leachates in lysimeter studies.

Some field sample bioassays conducted by the Department of Fisheries and Environment (DFE) found the toxicity of landfill woodwaste leachate to range between 8 to over 100% $^{v}/v$ as measured by 96-h LC50 static bioassays. School House Creek, a small tributary to the Fraser River was tested for toxicity on May 18, 1978 by the DFE, and all the fish died within 16 hours.

Present levels of bioassay information in woodwaste landfill leachates are inadequate to assess the toxic impact to aquatic biota in terms of the Fraser River and Estuary. No *in situ* or continuous flow bioassays using Fraser River water for dilution have been conducted to determine toxic effects of these wastes in the river.

Considering the relatively rapid attenuation of woodwaste leachate toxicity, and the large dilution offered by the Fraser River, it is doubtful that these leachates would have any toxic effect on the main river channels. However, they may impose toxicity problems in areas of limited dilution and mixing such as sloughs, backwaters and small tributaries, as was shown by the School House Creek sample.

5.7.3 Summary and Conclusions

Toxic components of woodwaste leachates have been reported to include resin acids and, in the case of cedar, tropolones.

Woodwaste landfills have been shown to attenuate to non-toxic levels after three years of exposure to local weather conditions.

Leachate samples collected from woodwaste landfills in the study area were often toxic to fish. The toxicity ranged from 8 to more than 100% $^{v}/v$ as measured by 96-h LC50 static bioassays.

Present levels of bioassay information are inadequate to assess toxic effects in the Fraser River and Estuary. However, no toxicity problems are expected in the main river channels due to the relatively rapid attenuation of leachates toxicity. In areas of limited dilution leachate may produce anaerobic conditions unsafe for fish. One small creek contaminated with woodwaste leachate has been found toxic to fish.

5.7.4 Recommendations for Municipal and Woodwaste Landfills

The identification of toxic components of landfill leachates may assist in deciding leachate treatment methods and acceptable disposal procedures.

Accurate flow measurements as well as continuous flow bioassays using Fraser River dilution water are required to assess potential toxic conditions in the river.

The "corticosteroid" stress response bioassay has also been suggested for determining sublethal concentrations of landfill leachate.

Landfilling of known toxic or hazardous wastes in sites adjacent to the Fraser River is unacceptable and alternative disposal methods should be considered.

5.8 Stormwater

In total, there are more than 100 separate stormwater discharges and 12 combined sewage and stormwater discharges to the lower Fraser River and Estuary (Ferguson and Hall, 1979). Static bioassays have been conducted on 18 storm sewers within the Greater Vancouver Regional Distict in 1976 (EPS, unpublished data). All samples were found to be not acutely toxic to rainbow trout at 100% concentration, as measured by 96-h LC50's.

Dilution by stormwater has been reported to reduce the acute toxicity of sewage treatment plant effluent. Tanner et al. (1973) concluded that the dilution of sewage by stormwater during wet weather flows reduced the acute toxicity of the Iona STP effluent. Similarly, Martens and Servizi (1978) found the acute toxicity of the Annacis STP effluent to be significantly less during wet weather flows.

After extended dry weather periods, high concentrations of pollutants discharged during the first flush may be detrimental to aquatic biota in the lower Fraser River and Estuary. No toxicity data were available for stormwater discharged during first flush conditions.

5.8.1 Recommendations

Further studies relating to the acute, chronic and sublethal toxicity of stormwater discharges are required to assess the impact of these sources on the aquatic biota in the river.

Data are required to confirm the possibility of first flush toxicity from stormwater discharges.

The identification of toxic components of stormwater may assist in determining the need for stormwater management.

6. INDUSTRIAL DISCHARGES TO THE STUDY AREA

In 1968, the Pollution Control Board established a policy whereby all municipal effluents discharged to the Fraser River downstream of Hope were to have at least primary treatment and chlorination by January 1, 1975. For the North and Middle Arms of the river secondary treatment would be required. Due, in part, to strict pollution control objectives for direct industrial discharges, many industrial wastewaters which were originally discharged directly to the river, have been diverted to the sewerage system for discharge through the Lulu, Iona or Annacis STP's. Also, some petroleum refineries, which originally discharged acutely toxic process effluent to Burrard Inlet in the past, have been connected to the sewerage system. The overall trend, therefore, has been to transfer industrial effluents from a multiplicity of smaller outfalls and to combine them with municipal effluents for primary treatment and subsequent discharge from fewer and larger outfalls. After the diversion of industrial wastewaters, the responsibility for the admission of wastes to sewer is then shifted to municipalities and to the GVS & DD. Because of overlappng jurisdictions, present monitoring programs are inadequate and bioassay data are not available in most cases.

The locations of the major industries which still discharge wastewater directly to the lower Fraser River and Estuary are shown in Figure 9.

The following sections of this report involve a discussion of the various types of industry discharging effluent within the study area. The industry types include forest products, chemical and petroleum, food processing, metal finishing and other miscellaneous industries.

6.1 Forest Products Industries

In the lower Fraser River study area the forest products industry comprises sawmills, paper mills, paper recycling plants and specialty board plants. Several of these operations are located on the heavily industrialized North Arm where indications of water quality degradation have been reported (Westwater, 1976). The forest products industry has been a major source of effluent to the North Arm in the past. However, many industries have improved their effluents, especially by elmination of hydraulic debarkers, and some have diverted their waste to the Annacis STP, which began operations in May, 1975.

The forest products industries are responsible for about 22% of the industrial effluent volume discharged to sewers and over 60% of the industrial effluent discharged directly to the river. The majority of the direct discharges are to the North Arm of the Fraser River.

6.1.1 Toxic Components of Forest Products Effluent

Considerable work has been done to isolate and identify the toxic components in forest products effluents (Marier, 1973; Walden, 1976; Rogers et al., 1977). The toxic components vary according to the industry and the species of trees being processed but generally include resin acids and unsaturated fatty acids. When chemical pulping and bleaching with chlorine are practiced, volatile bivalent sulphur compounds, chlorinated resin acids and chlorinated lignin degradation products may occur (Walden, 1976). Also, high levels of polychlorinated biphyenyls (PCB), up to 1500 ppb, have been reported in sediment samples collected by EPS near the Belkin Paperboard (PE-17) outfall. Garrett (1980) reported that these high levels were probably associated with the PCB's used in paper coating and printer's ink from recycled paper. Other chlorinated organic toxicants which may be associated with wastewaters from the forest products industry are discussed by Garrett (1980). Woodwaste leachates are discussed in Section 5.7 of this report.

6.1.2 Discussion of Bioassay Data for the Forest Products Industries

The available bioassay data for wastewaters discharged from the forest product industries located in the study area are summarized in Table 5. Some of these data are outdated because of the elimination of a discharge, the transfer of effluent to the sewerage system, or the upgrading of facilities at certain operations.

Belkin Paperboard Ltd. (PE-17) is a paper recycling plant located in Burnaby. The process effluent is discharged to the North Arm of the Fraser River through a series of diffusers. Data from routine bioassay monitoring, conducted by the EPS in 1976 and 1977, are summarized in Table 5. A total of 12 samples gave an average 96-h LC50 of 52% $^{V}/v$ to rainbow trout, with values ranging from 30 to more than 87% $^{V}/v$, as measured in static bioassays.

Table 3-C of the "Pollution Control Objectives for the Forest Products Industry" (Pollution Control Board, 1977) specifies 96-h LC50's of 100 and 30% $^{V}/v$ for Levels A and B, respectively. These objectives specify a static bioassay as the accepted

test method but the effluent sampling method (grab or composite) is not specified. A graphical comparison of the effluent bioassay data for Belkin with the provincial objectives is presented in Figure 10.

Federal "Pulp and Paper Effluent Regulations" established by the EPS (1971) for toxicity are different in interpretation to the provincial toxicity objectives. The Federal regulations specify that the effluent shall be regarded as toxic if less than 80% of the fish survive in an effluent concentration of 65% $^{v}/v$ over 96 hours. A graphical comparison of the effluent bioassay data with the federal regulations is presented in Figure 11. From a total of 17 static bioassay tests conducted between February, 1975 and June, 1977, the Belkin effluent was regarded as toxic 82% of the time by Federal standards.

The high level of effluent toxicity measured at Belkin Paperboard has instigated two separate studies (Gordon, 1977 and E.V.S. Consultants, 1978) to determine the source of toxicity in the plant. Gordon (1977) concluded that detergents, which are used in some processes and resin acids may have contributed to the toxicity of the effluent in addition to the high fibre content. A clarifier installed in 1976 failed to reduce the toxicity of the final effluent, possibly because of increased production rates (Swain, 1980). E.V.S. Consultants (1978) attributed the toxicity of the effluent to soluble toxic extractives from waste magazines, office papers and Bauer stock wood chips used in the manufacture of roofing felt. E.V.S. Consultants (1978) recommended that effluent toxicity could be reduced by recycling the most toxic portion and by further clarifying the total mill effluent.

A sawmill and shingle mill operated by B.C. Forest Products Ltd. in Hammond (PE-2756) discharges combined wastewater and cooling water to the main stem of the Fraser River. Cooling water comprises about 99% of the final discharge. Three static bioassays conducted in 1974, 1976 and 1977 showed that the effluent was not toxic to rainbow trout at a concentration of 100% $^{v}/v$, as measured by 96-h LC50's.

The Eburne Sawmill Division (PE-2115) operated by Canadian Forest Products Ltd. has discharged acutely toxic hydraulic debarker effluent to the North Arm of the Fraser River in the past. B.C. Research conducted 11 bioassays on the hydraulic debarker effluent in 1972. The average acute toxicity was 13% $^{v}/v$ and values ranged from less than 5 to 60% $^{v}/v$ as measured by 96-h LC50's in static bioassays. However, all three hydraulic debarkers have since been replaced by dry mechanical debarkers. The only effluent presently discharging to the North Arm consists of cooling water, steam condensate and boiler blowdown.

Canadian Forest Products Ltd. (Canfor) operates a hardboard mill (CE-1656) in New Westminster which has discharged extremely toxic process effluent to the Main Stem of the Fraser River, up to 1977. In 1974, 1975 and 1976 a total of 14 bioassays, conducted from 24-hour composite samples, gave an average 96-h LC50 of 4.9% $^{v}/v$ with values ranging from 3 to 12% $^{v}/v$. Both coho salmon and rainbow trout were used as test species in the bioassays. Rogers et al. (1979) identified the major toxic fractions in the Canfor effluents to be resin acids and neutral compounds. The process effluent from this plant was diverted to the Annacis STP on December 1, 1976.

The Fraser Mills complex (PE-412) is a sawmill and plywood mill operated by Crown Zellerbach Ltd. The complex discharges a mixture of boiler cleanout water, sawmill, plywood mill and barker plant effluent and cooling water to the Main Stem of the Fraser River. Four bioassays conducted in 1971, 1972 and 1973 were not toxic to coho salmon over 96 hours in single concentration bioassays of 65% $^{v}/v$. However, tests conducted by EPS indicated that intermittent acute toxicity may exist during boiler cleanout.

A paper conversion plant (PE-3265) operated by Crown Zellerbach Ltd. near Steveston has discharged effluent to the Main Arm of the Fraser in the past. One bioassay conducted on a sample of compressor cooling water and glue wastewater in 1974 showed the effluent was not acutely toxic to coho salmon at 100% concentration. The process effluent was diverted to the Lulu STP in March, 1976. The cooling water is discharged to Woodward's Slough.

Island Paper Mill (PE-35), a division of MacMilan Bloedel Ltd., is located on Annacis Island and has discharged effluent directly to the Main Arm of the Fraser River in the past. A total of 24 static bioassays conducted in 1976 and 1977 gave an average 96-h LC50 of 93% $^{v}/v$, with values ranging from 45.5 to more than 100% $^{v}/v$. The paper mill effluent was diverted to the Annacis STP in October, 1978.

The White Pine Division (PE-1666), operated by MacMillan Bloedel Ltd., is a sawmill located on the North Arm of the Fraser River. One static bioassay conducted in 1972 showed the effluent was not toxic to coho salmon at 100% concentration, as measured by a 96-h LC50. The hydraulic debarkers were replaced by dry mechanical debarkers in 1977 and the bark press effluent was diverted to the Annacis STP in 1978. Mill effluent still discharging to the Main Arm is composed mainly of cooling water. Tests conducted by EPS indicated that intermittent toxicity may exist during boiler cleanout.

The MacMillan Bloedel Ltd., specialty board plant (CE-4248) is located on the North Arm of the Fraser River. The effluent was not toxic to coho salmon at 100% concentration as measured by a 96-h LC50 from a single sample collected in 1973. The wastewater from the specialty board plant is composed mostly of cooling water. This wastewater plus the effluent from the neighbouring Vancouver Plywood Division of MacMillan Bloedel is discharged to a ditch and the combined effluents flow to the North Arm. The Vancouver Plywood Division effluent is also composed mostly of cooling water but no bioassay data existed for this discharge.

Scott Paper Ltd. (PE-335) originally discharged effluent to the North Arm via two separate outfalls. These two discharges were from the groundwood mill (PE-335-01) and the paper mill (PE-335-02). Three bioassays conducted on 24-hour composite samples from the groundwood mill effluent in 1975 showed the effluent was not toxic to coho salmon at 100% concentration as indicated by 96-h LC50's. For the paper mill effluent, nineteen bioassays were conducted on 24-hour composite samples in 1975, 1976 and 1977. Fifteen of the tests showed no toxicity to either rainbow trout or coho salmon at 100% concentration as indicated by 96-h LC50's. Four of the tests showed slight toxicity to the fish at 100% effluent concentration. The groundwood mill effluent was diverted to the Annacis STP in August, 1977 but the paper mill effluent continues to be discharged to the North Arm.

The Silvichemical Division (PE-3087) of Rayonier Canada Ltd. discharged effluent to the North Arm, up to 1976, via two separate outfalls. One bioassay conducted on the combined extraction plant effluent and condenser cooling water (PE-3087-01) in 1974 showed toxicity to coho salmon at a concentration of 45% $^{v}/v$, as measured by a 96-h LC50. The drying and evaporator plant effluent (PE-3087-02) gave a 96-h LC50 of 75% $^{v}/v$ to coho salmon from one bioassay conducted in 1974. This plant ceased operations in April, 1976.

6.1.3 Impact of the Forest Products Industry in the River/Estuary

The diversion of acutely toxic forest products industry effluent to the sewerage system may increase the effluent toxicity at the sewage treatment plants. Servizi et al. (1978) conducted continuous flow bioassays at the Annacis STP at the time of the Canadian Forest Products hardboard mill connection. Although no increase in acute toxicity was noted, the authors suggested that wet weather sewage flows may have obscured the toxic effects of the hardboard plant effluent at Annacis.

The acute toxicity data for the Belkin Paperboard effluent were extrapolated to the North Arm by the method described in Section 3. This calculation gave a maximum TCr of 0.02 toxic units in the river assuming a uniform dilution and an extreme low river flow. This value is between the safe levels of 0.01 and 0.05 toxic units for persistent and non-persistent toxicants respectively (National Academy of Sciences and National Academy of Engineering, 1973). Marier (1973) has suggested a safe level of 0.05 toxic units for pulp and paper effluent. The TCr calculated for the Belkin effluent is strictly a flow proportioned estimate of potential toxicity in the river and does not consider higher concentrations which may be encountered in the initial dilution zone. This value was calculated from static bioassay results rather than the more sensitive continuous flow bioassays.

The high fibre content of the Belkin effluent may also have a detrimental effect on the aquatic biota which cannot be estimated from the data available. Marier (1978) states that fibres discharged from pulping processes, bark and other wood wastes can form deposits on the river bottom producing anaerobic conditions. This condition can be detrimental to fish stocks due to the destruction of feeding and spawning grounds.

Bioassay data for the majority of the forest products industries in the study area are outdated because:

(1) the effluents have been diverted to the sewerage system; or

(2) the industrial facilities have been upgraded; or

(3) the discharges have been eliminated.

The few remaining industries not included in the above categories, for which bioassay data were available, usually discharged an effluent that was not acutely toxic to fish. However, data for some of these industries were based on single bioassays and therefore may not be representative of the normal quality of the effluent. For these reasons the toxicity emission rates for the industries presented in Table 5 cannot be applied to the river situation by the method described in Section 3 of this report. The values have been included for a general comparison to the toxicity emission rates of other industries. They also provide an estimate of the magnitude of toxicity loadings for discharges which have been diverted to the sewerage system.

The bioassay data compiled for the forest products industry applies only to point discharges. Other industry sources from which toxicants may originate include surface runoff from the mill yards, hog fuel leachates and log booming in the river. Hog fuel and woodwaste leachates are discussed in Section 5.7 of this report.

The storage of log booms in the Lower Fraser River is a common practice. Schaumburg (1973) conducted laboratory studies to simulate leachate problems which may be associated with the water storage of logs. A log leachate solution was prepared by submerging 50 cm log sections in 150-litre tanks for seven days. The species of timber selected for the study were Douglas fir, ponderosa pine and hemlock. Tests conducted on the leachate solution for the pine, hemlock and older Douglas fir sections, with and without bark, showed it was not acutely toxic to juvenile chinook salmon at 100% concentration, as measured by 96-h LC50's in static bioassays. Leachate from young Douglas fir log sections showed slight toxicity and the log sections without bark were more toxic than comparable sections with the bark intact.

