Fraser River Estuary Study
Water Quality

Summary Report of the Water Quality Work Group

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ABSTRACT

This report is part of the Fraser River Estuary Study, which was set up to develop a management plan for the estuary. The report summarizes a number of detailed technical reports which describe effluents discharged, water quality and aquatic biology.

Most water quality parameters in the river are not measurably changed by the major discharges to the river, except near effluent plumes. There is some accumulation of heavy metals and toxic organic contaminants in aquatic biota, including fish. The levels of these toxicants in fish from the river are usually within accepted food criteria, although mercury occasionally exceeds the criteria in some resident species.

Fecal coliform contamination is reduced during the summer months by effluent chlorination at the main municipal treatment plants. Bathing beaches at Boundary Bay, Tsawwassen and Spanish Banks are safe for swimming during the summer, although fecal coliform contamination at the University beaches occasionally approaches borderline levels. Water in the river is generally suitable for irrigation in the summer. The study area is closed to molluscan shellfish harvesting, and is likely to remain so in the foreseeable future.

The total volume of all discharges in the study area is, on average, nearly two million cubic metres per day. About 50 percent of this total is estimated to be storm water, 30 percent is municipal effluent, 18 percent is direct industrial discharges and less than 2 percent is landfill leachates.

The discharge from the Iona sewage treatment plant has degraded an area of Sturgeon Bank. Effluent from the plant, which accounts for about 65 percent of all municipal effluents in the area, has limited aquatic life in a zone about 3 km from the outfall. There is some evidence that this zone is increasing in size.

Effluent from the Annacis sewage treatment plant does not present an immediate acute toxicity problem in the river, outside the initial dilution zone. This situation can change as the effluent flow increases, especially during low flow when tidal conditions limit effluent dispersion. Based on complete dispersion, acute toxicity criteria in the river may be approached by the year 2020, when the Annacis effluent is discharged

at minimum river flow and at present effluent toxicity levels. Industrial discharges to the plant account for about 20 percent of the effluent flow, and contribute to acute toxicity. The sublethal effects of the Annacis effluent are not known. The possibility that such effects occur, especially in the dilution zone, cannot be disregarded.

Storm water is discharged through approximately 200 outfalls and ditches. The loading of contaminants from storm water is variable, but appears to be in the range of one half to twice the loading from the Annacis plant.

Recommendations in this report are designed to protect water quality, and are based on a technical assessment of the information. They are also intended to guide those planning the future of the estuary. They include recommendations to upgrade the Iona treatment plant and to control sources discharging to the municipal sewerage system. Action at Iona will help rehabilitate the degraded area of Sturgeon Bank, and source control will reduce the amount of toxic materials in municipal effluents. A facility to dispose of toxic sludges and hazardous wastes safely will be an integral part of the source control program.

Monitoring programs, aimed at clarifying the effects of storm water and municipal effluents on the river, are also recommended. Monitoring results, together with results of action already taken, will determine the need for future controls, the type of control required, and the timing.

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1. INTRODUCTION

1.1 History of the Study

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

The study looked at the land use, recreation, water quality and habitat for wildlife and fish. Four groups were organized, directed by a Federal-Provincial Steering Committee, to report on each of these subjects. Each group has issued a report, and the Steering Committee has published a summary report outlining a preliminary management plan.

As the water quality work group, we published an interim report(1) in August 1978, in which we reviewed easily accessible information from published documents. Since most of the data on water quality are unpublished, and not readily available, we were only able to reach tentative conclusions in the interim report. We therefore undertook to assemble and review the historical data on discharges, water quality and aquatic biota. The results of our work are integrated in this summary report.

1.2 Study Boundaries

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.

1.3 Objectives of the Summary Report

The main objectives are as follows:

- To summarize all the data collected between 1970 and 1978, which describe discharges, water quality and aquatic biota in the study area.

- To analyze these data in an attempt to understand how discharges and natural processes affect water quality and aquatic life.

- To recommend action that may be needed to prevent degradation of water quality over the next 20 years. The recommendations will be based on an analysis of control measures that can be used in the study area.

- To recommend programs to fill important data gaps.

- To recommend a monitoring program for the river and the main discharges. The program will suggest sampling sites, measurements to be made and frequency of sampling. The scheme may provide a more effective and economic way of monitoring water quality by integrating the present programs undertaken independently by various agencies.

1.4 Organization of the Work

The water quality work group is made up of scientists and engineers from federal, provincial and regional agencies. Individuals in the group prepared 16 detailed technical reports, with the following titles:

1.4.1 Background Reports

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

1.4.2 Ancillary Reports

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

The technical reports present, in summary form, data collected from a variety of sources between 1970 and 1978. In some cases the summaries deal with a large amount of data. For example, about 35 000 measurements have been made on effluents and about 55 000 measurements on water chemistry. In other cases, such as effluent toxicity, certain toxic contaminants and effects on aquatic biota, information is scarce. Copies of the background reports will be available at all main branches of the public libraries in the Lower Mainland. Copies of the ancillary reports will be available from the Ministry of Environment, Parliament Buildings, Victoria, B.C.

In this summary report, we have assembled the main findings of the technical reports. We have integrated the results to show how discharges affect water quality. We describe the effect of measures taken so far to protect water quality, and recommend certain actions to restore or maintain water quality in the future.

2. GENERAL DESCRIPTION OF THE STUDY AREA AND METHOD OF DATA PRESENTATION

The Fraser River drains an area of 230 000 square kilometres and flows about 1 400 kilometres from its headwaters in the Rocky Mountains to the Strait of Georgia.

The flow in the Fraser is considered large, relative to other rivers in the Province, but it is subject to seasonal variations. Approximate flow rates entering the study area are as follows:

- A minimum of 50 to 90 million m^3/d (cubic metres per day) from January to March.

- A maximum of up to 1 200 million m^3/d in June, which then decreases to the winter minimum.

- A yearly average of 300 million m^3/d.

The river entering the study area is called the Main Stem (Figure 1). The river then divides into two branches at New Westminster: the North Arm which contains 15 percent of the flow and the Main Arm (also referred to as the South Arm) which carries 85 percent of the flow. Near the mouth, the North Arm further divides into two, approximately equal branches, the south branch being called the Middle Arm. The Main Arm also subdivides into two branches, the smaller called Canoe Pass and carrying 5 percent of the flow.

Water movement is complex because it is affected by tides in much of the study area. The tidal cycle changes river speeds and water levels and reverses the direction of flow for varying times and distances. At high tide and low river flow, a salt wedge can move up the Main Arm, to as far as the Main Stem. The salt wedge also penetrates the North Arm, but does not reach the Main Stem as a discrete form from this direction.

The Fraser River in the study area has many uses. It supports a large commercial salmon fishery, and is also important for sports fishing. The river is a migration route for juvenile and adult salmon and a rearing area for various salmon and trout. It receives municipal effluent and stormwater originating from the largest population centre in the Province and points upstream. It also receives direct industrial discharges. It is used by commercial shipping and recreational boating, and for transporting log booms which are stored along much of its shore line. The water is not used as a public water supply, although it offers some opportunities for swimming. Water in ditches and backwaters is used for irrigation and agriculture in the summer.

The discharges in the study area are estimated to average, in total, approximately 2 000 000 m^3/d. Of this total, about 1 000 000 m^3/d (50 percent) is storm water, 600 000 m^3/d (30 percent) is municipal effluent and 370 000 m^3/d (18 percent) is industrial effluent. Upstream from the study area, in the interior of the Province, the river receives wastes from several population centres and industries.

In the following chapters we describe the sources of discharges in the study area and present data on their flows and compositions. We summarize the data on water quality and attempt to show how the discharges account for the present state of water quality. We then present data on aquatic biota and relate this information to water quality. Using these data, we discuss the effect of various measures to control the sources of discharges.

3. MUNICIPAL EFFLUENTS

3.1 Development of the Main Treatment Plants

The total volume of municipal effluent discharged in 1979 averaged about 600 000 m^3/d, or 31 percent of all discharges. This volume has increased over the years, and the quantity and composition of effluent discharged today reflect policies adopted over the last 25 years.

In 1953, consultants to the Vancouver and Districts Joint Sewerage and Drainage Board [(2)], recommended that continuous discharges of raw sewage to English Bay and Vancouver Harbour be eliminated over the period 1955 to 1965. The conclusion was based on public health and aesthetic considerations. Adoption of the recommendation led to the construction of the Iona Island sewage treatment plant (STP) in 1961 to 1963. This plant is located on Iona Island, at the mouth of the North Arm, and discharges primary treated effluent to Sturgeon Bank. The consultant also recommended the elimination of municipal discharges to the North Arm by 1970. These effluents now go to the Annacis Island STP, which was built to treat effluents from municipalities adjacent to Vancouver, as well as to the Iona Island STP.

The Provincial Pollution Control Board policy of 1968 recommended primary treatment and chlorination for all municipal discharges to the Lower Fraser by 1975. It also recommended secondary treatment and chlorination for all such discharges to the North and Middle Arms by 1975. This policy led to construction of the Annacis Island STP which discharges primary treated sewage to the Main Arm. The plant services several municipalities and eliminates raw sewage discharges to the river below New Westminster. It began operating in 1975. The Board policy also resulted in primary treatment being installed in 1973 at the Lulu Island STP, which is located on Lulu Island and discharges to the Main Arm, upstream from Steveston Island.

3.2 General Description of the Treatment Plants

Over 97 percent of municipal sewage in the study area is discharged from three primary treatment plants, located between New Westminster and the Banks. The plants, in decreasing order of volume discharged, are at Iona Island, Annacis Island and Lulu Island (Figure 1). The remaining 3 percent of municipal sewage is discharged at four points located between Maple Ridge and Ladner, in a state ranging from raw sewage to secondary treated effluent. There is a fourth major treatment plant in the Greater Vancouver Regional District, on the north shore at Lions Gate, but it is outside the study area.

The area served by the Iona Island plant includes Vancouver, the University of B.C. and Endowment Lands, Vancouver Airport and a small part of Burnaby (Figure 2). This area covers approximately 144 km^2 and contains a population estimated at 460 000. The population is projected to increase to 640 000 by 2020. Of the three main plants, Iona Island is the only one receiving a large proportion of storm water mixed with the municipal effluent. Storm water can increase the flow to the plant, during wet weather, by a factor of four or more. The plant handles, on average, 65 percent of total municipal sewage discharged in the study area.

The Annacis Island plant serves Coquitlam, Port Coquitlam, Delta, Langley City, New Westminister, Surrey, White Rock, Port Moody, Burnaby and a small part of Vancouver (Figure 2). This area covers 460 km^2 and has a population of approximately 370 000. The population is expected to grow to 490 000 by 1986, and 1 200 000 by 2020. The plant receives less storm water than Iona and treats, on average, 28 percent of the total sewage discharged in the study area. The fewer number of storm water connections and smaller population served explain the low volume discharged (Table3) compared to Iona.

The smallest of the main three plants is the Lulu Island plant, serving Richmond with an area of 53 km^3. This area contains a population of about 80 000, which is expected to increase to 141 000 by 2020. The plant handles 3.7 percent of the total municipal effluent discharged in the study area.

Storm water, and greater infiltration of groundwater to the sewers, increases the volume of sewage entering the plants during wet weather. This effect is most marked at the Iona Island plant because the sewer system in Vancouver was designed, in 1914, to handle combined flows of storm water and sanitary sewage. On certain occasions the hydraulic capacity of sewer lines can be exceeded, threatening backup and flooding. On these occasions, overflows of raw sewage diluted with storm water are directed to the river, and to the ocean outside the study area, instead of entering the plants. There is no direct measurement of these overflows or diversions, but they are estimated to be in the order of 23 000 m^3/year, or 0.01 percent of the total yearly discharge. Part of the diversions are to the North Arm where they may have a localized effect.

Bypassing of the plants can also occur, in addition to these overflows. Bypassing takes place if the hydraulic capacity of the plant is exceeded. At Iona, which is the only plant receiving appreciable amounts of storm water, the hydraulic capacity was exceeded from 10 to 40 percent of the time up to 1973. The plant was then expanded and, between 1974 and 1977, the hydraulic capacity was exceeded about 6 percent of the time. The hydraulic capacities of the Annacis Island and Lulu Island plants have never been exceeded. Bypassing of the plants can also occur if there is equipment breakdown, or if a special inspection is needed. Such situations have occurred very rarely.

3.3 Description of the Iona Island STP

The Iona Island plant was built in the period 1961 to 1963 and expanded in 1972 to 1973. The plant provides primary treatment using the following process: prechlorination, mechanical screening, comminution, preaeration, sedimentation, post-chlorination and sludge handling. Chlorination of the treated effluent is carried out to protect beaches used for swimming, and takes place from May to September inclusive.

The plant is located on Iona Island at the mouth of the North Arm. The effluent is discharged in an open channel across Sturgeon Bank to the Strait of Georgia. This channel is uncovered at low tide and covered again at high tide. The tidal action disperses effluent across the Bank, creating a localized effect which is described in the chapters on water quality and aquatic biology. The north side of the effluent channel is bordered by a jetty, which delays the flow of effluent directly across Point Grey into English Bay.

The settling tanks for removing solids are designed for peak flows of 12.7 m^3/s. The maximum pumping capacity in the plant, or hydraulic capacity, is 17.7 m^3/s.

Although the hydraulic capacity is now exceeded, about 6 percent of the time, the design flow for the settling tanks is exceeded, far more frequently, resulting in reduced removal of solids. The solids removed in settling are digested anaerobically. The weight of solids is reduced by 58 percent in this process and the methane gas produced is used in the plant. The digested sludge is stored in settling lagoons. There are four such lagoons, each with five years storage capacity. One of the lagoons was recently cleared by giving the sludge to a composting company. There is land available for four more lagoons.

A pollution control permit (No. PE-23) was issued for the plant in April, 1958. The permit has been amended several times, the latest amendment being January, 1979. Details of the amended permit are summarized in Table 1. The maximum dry weather flow allowed by permit is 318 000 m^3/d (3.7 m^3/s). The maximum allowed in wet weather equals the hydraulic capacity of 17.7 m^3/s. The permit sets limits for BOD_5 of 100 mg/L, suspended solids of 70 mg/L and pH of 6.7 to 7.3 in the effluent discharged. Industry contributes about 10 percent to the plant flow[20]. The composition of industrial waste is 41 percent from the food industry, 16 percent from the wood products industry, 10 percent from metal products and the remainder from various sources. Data on the industrial effluents are presented in Chapter 6. Data on the total effluent are presented and discussed in Section 3.6.

3.4 Description of the Annacis Island STP

The plant provides primary treatment using a process similar to the one at Iona. The main steps are: prechlorination, mechanical screening, preaeration, sedimentation, post-chlorination, dechlorination and sludge handling. Connections to the plant started in May, 1975 and 70 percent of the present flow was going through the plant by the fall of 1975. The result was removal of all raw sewage outfalls from the North Arm, apart from occasional overflows from the sewer lines as described in Section 3.2. Many other outfalls were also eliminated in Surrey, New Westminster, Port Coquitlam and Delta. Chlorination and dechlorination of the treated effluent occurred year round in 1976, from January to September in 1977, and from May to September in subsequent years.

The plant is located on Annacis Island. It discharges to Annieville channel, in the Main Arm, via a submerged diffuser system which extends to about mid channel. The relative flows of the river and the effluent are such that when the river flow is not affected by the tide, the minimum dilution of the effluent is usually in the range of 300 to 1 to 600 to 1, at the point of discharge. The average dilution is about 2 000 to 1 and the maximum dilution is over 7 000 to 1. Under the influence of the tide the flow of the river can be slowed, and sometimes even reversed for five or six hours.

The effect of tide on effluent dilution was measured approximately in a single dye test[3]. Dye was dispersed through one diffuser, at a known rate, and the dye concentration measured at various points in the river during a tidal cycle. From these data, we calculated the approximate dilution of effluent discharging from 1 to 18 diffusers under different conditions and for various effluent flows. The results are given in Table 2. The initial dilution zone, suggested by provincial objectives for municipal discharges [4], extends 100 m downstream and 100 m upstream from the outfall, and occupies about 25 percent of the river width, or 140 m. The dye test indicates that in 1977, at an average effluent flow of 1.9 m^3/s, the dilution within this zone varied from about 3 to 1 right above the diffuser at high slack tide, to 160 to 1 at the edge of the zone. On completion of the tidal cycle, the minimum dilution of effluent within the zone was about 440 to 1.

These results suggest that relatively low dilutions, in the order of 100 to 1, may occur in a localized area around the outfall, under certain tidal conditions. The effects of tidal action on effluent dilution are believed to last for only short periods, and are generally restricted to the initial dilution zone. These effects will be discussed in more detail in Sections 3.6 to 3.7 on effluent quality, and Chapter 8 on water quality.

The design capacity of the plant is 2.8 m^3/s (average dry weather flow) up to 1986, with an ultimate capacity of 6.8 m^3/s to be reached by 2020. The maximum pumping and hydraulic capacity is 10.2 m^3/s. Solids removed by sedimentation are treated in anaerobic digesters which reduce the weight of solids roughly by half. Sludge from the digesters is stored in two lagoons. There is approximately two years of storage left in the lagoons, and land is available for at least five more years of storage. Alternate methods of sludge disposal are under study.

A pollution control permit (No. PE-387) was issued in March, 1971, and amended in 1973, 1974 and 1977. The monitoring program was updated in January, 1979. The present permit conditions are summarized in Table 1. The maximum allowable flow is 586 000 m^3/d (6.8 m^3/s), which is the design flow for 2020. Other permit conditions limit effluent BOD_5 to 130 mg/L, suspended solids to 100 mg/L and pH to a range of 6.5 to 8.5. Certain limits for metals and effluent toxicity, listed in Table 1, are not imposed limits, but are used for comparison in administering the permit.

The question of whether secondary treatment should be installed at the Annacis plant has not yet been resolved. In April, 1975, the provincial cabinet approved the principle of secondary treatment, and directed a technical committee to examine the effect of further treatment. Their report was issued in November, 1976[5]. It recommended surveying the sources of toxic material and piloting a secondary treatment process. Two surveys of industries discharging to the sewerage system were completed recently[6, 20], and the results are incorporated in this report. The pilot plant was deferred by the Greater Vancouver Regional District pending a decision on effluent quality required from Annacis, especially with respect to toxic materials. We expect that our present report, which is a more comprehensive study of the question, may provide a better understanding of the direction to take on this issue.

Industrial discharges to the sewers contribute, on average, 20 percent of the volume entering the Annacis plant. An inventory of industrial sources[6] shows that food processing contributes 35 percent of the industrial input, wood products 30 percent, metal plating and fabricating 15 percent, petroleum industries 15 percent and miscellaneous the remaining 5 percent. These contributions are discussed in Chapter 6. There has been a tendency, over the last few years, for industry to connect to the municipal sewer system rather than discharge directly to surface waters. This is due to government policies for improving waste management and to stricter objectives for discharges to the river. As a result, the treatment plant receives industrial effluent that previously was discharged to the Fraser River or, in some cases, Burrard Inlet. The most significant factor is the introduction of toxic substances. The effluent toxicity is discussed in Section 3.7.

3.5 Description of the Lulu Island STP

This plant carries out primary treatment in much the same way as the other two main plants. The basic steps in the process are prechlorination, comminution, preaeration, sedimentation, post-chlorination, dechlorination and sludge handling. Primary treatment went into operation in 1973, replacing the discharge of raw sewage. Chlorination and dechlorination of the effluent was carried out all year from 1974 to the end of September, 1977, and from May to September in subsequent years.

The plant is located in Richmond (Lulu Island), and discharges to the Main Arm via a diffuser, upstream from Steveston Island. The flow from the plant is, on average, eight times less than the flow from Annacis. The dilution of effluent can therefore be expected to be at least eight times greater than the dilution of Annacis effluent, as discussed in Section 3.4. The solids removed by sedimentation are centrifuged then burned in a fluidized bed incinerator. Waste oil and certain waste solvents can be used as auxiliary fuel in the incinerator. Ash from the incinerator is landfilled on site.

The first pollution control permit for Lulu (No. PE-233) was issued in June 1968 for the discharge of raw sewage. The permit was amended last in March, 1971, to specify primary treatment. The monitoring program was updated in January, 1979. The maximum flow allowed is 132 500 m^3/d (1.5 m^3/s), which is the ultimate design flow for 2020. Effluent characteristics required by permit include a BOD_5 of 169 mg/L and suspended solids of 128 mg/L. The contribution of industrial waste is estimated at 9 percent of the plant flow(6). The composition of industrial waste is 66 percent from the food processing industry, 22 percent from metal plating and fabricating and 12 percent from miscellaneous sources. Since storm water is handled separately from municipal sewage, the concentrations of contaminants in Lulu effluent tend to be higher than in effluent from the other plants.

3.6 Discussion of Effluent Composition From the Three Main Plants

Approximately 35 000 measurements were made of effluent flow and composition, from 1972 to 1978. These data are presented and discussed in detail in a technical report on municipal effluents(7). The parameters measured in the effluent included biochemical oxygen demand (BOD_5), solids, nutrients, total coliforms, heavy metals and certain other toxic contaminants. The data on effluent composition and flow, for the three main plants, are summarized in Table 3. Coliform data collected in 1977 are summarized in Table 4. The data are discussed in this section using annual averages unless otherwise indicated.

3.6.1 Effluent Flow

The highest flow was from the Iona Island plant, where the annual average ranged from 318 000 m^3/d to 387 000 m^3/d, in the period 1972 to 1977. Since the plant receives a large proportion of storm water drainage, there were large fluctuations in the daily flow. For example, in 1977 the flow varied from 160 000 m^3/d to 946 000 m^3/d. As a result, the pollution control permit limit for average flow was exceeded 39 to 64 percent of the time in a year, between 1974 to 1977. Before 1974, when plant expansion took place, the plant's hydraulic capacity was exceeded 14 to 43 percent of the time, resulting in frequent plant bypasses. Since 1974, the plant was bypassed about 6 percent of the time, due to excess flow, and the plant's upper design limit of 1.1 million m^3/d (12.7 m^3/s) was exceeded 10 to 20 percent of the time, resulting in solids removal being less effective. These data illustrate the difficulty in operating a treatment plant which receives a large proportion of storm water together with municipal sewage.

At Annacis, the annual average flow ranged from 148 000 to 166 000 m^3/d between 1975 and 1977. The daily flow fluctuated between 100 000 and 200 000 m^3/d and the pollution control permit limit of 586 000 m^3/d, which equals the plant's hydraulic capacity, was never exceeded. The fluctuations were much less than those measured at Iona, due to the relatively smaller proportion of storm water entering the plant. Such improved flow control gives better plant performance in solids removal. The advantages and disadvantages of treating storm water with municipal sewage are discussed in Chapter 10 on control measures.