Servizi et al. (1971) conducted laboratory studies to determine the effects of decaying bark in fish spawning areas. Simulated spawning areas were constructed by depositing sockeye salmon eggs in gravel-filled incubation boxes. Bark was added to the boxes and a continuous flow of water passed over the mixtures. From the results of the tests the authors generally concluded that the oxygen demand of bark may be sufficient to create hazardous conditions in spawning grounds. The tests also indicated that fine bark particles clogged the gravel, causing mortalities of eggs. Furthermore it was noted that the bacteria, Sphaerotilus sp., could grow on bark and suffocate eggs and alevins due to its filamentous nature. The accumulation of bark debris in actual salmon spawning streams in the study area has not been documented.

6.1.4 Summary and Conclusions

The large volume of toxic wastewater diverted to the Annacis Island STP from the Canadian Forest Products Hardboard mill (CE-1656) could increase the toxicity of the plant effluent.

Belkin Paperboard effluent exceeded Level A (96-h LC50 of 100%) of the provincial objectives for toxicity 100% of the time, but was equivalent to or better than Level B 100% of the time. By federal standards, the Belkin effluent was regarded as toxic 82% of the time. The plant has been upgraded since these data were collected.

Extrapolation of the Belkin effluent toxicity to the river situation indicated conditions were between certain safe levels for fish except outside of the initial dilution zone. The high PCB levels measured in the sediments near the outfall area may have a detrimental effect on aquatic biota.

In several cases, the bioassay data collected from the forest products industry discharges are no longer relevant as a result of facility upgrading, elimination of a discharge or diversion of process effluent to the sewerage system.

Laboratory studies have indicated that leachate from log booms is sometimes slightly toxic to fish. Of greater importance is the accumulation of bark on the river bottom from log booming practices which can destroy spawning and feeding grounds. Although this is not expected to be a problem in the main river channels, it may produce anaerobic conditions in areas of little mixing, such as sloughs and backwaters.

6.1.5 Recommendations

Considering the extreme toxicity of effluent discharged to the Annacis STP from the Canadian Forest Products hardboard mill (CE-1656), control measures may be needed to minimize the toxicity of this effluent. More recent bioassay monitoring data are required for this effluent to determine its present toxicity.

Present monitoring programs for industrial effluents discharged to the sewerage system are inadequate and the industrial effluent toxicity cannot be assessed. Bioassay monitoring data are required for these sources to determine if control measures are required.

Continuous flow bioassays using Fraser River water for the test sample dilutions, should be conducted at Belkin Paperboard to obtain more accurate estimates of potential toxicity in the North Arm. E.V.S. consultants (1978) have recommended that effluent toxicity be reduced by recycling the most toxic portion and by further clarifying the total mill effluent, and these improvements are presently underway.

Further bioassay monitoring data are required for forest products industries still discharging to the river.

6.2 Chemical Industry

Bioassay data have been collected for the process effluent discharged from a phenol plant on Tilbury Island operated by Dow Chemical Ltd., (PE-41).

The process effluent from the phenol plant is subjected to biological treatment (activated sludge) before mixing with cooling water and final discharge to the Main Arm of the Fraser River. According to a Pollution Control Branch site inspection report by Wong (1977), the effluent quality had met the Pollution Control Permit specifications. Wong (1977) noted that the fluctuation of suspended solids in the effluent and the possibility of shock loadings of acetic acid to the biological treatment plant were the only areas of concern.

6.2.1 Comparison of Bioassay Monitoring Data With Provincial Objectives

From 1974 to 1976 B.C. Research conducted a total of 11 static bioassays on the process effluent discharged from the Dow phenol plant using both rainbow trout and coho salmon. The results of these tests gave an average 96-h LC50 of 77.2% $^{v}/v$, with values ranging from 8.5 to over 100% $^{v}/v$. Sixty four percent of the tests were non-acutely toxic at 100% effluent concentration. The variability of the bioassay results indicates that although the majority of the tests were non-acutely toxic at 100% effluent concentration, sporadic toxic discharges were apparent. The bioassay data are summarized in Table 6.

Table IX of the "Pollution Control Objectives for the Chemical and Petroleum Industries of British Columbia" (Pollution Control Board, 1974) specifies 96-h LC50's of 100, 90 and 50% $^{v}/v$ for Levels A, B and C, respectively. A graphical comparison of the bioassay results with the Pollution Control objectives is shown in Figure 12. The effluent toxicity exceeded Level C in 18% of the tests, Level B in 36% of the tests but corresponded to Level A in 64% of the tests.

6.2.2 Toxic Components of the Effluent

Chemical analyses for the effluent samples used in the bioassay tests included COD, BOD_5, phenols and suspended solids. No correlation was noted between the bioassays which exhibited toxicity and the results of the chemical analyses. Phenol concentrations were less than 0.02 mg/L for all the effluent samples which exhibited toxicity. The lowest recorded lethal concentration of phenol from the literature was 0.079 mg/L which was lethal to minnows in 30 minutes (McKee and Wolf, 1963). Clarke

(1974) suggests an acceptable limit of 0.1 mg/L phenol for the protection of freshwater aquatic life. For the most toxic effluent sample (96-h LC50 of 8.5% $^{v}/v$) suspended solids measured 8.0 mg/L. The lowest recorded toxic concentration for inert suspended solids was 82 mg/L which was lethal to Daphnia (Clarke, 1974). The acceptable limit of suspended solids suggested for the protection of freshwater aquatic life was 25 mg/L (Clarke, 1974). The results of the chemical analyses indicate that compounds other than those measured, contributed to the acute toxicity of the effluent.

6.2.3 Dilution of Effluent in the River/Estuary

A TCr of 0.4×10^{-4} toxic units was calculated for the phenol plant process effluent in the Main Arm of the Fraser River by the method described in Section 3. This value was calculated using the most toxic sample measured at Dow Chemical (96-h LC50 of 8.5% $^{v}/v$) and the extreme low flow in the Main Arm (4.97×10^{7} m^{3}/day). Compared to the safe levels of 0.01 toxic units for persistent toxicants recommended by the National Academy of Sciences and the National Academy of Engineering (1973), the calculated TCr indicates a negligible toxic effect after complete uniform dispersion of the effluent in the river.

6.2.4 Summary and Conclusions

The Dow phenol plant effluent was generally not toxic to fish except, at times, when occasional toxic "slugs" of effluent were apparent.

Toxicants other than phenol appeared to be responsible for the acute toxicity of the effluent, but were not identified.

Extrapolation of the acute toxicity data to the river situation indicated a negligible effect on fish outside the initial dilution zone. Safe conditions to fish probably occur inside the initial dilution zone most of the time except during occasional toxic "slugs" of effluent.

6.2.5 Recommendations

Bioassays should be conducted monthly on the plant effluent. If highly toxic discharges persist, corrective measures should be taken.

Identification of the toxic components may help to determine the proper corrective measures.

6.3 Petroleum Refineries

Three oil refineries (Chevron, PE-447; Shell, PE-449; and Gulf Oil, PE-22) which previously discharged to Burrard Inlet, have diverted all process effluents to the sewerage system within the past few years. The Chevron oil refinery effluent was diverted to the Iona STP in June, 1977. The Gulf Oil refinery effluent was diverted to the Annacis STP when the plant began operations in June, 1975. The Shell refinery effluent was diverted to the Annacis STP in December, 1975. These oil refineries are responsible for approximately 11% of the industrial wastewater discharged to the sewerage system. The bioassay data for the oil refineries are summarized in Table 6.

6.3.1 Federal Toxicity Guidelines for Petroleum Refineries

Federal toxicity guidelines have been established for petroleum refinery effluent by the EPS (1974). The acceptable level of effluent toxicity is defined as 50% survival of the test species over 96 hours in an effluent concentration determined from the quantity of crude oil processed and the effluent discharge rate. The rationale for determining the effluent concentration in this way was to encourage better effluent quality without penalizing refineries for low water consumption levels. In other words, a newer more efficient refinery with low water usage would tend to discharge a more toxic but smaller volume of effluent than an older refinery designed for greater water consumption. Therefore, a refinery with less water consumption is granted a dilution allowance when determining the sample concentrations for the bioassay tests. The data required to calculate a dilution allowance for the petroleum refineries were not available, thus, comparisons are not possible with the federal guidelines.

6.3.2 Provincial Objectives for Petroleum Refineries

Table VIII of the "Pollution Control Objectives for the Chemical and Petroleum Industries of British Columbia" (Pollution Control Board, 1974) specify 96-h LC50's of 75, 50 and 5% $^{v}/v$ for Levels A, B and C, respectively, and apply to discharges to marine waters. Objectives for refinery effluent discharged to fresh water specify 96-h LC50's of 100, 75 and 5% $^{v}/v$ for Levels A, B and C, respectively. These levels are imposed on an "as required basis" by the Director of the Pollution Control Branch but do not apply after the effluent has been diverted to the sewerage system. Toxicity objective levels for the refineries had not been decided upon prior to the sewer connections and therefore were never included in the Pollution Control Branch permits (Chevron, PE-447; Shell, PE-449 and Gulf Oil, PE-22).

6.3.3 Chevron Oil Refinery

B.C. Research conducted a total of 22 static bioassays on the Chevron refinery effluent from March, 1973 to November, 1978. The tests indicated that the effluent was extremely toxic to rainbow trout until a sour water stripper was installed at the refinery in January, 1977. A total of 15 bioassays conducted prior to the installation of the sour water stripper gave an average 96-h LC50 of 1.0% $^{v}/v$ with values ranging from 0.16 to 3.0% $^{v}/v$. Comparison of these bioassay data with the provincial toxicity objectives for petroleum refinery effluent discharged to marine waters indicated that Level C was exceeded 100% of the time (Figure 13). The effluent toxicity was reduced considerably after the installation of the sour water stripper. Three of seven bioassays to the end of 1978 were not toxic to rainbow trout at 100% $^{v}/v$ refinery effluent concentration.

The Chevron refinery effluent has not affected the toxicity of the Iona STP effluent after the connection. A total of nine bioassays conducted on the Iona STP effluent in 1978 by B.C. Research were all non-acutely toxic to rainbow trout at 100% $^{v}/v$ effluent concentration, as indicated by 96-h LC50's. As the sour water stripper installation at the refinery closely coincided with the connection to the sewerage system, it was assumed that the improved effluent quality may have prevented an increase in toxicity at the Iona STP. Also, storm water inputs to the sewerage system may obscure any toxic effects of the refinery effluent at the Iona STP.

6.3.4 Gulf Oil Refinery

B.C. Research conducted a total of 21 static bioassays on the Gulf Oil refinery effluent after April, 1978. These tests gave an average 96-h LC50 of 50% $^{v}/v$ with values ranging from 7.5 to more than 100% $^{v}/v$ for both coho salmon and rainbow trout. The large range of toxicity values for the refinery effluent is indicative of sporadic toxic discharges. During the period of discharge to Burrard Inlet the effluent exceeded Level B of the provincial toxicity objectives for petroleum refinery effluent 67% of the time (Figure 14). The refinery effluent was diverted from Burrard Inlet to the sewerage system in December, 1974 and was discharged via the Annacis STP to the Main Arm of the Fraser River when the plant began operations in June, 1975. Thus, any toxic effects of the refinery effluent would be included in all the bioassays conducted at the Annacis STP.

6.3.5 Shell Oil Refinery

B.C. Research conducted a total of 16 static bioassays on the Shell Oil refinery effluent from April, 1972 to May, 1975. These tests gave an average 96-h LC50 of 49.2% $^{v}/v$, with values ranging from 2.5 to more than 100% $^{v}/v$ for both coho salmon and rainbow trout. The range of toxicity values for the Shell refinery effluent was similar to that for the Gulf Oil refinery effluent and is indicative of sporadic toxic discharges. These 16 bioassays were all conducted during the period of discharge to Burrard Inlet. Comparison of these bioassay data with the provincial toxicity objectives for petroleum refinery effluent discharged to marine waters indicated that Level C was exceeded 13% of the time; Level B 47% of the time and Level A 60% of the time (Figure 15).

A series of 24-h LC50's has been conducted on the Shell refinery effluent after it was diverted to the Annacis STP in December, 1975. A total of 19 static bioassays from July, 1976 to December, 1978 gave an average 24-h LC50 of 90% $^{v}/v$,with values ranging from 61 to more than 100% $^{v}/v$. The results of the 24-h LC50's are not comparable with the results of the 96-h LC50's. The difference in the time period of the two sets of tests would explain the lower mortality in the 24-hour bioassays as compared to the 96 hour bioassays. The results of the 24-h LC50 bioassays for the Shell refinery effluent are presented in Figure 16. All the bioassays for the Annacis STP effluent were conducted after the Shell refinery connection, therefore any toxic effects of the refinery effluent would be included in the measurements for Annacis.

6.3.6 Toxic Components of the Petroleum Refinery Effluent

Components of the oil refinery effluents which have been implicated as contributing to the acute toxicity include cyanide, ammonia and sulphides.

On two occasions the Shell refinery effluent has shown a reduction in acute toxicity when the catalytic cracking unit was not in operation. The 96-h LC50's of the effluent on these two occasions were 90 and 75% $^{v}/v$. Two bioassay samples collected under normal operating conditions, each shortly before the catalytic cracker became inoperative, gave 96-h LC50's of 7 and 5.1% $^{v}/v$. Federal Fisheries suggested that the lower toxicity values, obtained when the catalytic cracker was inoperative, may be associated with lower ammonia levels (Weldon, PCB File PE-449). Analytical results appeared to confirm this on at least one of the two occasions as follows:

	96-h LC50 (% $^{v}/v$)	Ammonia (mg/l)
Normal Effluent	5.1	55.0
Catalytic Cracker Inoperative	75.0	18.0

Weldon (PCB File PE-449) suggested that the different bioassay results also may be due to differences in cyanide concentrations. Cyanides are produced in the catalytic cracking process however, no cyanide analyses were available for the bioassay samples. McKee and Wolf (1963) state that ammonia and cyanide ions together are more toxic than either ion alone.

After the installation of the sour water stripper at the Chevron oil refinery, the acute toxicity of the process effluent was reduced significantly. A sour water stripper is reported to reduce sulphide and ammonia levels in the process effluent (Weldon, PCB File PE-449). Hence, it would appear that sulphide and ammonia contributed to the acute toxicity of the Chevron refinery effluent prior to the installation of the sour water stripper.

Refinery effluent components other than ammonia, sulphides and cyanide, also may contribute to the acute toxicity of the process effluent. However, no correlations have been made between chemical analyses and acute toxicity of the effluent.

6.3.7 Summary and Conclusions

The Chevron refinery effluent was extremely toxic to fish prior to the installation of a sour water stripper. The added treatment considerably improved the effluent quality and may have prevented an increase in toxicity of the Iona STP effluent when the Chevron effluent was diverted to the sewerage system.

Bioassay monitoring data for the Gulf Oil refinery has indicated sporadic toxic discharges. Since this refinery effluent was discharged to the Annacis STP when the plant began operations, any toxic effects of the effluent would be included in tests conducted at Annacis. The degree of toxic influence on the Annacis effluent is not known.

Bioassay monitoring data for the Shell Oil refinery has indicated sporadic toxic discharges. A series of 24-h LC50 bioassays conducted after the refinery effluent was diverted to Annacis has indicated moderately toxic to non-toxic effluent. The short test periods of these bioassays may underestimate the effluent toxicity.

Toxic components of petroleum refinery effluent include cyanide, ammonia and sulphides. Other substances may also contribute to the toxicity.

6.3.8 Recommendations

Static bioassays should be conducted on the petroleum refinery effluents monthly and if high levels of toxicity persist, further treatment at the refineries should be considered.

The further identification of toxic components of refinery effluent may help to determine the best available technology for treatment.

The 24-h LC50 bioassays conducted on the Shell refinery effluent should be replaced by 96-h LC50 bioassays.

6.4 Food Processing Industries

Acute toxicity data have been collected for only a few food processing industries which discharge effluent in the study area. These industries include a fruit and vegetable cannery, two slaughterhouse operations, a poultry processing plant, a pet food processing plant and three fish processing plants. The toxicity data for these operations are summarized in Table 7.

6.4.1 Provincial Toxicity Requirements for Food Processing Industries

The only provincial toxicity requirements as yet established for the food processing industries are guidelines for the quality of receiving waters. Table 20 of the "Pollution Control Objectives for Food-processing, Agriculturally Orientated, and Other Miscellaneous Industries of British Columbia", (Pollution Control Board, 1975) states that toxicity is not to be detected outside of the initial dilution zone. The initial dilution zone for rivers is defined as waters contained within an area extending 300 feet down current from a point of discharge and within a lateral distance not exceeding one-half the width of a river or stream at the point of discharge. For marine waters, the initial dilution zone is an area extending 300 feet in all directions from the point of discharge. No toxicity data were available for the receiving waters to compare with the provincial objectives.

6.4.2 Federal Toxicity Requirements for Food Processing Industries

For the food processing industries listed in Table 7, federal toxicity requirements have been established only for effluent originating from meat and poultry processing. "Meat and Poultry Products Plant Liquid Effluent Regulations and Guidelines" (EPS, 1977) specify greater than 50% survival of rainbow trout in 100% effluent concentration. The test methods call for a representative composite effluent sample used in:

(1) a continuous flow bioassay to be conducted on a periodic basis by the Minister or his designated representative to determine the acute lethality of a plant effluent; and

(2) a static bioassay to be conducted by each plant as a routine check on effluent lethality.