The annual average flow from the Lulu Island plant increased from 11 500 m^3/d to 21 600 m^3/d, in the period 1973 to 1977. The permit limit of 132 000 m^3/d, which is the maximum design level, was never exceeded. In 1977, the daily flows ranged from 13 600 m^3/d to 42 300 m^3/d, reflecting the relatively small amount of storm water infiltration occurring in the collection system.

3.6.2 Suspended Solids and Sludge Handling

At Iona, the quantity of suspended solids discharged in the effluent averaged 15 500 to 18 500 kg/d, from 1972 to 1977. The average concentration in the effluent was close to 48 mg/L. The average removal of solids by the plant was 58 percent. This average varied from 68 percent during the dry months of May to October to 48 percent during the wet months of November to April. This result shows how plant performance is lowered by increases in flow due to storm water input. The pollution control permit limit of 70 mg/L was exceeded about 8 percent of the time from 1975 to 1977.

Results from Annacis were similar. The plant discharged less suspended solids (7 700 to 11 000 kg/d average) since the volume of effluent treated was less, although the concentration in the discharge was slightly higher (52 - 65 mg/L average). The efficiency of solids removal was similar (62 percent average from 1976 to 1977). The permit limit of 100 mg/L was exceeded less than 2.5 percent of the time. The water quality data indicate that the quantity of suspended solids discharged by the Annacis plant is insignificant compared to the suspended solids naturally present in the river (Chapter 8). However, the solids from the plant are mainly organic in nature, whereas solids in the river are mainly inorganic.

The Lulu Island plant contributed a relatively small amount of suspended solids (1 000 to 1 800 kg/d). The concentration in the effluent was higher (81 to 91 mg/L average) than for the other plants, but the efficiency of solids removal was also higher (68 percent). The permit limit (128 mg/L) was not exceeded.

These results indicate that solids removal at the three main plants was within limits expected for primary treatment. The weight of dry solids removed per day was 29 t/d at Iona, 19.4 t/d at Annacis and 4 t/d at Lulu. At Iona and Annacis, the weight of these solids was reduced by about half by anaerobic digestion, and the digested sludge stored in lagoons. At Lulu, the raw sludge was incinerated. Sludge from the digesters contained about 4 percent solids. Digested sludge settled slowly in the lagoons. After three years of storage, the solids content of sludge was about 10 percent, and after twelve years it was 25 percent.

Heavy metals are concentrated in the settling solids during primary treatment. A summary of the heavy metal content of sludge is given in Table 5. Iron content was in the order of 6 000 ppm and zinc, copper, lead and chromium content were in the range of 100 to 700 ppm, on a dry weight basis. Toxic organic chemicals also concentrated in the sludge. Two analyses of Iona sludge showed concentrations of polychlorinated biphenyls (PCB's) of less than 0.01 and of 27 ppm, dry weight. The data on PCB's in sludge are uncertain and indicate that more analyses are required.

The question of sludge disposal has not been completely resolved. Incineration is costly (estimated at $100/dry tonne at Lulu) and requires special controls to avoid air pollution. Composting is cheaper (composting of Iona sludge with sawdust estimated at $17/dry tonne), but the effect of adding heavy metals and toxic organic materials to soil must be assessed. There is also a possibility that digested sludge can contain viruses and other organisms that may be a health hazard.

3.6.3 Biochemical Oxygen Demand (BOD_5)

The removal of suspended solids in primary treatment lowers the BOD_5 of the effluent, although most of the BOD_5 is exerted by dissolved organic material. At Iona, the average BOD_5 in the effluent varied from 77 to 105 mg/L. The average BOD_5 removal was 31 percent. In the period 1975 to 1977, the permit limit of 100 mg/L was exceeded 40 to 50 percent of the time. The performance of the Annacis plant was similar. The BOD_5 in the effluent averaged 88 to 96 mg/L, the removal rate was 32 percent, and the permit limit of 130 mg/L was exceeded 40 to 60 percent of the time. The strength of waste at the Lulu plant was higher than at the other two plants. This gave a higher concentration of BOD_5 in the effluent (113-142 mg/L average), although the removal rate was similar (33 percent). The permit limit at this plant (169 mg/L) was exceeded 20 percent of the time.

The reduction in BOD_5, achieved at the three main plants, was within limits expected for primary treatment. Measurements show that the permit limits were exceeded about 50 percent of the time. However, the water quality data show that BOD_5 has not been a problem in the main channels of the river (Chapter 8).

3.6.4 Heavy Metals

Heavy metals occur in the effluent, partly in the soluble or dissolved form, and partly in the insoluble form associated with suspended solids. An analysis of total metal includes soluble and acid soluble forms. In this report, analyses of metals in the effluent were usually for the extractable form which gives a slightly lower result than total metals. However, to simplify this summary, extractable metal will be equated with total metal. A full discussion of this subject, and of the various detection limits for heavy metals, is given in the technical report on water chemistry[27].

In the sewer and primary treatment plants, the heavy metals tend to precipitate from solution and to adsorb onto suspended particulate matter. A proportion of the heavy metals is thus removed in the sedimentation process. Removals of 30 to 60 percent have been measured for most metals in primary treatment, excluding nickel[8]. The accumulation of heavy metals in the sludge is a result of this process (see Section 3.6.2). The amount of each metal removed at the main treatment plants was approximately 25 percent, and the concentrations in the effluents were generally within level BB of the Provincial Objectives[4].

a) Iron

In the Iona and Annacis effluents, the concentration of total iron averaged 1.0 to 1.2 mg/L. In Lulu effluent it was higher, ranging on average from 2.9 to 3.8 mg/L. The average amount discharged was up to 500 kg/d from Iona, 200 kg/d from Annacis and 60 kg/d from Lulu. The percentage removal was similar at all three plants (approximately 20 to 30 percent).

There were only a few measurements of soluble iron in the effluent. These averaged 0.6 mg/L at Annacis, and were below 0.4 mg/L at Iona. All measurements were within the level BB objective of 1.0 mg/L. The background concentration of total iron in the river, although variable, was about 1.0 mg/L, and soluble iron about 0.1 mg/L (Chapter 8). Since these concentrations were similar to the effluent concentrations, the effect of iron from the effluents is considered to be negligible.

b) Zinc

The average concentration of total zinc varied from 0.11 to 0.21 mg/L at the Iona and Annacis plants. At Lulu, the range was 0.18 to 0.42 mg/L. All values were within the level BB objective of 5.0 mg/L. The percent removal varied from about 23 percent at Annacis, to a range of 17-34 percent at Iona and 23-38 percent at Lulu. The zinc concentration in the river was similar to the concentration in most other streams of the Province (Chapter 8). Concentrations in the order of 0.01 mg/L total zinc were theoretically possible in the initial dilution zone off Annacis, under certain tide and river flow conditions. These localized effects are discussed in more detail in Chapter 8.

c) Copper

The concentration of copper in the effluent was similar to that of zinc. The average was in the range of 0.13 to 0.20 mg/L at Iona and Annacis, and 0.18 to 0.33 mg/L at Lulu. All values for total copper were within the level BB objective of 0.5 mg/L dissolved copper. The percentage removal was greatest at Iona, where it averaged about 50 percent. This result may be high due to copper contamination from the influent sampler at the Iona plant. At Annacis, copper removal averaged 26 percent, and at Lulu 20 percent. Over 98 percent of samples taken from the river had a concentration of less than 0.01 mg/L (Chapter 8).

d) Lead

The concentration of total lead was lowest in the Annacis effluent, where it averaged 0.02 to 0.03 mg/L. Only a few values occasionally exceeded the level BB objective of 0.10 mg/L. At Iona and Lulu, the average concentration was nearer 0.1 mg/L. The percent removal was about 24 percent at Annacis and variable at the other plants, averaging up to 50 percent at Iona and 29 percent at Lulu. Nearly 80 percent of the measurements of lead in the river were below the detectable limit. The maximum values recorded were below the level of 0.03 mg/L, considered safe for aquatic life (Chapter 8).

e) Chromium

The average concentration did not exceed 0.07 mg/L at Annacis, 0.15 mg/L at Iona and 0.13 mg/L at Lulu. Many values were below the detection limit, and none exceeded the level BB objective of 0.3 mg/L total. Virtually all concentrations in the river were within 0.05 mg/L, which is the limit suggested as safe for aquatic life (Chapter 8).

f) Nickel

At Annacis and Iona, the average concentration was 0.08 mg/L or less. Many values were below the detection limit. At Lulu, the average concentration ranged from 0.13 to 0.17 mg/L. These higher values reflect the greater percentage of plating wastes directed to the plant at Lulu. Over 90 percent of nickel measurements in the river were below the detection limit (Chapter 8).

g) Other Toxic Elements

Measurements were made of other toxic elements. These included arsenic, barium, boron, cadmium, cobalt, mercury, molybdenum, selenium, silver and tin. The levels in the effluents were generally below detectable limits. Concentrations in the river, which were also low, are discussed in Chapter 8. Accumulation in aquatic biota, especially of mercury, is discussed in Chapter 9.

3.6.5 Phenolic Materials and Other Toxic Compounds

Eleven grab samples, taken from all three plants in 1977, gave an average concentration of phenolic material varying from 0.02 mg/L at Iona to 0.06 at Annacis. The values ranged from less than 0.01 to 0.15 mg/L. There were no values above the level BB objective of 0.4 mg/L phenolic material.

A more detailed analysis of the effluents for phenolic materials was carrried out by gas chromatography[9]. The results are based on a single 24-hour composite sample obtained from each treatment plant. Although a large variety of phenolic compounds was found to be present in the municipal effluents, the three main compounds were pentachlorophenol, tetrachlorophenol and trichlorophenol. The analytical procedure gave the following, approximate concentrations. Pentachlorophenol: 1 to 3 μg/L, tetrachlorophenol: 0.5 to 1.7 μg/L, except at Annacis where a value of 22 μg/L was measured, trichlorophenol: 0.02 to 1.0 μg/L. These chlorinated phenolic compounds degrade slowly and can be toxic to fish at concentrations in the order of 40 μg/L. We expect the maximum concentration of these compounds to be about 1 μg/L in the initial dilution zone off Annacis, and less than 0.1 μg/L after complete mixing. Given these facts, the compounds are unlikely to cause any immediate harm to fish in the river, although some accumulation in fish tissue occurs (Chapter 9, section 9.4).

The concentrations of cyanide and sulphide were generally below the detection limit in the effluents. In cases when values were obtained, they were below the Annacis permit limits of 0.5 mg/L for cyanide and 1.0 mg/L for sulphide.

Polychlorinated biphenyls (PCB's) were measured in the effluent during a four day sampling trial in 1976. The final effluent contained 0.034 μg/L at Annacis and 0.077 μg/L at Iona. Although these concentrations are very low, they show that measurable amounts of PCB's are present in municpal effluent. One source of PCB's is street runoff, since street sediments can contain 0.05 to 0.150 ppm PCB's on a dry weight basis (Table 9). The removal of PCB's in the primary process was 42 percent at Annacis and 46 percent at Iona. The material is concentrated in the sludge, as indicated by measurements reported in Table 5.

3.6.6 pH

The pH of the effluent varied according to the plant. At Annacis and Lulu, it tended to be on the acidic side, and at Iona on the neutral to basic side. At Annacis there was a trend, over time, towards a lower pH. Although no values were above the upper permit limit of 8.5, 28 percent of the values were below the lower limit of 6.5 in 1977. The lowering of the pH was due mainly to chlorination and dechlorination of the effluent.

At Lulu, 90 percent of the readings were between 6.7 and 7.1. This result was probably due to chlorination and dechlorination of the effluents. At Iona, in 1977, 25 percent of the values were over the upper permit limit of 7.3 and 15 percent were less than the lower permit limit of 6.7.

3.6.7 Nutrients

Phosphorus and nitrogen are discharged by all municipal sewage treatment plants. Iona and Annacis each discharged from 700 to 1 000 kg/d of phosphorus and from 3 700 to 5 600 kg/d of nitrogen. The three main treatment plants contributed about 10 to 20 percent of the phosphorus and nitrogen already present in the river. The effect of these contributions on the biological productivity of the estuary is discussed in Chapters 8 and 9.

The average concentration of phosphorus in the effluents was in the range of 5 mg/L, ammonia nitrogen 15 mg/L, and Kjeldahl nitrogen 25 mg/L. The concentrations varied from plant to plant, but the main concerns are possible nutrient enrichment in a localized area, before complete dilution of effluent, and toxicity due to ammonia.

The effects of nutrients on algae are discussed in detail in Chapter 9, on aquatic biota. The nutrients in the river caused few algae blooms, owing largely to natural turbidity which limits light penetration during high flow. Ammonia was one of many potentially toxic compounds present in the effluent. The toxicity of this compound is due to the concentration of un-ionized ammonia, which is dependent on river pH, temperature and dissolved ions. Water quality data show that the concentration of un-ionized ammonia in the river was always within the limit of 0.02 mg/L, considered safe for aquatic life (Chapter 8), in areas where dilution of municipal effluent was greater than 15 to 1. A more detailed discussion of toxicity is presented in Section 3.7.

3.6.8 Coliforms

Measurements carried out on municipal effluents were usually for total coliforms. Experience has shown that values for fecal coliforms in sewage are less than for total coliforms. It is therefore difficult to relate directly total coliform measurements in municipal discharges to fecal coliform measurements in receiving water.

The monthly geometric mean coliform concentrations, listed in Table 4, show that the coliform counts in the effluents varied widely. As expected, there was a large difference between chlorinated effluent and unchlorinated effluent. At Iona, the monthly geometric mean averaged 400 MPN/100 mL with chlorination, and 2.6 million MPN/100 mL without chlorination. At Annacis, the equivalent values were 5 700 and 5.5 million, and at Lulu, 12 000 and 21 million. These data show that chlorination reduced the coliform count in the effluent by a factor of 1 000 to 6 000. At Annacis and Lulu, where dechlorination using sulphur dioxide was carried out, there was an excess of sulphur dioxide in the effluent and no chlorine residual.

Fecal coliform counts in the river were highly variable (Chapter 8). The geometric mean averaged, very roughly, 100 to 300 MPN/100 mL at sites upstream from Douglas Island, and 1 000 MPN/100 mL or less in the Main Arm and in the North Arm, after startup of the Annacis plant. The effluent contribution to coliforms in the river was low in the summer and high in the winter. Another source of coliforms is storm water, which enters the river untreated, through a number of outfalls (Chapter 4).

3.7 Effluent Toxicity

3.7.1 Limitations of the Data

The acute toxicity of municipal effluent was tested using fish bioassays. Results were expressed as the 96 hour lethal concentration for 50 percent mortality, or $96hLC_{50}$. This is the concentration of effluent in dilution water, expressed as percent, at which 50 percent of the test fish die after 96 hours (4 days) exposure.

The toxicity data, obtained on effluents from the three main treatment plants, were influenced by a variety of factors. Two different test methods were used: the static bioassay and the continuous flow bioassay. In the static test, the effluent remained in the fish tank, at given dilutions, for four days, without replacement. In the continuous flow test, effluent was continually pumped through each tank, at given dilutions for four days. Effluent used in the static tests was obtained either from grab samples, or from 24-hour composite samples. Effluent used in the continuous flow tests was drawn continuously from the plant, and the tests were therefore conducted at the plant site, using river water for dilution.

The sensitivity of the two methods differs, thus influencing the results. The continuous flow test is more sensitive to the effects of shock loading and of volatile or unstable toxic compounds, and is recommended by Standard Methods[37]. The static test, using a 24-hour composite sample, will indicate the average toxicity. The static test, using a grab sample, could give more variable results than the test with a composite sample.

Other factors influencing the results included the use of different test species (generally sockeye salmon, coho salmon or rainbow trout), different methods of acclimating fish, varying fish densities, the use of different dilution water, varying pH control, and sample age and preparation. The results of such bioassays tests are therefore different. Extrapolation of the data to the river is a very approximate method of estimating the impact of toxicants on fish in the river. Results of continuous flow bioassays are the best data available upon which to judge acute toxicity in the river.

3.7.2 Pollution Control Objectives

The objectives for municipal effluents require a $96hLC_{50}$ of 100 percent for level AA and 75 percent for level BB[4]. The objectives do not describe the test procedure, but do stipulate that the effluent should be sampled and tested before chlorination. The criterion used for comparison at the Annacis plant is level BB (96h LC_{50} = 75 percent), on a monthly grab sample of effluent, obtained before chlorination. A static bioassay test was selected.

3.7.3 Test Results

The results of the acute bioassay tests are presented and discussed in detail in a separate report [10]. A summary of results obtained for the three main treatment plants up to 1978 is given in Table 6. There were 20 bioassays conducted at Annacis, 23 at Iona and 6 at Lulu. Each result from continuous flow bioassays was often deduced from a large number of tests carried out at different concentrations.

The range of results, due to the use of different test methods or procedures, is illustrated by data obtained from Annacis. The average toxicities of dechlorinated effluent were as follows:

$96hLC_{50}$	=	93 percent for static tests on monthly grab samples.
$96hLC_{50}$	=	36 to 68 percent for static tests on 24-hour composite samples, using different procedures.
$96hLC_{50}$	=	26 percent for continuous flow tests (17 percent for dry weather flow, 33 percent for wet weather flow).

The results of static tests on monthly grab samples frequently met level AA, and were usually within level BB of the provincial objectives. As expected, the static tests showed higher toxicity on composite than on grab samples, and the continuous flow tests showed the highest toxicity.

Similar results were obtained from tests carried out on Iona effluent. The average $96hLC_{50}$ for non-chlorinated effluent, from continuous flow tests, was 45 percent. These results suggest that the Iona effluent may be less toxic than the Annacis effluent. Continuous flow tests on dechlorinated effluent from Lulu gave an average 96h LC_{50} of 25 percent, which is similar to the result obtained at Annacis.

3.7.4 Discussion of Results

Some of the toxic constituents of municipal effluents are ammonia, surfactants, cyanide, sulphide, phenol and heavy metals. An attempt to calculate a theoretical toxicity for the whole effluent, by adding the toxicities of certain components of the effluent, failed to account for all the toxicity present[11]. There are also possible synergistic or antagonistic effects among toxic components, and effects from certain organic compounds, which are present at low concentrations. These compounds include chlorinated hydrocarbons, chlorinated phenolics, fatty acids, phthalate esters and terpenes. They are present in the effluents at either very low concentrations, below 1 μg/L, or at concentrations in the range of 1 to 100 μg/L. More information concerning trace contaminants is presented in two separate reports[9,12]. One source of contaminants is industrial effluents which discharge to the sewer. A discussion of the composition and flow of these effluents is given in Chapter 6.

An approximate method of predicting the effect of a toxic discharge on the river is to calculate the toxicity concentration in the river. This concentration in the river, expressed in toxicity units, is calculated as follows, assuming complete mixing:

$$\text{Toxicity concentration} = \frac{100}{96hLC_{50}} \times \frac{\text{effluent discharge rate } (m^3/d)}{\text{river flow } (m^3/d)}$$

A toxicity concentration in the river was calculated for Annacis effluent, assuming complete mixing and that the following extreme conditions occurred simultaneously:

Minimum $96hLC_{50}$ = 17 percent

Present maximum effluent discharge rate= 220 000 m^3/d

Minimum flow in the Main Arm (March to April) = $49.7 \times 10^6\ m^3/d$

These values gave a toxicity concentration in the river of 0.03 toxic units. With the maximum effluent discharge rate allowed by permit (586 000 m^3/d) to be reached in 2020, (based on 1970 projected growth rate), the toxicity concentration would be 0.06 toxic units. Safe concentration limits for fish are considered to be in the range of 0.05 to 0.10 toxic units for non-persistent toxicants, and 0.01 to 0.10 toxic units for persistent toxicants(13). On this basis it appears that, under extreme conditions, the lower safe limit may be approached in the river by 2020. This estimate does not account for the smaller effect on the river of Lulu effluent, storm water and other discharges. Also, concentrations exceeding safe limits could occur in localized areas, before complete mixing.

A graph showing the change in toxicity concentration in the river with increasing $96hLC_{50}$, at the maximum allowable effluent flow at Annacis (586 000 m^3/d) and the minimum river flow (49.7 x 10^6 m^3/d), is given in Figure 3. This plot indicates that conditions which are unsafe for fish could be reached assuming complete mixing under these special circumstances, if the $96hLC_{50}$ dropped to 10 percent or less. The maximum allowable effluent flow will not be reached until about 2020 and this minimum river flow occurs only rarely. The analysis, however, demonstrates the need for continued monitoring of toxicity, with a view to applying controls, either at the treatment plant or at the source connecting to the sewer. A discussion of control measures and their expected effects is given in Chapter 10.

A discussion of the dilution of Annacis effluent (Section 3.4), indicates that dilutions ranging from 3 to 1 to 160 to 1 can occur at times in the initial dilution zone. Although the lowest dilutions are less than the worst $96hLC_{50}$ of 17 percent, they occur for less than 12 hours and in only a very localized zone above the outfall. Thus, relatively safe conditions probably exist in the river outside the dilution zone, with regard to the acute toxicity. However, chronic and sublethal effects can occur at lower concentrations, and the possibility that such effects are felt in a localized area cannot be completely disregarded.

4. STORM WATER DISCHARGES

As mentioned in the general description of Chapter 2, storm water constitutes about half the volume of discharges in the study area. In spite of this, very little information has been collected in the region on storm water, compared to data available on sewage treatment plant effluents and river water quality. In this chapter, we describe the storm water collection system, and summarize data on storm water flows and composition.

4.1 Description of Storm Water Collection in the Study Area

We have used the term storm water to include rain water and snowmelt which runs off streets, roofs and open areas, and ground water or any other water, which is collected by storm drains and ditches. The ground water flows during all seasons, and is augmented by rainfall mostly during the fall and winter months.

Storm water is collected in three main ways: underground sewers, open ditches and natural creeks or streams. The underground sewers are in the developed areas, ditches are used in the agricultural and low lying areas, and the natural streams occur mostly in Burnaby, New Westminster, Surrey and Coquitlam. There are approximately 140 municipal storm sewer outfalls and 40 ditches and streams. According to rough estimates, 30 percent of the storm water outfalls in the study area discharge to the North Arm, and 60 percent discharge to the Main Arm, either directly or via the Main Stem. The remainder discharge to Boundary Bay and the Strait of Georgia. A survey of storm water outfalls, describing their appearance and location, was carried out recently[14]. A map showing the location of outfalls is reproduced in Figure 4.