Federal guidelines have been published separately for fish processing operations (EPS, 1975) however, toxicity requirements are not included. The guidelines generally suggest that all fish processing plants should apply the best practicable treatment to their liquid effluent.

Data for only a few scattered bioassays using grab samples and coho salmon were available for the food processing industries. Neither the test methods or test species are those specified by EPS (1977). Thus, comparisons cannot be made between the bioassay results and the federal toxicity requirements.

6.4.3 Discussion of Bioassay Data

The small amount of bioassay data indicates that the effluents discharged from food processing operations can be acutely toxic to fish.

One bioassay conducted on a peach sediment solution obtained from a settling tank at Berryland Canning Co. Ltd. (PE-260) showed the solution was toxic to coho salmon at 42% $^{v}/v$, as measured in a 96-h LC50 static bioassay.

Slaughterhouse effluent discharged from Clappison Packers (PE-3743) in Haney was not toxic to coho salmon at 100% concentration, as measured in a 96-h LC50 static bioassay.

Slaughterhouse effluent discharged from Richmond Packing Ltd. (PE-90) is treated by a coal filtration system before final discharge to the North Arm. The final effluent was not toxic to coho salmon at 100% concentration in two tests, as measured by 96-h LC50 static bioassays.

Panco Poultry Ltd. (PE-79), a poultry processing plant in Delta, originally discharged effluent to Bear Creek and the Serpentine River. In one bioassay conducted in 1974, the effluent gave a 96-h LC50 of 36.5% $^{V}/v$. The effluent was diverted to the municipal sewer on February 19, 1968, and this sewer now discharges to the Annacis STP.

Standard Brands Ltd. (PE-2063), a pet food processing plant in Richmond, originally discharged effluent to the North Arm. A single static bioassay conducted on the effluent in 1974 gave a 96-h LC50 of 24.5% $^{V}/v$ to coho salmon. The process effluent was diverted to the Lulu STP on January 16, 1975.

The Cassiar Packing Co. (PE-1975), a fish processing plant in Richmond, discharges process effluent to the Main Arm. A single static bioassay conducted on the effluent in 1973 gave a 96-h LC50 of 13.5% $^{V}/v$ to coho salmon.

The B.C. Packers Ltd. Imperial Plant (PE-1830), a fish processing plant in Steveston, discharges process effluent to Cannery Channel on the Main Arm. A single bioassay conducted on the effluent in 1973 gave a 96-h LC50 of 56% $^{V}/v$ to coho salmon.

The Canadian Fishing Company Ltd. Home Plant (PE-1813) originally discharged fish processing effluent to Burrard Inlet. A single bioassay conducted on the effluent in 1973 showed that it was toxic to coho salmon at 100% concentration but the 96-h LC50 was not established. The effluent was diverted to the Iona STP on August 15, 1976.

The high BOD of food processing effluent is expected to be an indirect cause of the acute toxicity measured because it reduces dissolved oxygen. Food processing effluent is readily biodegradable and therefore, the acute toxicity is not expected to be a problem in the main river channels, where there is an abundance of dissolved oxygen. However, in areas of limited dilution, such as sloughs, backwaters and small tributaries, the effluent may lower the dissolved oxygen content to levels which are detrimental to fish and other aquatic biota.

In several cases, the toxicity data listed in Table 7 are not applicable due to diversion of the wastewaters to the sewerage system. Therefore, the toxicity emission rates calculated for these industries in Table 7 cannot be applied to the river situation because the effective reduction of acute toxicity in the sewage treatment plants and toxicant decay in the sewers is not known. The results have been included for a general comparison to other effluents discharged to the sewerage system. The acute toxicity component from these sources would be included in the bioassay results obtained from the sewage treatment plants.

6.4.4 Summary and Conclusions

The small amount of bioassay data available for the food processing industries is insufficient to accurately assess potential toxic conditions in the river.

Due to the absence of relevant bioassay data, comparisons cannot be made with provincial or federal toxicity requirements.

The high BOD of food processing effluent is expected to be the major cause of the acute toxicity.

Food processing effluent is not expected to have a measureable toxic effect in the main river channels due to the biodegradable nature of the effluent. Food processing effluent may cause anaerobic conditions in areas of limited dilution such as sloughs, backwaters and small tributaries.

6.4.5 Recommendations

More recent bioassay data are required from the food processing industries to isolate areas of concern. In addition, dissolved oxygen measurements at locations where limited receiving water dilution is available may indicate the need for treatment to reduce BOD levels.

6.5 Metal Finishing Industries

A small amount of bioassay data was available for two battery manufacturing operations and for two metal finishing plants which discharge to the study area. The bioassay data for these industries are summarized in Table 8.

6.5.1 Provincial Toxicity Requirements for Metal Finishing Industries

The only provincial toxicity requirements as yet established for the metal finishing industries are guidelines for the quality of receiving waters. The Pollution Control Board (1975) states that toxicity is not to be detected outside the initial dilution zone.

6.5.2 Federal Toxicity Requirements for Metal Finishing Industries

Federal guidelines have been published for metal finishing plants (EPS, 1977) however, toxicity requirements have not been included. Insufficient bioassay data have been collected from the metal finishing plants to provide a basis to establish a guideline for toxicity. However, it was stated by EPS (1977), that acute bioassay tests may be included in the guidelines at a later date. At present, federal guidelines generally stress good house-keeping practices to help prevent the contamination of effluent with heavy metals.

6.5.3 Discussion of Bioassay Data

Two battery manufacturing operations in Richmond, Metalex Products Ltd. (CE-2311) and Varta Batteries, have discharged acutely toxic effluent to the North Arm in the past. Five bioassays conducted on effluent discharged from Metalex Products in 1972 and 1973 gave an average 96-h LC50 of 1.5% $^{v}/v$, with results ranging from 0.23 to 6.15% $^{v}/v$. One bioassay conducted on effluent discharged from Varta Batteries in 1972 gave a 96-h LC50 of 2.4% $^{v}/v$. Effluents from both operations have been diverted to the sewerage system for discharge via the Lulu STP. Metalex Products effluent was diverted to the sewerage system on January 26, 1976 and Varta Batteries effluent on January 10, 1978.

Titan Steel and Wire Co., (PE-161), a metal finishing plant in Surrey, discharges process effluent to the Main Arm. This effluent has been extremely toxic to rainbow trout at times. Six bioassays conducted in 1976 and 1977 gave an average 96-h LC50 of 67% $^{v}/v$ with results ranging from 0.14 to more than 100% $^{v}/v$. The large range of the 96-h LC50 values is indicative of intermittent toxic discharges. The process effluent from this plant is to be diverted to the Annacis STP in the near future.

Tree Island Steel Co. Ltd. (PE-3190), a metal finishing plant in Richmond, discharges process effluent to a lagoon, which is adjacent to a blind channel connected to the North Arm at one end. According to a technical assessment of the plant by the Pollution Control Branch (PCB File, PE-3190) a large portion of the effluent is expected to exfiltrate to the blind channel, considering the proximity of the lagoon. One bioassay conducted on the lagoon contents in 1976 gave a 96-h LC50 of 4.2% $^{v}/v$. However, the actual toxic effect in the blind channel cannot be determined from the available information. Metal analyses of invertebrates provided evidence of bioaccumulation of zinc by oligochaetes collected in the blind channel (Stancil, 1980, data on site downstream from Poplar Island).

The Tree Island Steel Co. also discharges up to 1500 m^3/day of contaminated cooling water to the North Arm. No bioassay data were available for this discharge.

Metal finishing plants are a major source of trace metals in the Lower Fraser River and Estuary. The acute toxicity of trace metals in the river is discussed by Drinnan and Clark (1980). These authors reviewed all the available water quality data for the Lower Fraser River and Estuary. In summary, they concluded there was no toxicity problem in the river for most metals. About 25% of the total copper and zinc measurements taken in the river exceeded some recommended criteria. Whether this constitutes a toxicity problem is not known since most of the metal is associated with particulate material.

6.5.4 Summary and Conclusions

The effect of diverting battery manufacturing and metal finishing plant effluents to the sewage treatment plants is not known. In view of the extreme toxicity sometimes measured in these effluents, toxicity at the sewage treatment plants may increase.

Tree Island Steel discharges process effluent to an exfiltration pond located adjacent to a blind channel. The lagoon contents are toxic to fish and evidence of metal bioaccumulation in aquatic biota have been noted in the blind channel. This plant also discharges contaminated cooling water to the North Arm.

The toxic effect of metals in the river is not known.

6.5.5 Recommendations

The practice of diverting acutely toxic metal contaminated effluents to the sewage treatment plants requires review. Control measures should be established at the industries to minimize the discharge of these materials to sewage treatment plants.

In-plant control measures should be established to reduce metal contents of certain effluents discharging directly to the river. In addition, cooling water should be separated from wastewater streams to prevent contamination of cooling water discharges.

The acute toxicity of heavy metals in the river should be investigated. If possible, sublethal and chronic effects on aquatic biota should be measured.

Bioassays to determine the need for source control should be conducted on any industrial waste streams which are potential sources of toxicity.

6.6 Miscellaneous Industries

Bioassay data were available for a cement plant and a car dewaxing operation which discharge effluent within the study area. The bioassay data for these operations are summarized in Table 9.

6.6.1 Provincial Toxicity Requirements

The only provincial toxicity requirements as yet established for miscellaneous industries are guidelines for the quality of receiving waters. The Pollution Control Board (1975) states that toxicity is not to be detected outside the initial dilution zone.

6.6.2 Federal Toxicity Requirements

No federal toxicity requirements have been established for these industries.

6.6.3 Discussion of Bioassay Data

Lafarge Canada Ltd. (PE-42), a cement plant in Richmond, discharges effluent to the Main arm of the Fraser River. A total of 19 static bioassays on the final effluent gave an average 96-h LC50 of 93.2% $^{v}/v$ with results ranging from 56 to more than 100% $^{v}/v$. The effluent was not toxic to rainbow trout and coho salmon at 100% effluent concentration, 65% of the time.

According to a review of industrial effluents by Swain (1980) the Lafarge wastewater was normally alkaline and ranged between 10.3 and 13 pH units. Drinnan and Clark (1980) have expressed concern about high pH wastewaters discharged to the Fraser River, as the buffering capacity of the river toward alkaline discharges is poor. An increase of alkaline conditions in the river could cause an increase in un-ionized ammonia concentrations. Un-ionized ammonia has been widely accepted as the toxic fraction of total ammonia nitrogen measurements.

Fraser Wharves Ltd. (PE-1621), a car dewaxing operation in Richmond, has occasionally discharged acutely toxic effluent to the Main arm of the Fraser River. Two static bioassays conducted in 1973 and 1975 gave 96-h LC50's of 21 and 43% $^{v}/v$, respectively.

Swain (1980) reported that improvements in the wastewater treatment system may have been made after the bioassays were conducted.

6.6.4 Summary and Conclusions

Effluent discharged from Lafarge Canada Ltd. (PE-42) was usually non-toxic to fish. However, a concern has been expressed for the high pH of the effluent which may increase the un-ionized fraction of ammonia and ammonia salts in the river.

6.6.5 Recommendations

Additional facilities may be required at Lafarge Canada Ltd. (PE-42) to reduce the high pH of the effluent.

More recent bioassays are needed for Fraser Wharves (PE-1621) to determine the reduction in acute toxicity from the improved treatment facilities.

6.7 Source Control

Increased treatment facilities at the sewage treatment plants were discussed in Section 5.5 as one method for reducing the toxicity of effluent discharged from the sewage treatment plants.

An alternative method for reducing the toxicity of municipal effluent is control at the source. Tanner et al. (1973) have reported that sewers servicing residential/industrial areas were generally more toxic than those servicing residential areas alone. By controlling the discharges from a few large industries, substantial reductions in the toxicity of municipal effluent may be achieved.

Westwater (1976) reported that an industrial source control program in Los Angeles has reduced mercury loadings to the sewage treatment plants from 15 kg/day to 3 kg/day.

The installation of a sour water stripper at the Chevron Oil refinery (PE-447) in Burnaby has significantly reduced the refinery effluent toxicity as discussed in section 6.3.3. This treatment may have prevented increased toxicity of the Iona STP effluent when the refinery effluent was diverted to the sewerage system.

A "Hazardous, Toxic and Nuisance Wastes Survey" conducted by the GVS & DD (1978) has indicated the need for source control. In summary, the survey generally indicated that existing industrial pretreament facilities are ineffective and monitoring programs are inadequate because of jurisdictional control problems. New legislation possibly could be established to give the GVS & DD more direct power to institute a systematic source control program. If high levels of toxicity persist in the sewage treatment plant effluents after industrial source control has been established, further sewage treatment options should be examined at the central plants.

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FIGURE I

SEWERAGE AREAS FOR THE MAIN TREATMENT PLANTS

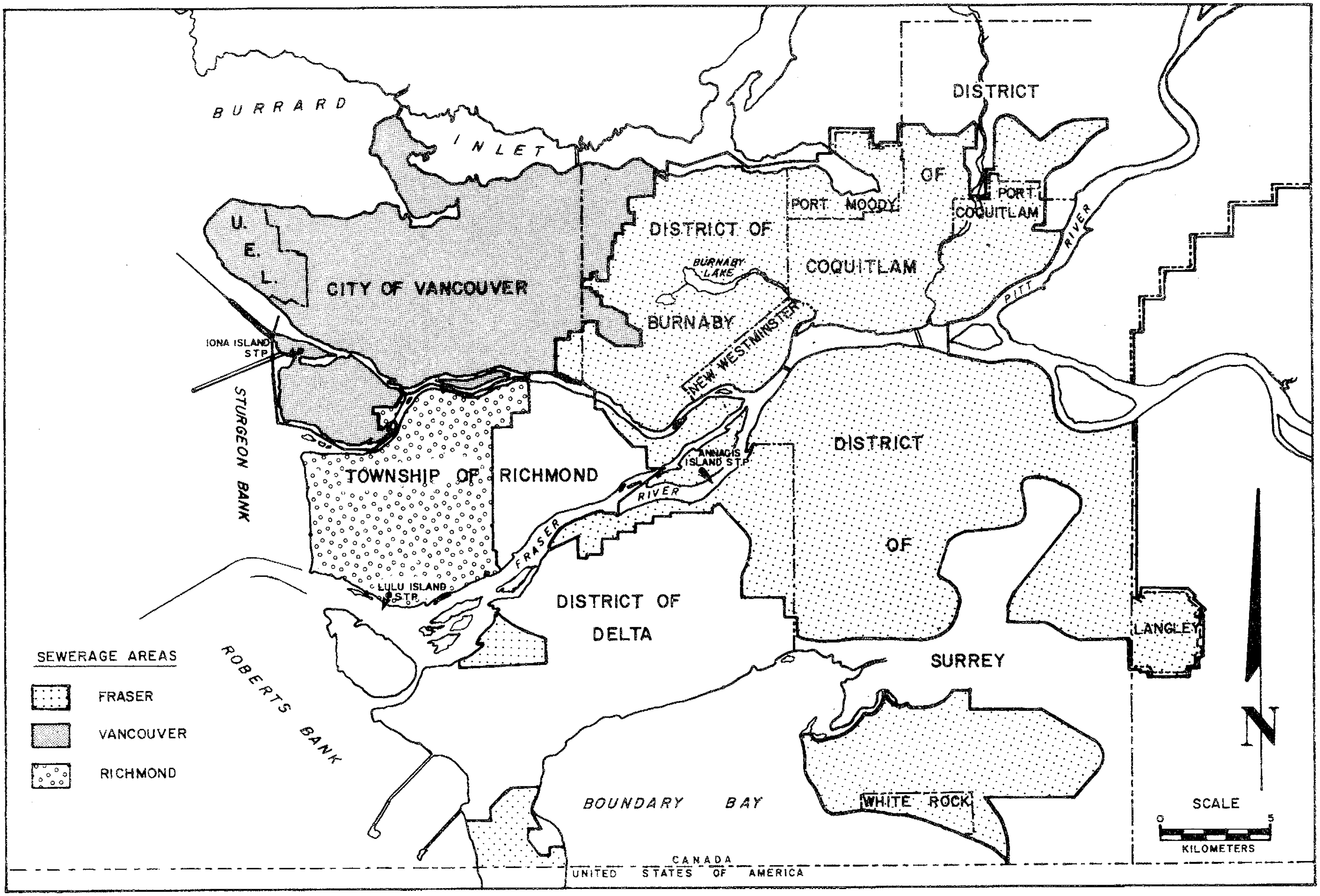


FIGURE 2

LOCATION OF IONA ISLAND SEWAGE TREATMENT PLANT AND OUTFALL CHANNEL

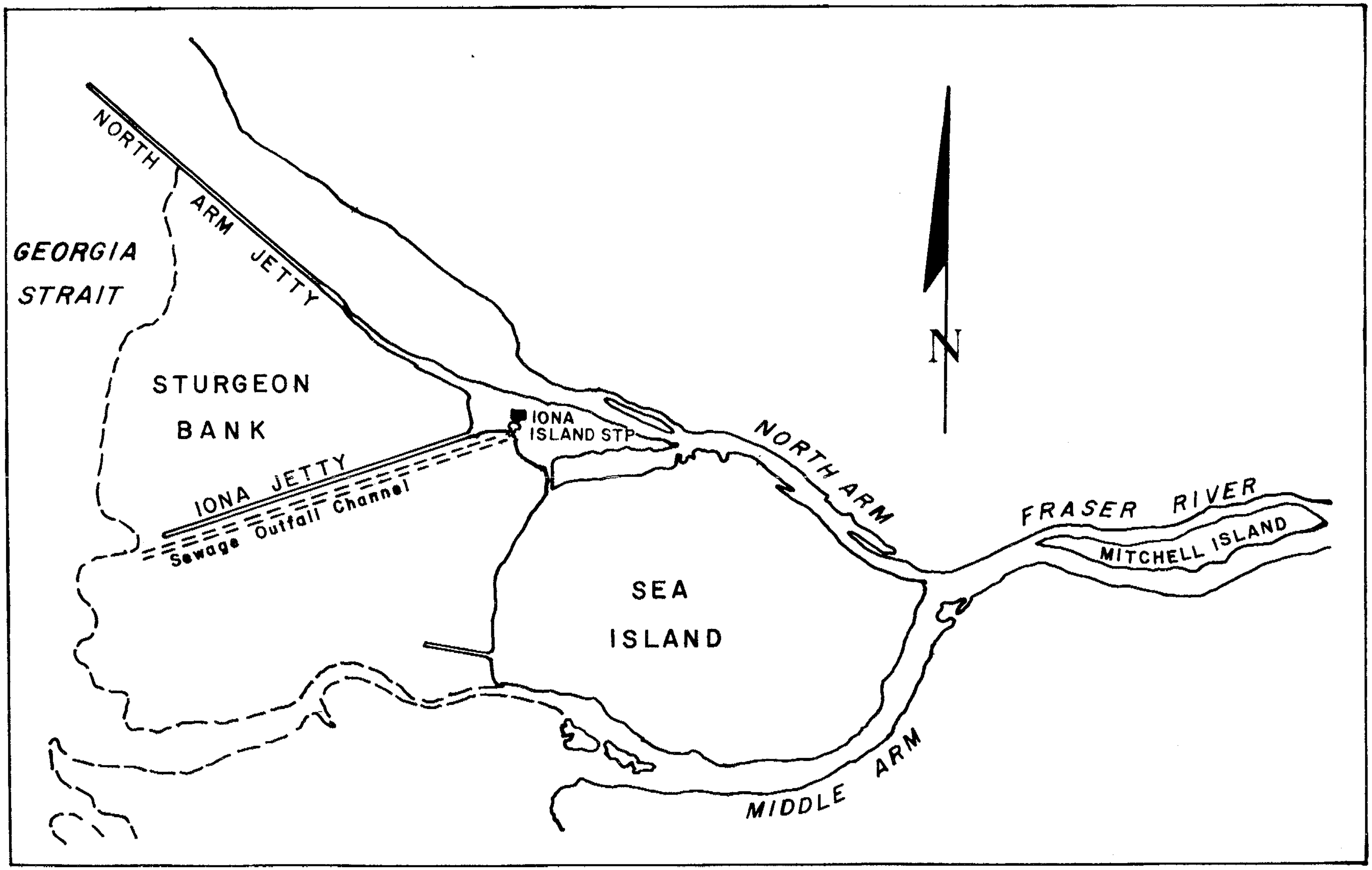


FIGURE 3

COMPARISON OF ACUTE TOXICITY OF LULU ISLAND SEWAGE TREATMENT PLANT EFFLUENT WITH PROVINCIAL OBJECTIVES

STATIC BIOASSAYS, GRAB SAMPLES

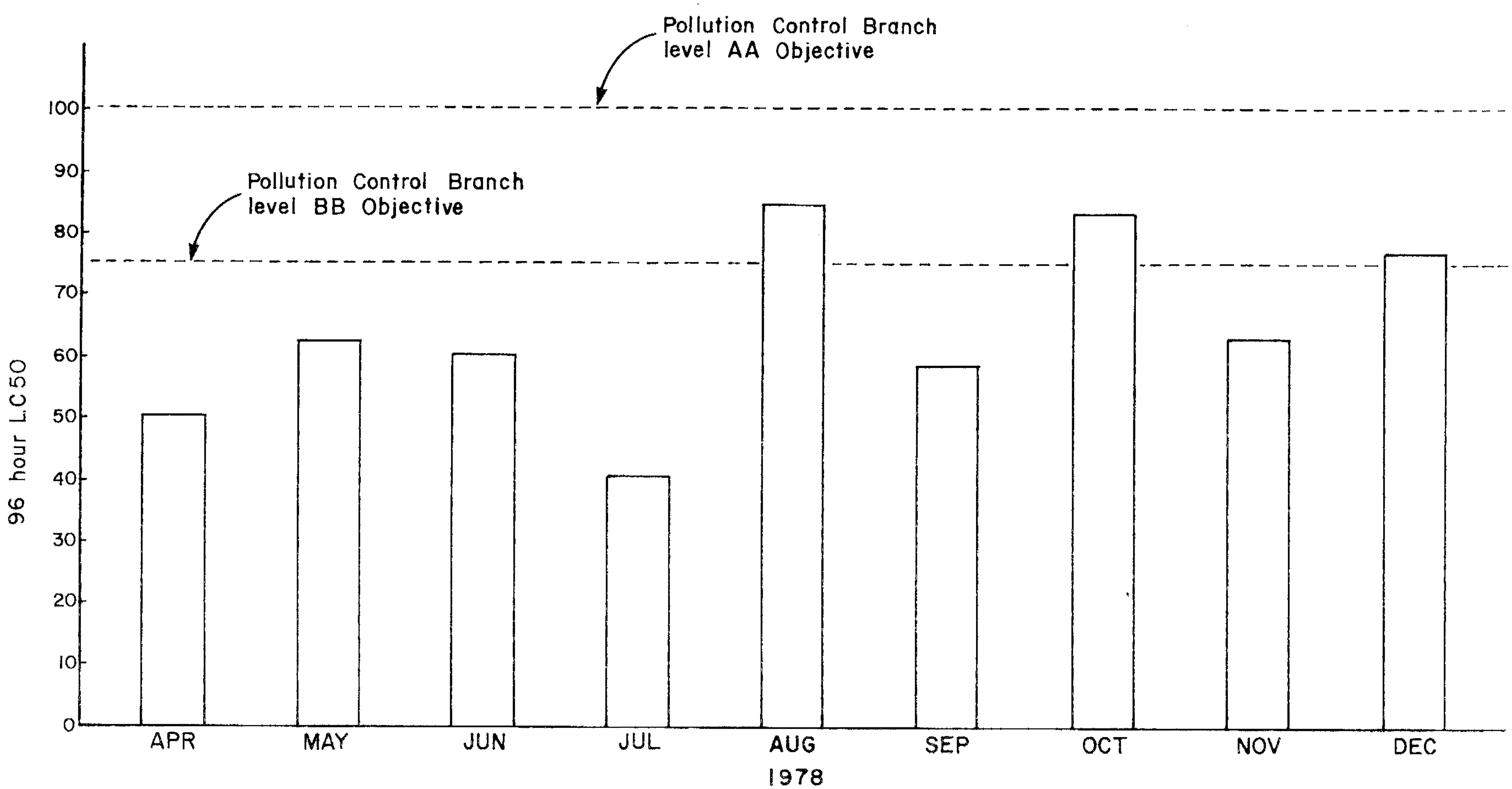


FIGURE 4

COMPARISON OF ACUTE TOXICITY OF ANNACIS SEWAGE TREATMENT PLANT EFFLUENT WITH PROVINCIAL OBJECTIVES

STATIC BIOASSAYS, GRAB SAMPLES

nt. = NON-TOXIC AT 100 % CONC.

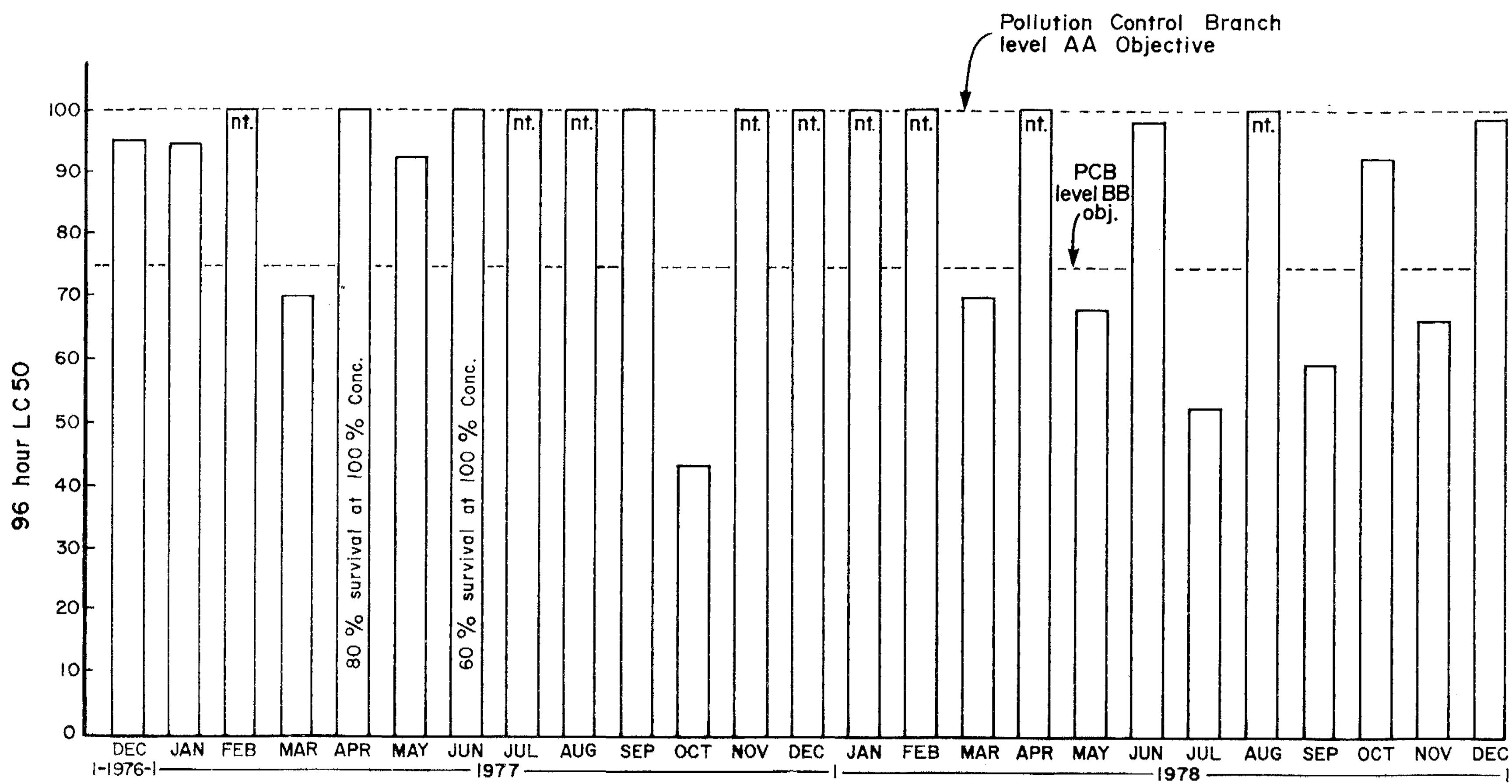
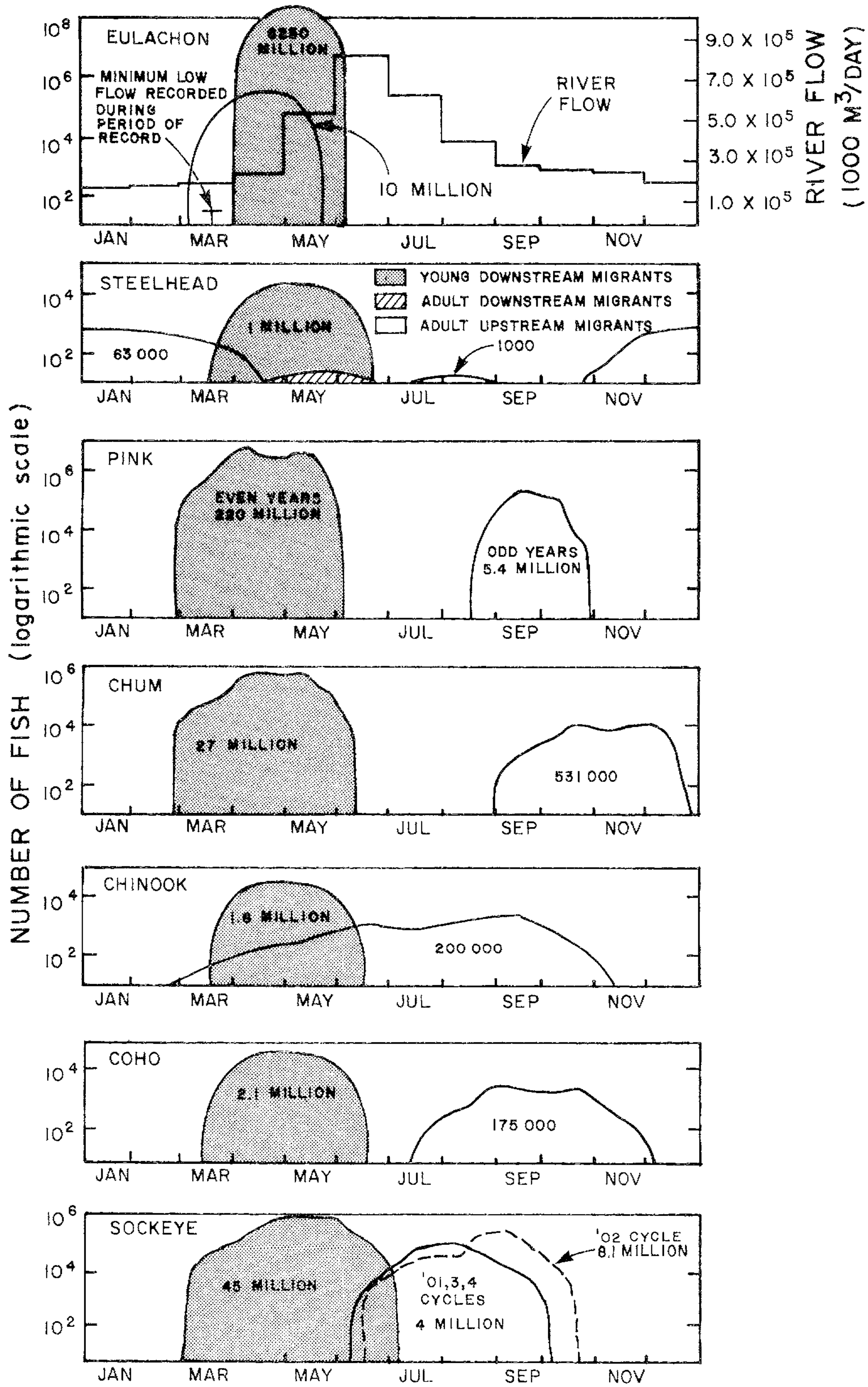


FIGURE 5

SEASONAL USAGE OF THE LOWER MAINSTEM FRASER RIVER BY THE MAJOR SPECIES OF MIGRATORY FISHES & MONTHLY AVERAGE FLOW RATES AT PORT MANN (1966-1972)



Modified after Northcote (1974)