The underground collection of storm water is carried out either together with domestic sewage in combined sewers, or separately. The first sewer systems that were built used combined sewers, so that this sytem is found in the older built-up areas. The tendency today is to build twin collection systems for storm water and domestic sewage, therefore the separate system occurs in the more recently developed areas. The advantages and disadvantages of the two collection methods are discussed in Chapter 10 on control measures.

Most combined sewers occur in Vancouver and parts of Burnaby. This area is serviced by the Iona Island treatment plant (Section 3.2). Combined sewers have produced certain operating problems in the plant, as discussed in Sections 3.6.1 and 3.6.2. There are some combined sewers in New Westminster also, and these account for the smaller proportion of storm water entering the Annacis Island treatment plant. In parts of downtown Vancouver, an attempt was made to direct only the first flush of storm water to the sanitary sewer, and hence to the Iona plant. Systems were installed which direct high flows to separate sanitary sewers. The effectiveness of the system, in separating contaminated from relatively uncontaminated storm water, is not known.

Most of Burnaby and Coquitlam, and parts of New Westminster, use separate underground storm sewers. In Surrey, Delta, Richmond and Port Coquitlam, the storm water generally flows to the river via open ditches. Still Creek, which flows through Burnaby into the Brunette River, and then into the Fraser River at New Westminster, is used extensively for storm water collection. The Coquitlam River, and certain other creeks, are also used although to a lesser extent.

Storm water collected in separate underground sewers and ditches is discharged, untreated, directly to the Fraser River. The outfalls to the river are equipped with gates to prevent river water from flowing back up the sewers. The gates act as check valves and come into operation when the river level rises under tidal action. During dry weather, the gates may close off the flow for up to 12 hours out of every 24, under the action of the tide.

4.2 Review of Data on Storm Water Composition and Flows

There have been very few measurements of storm water flow and composition in the study area. The data available have been presented and discussed in a separate report [15]. The report also includes theoretical flows and contaminant loadings, based on rainfall data and literature values. The results of the calculations and measurements are summarized in this section.

4.2.1 Theoretical Flows and Loadings From Rainfall

A very rough prediction of storm water flows, and loadings of suspended solids and BOD_5, was made by Franson[16] in 1973, for the Greater Vancouver Regional District.

Predictions were made for 1973, 1986 and 2000, assuming a certain urbanized land area, an average rainfall, a single runoff coefficient and a certain storm water composition. The results for 1973 are summarized in Table 7. Franson concluded that BOD_5 and suspended solids loadings from storm water may be similar to loadings from the main sewage treatment plants.

A more detailed calculation is presented in the background report[15]. This analysis divided each municipality draining to the Lower Fraser into five different land use areas. These were: roads and residential, commercial, industrial, agricultural and open. The area taken up by each land use in each municipality was estimated. The runoff volumes were calculated using the average annual precipitation for each municipality and an average runoff coefficient for each land use. The concentrations of contaminants in runoff were estimated from a literature survey, including data on trace metals obtained from the study area. The concentrations were generally assumed to be higher in runoff from roads, commercial and industrial areas than in runoff from agricultural areas. Results are summarized in Table 7.

Storm water contributions via natural streams, such as the Brunette and Coquitlam Rivers, were estimated to be less than one percent of the total storm water contribution in the study area[27].

4.2.2 Measured Flows and Concentrations

There have been very few measurements of storm water flow and composition in the study area. The most comprehensive set of data is from a survey done during the summer of 1978. The results of this survey, and of a few other isolated studies, are presented below:

a) Storm Water Survey of 1978

This survey was carried out to estimate the contribution of storm water to the river during the dry months of the year. The results of this work are the subject of a separate report[17]. Sampling took place in July, August, September and October at various sites in the study area. Grab samples for analysis were taken twice from 34 outfalls, and rough flow rate measurements were made at several locations.

Flow rate measurements were carried out on dry weather flows. An average value of 0.015 m^3/s per pipe was obtained from outfalls connected to underground sewers, and 0.121 m^3/s per pipe from outfalls connected to drainage ditches. An estimate of total daily dry weather flow was obtained by multiplying these values by the corresponding number of outfalls. Allowance was made in this calculation for interruption of the flow, at a number of outfalls, for 12 hours a day due to tidal action.

The concentrations of contaminants in storm water were classified according to land use. For the purpose of calculating a general daily loading to the river, an overall average concentration for each contaminant was used. A summary of results is presented in Table 8.

b) Results of Miscellaneous Analyses

Storm water samples were collected in 1974 from the Renfrew Street sewer, in an area believed to have no sanitary sewer connections(15). Analyses for dry weather and wet weather flow are summarized in Table 9. In 1976, grab samples were collected from 18 sewers between the University and Surrey(15). The results are also summarized in Table 9, together with some data on polychlorinated biphenyls measured in sediments from street surfaces(15).

4.2.3 Discussion of Results

Calculations of storm water runoff volumes from rainfall (Table 7) indicate that the average flow (up to 700 000 m^3/d) is of the same order as the daily discharge from all municipal treatment plants (600 000 m^3/d). The calculated average flow of 700 000 m^3/d is judged as the most reliable value available so far since it is based on a fairly detailed analysis of drainage areas, land use and rainfall. As it is a daily average for the whole year, actual flows will at times be higher or lower, due to the seasonal nature of rainfall. About 11 percent of the storm runoff is collected in combined sewers and becomes part of municipal effluent. The remainder, an average of 620 000 m^3/d, is discharged through storm sewers and ditches.

Measurements made in the summer of 1978, on days without rain, indicate that the daily discharge from storm water drains was in the order of 300 000 m^3/d (Table 8). This flow originates from groundwater movement, seepage or springs, and represents the approximate dry weather discharge of storm water in the study area. The total daily average stormwater flow is therefore expected to be approximately 1 000 000 m^3/d. More measurements during rainy periods are required to confirm this value.

Contaminants in storm water originate from dustfall and other material deposited on roofs, streets and paved areas, or in particulates entrained by raindrops. Solids are also entrained from ditches and open areas. Studies show that the major contaminants are suspended solids and coliform bacteria[15]. Studies also show that up to 75 percent of the contaminants may be entrained in the first flush, which occurs with the first few hours of rainfall. These fluctuations make sampling and flow measurements difficult, so that loading estimates are approximate. The sporadic pattern of flow and concentrations also complicates control and treatment of storm water.

In Table 10, we have listed the average concentrations and loadings from storm water, for rainfall and dry weather flow. These are compared, in the table, to average values for the municipal effluents. Values for storm water are taken from Tables 7 and 8. Values for municipal effluents are averaged for Iona and Annacis from Table 3. Values are rounded off for ease of comparison.

The concentrations of contaminants in municipal effluents are relatively constant, compared to those in storm water, which can vary over a wide range. On average, however, the concentrations of suspended solids were similar although their composition is different. The concentrations of most other constituents, including heavy metals such as copper, lead and zinc were, on average, three to ten times lower in storm water (Table 10).

The loadings, or quantities of contaminant discharged, depend on flow and concentration. Although the information is incomplete, the loading of suspended solids was at least the same from storm water and municipal effluents. For most other constituents, the loadings from storm water were lower. Lead from storm water was approximately 50 percent of lead from municipal effluents, zinc was approximately 30 percent and copper 16 percent. Iron was an exception, being three times higher from storm water than from municipal effluents. To compare storm water with municipal effluents that discharge only to the Fraser River, we should exclude the contribution from Iona, thereby reducing municipal effluent loadings by about two thirds. On this basis, the loadings from storm sewers discharging to the river ranged from about one half to double the loadings from municipal effluents discharging to the river.

These results indicate that untreated storm water discharges to the river appear to contribute about the same amount of contaminants as primary treated municipal effluents. The effects of storm water on water quality are difficult to separate from the effects of municipal discharges. Although the average concentrations of many constituents are lower in storm water, temporary high concentrations may exist in the first flush of a rainfall. The magnitude and duration of these concentrations have yet to be documented, but they may cause localized effects. On the other hand, the effect of storm water will generally be more diffuse, since it discharges through 180 outfalls, compared to two main outfalls for municipal effluents. Storm water contains a variety of toxic materials, such as oils and chlorinated hydrocarbons, which are washed from paved areas and open spaces[15]. The amounts and types have not yet been well established, although the existence of polychlorinated biphenyls in street sediment has been shown (Table 9). Limited bioassay tests suggest that storm water is not acutely toxic to fish[15].

Few measurements have been made of the coliform content of storm water. According to some estimates, storm water is a major source of coliforms, with fecal coliform counts in the range of 600 to 11 000 MPN/100 mL (Table 7). Some of this contamination is believed to come from connections between sanitary and storm sewers.

Data on the impact of such discharges on water quality and aquatic biota are discussed in Chapters 8 and 9, and a discussion of control measures is given in Chapter 10.

5. INDUSTRIAL EFFLUENTS DISCHARGED DIRECTLY TO THE RIVER

Industry in the study area discharges, on average, about 370 000 m^3/d of effluent directly to the river. This flow is 18 percent of all discharges in the study area, and 24 percent of all discharges to the river, excluding the Iona discharge to Sturgeon Bank. In this chapter, we discuss effluents discharged directly to the river by industry. These exclude sewage treatment plant effluents discussed in Chapter 3, storm water discussed in Chapter 4 and landfill leachates discussed in Chapter 7. Data were obtained from the Provincial data bank (EQUIS), and from Pollution Control Branch files. A more detailed analysis of the subject is presented in a background report on industrial effluents(33).

A large variety of industries discharge to the Fraser River. In order to characterize the type and quantity of contaminants discharged, we have divided the effluents into the following seven categories: municipal, forest, food, metal, cement, miscellaneous and uncontaminated cooling water.

The municipal-type effluents comprise domestic sewage discharged by industries, and effluents from hotels and restaurants, which are not connected to the sewerage system. The forest industry effluents are mainly from sawmills and plywood mills. There are also two paper mills and a board mill. The food industry effluents come mostly from fish processing plants, and a few fruit and vegetable canneries and meat packers. Metal fabricating covers galvanizing, foundries, wire and other metal products. The cement industry consists of cement plants, ready-mix operations and the fabrication of concrete products. The miscellaneous category includes small chemical plants, docks, car de-waxing, wood preserving and storm water from industrial areas. Many of the industries, in each category, discharge large volumes of cooling water. We have grouped cooling water, uncontaminated by the process, into a separate category.

5.1 Effluent Flow

There are approximately 108 industrial outfalls to the river. Of this total, 29 percent are located on the Main Stem, 29 percent on the Main Arm, and 42 percent on the North Arm. The concentration of industry around the North Arm is also shown by the distribution of effluent volume. Of the total volume discharged to the river, 44 percent is to the North Arm, 30 percent to the Main Stem and 26 percent to the Main Arm. On the basis of flow and dilution, we can expect industrial effluents to have the greatest effect in the North Arm, which carries only 15 percent of the river flow, and the least effect in the Main Arm.

A breakdown of effluent flow in the three main reaches of the river, by industry category, is given in Table 11. The forest industry contributes the greatest volume overall (61 percent), followed by miscellaneous industries (19 percent), uncontaminated cooling water (9 percent) and metal fabricating (7 percent). Each of the other categories, including food, cement and municipal type effluents, contributes about two percent or less.

The distribution of flow among the reaches shows some variation. The forest industry is the main contributor in the Main Stem (93 percent) and the North Arm (75 percent), but has a minor input to the Main Arm (less than 5 percent). The major inputs to the Main Arm are from miscellaneous industries (72 percent), followed by uncontaminated cooling water (19 percent). In the North Arm, metal fabrication is the second largest contributor of effluent (16 percent).

On the basis of flow, the major discharges occur in the Main Stem and the North Arm, from sawmill operations. These industries discharge large volumes of cooling water contaminated by the process and by boiler blowdown. The contaminants are mainly wood waste (sawdust, chip and hog fuel particles) present in the form of suspended solids. These contaminants may have a localized effect but are unlikely to have any general effect on river water quality, in comparison with suspended solids naturally present or derived from log booms stored along the banks. Some data on specific industries are provided in Section 5.2, on the main industrial effluents.

There are two important metal fabricating industries discharging to the North Arm. Since they contribute about 16 percent of the total industrial discharge to the North Arm, they may be a significant source of heavy metals. Some data on these industries are given in the following Section 5.2.

The food industry is concentrated mostly on the Main Arm. Its waste is largely organic and usually contains a high BOD_5 (in the range of 1 000 to 3 000 mg/L). Such wastes, although not cumulatively toxic, can have a localized effect on dissolved oxygen. However, the volumes discharged are low compared to other effluents, and the wastes are unlikely to have a general effect on the water quality of the river.

The description of effluent flows, given in this section, is approximate. The general picture changes as new industries start up and old industries expand or close. Another factor is the general trend for industries to connect to municipal treatment plants as sewers become available. A rough outline of this trend is described in the following sections.

5.2 Main Industrial Effluents Discharging in the Study Area

This section deals with specific industries that discharged major effluents to the river in the period 1970 to 1978. There has been little monitoring of industrial effluents so that data on effluent quality are scarce. The data for 19 of the main industrial plants are summarized in Table 12. The location of their discharges is shown in Figure 5. In our discussion of the data we have made a rough evaluation of the impact of effluents on water quality. More detailed evaluations are presented in Chapter 8 on water quality, in cases where there is enough information available.

5.2.1 Discharges to the Main Stem

Nearly 90 percent of the effluent volume is from two sawmills. B.C. Forest Products Ltd. (PE-2756) discharges 45 800 m^3/d upstream from Barnston Island. The effluent averaged 530 mg/L suspended solids and 58 mg/L BOD_5. Further downstream, Crown Zellerbach Canada Ltd. (PE-412) discharges 53 400 m^3/d containing, on average, 89 mg/L suspended solids and 10 mg/L BOD_5. The suspended solids in the river averages over 45 mg/L upstream from Barnston Island and over 20 mg/L further downstream. These discharges are unlikely to have any noticeable effect on the Main Stem water quality.

Together the two sawmills discharge approximately 29 000 kg/d of suspended solids and 3 000 kg/d of BOD_5. About 90 percent of these loads enter the Main Arm. A major discharge here is municipal effluent from the Annacis Island sewage treatment plant. Loadings from this treatment plant are about 11 000 kg/d suspended solids and 15 000 kg/d BOD_5. The comparison shows that the sawmills are major contributors of suspended solids, and to some extent BOD_5, to the river. The solids are in the form of wood wastes. No contaminants showing cumulative toxicity, such as heavy metals or organic compounds, are expected to be in the discharges, except in trace amounts.

Three bioassay tests were carried out in 1974, 1976 and 1977 on the effluent from B.C. Forest Products Ltd., using rainbow trout. There was no toxicity in 100 percent effluent over 96 hours[10]. Four tests were also performed with the Crown Zellerbach effluent, between 1971 and 1973, using coho salmon. The effluent was non-toxic at a concentration of 65 percent, indicating it met the federal objective for the forest industry (96 h LC_{80} = 65 percent)[10]. Based on these data, no significant influence would be expected on the river due to this discharge.

Canadian Forest Products Ltd. (CE-1656) operates a hardboard and plywood mill which discharged to the Main Stem until December, 1976. The discharge was then diverted to the Annacis Island treatment plant. The effluent flow averaged 6 800 m^3/d, or 6 percent of the total industrial discharge to the Main Stem. The effluent contained high suspended solids (500 mg/L) and BOD_5 (1 400 mg/L). It also contained phenolic materials at a level around 1.9 mg/L, although no actual analyses for phenolics are available. There were no consistently high phenol concentrations in the river downstream, probably because of the high dilution of effluent in the river (not less than 7 000 to 1).

Bioassay tests were carried out on the effluent from Canadian Forest Products in 1974, 1975 and 1976, using coho salmon and rainbow trout. Fourteen tests gave an average $96hLC_{50}$ of 4.9 percent effluent concentration in water. The results ranged from 3 to 12 percent, however 86 percent of the tests gave a $96hLC_{50}$ below 5 percent[10]. These results indicate that the effluent was very toxic. The effect on the river can be approximated by calculating a toxicity concentration in the river, as was done with the Annacis effluent in Section 3.7.4. Assuming a minimum river flow of 50×10^6 m^3/d, an effluent toxicity of 5 percent and an effluent flow of 6 800 m^3/d, the toxicity concentration would be: $\frac{100 \times 6\,800}{5 \times 50 \times 10}6 \simeq 0.003$ toxic units, outside the dilution zone. This is well within the limits of 0.01 to 0.10 toxic units considered safe for fish, although unsafe conditions could exist at times in the mixing zone. After the effluent was diverted to the Annacis treatment plant, in December 1976, limited measurements detected no change in the toxicity of Annacis effluent. However, as discussed in Section 3.7.4, this situation could change as more toxic effluents are connected to the sewer system. A discussion of measures to lessen the additive effect of toxic effluents is given in Chapter 10.

5.2.2 Discharges to the Main Arm

Six industries generate approximately 90 percent of the industrial effluents discharged to the Main Arm, or discharge toxic materials in significant amounts. They are listed in Table 12 and are discussed in this section.

The largest discharger is Dow Chemical of Canada Ltd. (PE-41), which operates a phenol plant on Tilbury Island. It discharges 66 000 m^3/d of cooling water, containing 160 m^3/d of process effluent. The total effluent contained, on average, 0.014 mg/L phenol, (maximum: 0.2 mg/L). This effluent is treated in an activated sludge process before discharge. The level of phenolic material in the river averaged usually 0.004 to 0.015 mg/L. The discharge is therefore not expected to have any noticeable effect on water quality, although phenolics in the river were slightly higher near Tilbury Island. Eight bioassay tests were conducted with the process effluent, between 1974 and 1976, using coho salmon and rainbow trout. The results gave an average $96hLC_{50}$ of 77 percent effluent in water. The toxicity ranged from 8.5 percent to 100 percent effluent concentration with 64 percent of the tests showing no toxicity(10). Based on these data no significant influence would be expected on the river from this discharge, outside of the immediate mixing zone.

The second largest discharger is Genstar Ltd. (PE-4513), a cement plant on Tilbury Island, which discharges 18 200 m^3/d of uncontaminated cooling water. This effluent constitutes 18 percent of the volume of industrial effluent discharged to the Main Arm, and produces no known adverse effect. Another discharge in a similar category is the flow of 5 500 m^3/d from Western Peat Moss Ltd. (PE-4382). This effluent originates from washing peat moss and exfiltrates to the ground off Tilbury Island. It may contain tannin and lignin type materials but these are readily absorbed by soil.

The main forest industry discharge was from the fine paper mill of McMillan Bloedel Ltd. (PE-35), which was diverted to Annacis in October, 1978. The mill discharged 3 050 m^3/d (3 percent of the industrial flow to the Main Arm) from Annacis Island, upstream from the sewage treatment plant. The effluent contained, on average, 187 mg/L suspended solids and 157 mg/L BOD_5. The concentrations were approximately two to three times higher than those in the municipal effluent from Annacis. However, the total quantities of suspended solids and BOD_5 discharged by the mill were 5 percent or less than the equivalent loadings from the municipal plant. In 1976 and 1977, 24 bioassay tests were performed on the effluent using rainbow trout. These tests gave a $96hLC_{50}$ of 90.3 percent effluent in water. The highest toxicity was 45.5 percent and 67 percent of the tests gave a $96hLC_{50}$ of over 90 percent. The effluent is unlikely to have affected fish in the river.

The fifth largest discharge is from the cement plant of Lafarge Canada Ltd. (PE-42), in Richmond. The effluent flow averages 1 230 m^3/d, or 1.2 percent of the total industrial discharge to the Main Arm. The suspended solids in the effluent was high (1 208 mg/L average) but the BOD_5 was low (32 mg/L average), indicating that the effluent contained mainly inorganic salts. This conclusion is confirmed by the high potassium content of the effluent (751 mg/L average). The concentrations of heavy metals in the effluent were quite low, the highest being lead, which averaged 0.42 mg/L and zinc, which averaged 0.17 mg/L. Bioassay tests conducted on coho salmon and rainbow trout, between 1971 and 1977, showed that the effluent was usually relatively non-toxic. The average 96 hLC_{50} from 19 tests was 93.2 percent effluent concentration. The most toxic value was 56 percent, and 68 percent of the tests showed no toxicity.

The major industrial discharge of heavy metals in the Main Arm is from the metal finishing plant of Titan Steel and Wire Co. Ltd. (PE-161). Although the process effluent (270 m^3/d) is less than one percent of the total industrial discharge to the Main Arm, it contained high levels of heavy metals. The total iron averaged 633 mg/L, the total lead 7 mg/L and the total zinc 4.6 mg/L. This discharge occurs near Gunderson Slough, just upstream from the Annacis Treatment Plant. The concentration of iron in the industrial effluent was approximately 600 times higher than in the municipal effluent from Annacis, the concentration of lead was about 200 times higher, and the concentration of zinc 20 to 30 times higher. As a result, the total quantities of iron and lead discharged daily by the metal plating plant and the Annacis municipal effluent were comparable (up to 200 kg/d of iron and 5 kg/d of lead). The amount of zinc discharged by the metal plant was about 30 times less than the amount discharged by Annacis (1.2 kg/d versus 35 kg/d). The immediate effect of the industrial discharge on water quality has not been documented, since the nearest river sites measuring heavy metals are downstream from the Annacis Treatment Plant.

Bioassays were performed on the process effluent from Titan Steel and Wire Co. Ltd., in 1976 and 1977, using rainbow trout. The toxicity varied over a wide range.

The most toxic effluent gave a $96hLC_{50}$ of 0.14 percent effluent concentration. The average $96hLC_{50}$ from six tests was 67 percent effluent concentration, and two thirds of the tests showed no toxicity. In view of the intermittently toxic nature of this effluent and its relatively large contribution to the total load of heavy metals entering the river, we recommend further treatment before discharge. The final effluent quality should conform to Level A of the Pollution Control Objectives for miscellaneous industries[18].

Cooling water from Titan Steel and Wire Co. Ltd. is discharged directly to Gunderson Slough. The effluent contained relatively low levels of heavy metals. The total iron averaged 0.79 mg/L, total lead 0.03 mg/L and total zinc 0.28 mg/L.

5.2.3 Discharges to the North Arm

We have listed ten industries in Table 12 which contribute major volumes of effluent, or discharge toxic contaminants to the North Arm. There are six forest industrial plants and four metal processing plants discharging mainly heavy metals.

a) Forest Industries

The largest volume is discharged by a sawmill of MacMillan Bloedel Ltd. (Canadian White Pine Division, PE-1666). It contributes 45 percent of the total effluent volume discharged to the North Arm. The effluent consists mainly of cooling water, with some boiler blowdown. A bioassay test, carried out in 1972, showed that the effluent was not toxic to coho salmon over 96 hours. This effluent should have no detrimental effect on water quality of the river.