FIGURE 6

EFFECT OF ANNACIS EFFLUENT TOXICITY AT MAXIMUM ALLOWABLE EFFLUENT FLOW AND MINIMUM RIVER FLOW

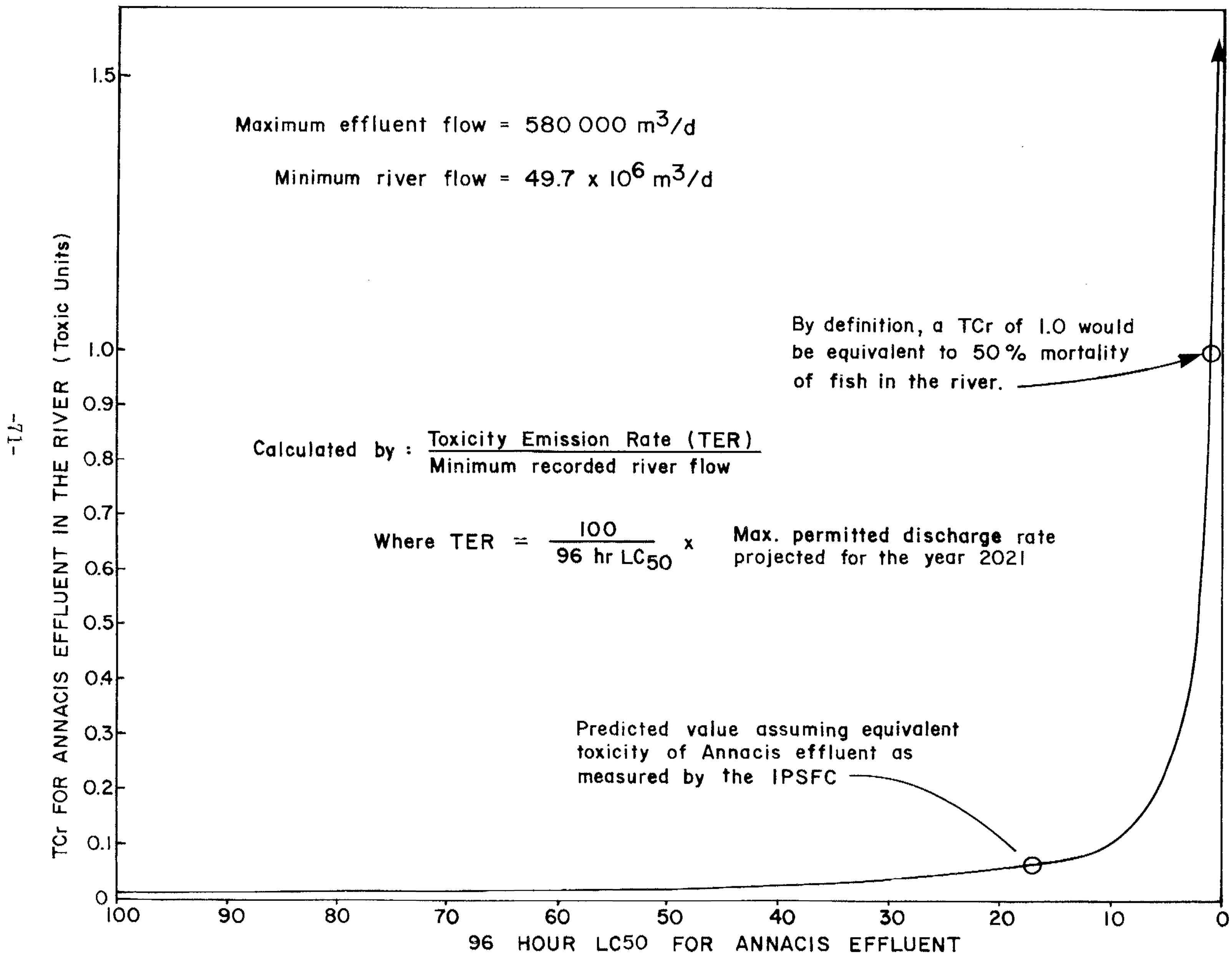


FIGURE 7

ACUTE TOXICITY OF TREATED MUNICIPAL WASTEWATERS IN THE SAN FRANCISCO AREA (Esvelt et al, 1973)

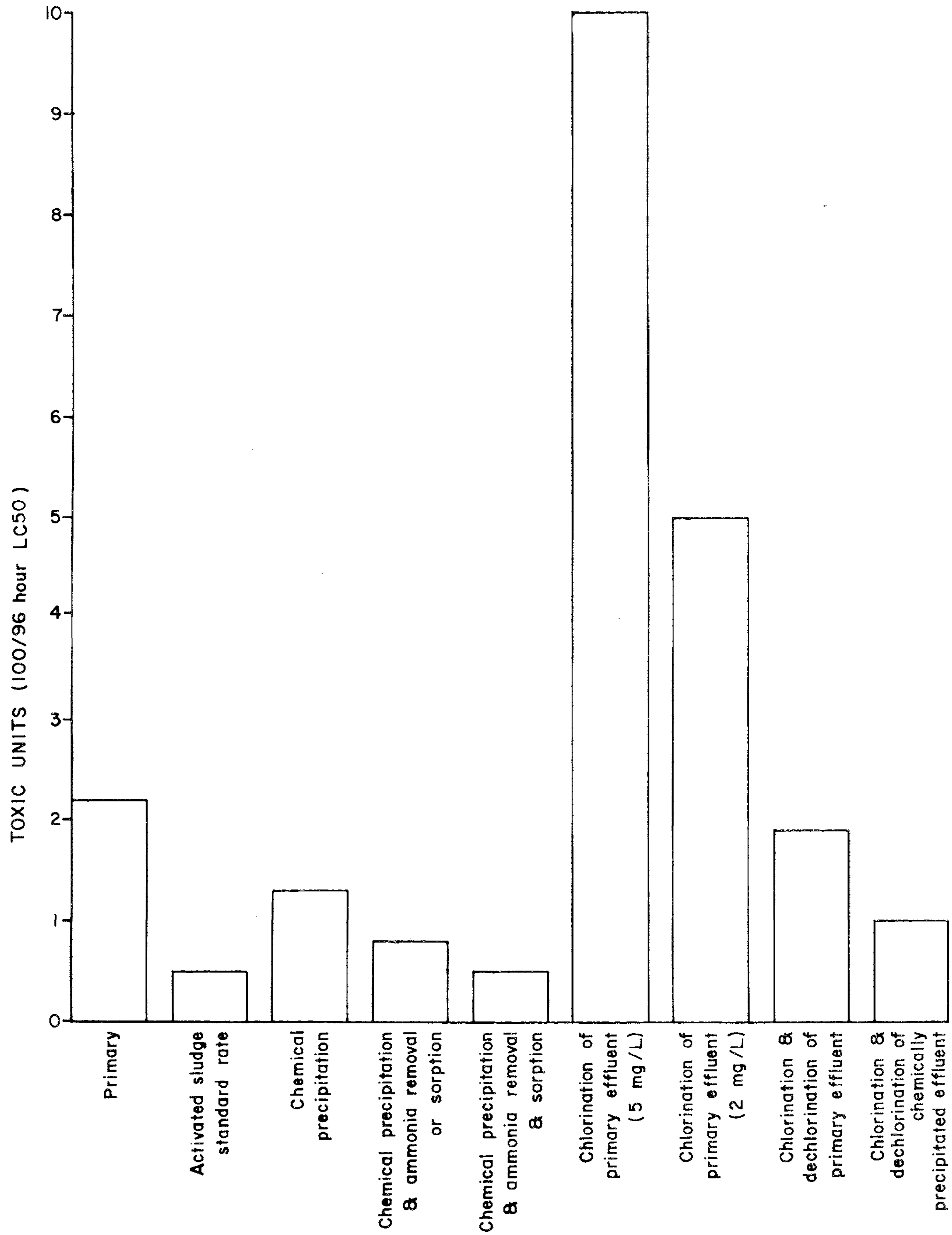


FIGURE 8
LOCATION OF THE MAJOR LANDFILL SITES

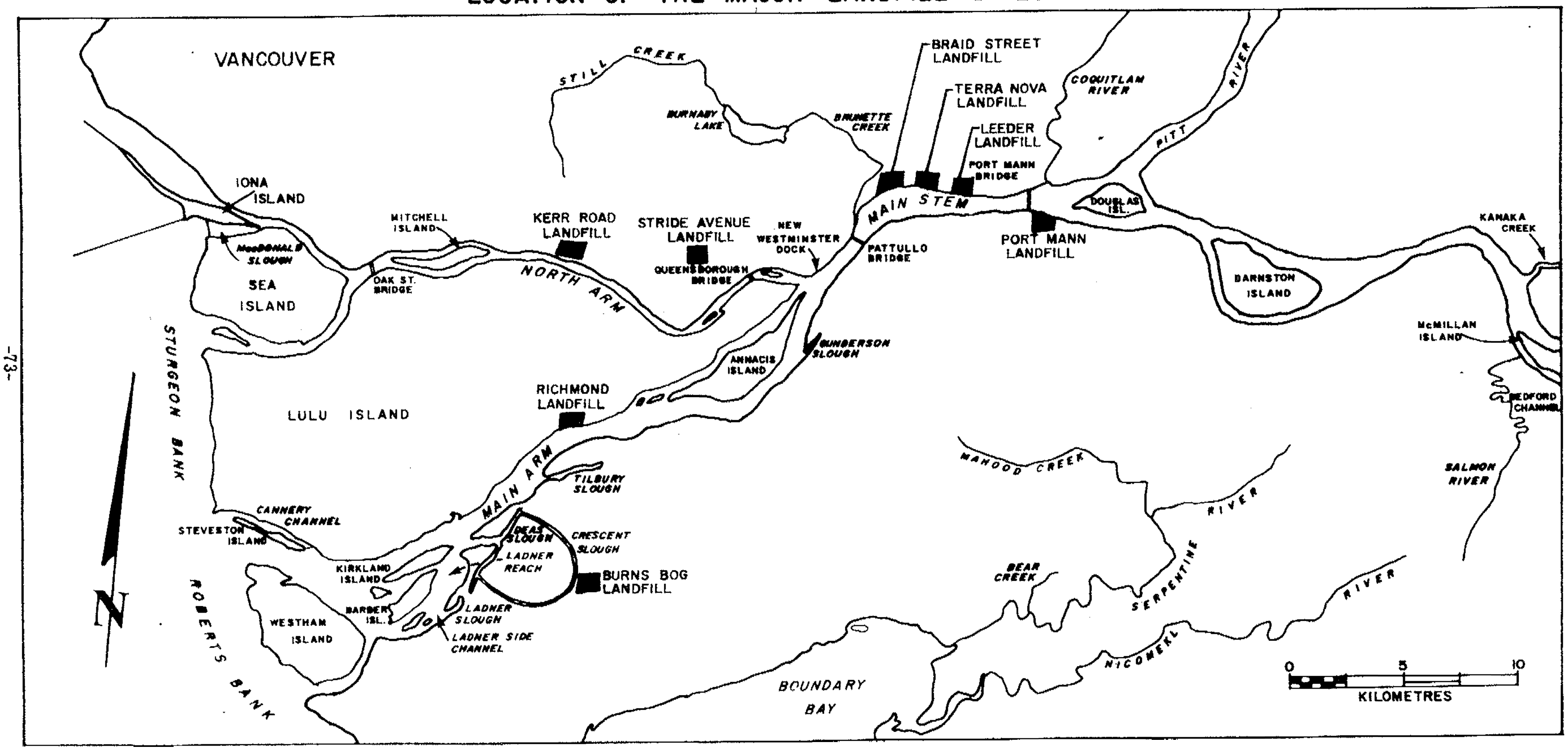


FIGURE 9
LOCATION OF THE MAIN INDUSTRIES DISCHARGING TO THE FRASER RIVER

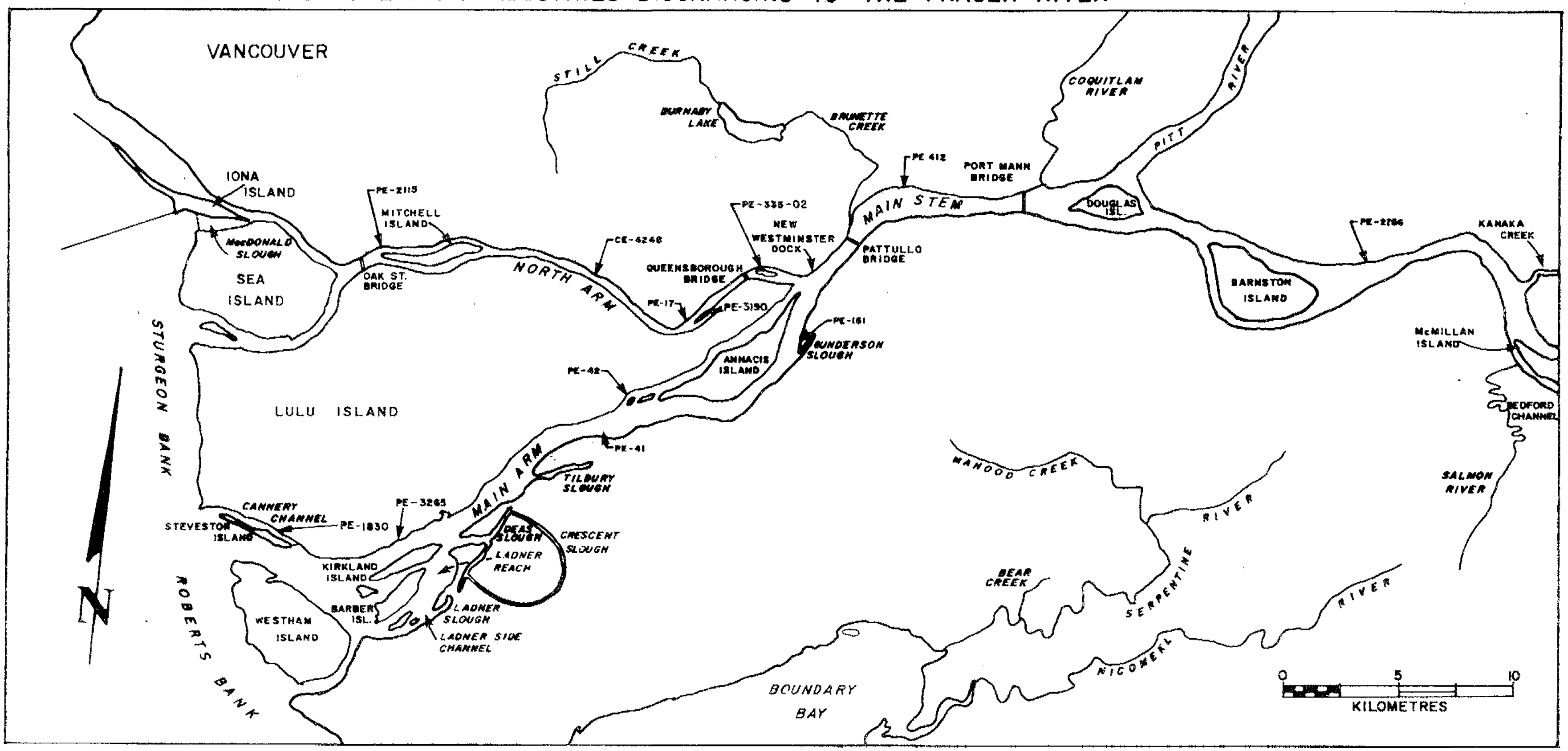


FIGURE 10

ACUTE TOXICITY OF EFFLUENT FROM BELKIN PAPERBOARD LTD. COMPARED TO PROVINCIAL OBJECTIVES

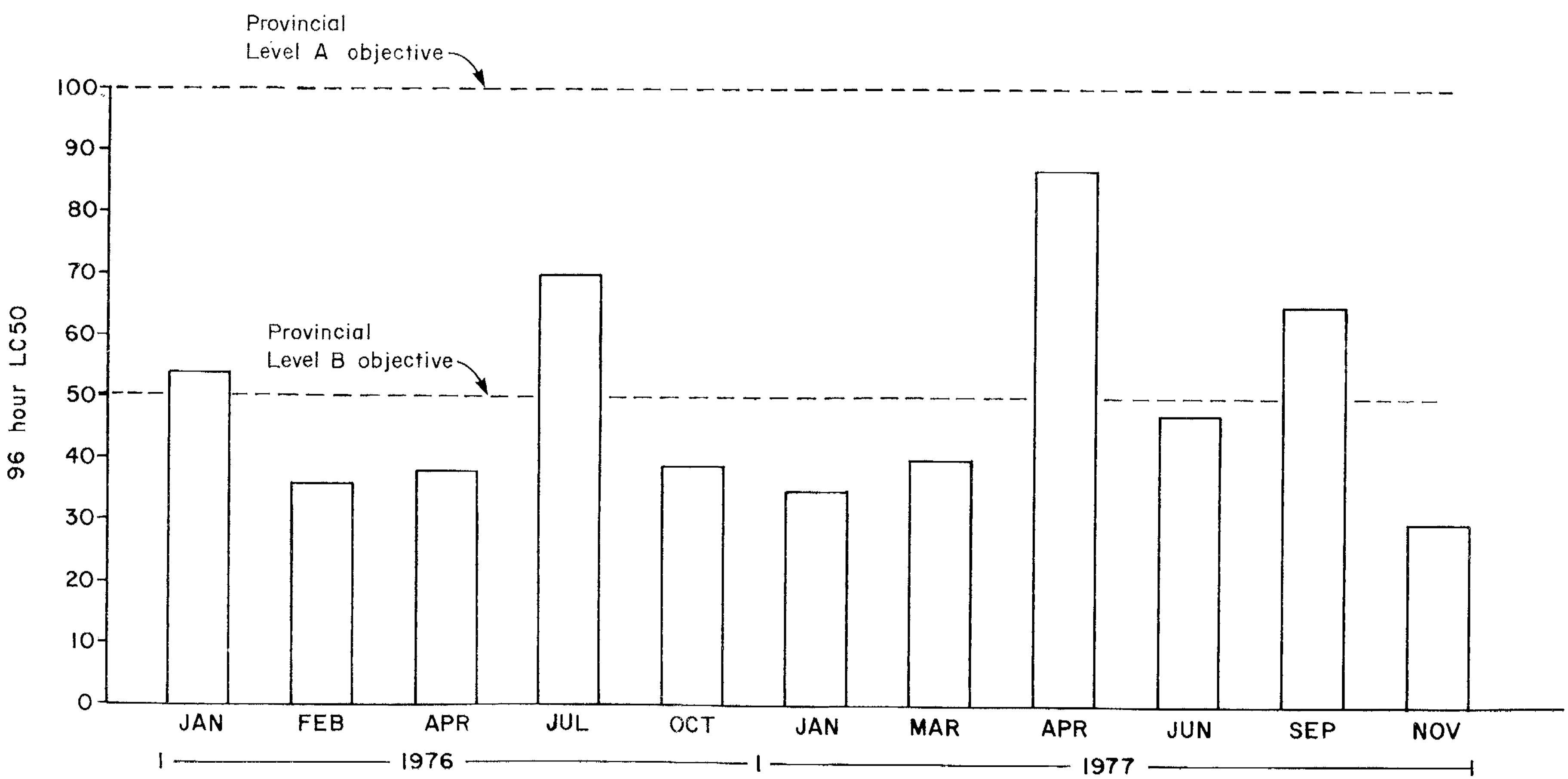


FIGURE II

ACUTE TOXICITY OF EFFLUENT FROM BELKIN PAPERBOARD LTD. COMPARED TO THE FEDERAL REGULATION

* 0 % Survival at an effluent conc. of 65%

** Sample neutralized before test

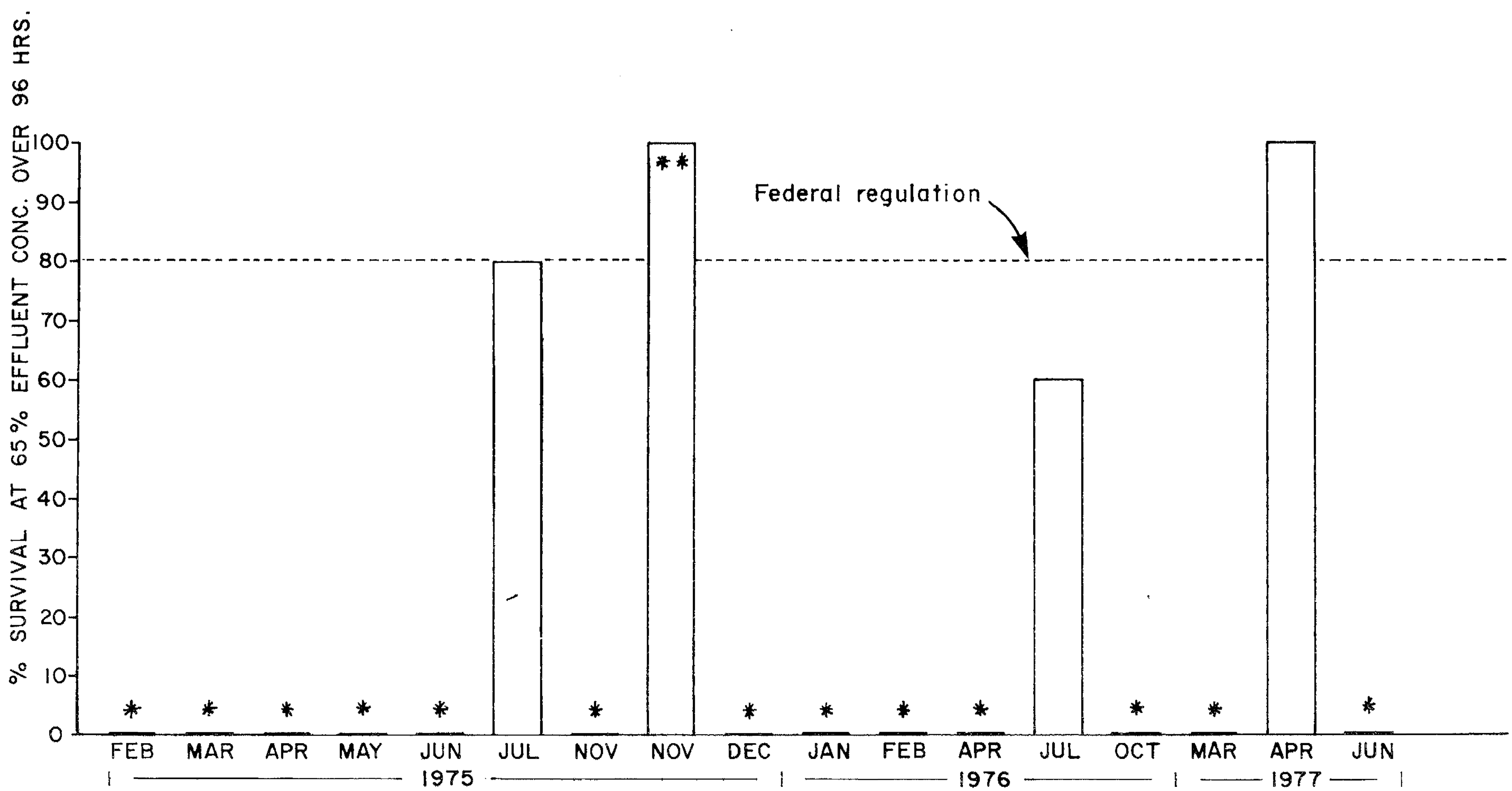


FIGURE 12

ACUTE TOXICITY OF PROCESS EFFLUENT FROM DOW CHEMICAL LTD. COMPARED TO PROVINCIAL OBJECTIVES

nt. Non toxic at 100 % conc.

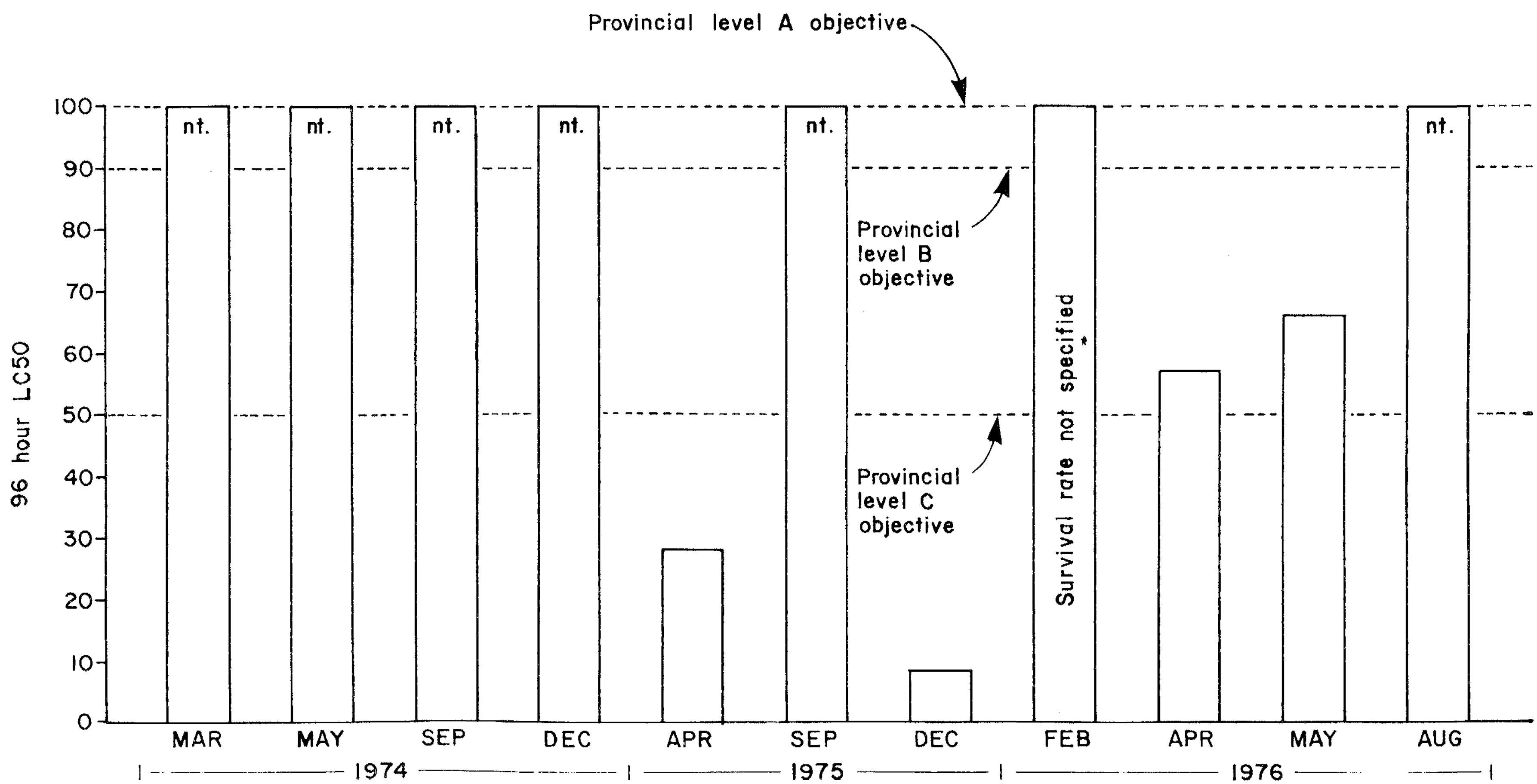


FIGURE 13

ACUTE TOXICITY OF EFFLUENT FROM CHEVRON CANADA LTD. COMPARED TO PROVINCIAL OBJECTIVES

Effluent diverted from Burrard Inlet to Iona Sewage Treatment Plant on June 25, 1977.

nt. Non toxic at 100% Conc.

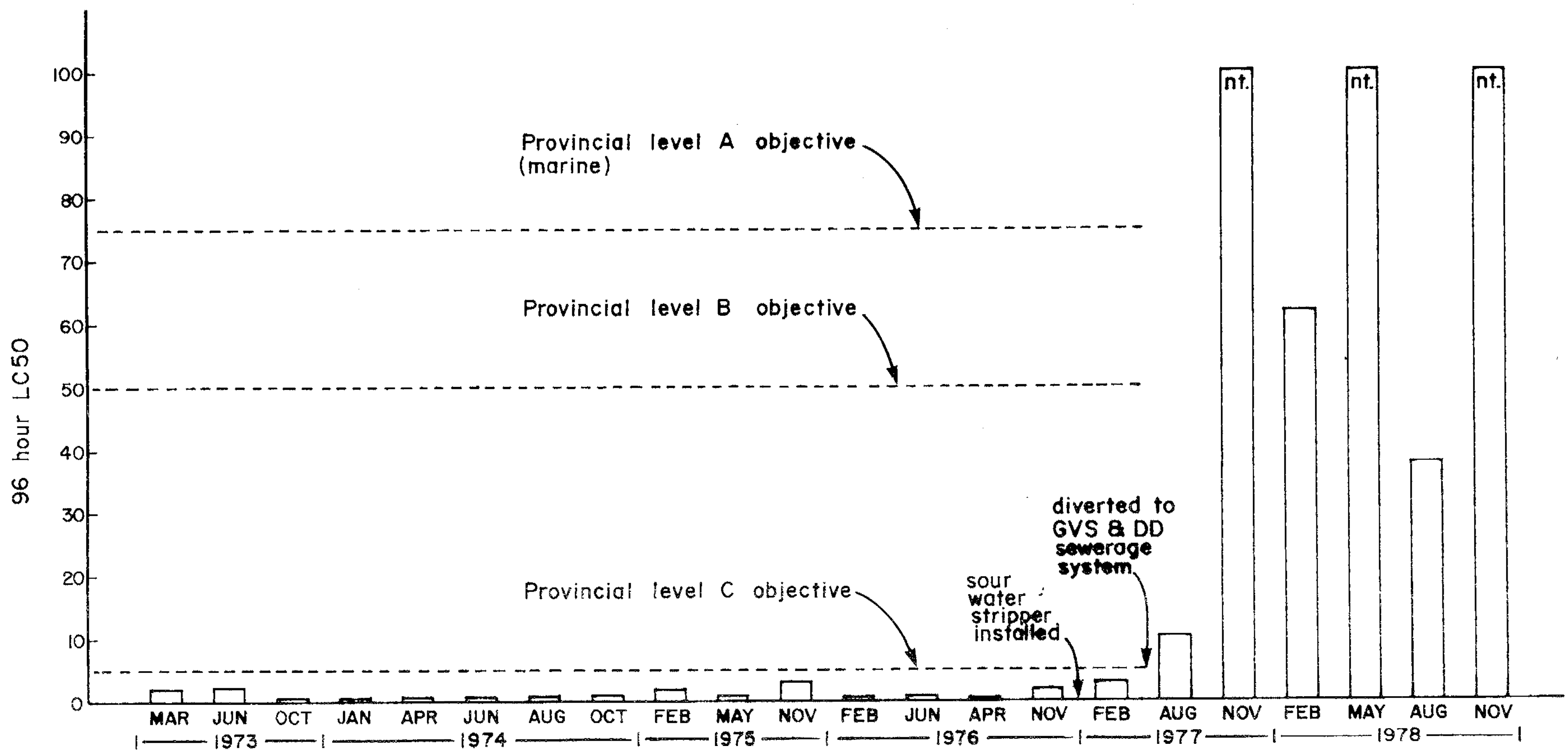


FIGURE 14

ACUTE TOXICITY OF EFFLUENT FROM GULF OIL CANADA LTD. COMPARED TO PROVINCIAL OBJECTIVES

nt. Non toxic at 100 % Conc.

Effluent diverted from Burrard Inlet to the GVS & DD sewerage system on December 11 1974.

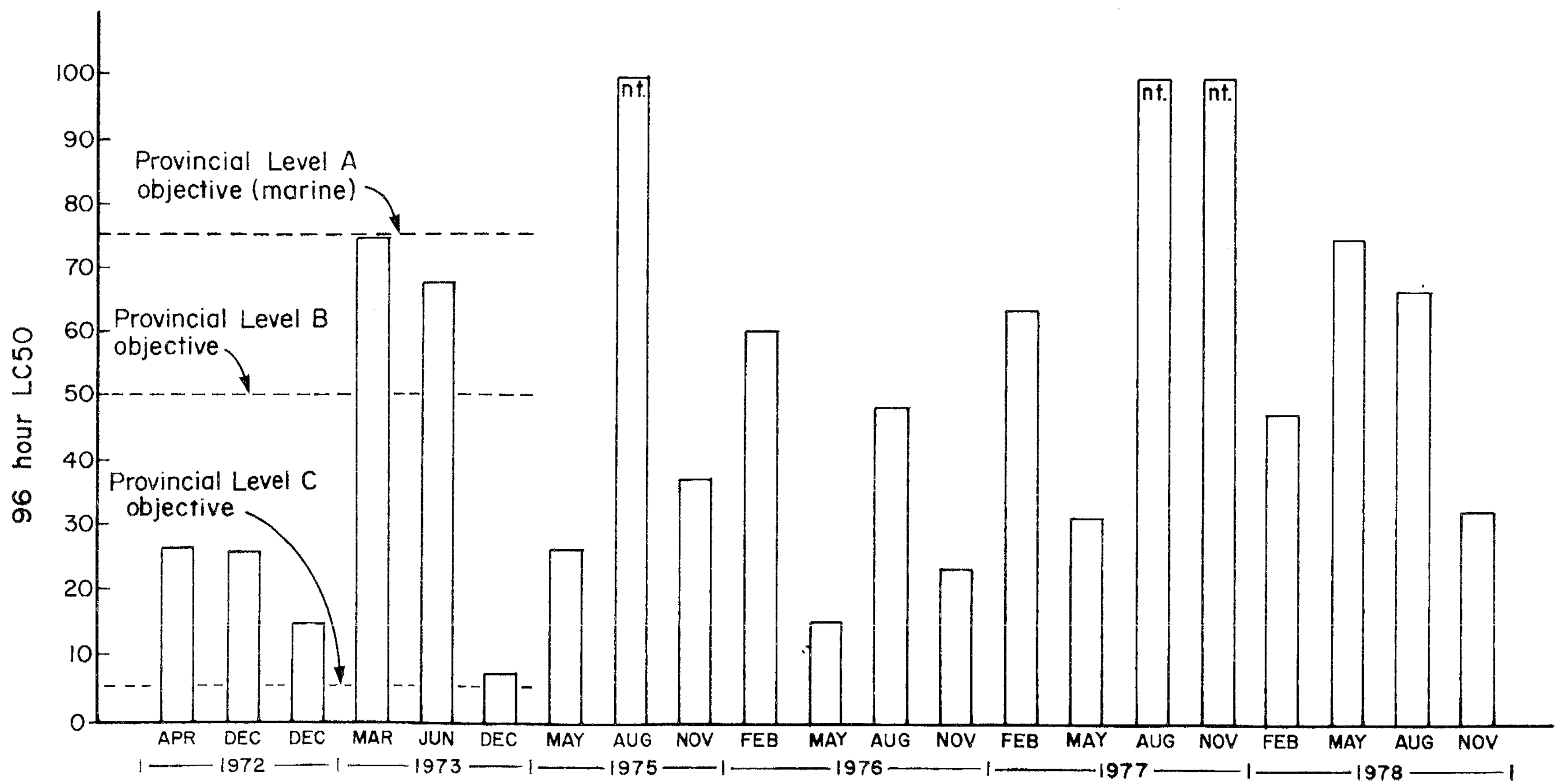


FIGURE 15

ACUTE TOXICITY OF EFFLUENT FROM SHELL CANADA LTD. COMPARED TO PROVINCIAL OBJECTIVES

All bioassays conducted during effluent discharge to Burrard Inlet.

Effluent diverted to Annacis Sewage Treatment Plant on December 15, 1975.

nt. Non toxic at 100 % conc.