The second largest discharger in this category is Belkin Paperboard Ltd. (PE-17), which discharges 10 percent of the total effluent entering the North Arm. The Company operates a paperboard mill and the effluent contained relatively high levels of suspended solids (700 mg/L average) and BOD_5 (207 mg/L average). There was also an indication that the effluent may contain high concentrations of zinc (2.7 mg/L total zinc, average of three values between 1965 and 1973).

Sludge from the effluent clarifier contained high levels of polychlorinated biphenyls (PCB's), according to tests carried out in April-May, 1979[12]. The average concentration of PCB's in the sludge was 22.5 mg/kg, and the maximum value 70 mg/kg.

The sludge is mainly fibre, and is recycled to the process. The PCB's are believed to come from the recycling of carbonless copy paper. Overloading of the clarifier appears to be the cause of high PCB levels in sediments adjacent to the outfall (Chapter 9, section 9.4).

Twelve measurements of effluent toxicity, carried out on rainbow trout in 1976 and 1977, gave an average $96hLC_{50}$ of 52 percent effluent concentration[10]. Consultants for the company recently completed a detailed study of effluent treatability and toxicity[19]. They found a wide variation in $96hLC_{50}$, from 10 to 100 percent, depending upon the origin of the effluent in the process. The mill produces roofing felt, linerboard, corrugating medium and wallboard from wastepaper, pure fibre and unpulped wood chips. The toxicities of the different effluents vary, but are not related to any specific constituent in the effluents. The report concludes that the total effluent quality could be improved by recycling the most toxic portions and by clarifying the total mill effluent further. We recommend that these corrective measures be carried out, especially improved clarification, so that the final effluent meets the pollution control toxicity criterion ($96hLC_{50}$ = 90 percent). We also recommend that the effluent be checked for heavy metal content, especially zinc.

Canadian Forest Products Ltd. (PE-2115) operates a sawmill at its Eburne Sawmill Division. It discharges up to 9 200 m^3/d, or 6 percent of the total industrial discharge to the North Arm. In 1974 and 1975, the Company changed its three hydraulic debarkers to mechanical debarkers. As a result, the discharge of high concentrations of suspended solids was eliminated. Bioassays carried out in 1972, while the hydraulic debarkers were in operation, indicated the effluent was quite toxic. The average 96h LC_{50} from 11 tests was 13 percent effluent concentration. Eighty percent of the tests showed a $96hLC_{50}$ below 10 percent. Since installation of the mechanical debarkers, the effluent consists of cooling water, steam condensate and boiler blowdown. It should have no measurable effect on the river.

A groundwood mill and a fine paper mill are operated by Scott Paper Ltd. (PE-335), in New Westminster. The fine paper mill discharges the larger volume of effluent (8 960 m^3/d) and it contains suspended solids and BOD_5 in about the same concentration range as municipal effluent. The groundwood mill discharges less than 2 000 m^3/d and this effluent was diverted to the Annacis treatment plant in August, 1977. Neither effluent showed any appreciable toxicity to fish in bioassay tests[10]. The groundwood mill effluent was non-toxic in three tests on coho salmon in 1975. The paper mill showed slight toxicity in 19 tests on coho salmon and rainbow trout, carried out in 1975, 1976 and 1977.

Rayonier Canada (B.C.) Ltd. (PE-3087) operated a hemlock bark extraction plant in Vancouver, until the plant closed in April, 1976. The total plant effluent accounted for 7.5 percent of the industrial discharges to the North Arm. There are no monitoring data on the plant effluent. Possible effluent constituents, which could have been toxic to aquatic life, included sodium bisulphite and certain heavy metals such as chromium, copper, iron and zinc. Bioassay tests carried out in 1974, with coho salmon, indicated the effluent had moderate toxicity[10]. The extraction plant effluent had a 96h LC_{50} of 45 percent effluent concentration, and the drier and evaporator plant had a 96h LC_{50} of 75 percent.

The discharge from MacMillan Bloedel's Vancouver Plywood Division (CE-4248) is mostly effluent from the plywood plant, plus some cooling water from the speciality board plant (total combined flow about 2 350 m^3/d). A bioassay test in 1973, with coho salmon, indicated that the speciality board effluent was non-toxic[10]. Although no measurements are available yet on the plywood plant effluent, it is believed to be mainly uncontaminated cooling water.

b) Metal Fabricating Industries

The second largest discharger to the North Arm is Western Canada Steel Ltd. (PE-2087). It operates a steel rolling mill in Richmond, and discharges 25 000 m^3/d, or 15 percent of industrial effluents entering the North Arm. The main toxic constituents of the effluent are iron and zinc. The concentrations of the dissolved metals averaged 0.6 mg/L for iron and 0.02 mg/L for zinc. The concentration of dissolved zinc was within Level A (0.3 mg/L) of the Pollution Control Objectives for such industries[18], and the average dissolved iron was close to Level A (0.5 mg/L). No localized effect on water chemistry was documented in the North Arm. The discharge of zinc may be a factor in the generally higher zinc concentrations being recorded in the North Arm compared to the Main Arm (Chapter 8).

A major discharger of heavy metals to the North Arm is the metal finishing plant of Tree Island Steel Co. Ltd. (PE-3190), in New Westminster. Although the total volume of effluent is low (about 1 percent of all industrial discharges), the concentrations of certain heavy metals were high. In the process water, the total iron averaged 73 mg/L, total lead 4.8 mg/L and total zinc 26 mg/L. In the cooling water the total zinc averaged 65 mg/L from three measurements. The total load of heavy metals discharged to the river averaged about 60 kg/d of iron, 4 kg/d of lead and 70 kg/d of zinc. A comparison with the equivalent loads from the Annacis treatment plant (iron: 200 kg/d, lead: 5 kg/d and zinc: 35 kg/d) shows that Tree Island Steel Co. Ltd. was another major contributor of heavy metals in the study area.

As expected, bioassay tests on the process effluent showed it was toxic. A single experiment in 1976 gave a $96hLC_{50}$ of 4.2 percent effluent concentration[10]. There has been a lack of pH control of the effluent which probably caused metals, trapped as sludge in settling lagoons, to redissolve. This effluent was recently upgraded to generally meet Level A of the Pollution Control Objectives for miscellaneous industries[18].

Two industries in Richmond have discharged lead and cadmium to the North Arm, opposite Mitchell Island. Both now discharge to the Lulu Island sewage treatment plant. Varta Batteries Ltd. (CE-4661) was connected to the plant in August, 1977 and Metalex Products Ltd. (CE-2311) was connected in January, 1976. There is very little information on the effluent quality from these plants, and on the total quantity of metal discharged, although the effluent flows were small (about 0.02 percent of all effluents discharged to the North Arm). Bioassay data on the effluents indicate they were quite toxic. The $96hLC_{50}$ averaged 1.5 percent effluent concentration for Metalex Products Ltd., and 2.4 percent for Varta Batteries Ltd.[10]. No downstream effects on water quality were documented.

6. INDUSTRIAL EFFLUENTS DISCHARGED TO THE MUNICIPAL SEWERS

Industry in the study area discharges about 73 000 m^3/d of effluent to the municipal sewer. Approximately 37 000 m^3/d flows to the Iona treatment plant (10 percent of plant flow), 34 000 m^3/d flows to Annacis (20 percent of plant flow) and 2 000 m^3/d flows to Lulu (9 percent of plant flow). Data on effluents discharged to sewer are contained in surveys by the Greater Vancouver Regional District[6] and the City of Vancouver[20]. The Regional District's survey includes ten municipalities within the study area. The Vancouver survey covers the City of Vancouver only. These surveys provide approximate information and their main findings are summarized in this chapter. Data on oil refineries are from the provincial data bank (EQUIS).

6.1 Effluent Flows and Compositions

An estimate of effluent flows is presented in Table 13 for 14 categories of industry discharging to sewer. The estimate is based on water consumption by industry, because effluent discharge rates are not metered. The effluents are grouped into those going to the Iona treatment plant, those going to Annacis and those going to Lulu.

The Iona plant receives industrial effluent from Burnaby (in part) and Vancouver. The Annacis plant receives industrial effluent from Burnaby (in part), Coquitlam, Delta, Port Coquitlam, Port Moody, Langley, New Westminster and Surrey. The Lulu plant receives industrial effluent from Richmond. White Rock sewage, which goes to Annacis, contains no industrial effluent. Sewage from the University of B.C. (4 500 m^3/d) and the Vancouver International Airport (2 700 m^3/d) goes to Iona. However, the flows are not included in Table 13 since the industrial portion of the total flow was not estimated[6].

Approximate analyses of industrial effluents discharged in the Annacis and Lulu sewerage areas are listed in Table 14. These data, obtained by the Greater Vancouver Regional District, are based on intermittent sampling. They give only a broad idea of effluent quality from industries that use varying degrees of effluent control and treatment. Loadings from industries discharging in the Iona sewerage area are given in Table 15. These data were collected by the City of Vancouver, and represent the contribution from industries using some form of effluent control.

The largest volume of effluent, in all three sewerage areas, comes from the food industry, which contributes 38 percent of the industrial flow to sewers in the study area. Operations in this group include canneries, dairies, breweries, abattoirs, bottling plants, meat processors etc. Although the effluents do not contain materials that are cumulatively toxic, they are a major source of BOD_5, suspended solids, ammonia and oil and grease. For example, the BOD_5 is in the range of 500-14 000 mg/L compared to 150-300 mg/L for sanitary sewage. The effluents can have an important effect on the sewer collection system and the treatment plants.

The second largest contributor of effluent is the wood products industry, which discharges 22 percent of the industrial flow to sewers. This category contains sawmills, plywood and hardboard plants, pulp and paper mills, wood preservers, furniture and cabinet makers etc. The effluents contain fairly high BOD_5 (150-2 000 mg/L) and suspended solids (300-1 000 mg/L). They are moderately to highly toxic ($96hLC_{50}$ = 30-50 percent effluent in water), probably as a result of the high concentration of phenolic material (up to 68 mg/L). Certain operations, such as hardboard plants, have generated very toxic effluents (Chapter 5, Section 5.2.1).

The metal products industry generates the third largest volume of effluent. The industry accounts for 12 percent of all industrial effluents discharged to sewer in the study area. In the Lulu sewerage area, it is the second largest contributor, producing 20 percent of industrial effluent in that area. The industry includes electroplating, foundries, smelters, sheet metal shops, and metal fabricators of various kinds. The effluents are a major source of heavy metals to the sewer. An approximate calculation (Chapter 10, Section 10.3.1) indicates that the industry contributes at least 20 to 30 percent of the heavy metals entering the Annacis treatment plant. In the Iona sewerage area, the metal industries are subject to controls and contribute generally about 5 percent of the metals entering the Iona plant (from Tables 3 and 15). The industry is also a source of cyanide, and its effluent often has a widely varying pH.

The petroleum industry consists mainly of three oil refineries, which contribute 11 percent of the total industrial effluent discharged to sewer. The flows and compositions of these effluents are summarized in Table 16. The effluents were diverted from Burrard Inlet to the sewerage system between 1974 and 1977. The effluent toxicity varies from highly toxic to moderately toxic. Acute bioassay tests have been carried out on all three effluents[10]. Results for Chevron effluent, obtained between 1973 and 1977 using rainbow trout, gave an average $96hLC_{50}$ of 1.7 percent effluent in water. This high toxicity was probably due to high concentrations of ammonia, phenol and sulphides, and has since been reduced by further treatment at the plant. Similar tests with Gulf Oil effluent, using coho salmon, gave an average $96hLC_{50}$ of 36.3 percent. Shell effluent, had an average $96hLC_{50}$ of 49.2 percent using rainbow and coho.

Other industrial categories discharging to the sewer contribute 5 percent or less to the total industrial effluent flow. The chemical industry (5 percent) consists mainly of formulators who blend and package. The industry handles a large array of products, some of which change with time and market requirements. Effluents are produced from tank washdowns or spill cleanups. Printing and photography (4 percent) are a source of heavy metals and certain organic compounds. The paint industry (0.1 percent) is a minor source of similar compounds.

6.2 Sludges

Industry connected to sewers generates about 50 m^3/d of sludge in the study area. A rough breakdown of sludge quantity, by industry type and sewerage area, is given in Table 17. The data are from surveys carried out by the Greater Vancouver Regional District and the City of Vancouver[6,20]. The surveys give a general description of the sludges but present no data on sludge composition. Most of the sludges, which cannot be discharged to municipal sewer, are either processed or disposed of in landfills.

Measurable amounts of sludge are discharged by 10 of the 14 industrial categories. The largest volume comes from the food industry, which generates 40 percent of all sludges in the study area. About three quarters of the food industry sludge comes from restaurants, reduction plants and food processors in the Iona sewerage area. This sludge is trucked to Iona for disposal through the treatment plant. The sludge is made up of grease, waste grains, peelings and animal remains. Other sludge, which cannot be used in reduction plants or as animal feed, is sent to landfill.

The chemical industry is the second largest contributor of sludge, producing 27 percent of the total sludge volume. In the City of Vancouver (5.1 m^3/d of chemical sludge) much of the sludge is lime slurry from the acetylene industry and is recovered. In the Annacis sewerage area (7.2 m^3/d) much of the sludge is organic waste, and is sprayed on land. In the Lulu sewerage area (1.5 m^3/d) 80 percent of the sludge is recycled. Small amounts of chemicals, spilled in warehouses or by chemical formulators, may be washed into the sewer or disposed of in landfills.

The third largest contributor is the metal plating and fabricating industry, which generates 8 percent of the total volume of sludge. Nearly 60 percent of this sludge is produced in the Lulu sewerage area. The sludge is mainly the oxides, hydroxides and carbonates of various metals. Some of it is disposed of on site by the industry. Most of it is picked by septic tank services and presumably disposed of in landfills. This disposal method can produce landfill leachates containing high concentrations of heavy metals. Control of the problem is discussed in Chapter 10, Section 10.3.3.

The miscellaneous category covers a wide variety of small industries. Its contribution, which is 16 percent of the total sludge volume, goes to landfill. Other industry types contribute 4 percent or less of the total sludge volume. The paint industry (4 percent) produces mostly latex sludge from plant washings, which are landfilled. The wood products industry (2 percent) generates glue, ink and paint sludges and paper fibre, which are also landfilled.

6.3 Waste Oils and Solvents

Waste crankcase oil is the major source of waste hydrocarbon oils in the study area. The total volume averages 14.6 m^3/d. About 57 percent of the total comes from the Iona sewerage area. Due to the recent rise in oil prices, the value of the waste is such that most of it is recovered for rerefining. The acid sludge produced by the old rerefining process was usually landfilled. However there are new rerefining processes that do not produce a toxic sludge(26).

Waste solvents produced in the study area average about 3 m^3/d. Over 70 percent of this total is generated in the Iona sewerage area. A large part of the total waste is from dry cleaning, and all the solvent from this source is either recovered or lost on dry-cleaned fabrics. The metal industries, automotive body shops and the paint industry are other main producers of waste solvent. These solvents are disposed of by burning, evaporation, landfilling or reclamation in U.S. plants. A certain amount is stored until a suitable disposal method is found.

6.4 Regulations for Discharges to Sewer

The Greater Vancouver Regional District controls the main trunk sewers and the three main sewage treatment plants. The Regional District is responsible for the main discharges of municipal effluent to the river, through pollution control permits administered by the Province. However, the Regional District has no direct control over effluents discharged to sewers. This control is exercised by the municipalities through their plumbing bylaws.

There are eleven municipalities in the study area. Six have their own bylaws for control of sewage (Burnaby, Delta, New Westminster, Port Coquitlam, Surrey and Vancouver). Four use regulations issued by the Regional District (Coquitlam, Langley, Port Moody and Richmond). One has no industry connected to its sewerage system (White Rock). The bylaws contain similar regulations, with some being more detailed and specific than others.

All regulations specify the separation of storm water and sanitary sewage. The discharge of substances (unspecified), which could damage the sewerage system or interfere with the operation of the sewage treatment plants, is generally prohibited.

Restrictions on the type of solids that can be discharged vary according to the regulations. Most municipalities place an upper limit on suspended solids concentration of between 500 and 600 mg/L. There is a general restriction on the discharge of garbage, unless ground, and of ashes, cinders, sand, metals, shavings, asphalt, cement, wood, plastics and rags. Certain regulations (Regional District, Surrey, Vancouver) have a list of over 30 prohibited solids. It includes, in addition to those listed above, mud, straw, grass, animal remains (such as blood, bones, fish heads etc.), spent grains and paint residues.

The temperature of effluents discharged to sewers is restricted to a maximum of 65^{o} C by most municipalites (Delta: 40^{o} C). The allowable pH range is 5 to 9.5. There is a general prohibition on the discharge of hydrocarbons, including benzene, gasoline, fuel oil, naptha, explosive and flammable materials. The biochemical oxygen demand of discharges is limited in some cases to a BOD_5 of 400 mg/L (Burnaby) or 600 mg/L (Delta, New Westminster). In other cases, the restriction applies to materials exerting an unusual biochemical oxygen demand (Regional District, Surrey, Vancouver).

There is a general restriction on wastes which constitute a hazard to humans or animals, or that may create a hazard to the receiving water. In addition to this general restriction, certain regulations specify maximum concentrations for toxic wastes, consisting mainly of heavy metals (Regional District, Surrey, Vancouver). These concentrations are presented in Table 20.

The discharge of radioactive materials to sewers is generally banned (allowable under AEC License by Regional District and Vancouver). There is also a general ban on the discharge of septic tank waste and noxious or odorous gases (unspecified).

Several municipalities have no specific rule requiring a sampling point for the discharge (Burnaby, Delta, New Westminster, Port Coquitlam). Some of the regulations specify that a manhole should be provided for sampling (Regional District, Surrey, Vancouver). The right to inspect premises etc. is included in all the regulations. The penalty for violating the regulations is generally a maximum fine of $500 and/or 30 days in prison. There are also provisions to prohibit the discharge. The Regional District regulations do not include any penalties.

The degree to which these regulations are enforced varies among municipalities. It depends on the facilities and staff available for inspection and monitoring. For example, only the Regional District and Vancouver operate laboratories for effluent analysis. Vancouver has a regular program of inspection and sampling. The Regional District collects effluent samples for analysis, when requested by the municipalities or for trouble-shooting purposes. Regular monitoring of industrial effluents is not carried out by the other municipalities. Methods of controlling industrial effluents discharging to sewers are discussed in Chapter 10.

7. LANDFILLS

Descriptions of landfills in the study area are presented in a detailed report[30]. Information is given on geology of underlying soils, landfill operation, leachate movement and analysis and other factors. Data from the report are summarized in this chapter, with emphasis on leachates and their effect on water quality.

7.1 Introduction

Solid waste in the study area is disposed of exclusively in landfills. There are five major active sites and three major sites now inactive. There are also eight small municipal sites, of which only one is now active. About 800 000 tonnes per annum (t/a) of municipal, commercial and industrial waste is landfilled at the active sites. In addition, approximately 430 000 t/a of wood waste is landfilled at about 35 sites near the Fraser River.

Usually, the major sites are in low-lying, poorly drained areas near the river, which are sometimes important habitat for fish and wildlife. Leachates, produced mainly by rainwater and surface water percolating through the fill, either drain to the river and tributaries or are pumped to the Annacis Island sewage treatment plant.

Data have been collected on leachate composition and toxicity, but there are few measurements of leachate flow rate to the river. The lack of flow data is partly due to the complicated nature of water flow through the landfills. This flow depends on rainfall, water content and permeability of the refuse and cover material, groundwater and surface water flows, and stage of the tide for landfills bordering the river. Contaminated leachate will flow from inactive landfills for as long as 10 to 25 years after the operation is closed. The concentrations of contaminants in the leachate drop by a factor of five to ten when the landfill has been closed for three to six years. The leachate from wood waste landfills is believed to be fairly innocuous after the fill has been in place for three to five years.

In the following sub-sections we discuss the major municipal landfills, both active and closed, and the influence of wood waste landfills.

7.2 Major Active Landfills

The five major active landfills are discussed below in the order of waste quantity landfilled per annum. The landfills, in this order are: Richmond, Burns Bog, Braid Street, Leeder and Port Mann. Their location is shown in Figure 1.

Leachates from these landfills flowed for many years, directly and indirectly, to the Fraser River. In March-April, 1976, leachate from Braid Street was diverted from the Brunette River to the municipal sewer, and pumped to the Annacis primary treatment plant. There are plans to pump leachate from Port Mann to Annacis by the end of 1979, and from Burns Bog to Annacis by mid-1980. This will leave leachate from Richmond and Leeder only, flowing directly to the Fraser River. A discussion of leachate control measures, including primary and secondary treatment, is given in Chapter 10.

The average compositions and flows of leachate from the major active landfills are summarized in Table 25. The data on contaminant concentrations were obtained from the analysis of samples taken over a period of time by government agencies, at several sites around the landfills (wells, ditches etc.). There were large variations in the concentrations, depending on the sampling site and the time of sampling. Leachate flow rates were rarely measured directly. Approximate estimates of flow were obtained from water balance calculations. Recent measurements suggest that the actual flow at Burns Bog may be only 10 percent of the estimated flow. Thus, the values in Table 25 provide only a rough indication of leachate flows, and an average view of their compositions.

7.2.1 Richmond Landfill

This landfill is located on Lulu Island, on the north bank of the Main Arm (Figure 1). There is a 125 ha active site, which is nearly full, and a 140 ha reserve site adjacent to it. The landfill has been in use since 1965. The present life expectancy is about 7 years, and the site may then be used for port and industrial facilities.

Material landfilled is made up of municipal refuse from the municipality of Richmond and private handlers, and commercial, industrial and demolition wastes. The pollution control permit (PR-5113) for the operation was superseded recently by a new permit application (AR-5582, May 1979). The application indicates that the amount landfilled may be reduced (163 000 t/a compared to previous estimate of 250 000 t/a).

The site consists of peat at a depth of 0 to 5 m, underlain by a silt and clay layer 1 to 8 m thick, which in turn is underlain by sand. The water table is near the surface and most of the leachate is intercepted by ditches and discharged to the river. Since compressed peat becomes impermeable and clay is present, there is little vertical movement of leachate through the soil. There is some tendency for the river water to enter the fill then drain as the river level changes with tide and season.

The leachate quality is characterized by a high organic and ammonia nitrogen content (Table 25). The chemical oxygen demand (COD) averaged about 700 mg/L, which is more than double the COD concentration in municipal effluent discharged to the river by the main treatment plants (the COD concentrations in primary - treated municipal effluents are about double the BOD_5 values reported in Table 3[7]). The ammonia nitrogen in the leachate averaged 50 mg/L, which is two to seven times higher than concentrations in primary-treated municipal effluent.

The total loadings discharged to the river were about 3 400 kg/d of COD and 250 kg/d ammonia nitrogen. These values are very approximate, due to the uncertainty in our knowledge of leachate flow rate. The leachate loadings are about 10 to 12 percent of the COD and ammonia nitrogen discharged by the Annacis treatment plant, further upstream. Given the high dissolved oxygen and low ammonia levels in the Main Arm of the river (Chapter 8), those loadings are unlikely to have any measurable effect on overall water quality. However, at certain stages of the tide, concentrations of organic matter and ammonia in the leachate may be high enough to degrade water quality in a localized area.

The concentrations of toxic heavy metals were generally low, and about the same in the leachate as in the primary - treated municipal effluents. Values for iron and manganese were higher in the leachate, but were still at levels unlikely to have any effect on water quality in the Main Arm. The low levels of metals in the leachate were consistent with its pH (7.2 average). At this pH dissolution of metals is slow. There may also be a tendency for soluble metals to adsorb initially onto peat lining the fill.

The acute toxicity to rainbow trout of the leachate has been measured in static bioassay tests [30]. The $96hLC_{50}$ varied between 22 and 75 percent depending on the sampling point. The most common result was a $96hLC_{50}$ of about 40 percent. Those values indicate that the leachate is somewhat more toxic than primary treated municipal effluent (Chapter 3, Section 3.7.1). The high toxicity is believed to be due mainly to the greater concentration of ammonia in the leachate, and possibly, in part, to the presence of more organic contaminants. The agency responsible for the landfill has undertaken to meet municipal effluent objectives [4], in its application for a pollution control permit, and has retained consultants to study leachate treatment.

7.2.2 Burns Bog Landfill

The site covers 400 ha of Burns Bog, located in Delta about 4 km south of the Main Arm (Figure 1). The operation was started in 1966, and about 40 ha has been landfilled to date. The life expectancy of the site is 40 years, after which time it will be used for recreation.

About 60 to 70 percent of the waste sent to the landfill is refuse from the City of Vancouver. Refuse from Delta and White Rock and waste from industrial and commercial sources also go to the landfill. The total amount landfilled is estimated to be 230 000 t/a, which is equivalent to the quantity authorized by the pollution control permit (PR-1611) issued for the operation in December, 1977.

The site consists of a 3 m layer of peat and decomposed peat, underlain by a thin layer of clay, in turn underlain by a thick layer of silt and sand. Groundwater is at or near the surface all year. The fill compresses the peat, rendering it less permeable and reducing vertical movement of leachate. The leachate collects under the fill and flows with natural drainage and runoff via ditches to Crescent Slough. Water in Crescent Slough discharges to the Main Arm, as shown in Figure 1. Plans have been made to pump the leachate to the Annacis treatment plant by mid-1980.

The leachate was, on average, similar in quality to leachate from the Richmond landfill (Table 25). The ammonia nitrogen concentration was relatively high (90 mg/L average). All other constituents, including COD (250 mg/L average), were at the same level, or lower, than in primary-treated municipal effluent. The leachate had some effect on Crescent Slough, as shown by water quality data summarized in Table 26. The main effect was an increase in ammonia nitrogen, from an average of 19 mg/L upstream to 52 mg/L downstream. The background water quality in Crescent Slough was poor. The slough supports catfish, trout and carp, but no salmon. No effects have been documented in the Main Arm from the discharge of Crescent Slough. However, there could be localized problems in the dilution zone from toxicity due to ammonia, at certain tidal conditions.

Acute toxicity bioassays showed that the leachate was fairly toxic. The $96hLC_{50}$ ranged from 6.5 percent for undiluted leachate that collects under the fill, to 18 percent for ditch water[30]. The most likely cause of the toxicity appeared to be the high ammonia concentration, since other contaminants were at concentration, similar to those in primary-treated municipal effluent. The total ammonia nitrogen load from Burns Bog was estimated, very roughly, to average 365 kg/d. Recent leachate flow data suggest that the actual load may only be 10 percent of this amount. The load of 365 kg/d is about 18 percent of the ammonia nitrogen discharged from the Annacis treatment plant in 1977 (1990 kg/d). When the leachate is pumped to the Annacis plant, in mid-1980, the toxicity of the primary effluent may be increased. The main effect could be higher toxicity in the dilution zone of the effluent, at certain tidal conditions. There should be no effect on the river as a whole, since the pH and temperature of the river ensure that concentrations of un-ionized ammonia remain at low levels (Chapter 8). Since effluent chlorination is followed by dechlorination, there should be no increase in the discharge of toxic chloramines. The effect of primary treatment on landfill leachate, and the need for further treatment, are discussed in Chapter 10, section 10.4.

7.2.3 Braid Street Landfill

The Braid Street Landfill is located in Coquitlam, on the east side of the Brunette River, and about 300 m north of the Main Stem (Figure 1). The site covers 30 ha and has been in operation for several years. The present life expectancy is six to eight years.

The pollution control permit (PR-4385), issued March, 1976, authorizes the discharge of 408 t/d, or about 150 000 t/a. About 65 percent of the waste is residential refuse from New Westminster, Coquitlam, Port Coquitlam and Burnaby. The remainder is commercial, industrial and building material waste.

The soil at the site is silty clay, underlain by blue clay. Due to the impermeable nature of the soil there is little vertical migration of leachate. Up to April, 1976, leachate flowed to the Brunette River, and then into the Fraser River. After this date the leachate, collected by drainage pipes and interceptor ditches, was pumped via the sewer to the Annacis treatment plant. There is no direct discharge of leachate to the Fraser River, although there is provision to direct storm water runoff to the river.

The leachate quality was similar to that from the Richmond landfill. The main characteristics were high chemical oxygen demand (840 mg/L average), and high ammonia nitrogen (30 mg/L average). The leachate contained about 2 percent of the COD and ammonia discharged from Annacis in 1977. The toxicity of the leachate was mid-way between the toxicities of Richmond and Burns Bog leachates. Bioassay tests gave $96hLC_{50}$ results of 24 to 36 percent.

7.2.4 Leeder Landfill

The Leeder Landfill is east of the Braid Street site, along the north bank of the Main Stem (Figure 1). The site, covering 23 ha, has been operation since 1965 and is nearly filled. A pollution control permit (PR-1350), issued in October, 1972, allows the discharge of a variety of wastes. However, most of the waste is industrial, commercial and building material refuse, although some garbage has been discharged at the site. The total amount discharged is about 270 t/d, or 100 000 t/a. The operation is expected to close within a year, and the site will be used for industrial and commercial development.

The soil at the site consists of a silt and clay layer, 1.5 to 2.4 m thick, underlain by sand and silt. Since the impermeable clay layer is thin, the underlying sand may be exposed in places, allowing vertical movement of leachate. The leachate is discharged to the river mainly via groundwater.

The leachate contains relatively little organic material (average organic carbon: 40 mg/L) and ammonia nitrogen (0.3 mg/L average). These results are probably due to the absence of municipal refuse in the landfill. The presence of tannin and lignin in the leachate (36 mg/L average) probably reflects the existence of waste wood in the fill. This leachate may have some measurable effect on the Fraser River water quality, since high tannin and lignin levels were detected in the river around the fill[27]. More data on leachate composition, including heavy metals, should be collected for a thorough assessment.

7.2.5 Port Mann Landfill

This landfill is located in Surrey, immediately upstream from the Port Mann Bridge, along the south bank of the Main Stem (Figure 1). The operation was started in 1969 and is expected to continue for another six to eight years. The strip along the river was recently expropriated by the CNR, and this reduction in size shortened the life expectancy of the operation.

About 80 percent of the waste entering the landfill is municipal refuse from Surrey. The total amount discharged is approximately 40 000 t/a. The site is a peat bog containing a layer of peat 1.2 to 7 m thick, underlain by organic silt, which in turn is underlain by sand and gravel. Settling of the peat renders it impermeable and reduces vertical movement of leachate.

The leachate and surface runoff are collected in ditches that flow to the river. The pollution control permit (PR-1686), issued in June, 1979, authorizes the flow of leachate to the municipal sewer, which runs to the Annacis treatment plant. The leachate transfer works should be in operation by the end of 1979.

The quality of the leachate is similar to that from other landfills containing municipal refuse (Richmond, Burns Bog, Braid Street). It is characterized by high chemical oxygen demand (500 mg/L average) and high ammonia nitrogen (45 mg/L average). The impact on the river is unlikely to be measurable beyond the dilution zone, due to the low leachate flow rate (estimated to average 870 m^3/d). Bioassay tests on leachate entering the river gave a $96hLC_{50}$ of 38 to 50 percent[30], which is similar to results for the Richmond and Braid Street landfills. The ammonia, which is believed to be responsible for most of the toxicity, will constitute about 2 percent of the ammonia discharged by the Annacis plant in 1977.

7.3 Major Closed Landfills

There are three large landfills, now closed, which continue to discharge leachate to the Fraser River. They are discussed in this section in chronological order of closure. The average flow of leachate from each of these landfills is estimated to be in the range of 320 to 370 m^3/d. In addition to this relatively low flow, the concentrations of contaminants in the leachate decrease markedly after the landfill has been closed for several years. Generally, the impact of the main closed landfills on water quality is believed to be minimal.

7.3.1 Kerr Road Landfill

The landfill site is located in the southeast corner of Vancouver, to the north of the North Arm (Figure 1). It was originally a gully, covering 38ha, and was operated by the City of Vancouver until it closed in 1966. The site will be used for a golf course. The soil at the site is till underlain by sand and gravel. A culvert running in the gully, under the fill, collects leachate and discharges it, via a submerged outfall, to the North Arm.

Historical data on leachate composition show how the concentrations of contaminants decreased, after the landfill had been closed for five to six years. For example, in 1971 the chemical oxygen demand was about 1 200 mg/L. By 1973 the concentration had dropped to 150 mg/L and has remained at this value since. Ammonia nitrogen showed a similar trend, going from 350 mg/L to 50 mg/L in the same period. The high initial concentrations in this leachate may have been due to the large depth of the fill and to the rapid runoff of surface water caused by the steep slope.

In the early 1970's the leachate could have caused water quality deterioration in a localized area of the North Arm. Contaminant concentrations have now stabilized to levels that are lower by a factor of seven or more, but are likely to persist for several years. An acute bioassay test carried out in January, 1979, gave a $96hLC_{50}$ of 24 percent[30]. These results indicate that the leachate is similar in quality to leachate from active landfills that is diluted with surface runoff.

7.3.2 Stride Avenue Landfill

This landfill is located in Burnaby, just west of the border with New Westminster, and about 1.2 km north of the North Arm (Figure 1). The landfill was in operation from about 1910 to 1969. Like Kerr Road, the site was originally a gully and now covers an area of 8 ha. Soils at the site are silt, sand and gravel. Leachate discharges to a ditch and flows to the North Arm, after dilution with groundwater and drainage from adjacent land.

Concentration of major contaminants in the leachate were relatively low. Some average values are COD 48 mg/L, ammonia nitrogen 14.8 mg/L, iron 4.5 mg/L and manganese 1.6 mg/L. Acute bioassay tests gave a $96hLC_{50}$ of 56 to 90 percent. The leachate is not expected to have any effect on the Fraser River. However, it will affect the quality of water in the drainage ditch, which is used for irrigation by local farmers.

7.3.3 Terra Nova Landfill

The site is in Coquitlam, along the north bank of the Main Stem and just west of the Leeder landfill (Figure 1). The landfill was in operation from 1965 to 1975, and covers an area of 60ha. One third of the fill was hog fuel when the operation started. In later years 10 percent of the fill was hog fuel and the remainder was commercial refuse. The site is now used for storing hog fuel piles.

Soils at the site are peat, silt and sand. Leachate flows into two creeks that drain the site (Mill Creek and Popeye Creek). Leachate also drains directly to the river. The concentrations of major contaminants in the creeks were low compared to other leachates. Average values were: COD 39-49 mg/L, ammonia nitrogen 1-3.2 mg/L, iron 3.5 mg/L, and manganese 0.5 mg/L. These discharges should have no measurable effect on main channel river water quality.

7.4 Woodwaste Landfills

Large volumes of woodwaste are generated in the study area. In 1977 about 1 000 000 m^3 of waste was incinerated and 2 700 000 m^3 was landfilled. Hog fuel boilers are being expanded in the area, so that the amount of waste being landfilled should be reduced by 20 percent in the near future. Landfills are operated to reclaim or raise land, as well as to dispose of excess waste.

In 1977 the Environmental Protection Service carried out an aerial survey of woodwaste sites in the study area[30]. The survey showed 35 sites covering an area of 130 ha. Nearly 90 percent of the sites were along the banks of the river. The survey did not detect covered sites, and since many fill operations are of short duration, the situation will change from year to year.

Through the use of aerial photographs, the survey produced an estimate of the total volume of woodwaste fill along various sections of the river. The total volume of fill in the 35 sites was estimated to be 4 400 000 m^3. About 3 400 000 m^3, or nearly 80 percent of the fill, was along the Main Stem, between Douglas Island and the bifurcation of the river. Other sections of the river foreshore contained roughly equal amounts of the remaining fill, except the Main Arm between Tilbury Island and the mouth, where no active sites were found.

The volume and composition of leachates from the landfills have not been measured directly. Two rough estimates of the amount of solids and COD leached were made, based on certain assumptions[30].

In the first estimate, the amount of wood waste landfilled in each of the last four years was assumed to equal the amount landfilled in 1977 (2.7×10^6 m^3/a). Also, lysimeter studies indicated that, after four years, about 1 percent of the dry weight of the wood is leached as total solids and 1.5 percent is leached as COD. Using this information, and assuming a certain density for the waste, the total amount leached per day in the study area was estimated to be 11 000 kg/d of solids and 16 000 kg/d of COD.

In the second estimate, results of limited measurements at a few sites were used. These results indicated that the average concentration of total solids in the leachate was 490 mg/L, and of COD was 740 mg/L. The total leachate flow was calculated to be an average of 6 800 m^3/d, assuming that 75 percent of the annual precipitation (95 cm) produced leachate from an area covering 260 ha. These data gave approximate total loadings of 3 300 kg/d total solids and 5 000 kg/d COD.

The estimates of contaminants leached from woodwaste landfills are approximate, and are presented to give just a rough idea of the potential problem. The quantity of total solids discharged is in the range of 4 to 15 percent of the total solids discharged from the Annacis treatment plant. For COD the quantity from leachate is in the range of 10 to 30 percent of COD from Annacis. About 80 percent of these quantities are discharged to the Main Stem. Given the water quality of the main reaches (Chapter 8), and the moderate toxicity of woodwaste leachate, these discharges are unlikely to have any measurable effect on main channel river water quality. However, in places where there is little dilution, such as sloughs, backwaters and small tributaries, the leachate lowers dissolved oxygen and is toxic to fish in some areas.

8. WATER QUALITY

In this chapter, we present data describing the state of the water in the Fraser River and estuary excluding tributary streams and the Banks. The information is drawn from two detailed reports on general water chemistry[27] and microbial water quality[28].

The summary of data, excluding coliforms, covers the period 1970 to 1978. During this time, about 55 000 measurements were made at over 200 sampling sites. These data were collected by a variety of federal, provincial and regional agencies. To carry out this study, we entered the data on the provincial Ministry of the Environment's data storage system, EQUIS (Environmental Quality Information System).

To assess the information, we divided the river in the study area into 22 reaches. Each reach contains a number of sampling sites that can be conveniently grouped together. The number and name of each reach are shown in Figure 6. Reaches 1 to 4 are on the Main Stem, reaches 5 to 13 on the Main Arm, reaches 14 to 19 on the North Arm, reaches 20 and 21 on Sturgeon Banks, and reach 22 is on the Middle Arm.

Over 70 parameters have been measured in the river at one time or other. In this summary, we deal with 45 of the more important parameters. For ease of discussion, these parameters are grouped into six categories (major ions and physical parameters, oxygen consuming materials, heavy metals, other toxic compounds, nutrients and coliforms). For each parameter we calculated the median value per reach for the period 1970 to 1978. The median value, or 50th percentile, is the value below which 50 percent of the measurements fall. This value was used instead of the arithmetic mean because it is not distorted by a few very high or very low values. To account for the extremes, we also calculated the 10th percentile (value below which 10 percent of the measurements fall) and the 90th percentile (value below which 90 percent of the measurements fall). The data for all reaches combined are summarized in Table 21. For certain critical parameters, the range or extreme values are discussed.

8.1 Major Ions and Physical Parameters

This category includes general ions (calcium, chloride, fluoride, hardness, magnesium, potassium, sodium and sulphate) and certain other parameters (alkalinity, colour, conductivity, pH, dissolved and suspended solids, temperature and turbidity).

The general ions are at their maximum concentration at low river flow, decreasing in freshet. These results are due to the contribution of groundwater containing dissolved salts, at low flow, and to the contribution of purer snowmelt water during high flow. The general ion concentrations increase sharply below Deas Island (reach 9) and Mitchell Island (reach 16) due to the presence of seawater. The intrusion of seawater up the river is greatest in winter at low river flow and high tide, and may occur as far as Annacis Island (reach 4) in the Main Arm. Brackish water has been detected as far as Queensborough (reach 14) in the North Arm, and occasionally Port Mann (reach 2) in the Main Stem. The dissolved solids criterion for irrigation water (200 mg/L) is met upstream from Deas Island and Mitchell Island.

The suspended solids concentrations in the Fraser River are high. Upstream from Hope, the median concentration was 135 mg/L. Between Hope and Mission it was 45 mg/L, and in the study area it was 30 mg/L. The general reduction from upstream to downstream is due to settling and to dilution with seawater in the estuary. The overall median for B.C. waters is much lower (6 mg/L). Turbidity follows the same trends.

The concentration of suspended solids in the Fraser River is dependent on river flow. During freshet (March to July) the flow increases up to six times, causing resuspension of bottom sediments and erosion of the river bed. This action gives the river its muddy appearance. Maximum concentrations in the study area were 80 to 180 mg/L from April to May. Minimum concentrations were 5 to 10 mg/L in late winter.

The contribution of discharges to the suspended solids load is relatively minor compared to the high natural load. For example the discharge from the Annacis treatment plant averaged about 11 000 kg/d of suspended solids in 1977. Assuming a low flow in the Main Arm of 62 million m^3/d, and a low suspended solids concentration of 10 mg/L, the Annacis discharge was less than 2 percent of the total river load of 620 000 kg/d. However, the solids from the plant are mainly organic in nature, whereas solids in the river are mainly inorganic.

Median pH values for all reaches were in the range of 7 to 8. These values are comparable to the pH of the Fraser upstream from the study area (7.7 to 8.2), and the median pH for other B.C. streams (7.8).

In April, 1978, unusually low pH values were recorded inside the south training wall, at New Westminster, at depths down to 10 m (5.8 to 6.8). Effluents and drainage ditches in the vicinity did not account for these low values, although values as low as these have been recorded upstream in the river and in some tributaries.

Virtually all pH measurements were within the range recommended for protection of aquatic life (6-8.5). The pH value is important in calculating chemical equilibria, including the relative proportions of ionized and un-ionized ammonia.

Total alkalinity was in the 40 to 50 mg/L range, suggesting that the river has a moderate buffering capacity. This result was illustrated by titration curves obtained with strong and weak acids. However, the river is very poorly buffered against strong and weak bases. Alkaline discharges to the river should therefore be curtailed since high pH (above 8.5) is the main factor governing ammonia toxicity in the river (section 8.5.5).

8.2 Oxygen Consuming Materials and Dissolved Oxygen

Values for oil and grease, volatile residues, total organic carbon, biochemical oxygen demand and chemical oxygen demand are very low in the river, often near the minimum detection limits (Table 21). Higher values are recorded occasionally in the dilution zone of the Annacis effluent.

The dissolved oxygen in the Fraser River is generally high. In the main channels the median value was above 10 mg/L, and the 10th percentile was over 7 mg/L. The dissolved oxygen in these channels was at, or near, saturation levels. These values compare favourably to the median for other B.C. waters (10.8 mg/L). There were seasonal variations, with the highest values occurring in the winter and the lowest values in late summer.

Within these ranges, there were variations among reaches. For example, the North Arm had a lower mean (10.8 mg/L) than the Main Arm (11.3 mg/L), due in part to the higher average temperature in the North Arm. The startup of the Annacis treatment plant in 1975 had no statistically significant effect on average dissolved oxygen in the river, although lower values were occasionally observed near the discharge point.

Exceptions to the high dissolved oxygen in the Fraser River are parts of certain sloughs and backwaters. In general, the dissolved oxygen in the sloughs was above 80 percent saturation, with concentrations over 8 mg/L. However, values of less than 5 mg/L have been recorded in the bottom water at the head of Ladner, Deas and McDonald sloughs, and in the bottom two metres of the centre of Cannery Channel. In Tilbury Slough, the median dissolved oxygen concentration was 6.9 mg/L in the summer, and 20 percent of all the measurements were less than 5 mg/L, with anaerobic conditions occurring occasionally in bottom waters.

The low dissolved oxygen could be harmful to fish. The recommended minimum dissolved oxygen to maintain good fish populations was 5 mg/L. More recent work recommends 7.75 mg/L for freshwater salmonids, 9.75 mg/L for salmonid larvae and 9.0 mg/L for anadromous marine fish[34]. In the sloughs, the problem is one of poorly flushed bottom waters, aggravated by drainage from adjacent lands and log booms. The pockets of bottom water may contain dense saline water, which is retained in depressions for several months. Increased microbial activity in these pockets lowers the dissolved oxygen.

8.3 Heavy Metals

This section summarizes data for eleven heavy metals. The results are reported either as dissolved metal or total metal. The dissolved metal represents metal in solution, since the analysis is carried out on a sample passed through a 0.45 µm filter. Total metal represents metal in solution and in suspension, because the analysis is done on the unfiltered sample. It may not include metal in the mineral fraction of suspended sediment, since the acid digestion used in the analysis may not dissolve the sample completely. The analytical results can vary, depending upon sample preservation method, storage time, digestion method and method of analysis. A factor that hinders the interpretation of metal data is the variation of detection limits. Depending upon the agency, and the year the analysis was carried out, the detection limits vary by a factor of 10 to 100. A full discussion of detection limits and methodology is given in the water chemistry report[27].