§ Catalytic cracker not in operation

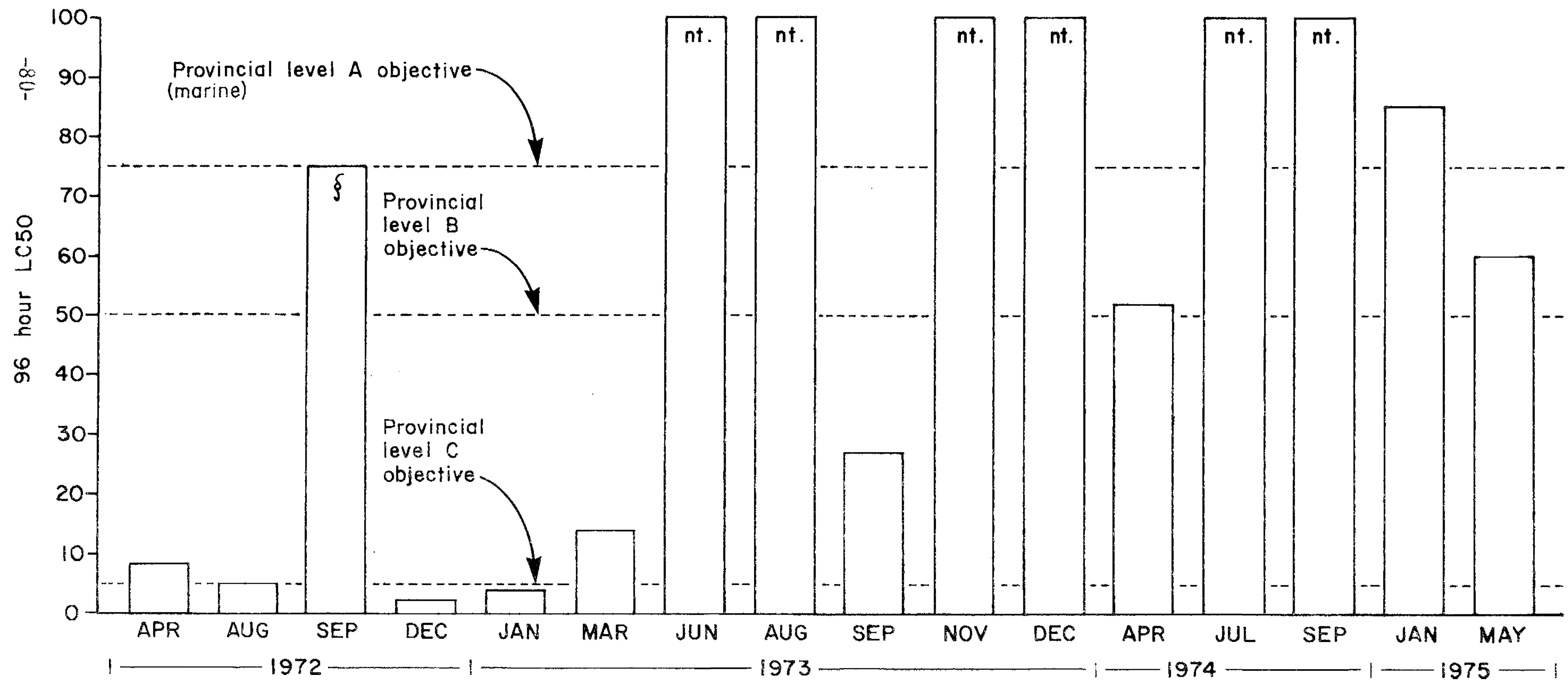


FIGURE 16

ACUTE TOXICITY OF EFFLUENT FROM SHELL CANADA LTD.

*NOTE: All bioassays shown here are 24 hour LC_{50}'s

Effluent diverted from Burrard Inlet to Annacis Sewage Treatment Plant on December 15, 1975.

nt. Non toxic at 100 % Conc.

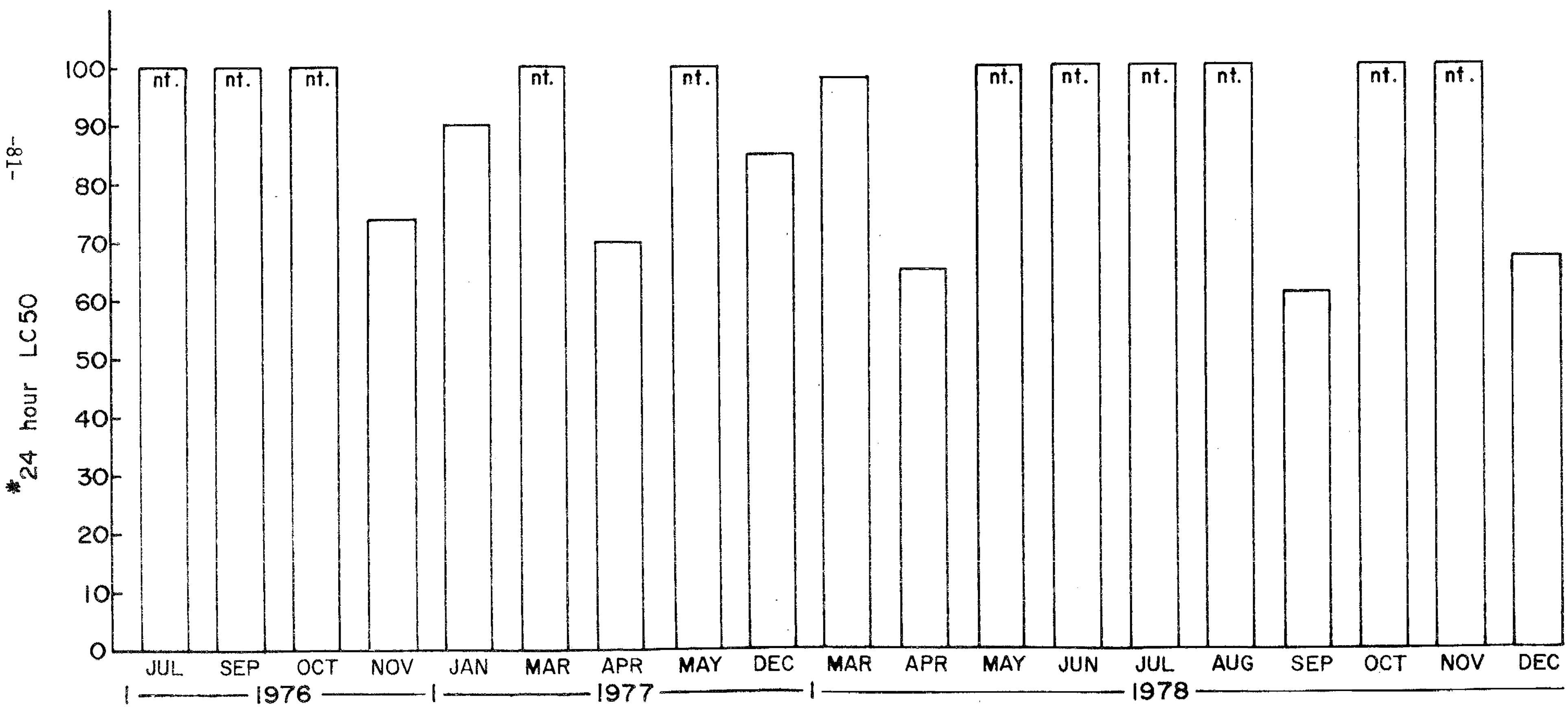


TABLE I
TOXICITY DATA FOR THE SEWAGE TREATMENT PLANTS

DISCHARGE SITE	SAMPLING AGENCY	TREATMENT OF SAMPLE	96-h LC50 mean (range)	TCe Toxic Units	TYPE OF BIOASSAY	(NUMBER OF BIOASSAYS) SPECIES TESTED	YEARS TESTED	DISCHARGE RATE 1000 m³/day	TER (TCe·DISCHARGE RATE) x10³	DISCHARGE RATE BASED ON	COMMENTS
IONA ISLAND SEWAGE TREATMENT PLANT PE-23	B.C. RESEARCH	PRIMARY UNCHLORINATED	100 % 100% of the tests non-toxic at 100% conc.	0	Static Single grab samples	(9) RAINBOW TROUT	1978	321	—	1976 daily average	Routine monitoring data
								602	—	average of the max. daily flows for Mar. & Apr. 1976.	
								318	—	Permit maximum	
	IPSFC Martens and Servizi, 1976	PRIMARY BEFORE CHLORINATION	45 % 42 % based on mean mortality	2.4	Continuous-flow 96 hour	(3 to 7 tests) SOCKEYE SALMON	1976	321	770	1976 daily average	
								602	1445	average of the max. daily flows for Mar. & Apr. 1976.	
								318	763	Permit maximum	
	EPS Tanner et al, 1973	PRIMARY CHLORINATED	90.3 % (24 – >100 %) 74% of the tests non-toxic at 100% conc.	0.5	Static 24 hour composite grab samples	(20) COHO SALMON	1971, 72	321	160	1976 daily average	These bioassays had extremely high fish loading densities & toxicity may be underestimated.
								602	301	average of the max. daily flows for Mar. & Apr. 1976.	
								318	159	Permit maximum	
	EPS Higgs, 1977	PRIMARY CHLORINATED	51.2 % (44 - 58.5 %)	2.0	Static 24 hour composite grab samples	(2) RAINBOW TROUT	1976	321	642	1976 daily average	2 of 4 bioassays not included as samples were not tested until 2 to 3 days after collection.
								602	1204	average of the max. daily flows for Mar. & Apr. 1976.	
								318	636	Permit maximum	
LULU ISLAND SEWAGE TREATMENT PLANT PE-233	B.C. RESEARCH	PRIMARY UNCHLORINATED or DECHLORINATED	65% (40.7 - 84.4 %)	1.6	Static Single grab samples	(9) RAINBOW TROUT	1978	19	30	1976 daily average	Routine monitoring data
								25	40	average of the max. daily flows for Mar. & Apr. 1976.	
								132	211	Permit maximum	
	IPSFC Martens and Servizi, 1974	PRIMARY BEFORE CHLORINATION	approx. 21 %	4.8	Continuous-flow 96 hour	(7) SOCKEYE SALMON	1974	19	91	1976 daily average	
								25	120	average of the max. daily flows for Mar. & Apr. 1976.	
								132	634	Permit maximum	
	IPSFC Martens and Servizi, 1975	PRIMARY DECHLORINATED	approx. 25 %	4.0	Continuous-flow 96 hour	(6) SOCKEYE SALMON	1975	19	76	1976 daily average	
								25	100	average of the max. daily flows for Mar. & Apr. 1976.	
								132	528	Permit maximum	
ANNACIS ISLAND SEWAGE TREATMENT PLANT PE-387	B.C. RESEARCH	PRIMARY UNCHLORINATED or DECHLORINATED	87.9 % (43 – >100 %) 72% of the tests ≥90 % conc.	0.7	Static Single grab samples	(25) RAINBOW TROUT	1976, 77, 78	163	114	1977 daily average	Routine monitoring data
								216	151	average of the max. daily flows for Mar. & Apr. 1977.	
								586	410	Permit maximum	
	EPS Higgs, 1977	PRIMARY DECHLORINATED	68 % (51 – 78 %)	1.5	Static 24 hour composite grab samples	(3) RAINBOW TROUT	1976	163	245	1977 daily average	Effluent samples aerated for 19 to 23 hours prior to testing.
								216	324	average of the max. daily flows for Mar. & Apr. 1977.	
								586	879	Permit maximum	
	IPSFC Servizi et al 1978	PRIMARY DECHLORINATED	38 %	2.6 calculated from av. 96-h LC50	Static 24 hour composite samples	(72 individual test concs.) SOCKEYE SALMON	1976	163	424 (static) 619 (cont. flow)	1977 daily average	
								216	561 (static) 821 (cont. flow)	average of the max. daily flows for Mar. & Apr. 1977.	
			26 %	3.8 calculated from av. 96-h LC50	Continuous-flow 96 hour	(104 individual test concs.) SOCKEYE SALMON	1976	244	634 (static) 927 (cont. flow)	projected flow for 1986.	
								586	1524 (static) 2227 (cont. flow)	Permit maximum	

TABLE 2

LITERATURE DATA FOR LETHAL AND SUBLETHAL EFFECTS OF CONSTITUENTS IN SEWAGE EFFLUENTS ON SALMONIDS AND CONCENTRATIONS OF SEWAGE CONSTITUENTS MEASURED AT IONA, LULU AND ANNACIS S.T.P.'s

Effluent Constituent	Median Lethal Concentration 96 h LC_{50}	Avoidance Concentration	Other Effects	Safe (No-Effect) Concentration	90th Percentile Effluent Concentration		
					Iona STP	Lulu STP	Annacis STP
Chlorine (mg/L)	0.01-Freshwater (2,6)						<0.02
Total Residual (Available) Chlorine (mg/L)	0.07-Seawater (16)	0.001-Slight (81) 0.01-Clearcut (81)	0.022-Growth Reduced (50) 0.009-Anaemia (17)	0.002 (15,89)	2.08	0	<0.02
Ammonia (Un-Ionized) (mg N/L)	0.16 (95)	Above Conc. in Sewage (40)		0.02 (89)	0.036†	0.10††	0.09**
Dissolved Copper (mg/L)	0.09-0.13*† (11)	0.002*-Laboratory (79) ~0.4 of 96-h LC_{50}-Field (70)		0.1 of 96-h LC_{50} (89)	0.37	1.0	0.19
Dissolved Zinc (mg/L)	1.1-1.4*† (11)	0.0056-Laboratory (80) ~0.4 of 96-h LC_{50}-Field (70)		0.01 of 96-h LC_{50} (89)	0.25	0.68	0.22
Dissolved Cadmium (mg/L)	0.007 (49)			0.0004 (89)	0.01	0.02	0.002

TABLE 2 (CONTINUED)

LITERATURE DATA FOR LETHAL AND SUBLETHAL EFFECTS OF CONSTITUENTS IN SEWAGE EFFLUENTS ON SALMONIDS AND CONCENTRATIONS OF SEWAGE CONSTITUENTS MEASURED AT IONA, LULU AND ANNACIS S.T.P!s

Effluent Constituent	Median Lethal Concentration 96 h LC_{50}	Avoidance Concentration	Other Effects	Safe (No-Effect) Concentration	90th Percentile Effluent Concentration		
					Iona STP	Lulu STP	Annacis STP
Dissolved Lead (mg/L)	1.2-1.4*† (11)			0.01 of 96-h LC_{50} (89)	0.2	0.24	0.11
Dissolved Chromium (mg/L)	69 (12)			0.1 (89) 0.2-0.35	0.32	11.9	0.09
Total Mercury (mg/L)	0.27 (71)			0.00005 (89)	<0.005		0.0003**
Detergents (mg/L)	0.6-37 (1)	0.37 (81)			1.1‡	8.8	4.6‡
Phenols (mg/L)	5.0-Phenol (59) 0.040-0.10-Pentachlorophenate (23)	Sublethal Concentrations not Avoided (81)	0.001-0.005 Flavour Tainting (25)	1.0 (38) 0.2 (58) 0.001 (89)			0.22**
Cyanide (mg/L)	0.05-0.1 (89)		0.01-Impaired Swimming Ability (89)	0.005 (89)	<0.02	0.36††	0.014**

* Ionic concentration.
† In non-turbid water of same hardness as the Fraser River.
‡ Maximum values reported by Higgs (1977).
†† Maximum values reported by Martens and Servizi (1974 and 1975).
** Maximum values reported by B.C. Research (1978).

Bracketed numbers refer to the list of references.

Modified after B.C. Research (1978).

TABLE 3

APPROXIMATE DILUTION OF ANNACIS EFFLUENT IN THE RIVER CALCULATED FROM DYE TEST DATA

	Rhodamine Dye Discharges From Terminal Riser For 5.5 Hours	Maximum Instantaneous Discharge Measured During First 21 Months of Operation	1977 Daily Average Discharge Rates	Projected Average Discharge Rate For the Year 1986	Projected Average Discharge Rate For the Year 2021
Number of Risers in Use	1	1	9	18	18
Discharge Rate	0.11 m^3/s	3.8 m^3/s	1.9 x m^3/s	2.8 m^3/s	6.8 m^3/s
Initial Release on Flood Tide -Upstream Flow	Narrow Band	-	-	-	-
Released on Ebb Tide and Returning on Flood Tide	x 840	x 24	x 440	x 600	x 240
Furthest Upstream Point Reached by Dye - 140 m Upstream of Outfall	x 530	x 15	x 280	x 380	x 160
High Slack Tide Pooled at Outfall (Surface)	x 5	Nil	x 3	x 4	x 1.5
Outside Initial Dilution Zone as Defined in *Pollution Control Branch Objectives	x >300	x 9	x 160	x 212	x >90

* Initial dilution zone extends 100 m upstream upstream and downstream from the outfall and 70 m either side laterally across the river (25% of river width).

$$\text{Approximate dilution of effluent} = \frac{\text{dye discharge rate X dye dilution measured in river X number of risers}}{\text{effluent discharge rate}}$$

TABLE 4

TOXICITY DATA FOR THE MUNICIPAL LANDFILLS

DISCHARGE SITE	SAMPLING AGENCY (DATA SOURCE)	OPERATIONAL STATUS	96-h LC50 mean (range)	TCe Toxic Units	TYPE OF BIOASSAY	(NUMBER OF BIOASSAYS) SPECIES TESTED	YEARS TESTED	DISCHARGE RATE 1000 m^3/day	TER (TCe · DISCHARGE RATE) x 10^3	COMMENTS
KERR ROAD LANDFILL	EPS (Atwater, 1980)	Closed to further dumping	24 %	4.2	Grab sample Static bioassay	(1) RAINBOW TROUT	1979	Unknown	—	Leachate sampled at Marine Drive. An additional leachate contaminated ditch sample gave a 34 minute LC50 at 100 % conc.
STRIDE AVENUE LANDFILL	EPS (Atwater, 1980)	Closed to further dumping	82 % (56 - 100%)	1.0	Grab samples Static bioassays	(3) RAINBOW TROUT	1979	Unknown	—	Leachate contaminated stream collected at Marine Drive.
BURNS BOG LANDFILL PR-1611	EPS	Active landfill	10.7 % (6.5 - 18 %)	11.4	Grab samples Static bioassays	(3) RAINBOW TROUT	1976, 78	1.6 (estimated by G. Giles, PCB)	18	Samples taken from ditches contaminated with leachate. Leachate presently discharged to Crescent Slough and to be diverted to GVS & DD (Annacis STP) by December, 1980.
BRAID STREET LANDFILL PR-4385	FMS (Atwater, 1980)	Active landfill	30.2 % (24 - 36.5 %)	3.2	Grab samples Static bioassays	(2) RAINBOW TROUT	1976	1.2 (Atwater, 1980)	4	Samples taken from ditch contaminated with leachate. Leachate previously discharged to Brunette River. Diverted to the GVS & DD (Annacis STP) in April, 1976.
PORT MANN LANDFILL PR-1686	FMS & EPS (Atwater, 1980)	Active landfill	43.3 % (38 - 50 %)	2.3	Grab samples Static bioassays	(2) RAINBOW TROUT	1976-FMS 1979-EPS	0.9 (Atwater, 1980)	2	Samples of leachate entering the Fraser River. Leachate was diverted to GVS & DD (Annacis STP) in the first half of 1980
RICHMOND LANDFILL AR-4922	EPS (Soper and McAlpine, 1977)	Active landfill	42.9 % (23.2 - 92 %) 83 % of the tests < 50 % conc.	2.6	Grab samples Static bioassays	(12) RAINBOW TROUT	1975-77	7.3 (Soper and McAlpine, 1977)	19	Samples taken from ditches contaminated with leachate.