The data for most metals were usually too variable to show differences between reaches. The exception was zinc, which was at a higher concentration in the North Arm than elsewhere. The concentrations of total copper, iron and zinc tended to increase with flow, like suspended solids, indicating an association with sediments. There were no clear effects of season or tide on the dissolved form of the metals. The data were too variable to show any effect from the startup of the Annacis treatment plant in 1975, although copper levels were sometimes higher immediately below the discharge point.

In general, 80 percent of the measurements for metals were below the detection limit, except for copper, iron and zinc. Most of the metals rarely exceeded levels considered toxic to aquatic life. Calculations of a theoretical worst-case toxicity, assuming the toxicities of the individual metals are additive, suggest that copper and zinc would account for most of any toxicity from heavy metals. Sediments and aquatic biota are a useful index of heavy metal pollution, since they tend to accumulate certain metals such as mercury. This subject is discussed in Chapter 9.

Since copper and zinc appear to have the most potential to affect water quality, we estimated the total discharge of these metals in the study area. The average loads entering the study area, based on monthly river flows and average concentrations, were about 1 150 kg/d of copper and 1 900 kg/d of zinc. The quantities discharged by sewage treatment plants, industry and storm water were about 120 kg/d copper and 260 kg/d zinc. This rough estimate indicates that 85 to 90 percent of these metals comes from sources upstream from the study area, mainly in the form of suspended solids. However, discharges in the study area can have localized effects and contribute to bio-accumulation. The following sub-sections summarize the water quality effects, and Chapter 9 discusses the effects on aquatic life.

8.3.1 Cadmium

Over 800 measurements were made, including the total and dissolved form, and only 7 percent were above the detection limit. The criteria used for protection of aquatic life are 0.0004 mg/L for sensitive aquatic life and 0.004 mg/L for less sensitive aquatic life. About 3 percent of the values were over 0.0004 mg/L and only 0.3 percent were over 0.004 mg/L.

A few high concentrations were measured. One was at Annieville Channel (reach 6, 0.13 mg/L) and one at Tilbury (reach 8, 0.01 mg/L). Neither of these samples contained organic nitrogen or other indicators of municipal sewage. Considering that more than 90 percent of all measurements were below detection limits, and very few values exceeded the most sensitive criteria, cadmium is not presently of concern in the river.

8.3.2 Chromium

About 80 percent of the 800 measurements made were below the detection limits. These limits ranged from 0.1 to 0.0002 mg/L. Maximum values (0.07 mg/L) were recorded at Annieville Channel upstream (reach 5) and at Tilbury (reach 8), but neither value was associated with sewage. Only two values exceeded the criterion for protection of aquatic life (0.05 mg/L). These data indicate that chromium is not of immediate concern in the river.

8.3.3 Copper

Over 900 measurements were made, and most of the values (75 percent) were greater than the detectable limits. The median values were 0.002 mg/L for dissolved copper and 0.005 for total copper. These values are of the same order as the median for other B.C. streams (0.002 mg/L, total and dissolved). Total copper tends to increase during freshet, when suspended solids concentrations increase.

Criteria for the protection of aquatic life range from 0.01 to 0.002 mg/L. For salmonids in soft water, a criterion of 0.003 mg/L has been suggested. Roughly half of the measurements exceeded the lowest criteria, but only one percent exceeded 0.01 mg/L. All measurements were within a $96hLC_{50}$ for salmonids of 0.03 mg/L. These data suggest that copper concentrations may be borderline. The biological availability of copper is not known, and further research is needed to establish the different chemical species of copper and their relative toxicities. Continued monitoring of the river and of the major sources is recommended. In the Main Arm, the largest source is the Annacis and Lulu treatment plants, which discharge 26 kg/d of copper. In the North Arm, most of the copper is from industrial effluents and storm water (4 kg/d), and on the Banks the main source is the Iona treatment plant (78 kg/d). About 90 percent of the total copper in the river (1 200 kg/d) appears to originate from upstream from the study area.

8.3.4 Iron

Over 1 100 measurements for iron were carried out. There was a clear difference betweeen the concentrations of dissolved and total iron. The median values were 0.2 mg/L dissolved and 1.0 mg/L total. The 90th percentiles were 0.14 mg/L dissolved and 3.4 mg/L total. These data indicate that most of the iron is present in the particulate form. The total iron also increased by a factor of 4 or 5 in freshet, in much the same way as suspended solids.

The median for other B.C. waters is 0.3 mg/L total iron. These results show that the background level of iron in the Fraser River is naturally higher than in other B.C. streams.

The criterion for protection of aquatic life is 1 mg/L, dissolved iron, which is above background levels in the river. Other criteria range from 0.01 to 0.3 mg/L for drinking and certain industrial uses. These values suggest that pretreatment of the water would be needed before most uses.

8.3.5 Lead

Close to 1 000 measurements of dissolved and total lead were performed. Nearly 80 percent of these were below the detection limits, which ranged from 0.001 to 0.0004 mg/L. Median values were 0.001 mg/L dissolved and 0.002 mg/L total. Virtually all measurements were within the criterion for protection of aquatic life (0.03 mg/L).

8.3.6 Manganese

Out of approximately 400 measurements, 12 percent were below the detection limit (0.01 mg/L). Most values for total manganese ranged between 0.01 and 0.1 mg/L. The median was 0.05 mg/L (median for B.C. waters: 0.03 mg/L). All values were within the criterion for irrigation waters (2 mg/L).

8.3.7 Mercury

About 300 measurements of dissolved and total mercury were carried out. Eighty-five percent of these were below the detection limit of 0.05 µg/L. The median values for total and dissolved mercury were 0.05 µg/L. The 90th percentiles were 0.05 µg/L dissolved and 0.14 µg/L total. There were nine total mercury values that exceeded 0.2 µg/L (six in the North Arm, three in the Main Arm). These values were measured before 1975, and no similar values have been measured since.

The criteria for the protection of aquatic life are 0.05 µg/L average and 0.2 µg/L maximum. Since mercury is very toxic and can be accumulated by biota, values above 0.2 µg/L are of concern, even though they are very infrequent. There have been sporadically high concentrations along the Fraser River, upstream from the study area. These results may have been due to mercury deposits in the watershed. In the study area, certain data suggest that mercury may have been discharged with raw sewage, near the Patullo Bridge before 1975. Sources of mercury in the study area need to be documented.

8.3.8 Molybdenum

Out of just under 100 measurements performed, 25 percent were below the detection limit (0.0005 mg/L). The concentrations in the river were very low (90th percentile = 0.0013 to 0.0063 mg/L). Virtually all values were within the criteria for irrigation waters (0.005 to 0.01 mg/L).

8.3.9 Nickel

Nearly 300 measurements were carried out, and 90 percent were below the detection limit (0.01 mg/L). The 90th percentile was 0.01 mg/L and the maximum values recorded were well within the criteria for irrigation (0.2-0.5 mg/L).

8.3.10 Zinc

Nearly 1 000 measurements were performed and most of the values (70 percent) were greater than the detectable limits. The median values were 0.005 mg/L dissolved and 0.008 mg/L total. They are similar to the median value for other B.C.

streams (0.006 mg/L, total and dissolved). Zinc concentrations in the North Arm (mean 0.014 mg/L) were significantly higher than in the Main Arm (mean 0.009 mg/L). The 90th percentiles for all reaches were 0.017 mg/L dissolved and 0.03 mg/L total.

Criteria for the protection of aquatic life range between 0.0002 and 0.01 mg/L. A level of 0.01 mg/L would be considered safe and a level of 0.10 mg/L could cause sublethal effects. One $96hLC_{50}$ for salmonids is 0.5 mg/L in soft water. Virtually all values were within 0.05 mg/L and zinc concentrations have not reached levels of concern in the river. However, the limit considered safe for aquatic life was exceeded on occasion, so that continued monitoring of the river and the main sources is advisable. In the Main Arm, the largest source of zinc is the Annacis and Lulu treatment plants (44 kg/d), whereas in the North Arm the main contributor is industry (120 kg/d). Upgrading of these industrial effluents is being investigated by the Province. On the Banks, the main source is the Iona treatment plant (43 kg/d). About 85 percent of the total zinc in the river (1 900 kg/d) appears to originate from upstream from the study area.

8.4 Other Toxic Compounds

This category includes compounds commonly present in municipal effluent at concentrations high enough to enable detection, after dilution with river water. Toxic organic compounds such as chlorinated phenolics and hydrocarbons, phthalate esters, fatty acids etc. are present in trace amounts in sewage[9]. Their concentrations in river water in the main channels are very low and are only important from the point of bioaccumulation (Chapter 9, section 9.4). However they can, and have, produced fish kills in certain tributary streams and backwaters.

8.4.1 Arsenic

Out of less than 100 measurements carried out in the study area, only 3 were above the detection limit of 0.005 mg/L. All concentrations were within the level considered safe for the protection of aquatic life (0.05 mg/L).

8.4.2 Residual Chlorine

Approximately 50 measurements were made in the Main Arm and all were below the detection limit (0.05 mg/L). Residual chlorine may be present from chlorination of the main municipal effluents, discharged from the Annacis and Lulu treatment plants. During the past few years these effluents have been dechlorinated before discharge and the chlorine residual was below the detection limit in the effluent. The importance of controlling chlorine is demonstrated by the low fresh water level suggested for protection of aquatic life (0.002 mg/L, free residual chlorine).

8.4.3 Cyanide

Approximately 200 measurements were performed and all were below the detection limit (0.01 mg/L). This limit is also the criterion used for protection of aquatic life.

8.4.4 Phenolic Compounds

These compounds include a number of hydroxy derivatives of benzene, as well as phenol. Some of these compounds are in leachates from wood waste, and may be as toxic and as capable of tainting fish as phenol and chlorinated phenol.

Measurements were carried out in the Main Arm and gave a median concentration of 0.004 mg/L and a 90th percentile of 0.017 mg/L. The equivalent values for other B.C. streams are 0.002 mg/L (median) and 0.011 mg/L (90th percentile). Some higher values were encountered at Tilbury (reach 8, median = 0.008 mg/L) and at Annieville Channel (reach 6).

Most concentrations exceeded 0.001 mg/L, a level at which fish tainting can occur with certain phenolics. However, there have been no complaints of fish tainting in the area. All concentrations were well below the level considered acutely toxic to fish (0.1 mg/L).

8.4.5 Sulphide

Sulphide was not usually detected in municipal effluents (Chapter 3, Section 3.6.5). It can be formed in the water by bacterial action on sulphates, when the dissolved oxygen level is near zero.

The criterion for protection of aquatic life is 0.002 mg/L, which is below most detection limits. Concentrations in the study area were less than 0.05 mg/L, except for a few high values at Tilbury (reach 8) and the North Arm Jetty (reach 19). Sulphide may sometimes occur in localized areas of certain sloughs, where the dissolved oxygen can be low (Section 8.2.1). Generally it will not be a problem in the main channels due to the high dissolved oxygen in all reaches.

8.4.6 Surfactants

Surface active agents are present in municipal sewage and are partly responsible for the toxicity of these effluents. The median concentration in the study area was 0.03 mg/L, which is the same as the median for other B.C. waters. The criterion for the protection of aquatic life (0.2 mg/L) was met with very few exceptions.

8.4.7 Tannin and Lignin Like Compounds

These compounds are present in leachates from wood wastes and, although not highly toxic, are coloured. The median value for all reaches was 0.5 mg/L. The highest values were recorded near the Port Mann Bridge (reach 2, median = 0.95 mg/L, maximum = 1.36 mg/L), and were probably due to leachate from the Leeder landfill. Similar values were encountered in the Fraser River upstream at Prince George (0.85 mg/L) and Quesnel (0.95 mg/L), near pulp mills.

8.5 Nutrients

Parameters discussed in this section are nitrogen, phosphorus and silica. Most of the nitrogen in the river is present as nitrate or organic nitrogen, and most of the phosphorus is in the particulate form. The concentrations of total nitrogen and dissolved orthophosphorus in the Fraser River are similar to those in other rivers of B.C. The concentration of total phosphorus, like suspended solids, is often higher in the Fraser. Concentrations range from 0.1 to 0.4 mg/L for total nitrogen and from 0.008 to 0.2 for total phosphorus. Although eutrophication could take place within these concentration ranges, it is unlikely to occur because high turbidity limits light penetration in the river in certain seasons.

The nitrogen and phosphorus discharged in 1977 by the main sewage treatment plants, storm water and industry constituted about 10 to 20 percent of the nutrients in the river. This was about double the amount discharged by these sources in 1967, although the total loading from the river remained roughly the same. Nitrogen may be a limiting factor for biological productivity in the ocean, but it is not known whether additional nitrogen from the river will increase the primary productivity in the Strait of Georgia. Phosphorus in the ocean is not generally limiting, so that increases in phosphorus should not increase primary productivity in the ocean.

Ammonia toxicity in the river was negligible. This result was due to the pH of the river being rarely over 8.5. The nutrient concentrations, loading and toxicity are discussed in the following sub-sections.

8.5.1 Nitrogen

The ammonia nitrogen in the river was generally low in all reaches. The median value (0.018 mg/L) was comparable to the median for all B.C. waters (0.015 mg/L). There was a seasonal variation, with higher values in the winter decreasing through freshet to a minimum in the summer. High values occurred occasionally in the dilution zone of municipal discharges (up to 3.24 mg/L in reach 6).

The median values for nitrate nitrogen ranged between 0.05 and 0.10 mg/L. The median for all reaches was 0.08 mg/L, which is similar to the median for all B.C. streams (0.07 mg/L). Nitrate nitrogen followed the same seasonal trend as ammonia nitrogen. The concentration increased in the downstream reaches, due to the presence of seawater. The nitrite nitrogen in the river was generally below the detection limit (0.005 mg/L).

The concentration of organic nitrogen was quite variable. The median value for other reaches was the same as the median value for other B.C. streams (0.14 mg/L). Nitrogen in the organic form may be converted to ammonia and nitrate by microbial action.

8.5.2 Phosphorus

In the dissolved ortho-phosphorus form, the median phosphorus concentration varied from 0.003 mg/L to 0.01 mg/L. There were higher values near the mouth of the estuary due to the presence of seawater. Upstream from Hope the median value ranged between 0.002 and 0.005 mg/L, and for other B.C. waters the median is 0.005 mg/L. There were some high dissolved phosphorus concentrations in reach 6 (up to 0.53 mg/L), and in the plume of the Annacis discharge.

The total phosphorus was four to six times higher than dissolved phosphorus. This result shows that most of the phosphorus in the river is associated with suspended solids. The median total phosphorus concentration in the different reaches ranged from 0.025 to 0.04 mg/L in the Main Arm, 0.04 to 0.07 mg/L in the North Arm and 0.02 to 0.06 mg/L upstream from Hope. The median for other B.C. waters is 0.025 mg/L, indicating that the Fraser River as a whole contains more phosphorus than average. The seasonal variation of total phosphorus is similar to turbidity, with maxima in freshet (May to June) and minima at low flow (January to March).

8.5.3 Silica

Silica, reported as concentration of reactive silica (SiO_2), is used by diatoms in forming their outer covering. The median concentration varied between 3 and 6 mg/L, and was similar to the median value for other B.C. waters (6.2 mg/L). Some values were occasionally over 10 mg/L, which is a criterion for certain industrial uses of water.

8.5.4 Nutrient Loadings

The amounts of total nitrogen and phosphorus in the river were calculated at Patullo Bridge (reach 3) for the 10th, 50th and 90th percentile flow and for the years 1967 and 1977. The data used were variable, since they were obtained by different agencies, sampling at various depths and using different analytical techniques[27]. The results, summarized in Table 22, are therefore approximate. For a low flow regime (2 500 m^3/s) the nitrogen loading was about 20 000 tonnes per annum (t/a), and for high flow (4 600 m^3/s) it was about 37 000 t/a at Patullo Bridge.

The mean annual loading of total nitrogen in 1977 was 27 000 t/a. An estimate of nutrients contributed by discharges in 1977 is presented in Table 23. The estimate is based on adding the contributions from municipal effluents, industrial effluents, landfills, storm water and general runoff. The total nitrogen from all discharges in the study area was about 5 100 t/a in 1977, or 19 percent of the total nitrogen entering the sea from the Fraser River.

In 1967 the total loading at Patullo Bridge was relatively unchanged (32 500 t/a). However, the amount in the discharges that year was estimated to be lower (2 700 t/a)[27]. Thus, in 1967 the discharges contributed 8 percent of the total nitrogen entering the sea.

Between 1967 and 1977 the contribution of total nitrogen from discharges in the study area doubled approximately. The effect of this increase on total nitrogen discharged to the sea from the Fraser River is hard to assess. The variability of the data (river flow, nitrogen concentration) is such that the total amount of nitrogen in the Fraser River appears to have changed little over the last ten years. Although nitrogen is often a limiting nutrient in primary productivity in the ocean, it is difficult to say whether the increased discharge from the study area accounts for the increase in phytoplankton growth, observed in Georgia Strait over the last ten years[29].

The average amounts of phosphorus at Patullo Bridge in 1977 were 400 t/a in the dissolved form and 7 000 t/a in the total form (Table 22). Discharges in the study area contributed about 860 t/a of phosphorus to the river in 1977 (Table 23). This amounts to about 12 percent of the total phosphorus discharged to the sea. If one assumes that all phosphorus in the discharges is in the dissolved form, the contribution to dissolved phosphorus entering the sea is about 70 percent. Since phosphorus is not usually a limiting nutrient in the ocean, additions of phosphorus should be expected to have no additional effect on primary productivity in the Strait of Georgia.

8.5.5 Ammonia Toxicity

The toxicity of ammonia is due to the presence of un-ionized ammonia in the water. The concentration of un-ionized ammonia increases with increasing pH and temperature and decreasing salinity. The criterion for protection of aquatic life is 0.02 mg/L un-ionized ammonia.

The concentrations of un-ionized ammonia can be estimated for any condition. For example, at a pH of 8, a temperature of 20°C, a salinity of zero and an ammonia nitrogen concentration of 0.1 mg/L, the concentration of un-ionized ammonia nitrogen would be 0.004 mg/L. This value is well within the criterion even though fairly extreme values were chosen for the variables. The calculation indicates that ammonia toxicity is unlikely to be a problem in the river. An exception is the dilution zone of the Annacis discharge. In this localized area, concentrations up to 0.7 mg/L un-ionized ammonia nitrogen may be possible on occasion. Calculations indicate that at dilutions of Annacis effluent exceeding 15:1 to 20:1, un-ionized ammonia will be less than 0.02 mg/L, under existing river conditions.

Since a relatively high pH (greater than 8.5) is needed to produce ammonia toxicity, and since the river is not well buffered against bases, the discharges of alkaline effluents should be avoided.

8.6 Fecal Coliforms

The coliform test is used to indicate the potential presence of pathogenic organisms in water polluted with fecal wastes. The total coliform test includes coliforms that come from soil, plants and fecal sources. The test for fecal coliforms gives results for coliforms of fecal origin only. Since this section is concerned with the health aspects of water quality, we present data on fecal coliforms only.

The main sources of fecal coliforms and pathogens are municipal effluents, storm water, and Fraser River water upstream from the study area. The limited information available indicates that, during months of non-chlorination, the input of coliforms is higher from sewage treatment plants than from storm sewers and upstream sources. During months of chlorination, there are insufficient data to show a significant difference between these three sources. Accurate loading calculations are not possible due to limited data on storm sewers and upstream inputs. It is also difficult to compare total coliform values, measured in municipal effluents, with fecal coliform values measured in water from other sources.

Data on fecal coliforms in receiving waters have been collected at over 100 sites by a number of government and private agencies. We have grouped the sites on the river into the same reaches that were used for other water quality parameters (Figure 6).

Water samples were collected under varying conditions, stored in different ways and sometimes analyzed by different methods. These factors, imposed on the natural variability of the data, tend to increase their uncertainty. The data are summarized as annual geometric means, and 10th and 90th percentiles for each reach, over the period 1970 to 1977. Units used are MPN/100 mL (MPN=most probable number).

8.6.1 Criteria for Various Water Uses

It is important to assess fecal contamination because of recreational uses of the river, such as fishing, boating and nature studies. Beaches on the river are closed to swimming. There is swimming within the study area at Tsawwassen, and Boundary Bay, and just outside the study area at Wreck Beach and Spanish Banks. Molluscan shellfish harvesting is banned inside the study area due to fecal coliform contamination.

Most of the licenses issued for use of Fraser River water in the study area are for industrial use (cooling, gravel washing, fire protection etc.). There are no licenses for domestic use. The water would need treatment before domestic use because of the high turbidity and variable salinity in some locations. One licence exists for irrigation, just downstream from Kanaka Creek. Fraser River water that backs up in storm ditches, under tidal influence, is often used for irrigation by farmers, on an unofficial basis.

Criteria for fecal coliforms, expressed as MPN/100 mL, exist for a number of uses. The maximum allowable in raw water, which is to be used for drinking water is 2 000/100 mL. For molluscan shellfish harvesting the limit is 14/100 mL, and for irrigation 1 000/100 mL. For swimming the standard is variable. Certain agencies in the U.S. and Great Britain believe there is no valid correlation between disease and swimming, and therefore make no recommendations on fecal coliform concentrations. In British Columbia a logarithmic mean of 200/100 mL must not be exceeded at swimming beaches. Standards for recreation are arbitrary. A committee convened by the World Health Organization suggested the following criteria, based on aesthetics: over 2 000/100 mL is a sign of heavy pollution, 1 000 - 2 000/100 mL is a sign of distinct pollution, 50 - 200/100 mL indicates slight pollution, and less than 50/100 mL is highly satisfactory.

8.6.2 Fecal Contamination in the Fraser River and Adjacent Beaches

A complete graphical representation of fecal coliform concentrations in the river is given in a detailed report[28]. A reach by reach summary of the data is presented in Table 24, for the period 1970 to 1977.

Upstream from the study area, between Mission and Hope, the geometric mean fecal coliform concentration varied between 100 and 300/100 mL. This result indicates slight pollution, probably from treated municipal effluents and storm water, although the water would usually be acceptable for irrigation use.

In the Main Arm the geometric mean was generally between 1 000 and 2 000/100 mL up to 1975. In 1976 and 1977 the geometric mean usually dropped below 1 000/100 mL. This improvement reflects installation of primary treatment at Annacis. The present coliform level still indicates a definite degree of pollution. This result is due partly to the uncontrolled discharge from many storm water outfalls, and partly to the discharge of unchlorinated municipal effluent in the winter months. Effluent data indicate that unchlorinated effluent contains from 1 000 to 6 000 times more coliforms than chlorinated effluent (Chapter 3, Section 3.6.8). The effluent is chlorinated in the summer to reduce the chance of contaminating bathing beaches (Spanish Banks and English Bay). Chlorination is discontinued in the winter.

A similar pattern of coliform concentrations exists in the North Arm. Geometric mean values of 2 000 to 5 000/100 mL were recorded in several reaches up to 1975. After the redirection of raw sewage from the North Arm to the Annacis plant, the geometric mean frequently dropped to below 1 000/100 mL in 1976 and 1977. Since sampling in the North arm was more frequent in the summer, the results may be biased towards lower summer counts.

Data at bathing beaches are collected two times a week in the summer, during May to September. At the Tsawwassen jetty and beach the geometric mean varied between 20 and 60/100 mL. All means were within the provincial standard for swimming (200/100 mL). Beaches off the University of B.C. Endowment Lands (Wreck and Tower Beach), although not within the study area, may be affected by the Fraser River. The geometric mean at Spanish Banks from 1976 to 1978 usually varied between 50 and 150/100 mL and rarely exceeded 200/100 mL. However, 90th percentile values at these beaches occasionally exceeded the provincial standard of 400/100 mL.

The pattern of coliform data suggests that, in the summer, water in the main reaches will frequently meet the irrigation standards (1 000/100 mL), but will rarely be within the swimming standards (200/100 mL). The standard for molluscan shellfish harvesting (14/100 mL) will not be met at any time within the study area. Considering the diversity of sources of fecal coliforms, and the problems in controlling these sources (Chapter 10), the molluscan shellfish harvesting standard is unlikely to be met in the future. Tsawwassen beaches are well within safe limits for swimming. Occasional 90th percentile values which exceed 400/100 mL at Spanish Banks, indicate this area may, in future, become borderline for swimming. Information is needed to determine whether the North Arm is the source of high coliform counts at other locations in the University of B.C. Endownment Lands. Vancouver beaches, although not in the study area, may also be affected by the Fraser River.

High fecal coliform levels in waters containing molluscan shellfish, off Mayne Island in the summer, have been attributed to the influence of the Fraser River(35). This condition may exist at other shellfish areas in the Gulf Islands, and at other times of the year.

In Boundary Bay, the median fecal coliform level is 56 MPN/100 mL(36). The data suggest that levels are well within swimming standards, but are too high to allow harvesting of molluscan shellfish. The Environmental Protection Service has recommended continued closure of the area. Fecal coliform levels in the water off Boundary Bay have not changed significantly since sewage was rerouted from the White Rock sewage treatment plant to the Annacis plant. The major sources of fecal coliforms are considered to be runoff from livestock and agricultural land into the Serpentine and Nicomekl rivers, and stations pumping land drainage along the shore of the bay.

8.7 Possible Effects of River Training Walls

The federal department of Public Works is proposing additions to the river training walls. The environmental impact of the proposal is currently being studied by consultants. The main impact on water quality will relate to the redistribution of sediments in the estuary, and the possible leaching of toxicants from these sediments.

The purpose of the training walls is to increase the river velocity, in order to deepen the channel in the Main Arm for navigation. Scouring of the river bed will result in deposition of sediments on the outer Banks. The effect of seawater on metals in the sediments is poorly known. For example, zinc and copper concentrations in the water appear to increase near the mouth of the river, due to increased salinity[27]. Although the toxicities of the various metal species associated with sediments are not known, we believe that acute toxicity from this source is unlikely to occur. There is a possibility that more metals will be available for biological accumulation. This may be a problem in localized areas, such as in accretion areas of the delta, or behind the training walls. Problems could also be created behind the walls if outfalls are not extended into the main river channels.

9. AQUATIC BIOLOGY AND SEDIMENTS

Information pertaining to sediments, algae, invertebrates and fish is presented in this chapter. The data are summarized from detailed reports on aquatic biota[31] and organic contaminants[12].

The amount of information available on aquatic biota is far less than on water quality. The collection and analysis of algae, invertebrate and fish samples is costly and time-consuming. Consequently, most of the data are obtained in separate studies rather than by ongoing monitoring. Conclusions and trends drawn from this type of work are more limited and uncertain than those based on several years of effluent and receiving water monitoring. There are many data gaps, including the impact of the Annacis discharge, of landfill leachates and of storm water on the biota of the river. The impact of discharges in small tributaries is also very poorly documented.

In this chapter we discuss the effects of the more important water quality parameters on biological communities. Data on heavy metals and organic contaminants, present in sediments and aquatic biota, are also presented.

9.1 Effect of Water Quality on the Biological Communities in the River

Water quality influences the distribution of algae, invertebrates and fish. The main factors are dissolved oxygen, nutrients, light intensity, salinity, water movement, substrate and accidental spills.

9.1.1 Dissolved Oxygen

The dissolved oxygen in the Fraser River was generally high (above 10 mg/L), being at or near saturation levels in most reaches (Chapter 8, section 8.2). Criteria recommended for freshwater salmonids (7.75 mg/L), salmonid larvae (9.75 mg/L) and anadromous marine fish (9.0 mg/L)[34], were met in the main channels of the river

Several species of periphytic algae found in each arm of the river in early autumn 1972 and early summer 1973, are those found in well oxygenated water. A high species diversity, indicating a non-stressed community, was generally recorded, at a time of year when dissolved oxygen can be expected to be at its lowest concentration.

The diversity of benthic invertebrates was measured in 1975 at nine sites. There were three sites in the Main Stem, including one upstream from Kanaka Creek, three in the Main Arm and three in the North Arm. Diversity indices indicated that the distribution of species was similar at all sites, except for the community in the North Arm, in Reach 15 (Figure 6), where a low index was recorded. The low value may have been caused by a decrease in the dissolved oxygen, from discharges of raw sewage at New Westminster. If this was the case, the situation should be improved since installation of the Annacis plant. Further sampling at the site would be needed to check the invertebrate population.

Low dissolved oxygen concentrations have been measured in certain backwaters and sloughs. Values ranging from less than 1 mg/L to 7 mg/L have occurred at times, and are believed due to accumulation of land drainage, log debris and poor flushing (Chapter 8, section 8.2). Such levels are below the criteria suggested for salmonids and can be harmful to fish. The effect on fish and invertebrates is currently under investigation by Fisheries and Oceans Canada. Studies also indicate that backwaters in the lower Main Arm are used by juvenile salmon, including chum, pink, chinook and sockeye. Although avoidance experiments show that adult salmon will try to stay out of areas of low dissolved oxygen, we do not know if juvenile salmon will behave in the same way. Low oxygen concentrations can also alter the distribution of invertebrates, upon which juvenile salmon feed. The present studies may show whether such changes are occurring in certain Fraser River sloughs.

9.1.2 Nutrients

Nutrients, such as phosphorus and nitrogen, control primary productivity, or growth of algae. Enhanced algal growth can result in nuisance blooms, which may alter the habitat of other organisms and degrade water quality. Phosphorus is considered the controlling nutrient in the river and nitrogen the controlling nutrient in the marine environment (Chapter 8, section 8.5).

The levels of total phosphorus, ammonia and nitrate were high enough to produce algal blooms, but these did not occur. This was due in part to phosphorus being mostly in a mineral state, and hence biologically unavailable. The reduction of light intensity by high turbidity, and the fluctuating river level from tidal action also prevented abundant algal growth.

9.1.3 Salinity

Salt water flows in and out of the lower reaches producing an estuarine habitat. A salt water wedge can extend up the Main Arm, as far as its confluence with the North Arm. The salt wedge can also flow almost as far up the North Arm.

The variable salinity produces different biological communities along the river. This effect must be allowed for when one compares the diversities of communities from different reaches.

The distribution of periphytic algae was partly dependent on water salinity. Most green algae were the freshwater types, although some were found in the lower part of the river where the water is frequently saline. Certain freshwater zooplankton were found lower in the river, where there is considerable mixing of fresh and salt water. Zooplankton found on the Banks were usually the marine form. Benthic invertebrates showed changes in species composition between fresh and salt water. In areas of fresh and salt water mixing, certain invertebrates, such as chironomid larvae and oligochaetes, can withstand rapid changes in salinity due to their burrowing life style. On the Banks the number and diversity of invertebrates naturally increased because of the marine environment.

9.1.4 Substrate

The substrate in the Main Stem, between Kanaka Creek and Barnston Island, is generally sand and gravel. In the remainder of the study area it is largely sand mixed in varying amounts with silt and clay. This substrate is formed by the settling of suspended material transported by the river. It does not support the high diversity of periphyton, macrophytes or benthic invertebrates found in cobble riffles of mountain streams. The diversity and biomass are greater on the Banks because of the marine environment and the stability of the sediment, as indicated in section 9.1.3 on salinity.

9.1.5 Spills

Accidental spills, especially of oil, and illegal discharges have created periodic toxicity problems, Although there are no quantitative data, incidences of fish kills, especially in tributary streams, have been documented by Fisheries and Oceans Canada.

9.2 Water Quality Effects Around the Iona Outfall on Sturgeon Bank

Primary treated effluent from the Iona plant is discharged to an open channel that traverses Sturgeon Bank, as explained in Chapter 3, section 3.3. A jetty was built along the northern length of the channel to direct the effluent out to Georgia Strait. The region immediately south of the jetty, adjacent to the outfall, has been the subject of the most detailed biological work done in the study area.

As a result of several studies, the area around the outfall can be divided into four zones: a zone of serious impact, about 300 m from the outfall; a zone of degradation, about 1 300 m from the outfall; a zone of eutrophication, 2 500 m away; and a zone of recovery, 3 500 m away. Changes in water chemistry, algal and invertebrate populations have been well documented[27, 28, 31], and are briefly summarized here.

In the zone of serious impact, the dissolved oxygen averaged 7.5 mg/L, with minimum values in the range 1.5 to 5.5 mg/L. Low oxygen values were also detected in the sewage channel. The low values were due to the oxygen demand of settling and benthic organic solids, and the depletion of oxygen in the water column and sediments by microbes. The reduced oxygen supply partly explained the complete lack of benthic invertebrates right at the outfall, and the presence of less than four percent of the total population in the rest of the zone. Another major factor limiting aquatic life was heavy sedimentation from the effluent. The sedimentation was responsible for the reduced growth of algae in the impact zone, although total phosphorus in the overlying water reached high values, in the range of 0.38 to 0.53 mg/L. Total nitrogen ranged from 0.34 to 0.42 mg/L.

The dissolved oxygen in the degradation zone, including the sewage channel, averaged 7 to 9 mg/L. Minimum values during an incoming tide were 4 to 6 mg/L. Total phosphorus was in the range of 0.2 to 0.4 mg/L, and total nitrogen 0.32 to 0.38 mg/L. This small improvement in water quality, together with less sedimentation, allowed about 30 percent of the numbers of organisms in the recovery zone to be present.

In the eutrophication zone, the dissolved oxygen averaged over 9 mg/L. The minimum value detected was 4.5 mg/L. The effect of sedimentation is reduced in this zone, but the nutrient concentrations remain high (total phosphorus exceeded 0.15 mg/L and nitrate exceeded 0.3 mg/L). These conditions stimulate the growth of macro and micro algae, which in turn enhance the numbers of invertebrates present. Although the invertebrate populations are large they are unstable, being characterized by many members of a few species. The numerous invertebrates, particularly mussels, support a large population of rats, which provide food for certain raptorial birds. Other birds feed directly on the invertebrates. Thus, the effect of eutrophication is felt by certain "higher" members of the food web.

In the recovery zone the number of aquatic species increased and the number of individuals decreased. This situation is more typical of stable populations found under unaltered conditions.

Aquatic life around the Iona outfall is also influenced by heavy metals and organic contaminants from the effluent. Metallic contamination limits the distribution of certain clams in the area (section 9.3), but the effects of metallic or organic contamination on the avian or mammalian species, now associated with the zone of eutrophication, are unknown. Although the hypoxic conditions previously discussed are confined to roughly 2 hectares, the effects of metallic and organic contaminants are not limited to the Iona area. Mobile organisms, such as zooplankton, crabs, fish, rats and birds feeding in the eutrophic zone, may transport contaminants to other areas of the Banks and marsh. Further information on metal concentrations in sediments and aquatic biota is discussed in section 9.3, and the accumulation of organic toxic contaminants in 9.4.

9.3 Metal Concentrations in Sediments and Aquatic Biota

Data on heavy metals in the river are discussed in Chapter 8 (Section 8.3). The concentrations of metals in the water are generally low, and only copper and zinc appear to have any potential to affect water chemistry. On average, the total amount of copper discharged by the river is about 1 100 kg/d, and the total amount of zinc is 1 900 kg/d. About 10 percent of the copper and 13 percent of the zinc come from municipal effluents, storm water and industrial effluents. The remainder comes from sources, mostly natural, upstream from the study area.

A large portion of the heavy metals is in the insoluble form, associated with suspended solids and sediments. In this form, the metals may be in a crystalline state, or adsorbed onto particles. Metals in these forms are considered often to be unavailable for uptake by aquatic biota. Data on metals in sediments, aquatic plants and animals, and the accumulation of metals by aquatic life are discussed in a detailed report[31]. Information from the report on sediments, algae, invertebrates, fish, crabs and bivalves are summarized in this section.

9.3.1 Sediments

A summary of average metal concentrations in sediments is given in Table 27. Analyses of sediments show that more fines (particles smaller than 75 μm) were present in the Main Stem and North Arm than in the Main Arm. Fines settle out in slower moving water and high metal concentrations were associated sometimes with this size fraction.

The metal concentrations were generally similar in the main body of water of all three main channels. Copper, on average, was in the range of 18 to 28 ppm, lead 1.9 to 29 ppm and zinc 44 to 85 ppm. In slower moving water and shallow areas concentrations were sometimes higher. For example, at the New Westminster dock and Ladner Side Channel average copper values were between 31 and 53 ppm, lead between 21 and 162 ppm, and zinc between 103 and 227 ppm. On the Banks, values were similar to those in the main channels. High values were recorded near the Iona outfall and south of the Iona jetty due to settling of solids from the effluent from the Iona treatment plant.

Data on metal concentrations in sediments from other river basins are given in Table 27 for comparison. Sediments in the Columbia River, immediately downstream from Cominco at Trail, are considered to be relatively contaminated (copper: 1 930 ppm, lead: 866 ppm and zinc: 12 600 ppm). Concentrations are higher than in the lower Fraser by a factor of about 100 for the main channels, and by a factor of 5 to 50 for the most contaminated areas, such as Iona. Sediments from the Illinois River, Illinois, a semi-industrialized area, have similar metal content to the Fraser main channel sediments. Sediments from Skeleton Creek, Oklahoma, an undisturbed stream, contain about five to ten times less metal than the Fraser main channel sediments.

Generally, the metal content of sediments in the Fraser River lies between what may be considered low and high values encountered in other river basins. Concentrations in the main channels probably reflect upstream conditions in most cases. In some areas, such as certain side channels and areas of slow moving water, there is evidence of localized contamination and, close to Iona, there is heavy contamination.

9.3.2 Algae

The accumulation of metals in algae is important, since algae are primary producers of the aquatic food chain. Periphytic algae may be a useful monitoring tool, since accumulation of toxicants can be related to specific sites and time periods. Average concentrations of metals in algae are summarized in Table 28. Data for the main channels (New Westminster, Marpole, Steveston) came from the analysis of periphyton grown on artificial substrates. Data from Iona resulted from the analysis of plants growing on the Iona jetty.

Algae accumulate metals from the water column and, possibly, from sediments. The data from the main river channels provide a high estimate of metals in algae, because both periphyton and associated sediments were analyzed for metal content. The metal levels in the samples were up to 50 ppm copper, up to 55 ppm lead and up to 185 ppm zinc (dry weight basis). These results show that metal levels in algae were much higher than in the water (by a factor of 1 000 or more).

Data from other localities (Table 28) indicate that levels in Fraser River algae are about ten times less than in algae from a heavily degraded area. On the other hand, the Fraser River algae contained five to ten times more metal than algae growing in uncontaminated water. These comparisons are rough since different types of algae accumulate metals in varying amounts.

9.3.3 River Invertebrates

In Table 29 we have summarized data for three different types of invertebrates: amphipods, oligochaetes and chironomid larvae. Amphipods, a type of crustacean, rest on top of the sediments, burrow into them or move through the water column. They feed on algae and detritus and are an important source of food for juvenile salmon. Oligochaetes are a dominant invertebrate of muddy sediments of fresh water systems. They ingest sediment and feed on bacteria associated with the organic fraction. Oligochaetes can be eaten by chironomid larvae and by bottom fish. Chironomid larvae live in the upper part of muddy sediments. They feed on detritus, algae and other invertebrates, and are a food for fish, including salmonids. Invertebrates can accumulate metals through the sediments, water and food.

Metal concentrations in invertebrates varied quite widely, making it difficult to relate metal concentration with invertebrate location. The concentration of metal in invertebrates was generally several hundred to several thousand times higher than in the water column. A large proportion of metals in the river is in the sediment, which is a significant source of metals to benthic invertebrates. The ratio of metal in organisms to metal in sediments was calculated as an indication of accumulation. When the ratio is greater than one, accumulation of metal in the invertebrate is probably taking place. These ratios are called concentration factors and are shown in brackets in Table 29.

The concentrations of metals in amphipods were generally lower than the concentrations in algae and sediments. These results suggest that amphipods do not bioconcentrate metals from algae and sediments. The data for oligochaetes and chironomid larvae show higher concentrations of mercury and zinc than in the sediments at most locations. There were also higher concentrations of copper in chironomid larvae at certain locations. Since oligochaetes and chironomid larvae are benthic, they probably get most metal from the sediments.

The concentration of mercury in riverine benthic invertebrates was most marked. Concentration factors were often in the range of 5 to 10. For copper and zinc the concentration factors were in the range of 2 to 4. These results suggest a high accumulation of mercury and a moderate accumulation of copper and zinc. The concentrations of metals in oligochaetes and chironomids were either similar or less than concentrations in algae, except for mercury. Average values for this element in invertebrates were in the range of 0.1 to 0.8 ppm dry weight.

The concentrations of metals in invertebrates in the lower Fraser River were about 10 to 100 times less than in invertebrates from the Columbia River, downstream from the smelter at Trail. Fraser River values were similar to those from the Illinois River, a semi-industralized area, and about 4 to 10 times higher than values from an uncontaminated area. Thus, as observed for algae and sediments, the metal contents of invertebrates were between higher and lower values measured in other river basins.

The accumulation of copper and zinc in invertebrates, although moderate, is not unexpected considering the concentration of these metals in the sediments, and the occasional high values measured in the water column. The accumulation of mercury is higher than might be expected from sediment and water quality data alone, although high mercury concentrations have been recorded in the water a few times (Chapter 8, Section 8.3.7). Sources of mercury in the study area have yet to be documented in detail.

9.3.4 Fish

The concentrations of copper, mercury and zinc in the muscle tissue of fish are summarized in Table 30. Other metals were either below detectable limits, or at levels that were low compared to levels in algae and invertebrates. The data in Table 30 are for fish caught at 14 sites between Hope and the mouth of the river. Since the results were generally independent of site location, the data for all sites were combined.

The feeding habits of fish influence their intake of contaminants. For example, certain salmon live in the water column and feed on drifting or planktonic organisms, while bottom fish feed on benthic invertebrates. Since benthic invertebrates tend to accumulate certain metals, fish that feed on them are more likely to accumulate these metals than fish that feed in the water column.

Metals that accumulated in the muscle tissue of fish were mercury, zinc and, to some extent, copper. Bottom feeding fish, such as suckers, chub, sturgeon and sculpin were those most affected. Fish usually used for human consumption, such as trout and salmon, contained low levels of metals. Levels were lowest in salmon, although only a small number of these fish have been sampled. The concentrations of copper and zinc in all fish were well within levels recommended as safe for human consumption (100 ppm wet weight). The concentration of mercury exceeded the recommended level at times, in certain bottom fish. Most of these fish are not usually used for human consumption, except for sturgeon. The high mercury results are not unexpected since mercury accumulated more than any other element in invertebrates, which are eaten by bottom feeding fish.

The levels of copper and zinc in fish tissue were generally not high enough to warrant immediate concern. In the Columbia River below Trail, where sediments and invertebrates contained much higher levels of metals than in the study area, the metal content of fish tissue was still well within recommended levels for food[32]. The concentration of mercury in certain fish suggests that contamination by this element may be a potential problem. Mercury settles in sediments where it is methylated by bacteria to mainly monomethyl mercury. In this form it is released to the water column where it can be taken up by fish and other organisms. As mentioned in other sections, the sources of mercury entering the river, whether natural or man made, need to be identified.

The effect of metal accumulation on the fish itself is not completely understood. The metals may stimulate the production of metallothionein, a protein, which binds the metal to amino acids, thus rendering the metal unavailable to exert a toxic effect. This mechanism may explain why relatively high concentrations of metal are not believed to be toxic to the fish and other aquatic organisms.

9.3.5 Crabs

Metals were measured in Dungeness crabs, which are harvested commercially off the Banks. It is difficult to relate results with point sources of metals due to the mobility of the crabs.

Most metal concentrations in crabs off the Banks, including areas around Iona, were similar to values found for crabs in Cowichan Bay and Kitimat Arm, which are considered to be relatively uncontaminated areas. For example, crabs off Iona contained

225 ppm dry weight zinc compared to 186 ppm in Cowichan Bay. Lead concentrations were below 2 ppm dry weight in both areas. Copper was somewhat higher in crabs off Iona (77 ppm dry weight) than in Cowichan Bay (43 ppm dry weight).

Mercury was the notable exception to this pattern, as it has been for sediments and other biota. Levels in crabs off the Banks averaged 1.7 ppm dry weight, compared to 0.16 ppm dry weight in crabs from Cowichan Bay. All values were within the Health and Welfare Canada guideline of 0.5 ppm wet weight, although some of the maximum concentrations approached this guideline.

9.3.6 Bivalves

Oysters and clams on the Banks have been analyzed for heavy metals. Data on oysters were obtained in 1973, 1975 and 1977 around the Iona outfall. An extensive survey of clams was made in 1976 on both Banks, and in 1977 around Iona. Information on metals in bivalves is a measure of the effect of discharges on the aquatic biota of the Banks. Bivalves in this area are no longer suitable for human consumption due to fecal coliform contamination. This situation is unlikely to change in the future because coliforms are continually discharged to the Banks and the criterion is very strict (Chapter 8, section 8.6).