TABLE 5
TOXICITY DATA FOR FOREST INDUSTRIES DISCHARGING TO THE LOWER FRASER RIVER

INDUSTRY P.C.B. PERMIT NO.	EFFLUENT SOURCE	DISCHARGE RATE 1000 m^3/day (CW) cooling water (PW) process water	96-h LC50 mean (range)	TCe Toxic Units	TER (TCe · Discharge Rate) x 10^3	(NUMBER OF BIOASSAYS) Species tested	YEARS TESTED	COMMENTS
BELKIN PAPER-BOARD LTD. PE-17 (BURNABY)	Paperboard mill	(PW) 11.4 (permit max.) (PW) 19.2 (actual yearly av. for 1977)	52 % (30 - >87 %) 0% of the tests ≥ 90 % conc.	2.2	25 (permit max.) 42 (actual av.)	(12) RAINBOW TROUT	1976, 77	Discharge to North Arm by submerged diffuser.
B.C. FOREST PRODUCTS PE-2756 (HAMMOND)	Hydraulic debarker effluent, boiler blow-down, sewage	(PW) 0.07 (permit max.) (CW) 42.3 (permit max.)	> 100 % all tests non-toxic at 100 % conc.	0	0	(3) RAINBOW TROUT	1974, 76, 77	Process effluent and cooling water combined and discharged to the Main Stem. Final wastewater is 99.8 % cooling water.
CAN. FOREST PRODUCTS LTD. PE-2115 (NEW WEST.)	Hydraulic debarker effluent, steam condensate, cooling water, boiler blowdown.	(PW) 6.8 (CW) 27.3 (permit max.)	13.3 % (< 5 - 60 %) 80 % of the tests ≤ 10 % conc.	14.4	98	(11) SPECIES UNKNOWN	1972	All 3 hydraulic debarkers changed over to mechanical debarkers in 1974 & 1975. Effluent still discharging to North Arm is composed of cooling water, steam condensate and boiler blowdown.
CAN. FOREST PRODUCTS LTD. CE-1656 (NEW WEST.)	Hardboard mill	(PW) 6.8 (permit av.) (PW) 9.0 (permit max.)	4.9 % (3 - 12 %) 86 % of the tests < 5 % conc.	22.2	151 (permit av.) 202 (permit max.)	(14) COHO SALMON & RAINBOW TROUT	1974, 75, 76	Previously discharged to the Main Stem. Diverted to GVS & DD (Annacis STP) on Dec. 1, 1976. All bioassay samples were 24 hour composites.
CROWN ZELLER-BACH LTD. PE-412 (FRASER MILLS)	Sawmill, boiler plant, plywood plant, debarker effluent.	(PW) 2.7 (permit max.) (CW) 50.8 (permit max.)	Final combined effluent not defined as 96-h LC50. Non-toxic at 65 % conc.	—	—	(4) COHO SALMON	1971, 72, 73	Process effluent and cooling water combined and discharged to the Main Stem. Bioassays conducted by EPS indicated intermittent toxicity during boiler cleanout.
CROWN ZELLER-BACH LTD. PE-3265 (STEVESTON)	Papermill and domestic effluent.	(PW) 0.14 (permit max.) (PW) 0.13 (permit av.) (CW) 0.09 (permit max.)	Non-toxic at 100 % conc.	0	0	(1) COHO SALMON	1974	Previously discharged to the Main Arm. Diverted to GVS & DD (Lulu STP) in Mar., 1976. Cooling water discharged to Woodward's Slough.
MacMILLAN BLOEDEL LTD. PE-35 (ISLAND PAPER DIV.)	Papermill effluent	(PW) 4.5 (permit max.) (PW) 3.1 (actual yearly av. for 1977.	90.3 % (45.5 - >100 %) 67 % of the tests ≥ 90 % conc.	0.7	3 (permit max.) 2 (actual av.)	(24) RAINBOW TROUT	1976, 77	Previously discharged to the Main Arm. Diverted to GVS & DD (Annacis STP) in Oct., 1978.
MacMILLAN BLOEDEL LTD. PE-1666 (WHITE PINE DIV.)	Sawmill effluent	73.0 (mostly cooling water)	Non-toxic at 100 % conc.	0	0	(1) COHO SALMON	1972	Hydraulic debarkers replaced by mechanical debarkers in 1977. Sanitary wastes and bark press effluent, previously discharged to the North Arm, were diverted to GVS & DD (Annacis STP) in 1977.
MacMILLAN BLOEDEL LTD. CE-4248 (BURNABY)	Specialty board plant	0.14 (permit max.) (mostly cooling water)	Non-toxic at 100 % conc.	0	0	(1) COHO SALMON	1973	Discharged to North Arm and to be mixed with M. & B. Van. Plywood Div. effluent. No bioassay data existed for the plywood plant effluent.
SCOTT PAPER LTD. PE-335 (NEW WEST.)	Groundwood mill PE-335-01	(PW) 0.9 (permit av.) (PW) 11.9 (permit max.)	Non-toxic at 100 % conc.	0	0	(3) COHO SALMON	1975	Previously discharged to the North Arm. Diverted to the GVS & DD (Annacis STP) in Aug. 1977. Process effluent combined with cooling water. All bioassays were from 24 hour composite samples.
	Papermill PE-335-02	(PW) 9.0 (permit av.) (PW) 11.5 (permit max.)	100 %	0	0	(19) COHO SALMON & RAINBOW TROUT	1975, 76, 77	Discharged to the North Arm. Combination of grab and 24 hour composite samples. Four samples showed slight toxicity at 100 % concentration.
RAYONIER CANADA LTD. PE-3087 SILVICHEMICAL DIV. (MARPOLE)	Combined extraction plant effluent & condenser cooling water. PE-3087-01	6.8 (permit max.)	45.5 %	2.2	15	(1) COHO SALMON	1974	Combined cooling water and process effluent previously discharged to the North Arm. Plant stopped operations on Apr. 9, 1976.
	Drying and evaporator plant effluent. PE-3087-02	5.5 (permit max.)	75.0 %	1.3	7	(1) COHO SALMON	1974	

All the bioassays were static tests conducted on grab samples unless otherwise noted.

TABLE 6
TOXICITY DATA FOR THE CHEMICAL AND PETROLEUM INDUSTRIES DISCHARGING TO THE LOWER FRASER RIVER

INDUSTRY PCB PERMIT NO.	EFFLUENT SOURCE	DISCHARGE RATE 1000 m^3/day (CW) Cooling Water (PW) Process Water	96-h LC50 mean (range)	TCe Toxic Units	TER (TCe · Discharge Rate) x 10^3	(NUMBER OF BIOASSAYS) Species tested	YEARS TESTED	COMMENTS
DOW CHEMICAL LTD. PE-41 (TILBURY ISLAND)	PHENOL PLANT	(PW)0.16 (permit max.) (PW)0.08 (actual av.) (CW)66.0 (permit max.) (CW)10.0 (actual av.)	77.2 % (8.5 - >100 %) 64 % of the tests non-toxic at 100 % conc.	1.9	(PW)0.3 (permit max.) (PW)0.15 (actual av.)	(8) COHO SALMON & RAINBOW TROUT	1974-76	Process effluent discharged with cooling water to the Main Arm after biological (activated sludge) treatment. Bioassays conducted on process effluent.
CHEVRON CANADA LTD. PE-447 (STANOVAN REFINERY)	PETROLEUM REFINERY	(PW)2.73 (permit max.)	19.5 % (0.16 - >100 %) 73 % of the tests < 5 % conc.	115	314	(22) RAINBOW TROUT	1973-78	Previously discharged to Burrard Inlet. Process effluent diverted to GVS & DD (Iona STP) on June 25, 1977. Sour water stripper installed in January, 1977.
GULF OIL OF CANADA LTD. PE-22 (PORT MOODY)	PETROLEUM REFINERY	(PW) 2.3 (estimated av. of actual flows)	50.0 % (7.5 - >100 %) 57 % of the tests < 50 % conc.	3.1	7	(21) COHO SALMON & RAINBOW TROUT	1972-78	Previously discharged to Burrard Inlet. Process effluent diverted to GVS & DD on Dec.11, 1974 and discharged via the Annacis STP when it began operations in June, 1975.
SHELL CANADA LTD. PE-449 (SHELLBURN REFINERY)	PETROLEUM REFINERY	(PW) 4.1 (av. of actual recorded flows)	49.2 % (2.5 - >100 %) 33 % of the tests < 10 % conc.	9.1	37	(16) COHO SALMON & RAINBOW TROUT	1972-75	Previously discharged to Burrard Inlet. Process effluent diverted to GVS & DD (Annacis STP) on Dec.15, 1975.

TABLE 7
TOXICITY DATA FOR FOOD PROCESSING INDUSTRIES DISCHARGING TO THE LOWER FRASER RIVER

INDUSTRY PCB PERMIT NO.	EFFLUENT SOURCE	DISCHARGE RATE 1000 m^3/day (CW) cooling water (PW) process water	96-h LC50 mean (range)	TCe Toxic Units	TER (TCe · Discharge Rate) x 10^3	(NUMBER OF BIOASSAYS) Species tested	YEARS TESTED	COMMENTS
BERRYLAND CANNING CO. PE-260 (HANEY)	Fruit and vegetable cannery	(PW) 0.41 (permit av.) (PW) 0.91 (permit max.) (CW) 0.45 (permit max.)	42 % (Peach sediment from settling tank)	2.4	Not sampled at outfall.	(1) COHO SALMON	1973	Process effluent discharged to the Main Stem. Cooling water discharged to Kanaka Creek.
CLAPPISON MEAT-PACKERS LTD. PE-3743 (HANEY)	Domestic sewage and slaughter-house effluent	(PW) 0.01 (permit max.)	Non-toxic at 100 % conc.	0	0	(1) COHO SALMON	1972	Process effluent discharged to the Main Stem. To be diverted to GVS & DD (Annacis STP) when available.
PANCO POULTRY LTD. PE-79 (DELTA)	Poultry processing	(PW) 0.91 (permit max.)	36.5 %	2.7	3	(1) COHO SALMON	1974	Process effluent previously discharged to Bear Creek and Serpentine River. Diverted to municipal sewer on Feb. 19, 1968, and now goes to Annacis STP.
CASSIAR PACKING CO. PE-1975 (RICHMOND)	Fish processing	(PW) 0.91 (permit max.) (CW) 0.45 (permit max.)	13.5 %	7.4	(PW) 7	(1) COHO SALMON	1973	Discharged to the Main Arm.
RICHMOND PACKING LTD. PE-90 (RICHMOND)	Domestic sewage and slaughter-house effluent	(PW) 0.05 (permit max.)	Non-toxic at 100 % conc.	0	0	(2) COHO SALMON	1974, 75	Effluent treated by coal filtration before discharge to the North Arm. To be diverted to GVS & DD (Lulu STP) when sewer available.
STANDARD BRANDS LTD. PE-2063 (RICHMOND)	Pet food processing	(PW) 0.18 (permit max.) (CW) 0.32 (permit max.)	24.5 %	4.1	(PW) 0.7	(1) COHO SALMON	1974	Process effluent previously discharged to the North Arm. Diverted to GVS & DD (Lulu STP) on Jan. 16, 1975. Cooling water discharged to the North Arm.
B.C. PACKERS LTD. IMPERIAL PLANT PE-1830 (CANNERY CHANNEL)	Fish processing	(PW) 5.68 (permit max.) (CW) 3.32 (permit max.)	56 %	1.8	(PW) 10	(1) COHO SALMON	1973	Process effluent and cooling water discharged to Cannery Channel.
CANADIAN FISHING CO. LTD. PE-1813 (BURRARD INLET)	Fish processing	(PW) 1.6 (permit max.)	Toxic at 100 % conc. but 96-h LC50 was not determined.	—	—	(1) COHO SALMON	1973	Previously discharged to Burrard Inlet. Diverted to GVS & DD (Iona STP) on Aug. 15, 1976.

All the bioassays were static tests conducted on grab samples

TABLE 8
TOXICITY DATA FOR METAL FINISHING INDUSTRIES DISCHARGING TO THE LOWER FRASER RIVER

INDUSTRY PCB PERMIT NO.	EFFLUENT SOURCE	DISCHARGE RATE 1000 m^3/day (CW) Cooling Water (PW) Process Water	96-h LC50 mean (range)	TCe Toxic Units	TER (TCe · Discharge Rate) x 10^3	(NUMBER OF BIOASSAYS) Species tested	YEARS TESTED	COMMENTS
METALEX PRODUCTS LTD. CE-2311 (RICHMOND)	Lead/acid battery manufacturing	(PW)0.004 (permit av.) (PW) 0.01 (permit max.)	1.5% (0.23-6.15%) 80% of the tests < 0.5% conc.	260	1.0 (permit av.) 3.0 (permit max.)	(5) COHO SALMON	1972,73	Previously discharged to the North Arm. Effluent diverted to GVS & DD (Lulu STP) on Jan. 26, 1976.
VARTA BATTERIES LTD. CE-4661 (RICHMOND)	Lead/acid battery manufacturing	(PW) 0.07 (permit av.) (PW) 0.01 (permit max.) (CW) 0.03 (permit av.) (CW) 0.03 (permit max.)	2.4%	42	(PW) 3.0 (permit av.) (PW) 4.0 (permit max.)	(1) COHO SALMON	1972	Previously discharged to the North Arm. Effluent diverted to GVS & DD (Lulu STP) on Jan. 10, 1978.
TITAN STEEL AND WIRE CO. PE-161 (SURREY)	Metal finishing plant	(PW) 0.4 (permit max.) (CW) 3.64 (permit max.)	67.0% (0.14 -> 100%) 67% of the tests non-toxic at 100% conc.	129	(PW) 52.0	(6) COHO SALMON & RAINBOW TROUT	1976,77	Process effluent discharged to the Main Arm. Cooling water discharged to Gunderson Slough. Process effluent subject to GVS & DD connection (Annacis STP) when available.
TREE ISLAND STEEL CO. PE-3190 (RICHMOND)	Metal finishing plant	(PW) 0.82 (permit av.) (PW) 0.01 (permit max.) (CW) 0.18 (permit av.) (CW) 0.27 (permit max.)	4.2% (lagoon contents)	24	(PW) 20.0 (permit av.) (PW) 24.0 (permit max.) (assuming 100% exfiltration)	(1) COHO SALMON	1976	Process effluent discharged to lagoon — exfiltration to North Arm. PCB file (PE-3190) states that because of proximity of lagoon to blind channel on North Arm, a large portion of effluent will exfiltrate to this channel.

All the bioassays were static tests conducted on grab samples

TABLE 9
TOXICITY DATA FOR MISCELLANEOUS INDUSTRIES DISCHARGING TO THE LOWER FRASER RIVER

INDUSTRY PCB PERMIT NO.	EFFLUENT SOURCE	DISCHARGE RATE 1000 m^3/day Wastewater	96-h LC50 mean (range)	TCe Toxic Units	TER (TCe · Discharge Rate) x 10^3	(NUMBER OF BIOASSAYS) Species tested	YEARS TESTED	COMMENTS
LAFARGE CANADA LTD. PE-42 (RICHMOND)	Cement plant	1.36 (permit av.)	93.2 % (56->100%) 65 % of the tests non-toxic at 100 % conc.	0.4	0.5	(19) COHO SALMON & RAINBOW TROUT	1971-77	Wastewater discharged to the Main Arm down stream from Annacis Island.
FRASER WHARVES LTD. PE-1621 (RICHMOND)	Car dewaxing operation	0.04 (permit av.)	32.0 % (21 - 43 %)	3.1	0.1	(2) RAINBOW TROUT	1973,75	Intermittent discharge to the North Arm.

All bioassays were static tests conducted on grab samples.