Data on oysters, collected near the Iona outfall, show that accumulation of copper and iron had occurred. Values for Iona oysters can be compared to values for oysters off the Oregon coast, a relatively uncontaminated area. Average levels of copper were 400 to 480 ppm dry weight off Iona, compared to 94 ppm dry weight off Oregon. Equivalent values for iron were 800 - 1 600 ppm compared to 422 ppm. Although zinc was relatively high in oysters off Iona (2 400 - 3 300 ppm dry weight), the metal appears to accumulate naturally (2 600 ppm dry weight off Oregon). Data on mercury in oysters near Iona are few, but indicate low contamination levels (0.22 ppm dry weight).

Information on clams indicates that copper, zinc and mercury were bio-centrated, especially by clams near the Iona outfall. In the zone of impact of the effluent, within one kilometre of the outfall, mercury concentrations were as high as 6.8 ppm dry weight. This is equivalent to 0.6 ppm wet weight, which is above the Federal guideline of 0.5 ppm wet weight for food. Further from the outfall, in the zone of recovery, the concentration of mercury in clams averaged 0.7 to 0.8 ppm dry weight. Elsewhere on Sturgeon and Roberts Banks, the mercury concentration ranged from 0.2 to 0.05 ppm dry weight. These data indicate that the Iona effluent has contaminated clams with mercury near the outfall, but there is evidence that mercury contamination is also originating from other additional sources.

The concentrations of copper, lead and zinc in clams from the Banks did not show regional variations, except for copper which was higher in clams from the Iona sewage channel. All concentrations of these metals were within the legislated levels for food. The range of values, on a dry weight basis, were as follows (legislated values in brackets): copper 14 - 136 ppm (500 ppm), lead 3.2 - 7.6 ppm (50 ppm), and zinc 95 - 422 ppm (500 ppm).

The survey of clams, in 1976, showed there was a complete absence of the species Macoma balthica close to the Iona outfall. The survey in 1977 indicated that the area of exclusion had widened. This is believed due to the effect of metal contaminated sediments on settling larvae. The data and observations on clams confirm the negative impact of the Iona effluent in the area of Sturgeon Bank, as described in section 9.2.

9.4 Accumulation of Organic Contaminants in Sediments and Aquatic Biota

Information on toxic organic substances, which have contaminated the Fraser River, is presented in a detailed report[12]. Sections of the report dealing with accumulation of organic contaminants in sediments, invertebrates and fish are summarized here. The information on this subject is sparse, hence trends are difficult to establish. However, there is evidence of contamination, mainly from polychlorinated biphenyls, chlorinated pesticides, hexachlorobenzene and chlorinated phenolics.

Polychlorinated biphenyls (PCB's) are very persistent in the environment, and they tend to accumulate in sediments and aquatic life. These compounds have been used in transformers, paints, printer's ink, carbonless copy paper, synthetic rubber and brake linings. Further use has now been discontinued in Canada, although PCB's are still in existing electrical equipment. The acute toxicity to fish, measured in bioassay tests, is generally in the range of 1 to 50 mg/L for the $96hLC_{50}$. Although this toxicity is not extremely high, compared to the toxicity of certain other substances, the problem lies in the ability of PCB's to accumulate without degrading. For certain estuarine invertebrates bioassays showed toxic effects at concentrations as low as 1 μg/L.

Chlorinated pesticides cover a wide range of products such as DDT, dieldrin, lindane, heptachlor and chlordane. Most were banned from use in the early 1970's because, like PCB's, they breakdown slowly and accumulate to toxic levels in the environment. The $96hLC_{50}$ for these compounds is generally about 0.02 mg/L, with a range of 0.001 to 0.2 mg/L. They are therefore quite toxic, although they are generally not a problem in the water column due to their low water solubility. They are soluble in fats and therefore tend to accumulate in body tissues.

Hexachlorobenzene (HCB) is one of the more persistent types of chlorinated benzenes released to the environment. Its use in agriculture was discontinued in 1971. It is currently used as an intermediate in wood preservatives and certain rubbers.

Chlorinated phenols are used in wood preservatives and certain pesticides. Pentachlorophenol is one of the most common of these compounds. It is fairly toxic ($96hLC_{50}$ in the range 0.2 to 0.3 mg/L to certain fish species), but it is degraded more easily and is thus less persistent than PCB's and DDT type compounds.

In general the toxic organic substances are less of a problem in the water column than in the sediments. They tend to accumulate in sediments and aquatic life, either on a long term basis, such as with PCB's and DDT, or on a more short term basis, such as with chlorinated phenols. This type of exposure will increase stress on certain organisms and detrimentally influence reproduction and survival. Sublethal effects of this type have been documented in laboratories but are very difficult to observe in the environment. The following discussion on toxic substances in sediments, invertebrates and fish is aimed at documenting the accumulation of these substances and their possible sublethal effect. Data on this subject are so incomplete, that only a general indication of the problem can be obtained.

9.4.1 Sediments

Sediments accumulate chlorinated organic compounds, because these compounds tend to bind to particulate matter. There is a continual, although very small exchange of these compounds between the sediments and the water column. Fish and invertebrates probably accumulate contaminants directly from the sediments, or from food affected by the sediments. Certain contaminants in the sediments are more quickly degraded by microorganisms, than in the water, because microbes are more numerous in the sediments. However, the degradation products can sometimes also be toxic and stable.

The presence of polychlorinated biphenyls (PCB's) was detected in sediments at certain locations only. In the Brunette River - Still Creek drainage, which is largely influenced by storm water, measurements carried out in February and June 1974, ranged from nondetectable to 780 parts per billion (ppb) dry weight. In this survey the average from 22 samples was 240 ppb dry weight. At these levels, sediments are not considered highly contaminated, but the data indicate low level contamination from a diffuse source, such as storm water.

Elsewhere in the river the concentration of PCB's in the sediments was low, except at a few locations. For example, in 1976 and 1977 in the Main Arm, values up to 30 ppb were recorded off the Richmond landfill, and up to 230 ppb off M.B. Ltd. Island Paper Mills Division. The highest values were measured in the North Arm, in 1976 and 1979, around the outfall of Belkin Paperboard Ltd. Levels up to 1 500 ppb were obtained, which were due to contamination from waste sludge. Action is required at the plant to reduce contamination from this source (Chapter 5, section 5.2.3).

Chlorinated pesticides, such as DDT, were at much lower levels in sediments than PCB's. In the Brunette River - Still Creek drainage they were often undetectable, or around 10 to 20 ppb dry weight. The maximum value in this location was 135 ppb dry weight. Elsewhere these compounds were not detected, except in the degraded area of Sturgeon Bank, around the Iona outfall (section 9.2). The soil and drainage ditch sediments at Later Chemicals in Richmond were severly contaminated (1 000 to 5 000 ppm), due to spills and poor housekeeping. This plant is now closed and the area is being cleaned up.

A survey of chlorinated phenols in sediments, carried out in 1979, showed that pentachlorophenol was the common contaminant in this category. It was found in river sediments, close to wood preserving plants, at levels between 10 and 35 ppb dry weight.

9.4.2 Invertebrates

The data on organic contaminants in invertebrates are very limited. They are restricted to organisms that live mostly on the Banks, in the marine environment.

The concentration of polychlorinated biphenyls (PCB's) was highest in Dungeness crabs around the Iona outfall. The concentration averaged from 780 to 1 050 ppb wet weight, with a maximum of 2 100 ppb wet weight. Although the concentration did not vary according to distance from the outfall, contamination was believed to be due largely to the Iona effluent. Crabs near sewage outfalls in coastal California have shown levels up to 4 900 ppb wet weight. Thus, although contamination was not extremely heavy, and was generally within Health and Welfare Canada guidelines of 2 000 ppb wet weight, there is an indication that PCB's are accumulating to unacceptable levels in crabs on Sturgeon Bank. The concentration of PCB's in clams off Iona was relatively low (less than 0.5 ppb). However, fecal coliform contamination rules out the use of clams for human consumption in this area.

The concentrations of DDT, and of most of its breakdown products, were low (less than 5 ppb) in crabs, mussels and oysters off the Iona outfall, However, DDE, one of the common and stable breakdown products, was present more frequently, at concentrations up to 300 ppb wet weight. These results are another indication of the degradation that has occurred around the Iona outfall (section 9.2).

9.4.3 Fish

Measurements have been carried out on 265 fish collected at various locations in 1972 and 1973. Although there are more data for fish than for invertebrates, the information is limited and is not recent.

The concentration of polychlorinated biphenyls (PCB's) in fish ranged between 100 and 900 ppb wet weight, for most species. Only one value exceeded the Health and

Welfare Canada guideline of 2 000 ppb wet weight. This was from a large scale sucker caught in the Chilliwack area (3 695 ppb wet weight). The second highest value was from a northern squawfish taken in the Main Arm (1 894 ppb wet weight). In general there was a tendency for the higher values to occur in coarse fish near industrialized areas. Although PCB's have not reached critical levels in fish, the values indicate that action is required to restrict discharges to the river. The most effective area for control is probably industrial and storm water discharges, effluents connected to municipal sewers, and restrictions in the use of PCB's.

The levels of chlorinated pesticides in fish were generally considered low. Most values for DDT and its breakdown products were at the nondetectable level, or below 200 ppb wet weight. An exception was DDE, which averaged 400 ppb in some coarse fish, with a maximum of 1 740 ppb wet weight. All values for these compounds were well within the Health and Welfare Canada guideline of 5 000 ppb wet weight. They were also well below concentrations measured in fish in polluted areas, such as in the Great Lakes (1 000 - 14 000 ppb) and off Southern California (1 000 ppb). Concentrations of lindane, chlordane and aldrin in fish were often nondetectabe or low (less than 11 ppb wet weight).

Hexachlorobenzene contamination was widespread, being present in most species. However, the concentration was low, averaging less than 10 ppb, with a maximum not exceeding 19 ppb wet weight.

Chlorophenols were not detected as frequently as hexachlorobenzene. Higher values were found in fish caught near industrial areas. When present, pentachlorophenol averaged 10 to 40 ppb with a maximum of 125 ppb wet weight. Trichlorophenol was detected with less frequency. When present it averaged 10 to 20 ppb, with a maximum of 62 ppb wet weight. Although these values are below levels of concern, they indicate that better control of storm runoff and effluents discharged by certain industries, such as the wood preserving industry, are necessary.

10. DISCUSSION OF POSSIBLE CONTROL MEASURES AND THEIR EFFECT ON WATER QUALITY

Data in previous chapters indicate that municipal effluents and storm water are the largest source of contaminants to the river. Landfills and most direct industrial discharges are generally less important. In this chapter, we describe certain measures that could reduce the loadings in the main discharges. These measures include secondary treatment of municipal effluent, control of storm water discharges, and control of sources that discharge directly to sewer.

The discussion can be used in drawing up a plan to manage water quality over the next 20 years. The nature or timing of specific control actions will require a more detailed analysis of processes, engineering feasibility and costs. Such an analysis is outside the scope of this study.

10.1 Secondary Treatment of Municipal Effluents

The three main sewage treatment plants (Iona, Annacis and Lulu) now have primary treatment. One method of improving effluent quality would be to install secondary treatment. In this section we discuss the effect of installing conventional biological treatment using the activated sludge process. This process is the one most widely used for secondary treatment, it employs proven technology, and is capable of reducing acute toxicity. We therefore chose this process to illustrate the potential effect of further effluent treatment on the Fraser River. There are variations of this process and other processes with different effectiveness, reliability and cost. These will have to be evaluated if a decision to upgrade effluent treatment is made.

10.1.1 Effectiveness of Biological Treatment

The amounts of contaminants removed from sewage by biological treatment vary over a wide range. In Table 18 we have listed the percent removal of certain contaminants for primary and secondary treatment. Data from several sources were used. We have also shown the average quantities removed by primary treatment in the three main sewage treatment plants. These quantities are at the bottom of the range obtained from the literature. Using these data, we have made a rough estimate of the percent removal that may be achieved by primary plus secondary treatment at the three main sewage treatment plants.

Table 18 indicates that 25 to 30 percent of most toxic compounds is removed by primary treatment. This removal is doubled to 45 percent or higher with secondary treatment. Exceptions appear to be nickel, arsenic and pesticides, for which removal by secondary treatment is in the range of 10 to 30 percent. The removal of heavy metals is due to pH control and adsorption of metals on the biological floc. This means that metals will tend to concentrate in the sludge that is removed from the process. The removal of compounds such as ammonia, cyanide, phenols and MBAS (methylene blue active substances or surface active agents) is through biochemical oxidation. For pesticides and polychlorinated biphenyls removal is probably mainly through adsorption on suspended solids. Some accumulation of toxic organic compounds in the sludge can therefore be expected.

In general, the loadings from municipal effluents discharging to the river range from one half to double the loadings from storm water (Section 4.2.3). For some toxicants, the contribution to the river from direct industrial discharges is important, and recommendations to correct this problem are made in Section 5.2. The impact of secondary treatment on the river can be calculated approximately. Assuming that the loadings from primary treated municipal effluent are double those from storm water, that storm water is untreated, and that secondary treatment of municipal effluent improves the removal rate from 25 percent to 50 percent, the total loading to the river will decrease by about 22 percent. Such a decrease will be difficult to measure in the river without a very intensive monitoring program. This is due to the low concentrations of toxic compounds in the water column and the variability of those concentrations (Chapter 8).

An important effect of secondary treatment is a decrease in the acute toxicity of the effluent. The $96hLC_{50}$ of secondary effluent is generally greater than 100 percent[5]. This means that mortality of fish ranges from nil to 50 percent in secondary effluent, over 96 hours. The reduction in toxicity is mainly due to removal of ammonia and MBAS, and to a lesser extent of heavy metals and toxic organic compounds. The toxicity of ammonia is not significant in the river, because the river pH and temperature prevent the formation of unsafe quantities of un-ionized ammonia (Section 3.6.7). A discussion of effluent toxicity (Section 3.7.4) indicates that acute toxicity is not a problem at this time outside the dilution zone. However, if effluent toxicity increased in conjunction with increasing effluent flow, conditions unsafe to fish could be reached. Secondary treatment could be used to safeguard the river for fish, if unsafe conditions are predicted by monitoring results.

Our analysis so far indicates that secondary treatment will reduce the discharge of toxic compounds and reduce acute toxicity. The effect of these reductions may be difficult to measure in the environment. However, secondary treatment will provide an extra margin of safety, which is always desirable given the uncertainty surrounding the effects of toxic compounds. This gain must be balanced against the cost of treatment, the need to control storm water discharges, and the effect of controlling sources that discharge directly to sewer.

Secondary treatment will also improve the microbial quality of the effluent. The data in Table 4 show that chlorination of primary treated effluent can reduce the geometric mean total coliform count in the effluent to 1 000 MPN/100 mL or less. A large part of the coliforms in the effluent is associated with the suspended solids. Since secondary treatment improves the removal of suspended solids, the chlorination of secondary effluent reduces coliform levels even further. Values of 200 MPN/100 mL are readily attainable. Values of 20 MPN/100 mL or less are possible if longer chlorine contact times, of about three hours, are used[22]. Secondary treatment can therefore be expected to bring about a marked improvement in microbial water quality. This improvement is unlikely to be enough to enable important other water uses, such as shellfish harvesting in the study area, although it may protect shellfish growing waters outside the study area.

For molluscan shellfish harvesting, the fecal coliform count in the water must not exceed 14 MPN/100 mL. If this criterion is to be met consistently in the estuary, all sources of coliforms must be controlled year-round (Chapter 8). These sources include storm water, industrial effluents and discharges to the Fraser River upstream from the study area, as well as the municipal effluents. Even if such controls were possible, the occasional upsets which occur in any treatment process, however well controlled, would tend to rule out the harvesting of shellfish immediately downstream from sewage and storm water discharges of this magnitude.

10.1.2 Disposal of Sludge From Secondary Treatment

Secondary treatment will approximately double the volume of sludge generated by primary treatment alone. This estimate was based on a primary sludge thickened to 4 percent solids[23]. At the present rate of primary sludge production, there is about 20 to 25 years of storage left at Iona and about 7 years left at Annacis (Sections 3.3 and 3.4). Secondary treatment at these plants would halve the time left for storage, assuming such treatment started immediately. Thus, any plan to install secondary treatment must include methods of disposing of the sludge, other than storage at the plant site.

Alternate methods of sludge disposal fall into three main categories: landfilling, incineration or application to agricultural land. These methods are described in detail elsewhere[23]. Landfilling is the most common method, but the sludge must first be dewatered. This is done by centrifuging, vacuum filtration or pressure filtration. Incineration also requires dewatering first. In a large installation, some of the heat of combustion may be recoverable, thus decreasing the cost of operation. Incineration can emit the vapour of some of the more volatile metals that accumulate in sludges. These include mercury, zinc, lead and cadmium. Special smoke abatement equipment is required to prevent the release of these metals in particulate form. Sludge can be applied to agricultural land in either a liquid state, or in a dry state, after sterilization to kill pathogens. One of the main factors governing this use is the uptake by plants of heavy metals present in the sludge. The heavy metal uptake depends on many variables, including metal type and concentration, soil characteristics, soil moisture and temperature and plant type. The long-term hazards of land application of sludge have not yet been identified.

The benefits and costs of the various sludge disposal methods will need to be studied in conjunction with any plan considering secondary treatment. There are other less conventional ways of using sludge, such as composting, wet air oxidation and pyrolysis. These methods are either limited in application or are not well established.

10.1.3 Approximate Cost of Secondary Treatment

For a rough estimate, we assumed that the cost of constructing a secondary treatment plant was 80 percent of the cost of the existing primary plant(7). The costs of the main primary plants were updated to 1979 values using the Engineering News Record cost index. The results are as follows:

a) Iona

Primary Cost:	1963 = $ 6.6 Million	1979 Update = $22.3 Million
	1973 = $ 3.6 "	" " = $ 5.8 "
	1978 = $ 4.0 "	" " = $ 4.4 "
Total Primary Cost:	$14.2 Million	1979 Update = $32.5 Million
Total Secondary Cost:	0.8 x 32.5	= $26.0 Million

b) Annacis

Primary Cost:	1975 = $14.9 Million	1979 Update = $20.5 Million
Secondary Cost:	0.8 x 20.5	=$16.4 Million

c) Lulu

Primary Cost:	1973 = $4.6 Million	1979 Update = $7.4 Million
Secondary Cost:	0.8 x 7.4	= $5.9 Million

This estimate gives a rough idea of the cost of upgrading the municipal effluents. The total cost for the three main plants would be approximately $48 million at 1979 prices. The acquisition of land, if required, and of facilities for sludge disposal would be extra.

The total operating cost for the three primary plants is projected to be about $2.9 million for 1979. For a very rough estimate, we have assumed that secondary treatment alone would cost about the same as primary. Thus, the additional operating cost of secondary treatment, at the three plants, would be about $2.9 million per year, at 1979 values.

10.2 Management of Storm Water

Contaminant loadings to the Fraser River from storm water are estimated to be in the range of one half to double those from municipal effluent, depending on the contaminant (Section 4.2.3). The importance of controlling pollutants from this source has only been realized recently. Thus, data on control methods, their cost and effectiveness are still preliminary. Established methods of dealing with storm water are not highly developed. Storm water may be collected either in the same sewer with municipal effluent, or in a separate sewer. Reduction of contaminants can be achieved either by source control or by storage and treatment. These alternatives and some approximate treatment costs are discussed in this section.

10.2.1 Combined and Separate Sewer Systems

In the early part of this century, the approach on sewer construction was to combine storm water and municipal effluent in the same sewer. This approach worked well as long as sewage was discharged untreated. It explains the existence of a combined system in the older developed areas. When storm water surges occur, the combined sewage overflows directly at various points to the receiving water, to avoid overloading the sewer system.

With the construction and planning of sewage treatment plants, recently developed areas build separate collection systems. This prevents surges of storm water from reducing the settling time of sewage solids in primary treatment. The surges can also upset secondary treatment by washing out the activated sludge. The advantages of separate systems are that each waste stream can be treated separately, the municipal effluent is not diluted before treatment, upsets at the sewage treatment plant are avoided, and the incidence of combined sewer overflows is reduced.

However, the cost of sewer installation is higher for the separate system than for the combined system. The cost of separating existing combined sewers is even higher. Thus, the combined system has the advantage of lower costs and a degree of treatment of storm water, as long as the combined flow does not exceed the design capacity of the treatment plant. To prevent contamination of receiving water during high flows, treatment of sewage overflows may be necessary.

This discussion shows that both combined and separate sewer systems have advantages and drawbacks. We have made no study of sewer costs and we have only rough estimates of the flow of storm water and of combined sewer overflows. There is therefore not enough information, at this time, to resolve the question of which collection system is better for the study area.

10.2.2 Source Control

The load of contaminants discharged by storm water can be controlled by reducing the amounts entering the sewer. The volume of storm water can be reduced through the use of seepage pits or tile fields, or the possible use of porous pavements now being developed. Flows can be controlled and combined sewer overflows reduced by roof storage or other impoundments. These measures require further study since their effectiveness is unknown.

The quantity of sediment and other contaminants entering storm sewers can be reduced in various ways. These include limiting dustfall, controlling erosion at construction sites and street sweeping. Dustfall is monitored throughout the region by the Greater Vancouver Regional District, in order to control air pollution. The production of sediments at construction sites can be controlled by municipalities. Street sweeping will decrease storm water contamination if carried out properly[15]. Broom type sweepers do not remove fine particles, below 400 micrometres in size, which contain a large part of the contaminant load. On the other hand, vacuum equipment can remove up to 95 percent of accumulated fine sediment.

10.2.3 Storage and Treatment

A practical way of treating storm water is by storage in a series of in-line ponds. These systems are not common and there are few data available on removal rates or operating problems. Preliminary results indicate that ponds, with a retention time of at least 24 hours, can remove about 70 percent of the suspended solids, 30 percent of the BOD_5, 50 percent of the coliforms and 60 percent of the nutrients. Removal of sediments should result in removal of other contaminants in the same way that primary treatment removes these substances (Section 10.1.1). Flocculents can be added to improve the sedimentation rate. Chlorination of the discharge can be used to reduce coliform levels, but without dechlorination this could result in the discharge of more toxic effluent.

By making certain simplifying assumptions, including the availability of land, a rough cost estimate was prepared for a system to treat storm water in the study area[15]. Storm water draining to the river from land in the Iona sewerage area could be handled by the existing combined sewers and treatment plant. We assumed that 40 percent of the suspended solids is removed by the present system. Storm water from the Annacis sewerage area, draining to the river, could be treated in ponds. A system to remove 50 percent of the suspended solids is estimated to cost about $26 million. A similar system for the Lulu sewerage area will cost about $8.5 million. Thus, the total cost of installing storm water treatment, to a level approximating primary treatment, is about $34.5 million. A major part of the operating cost would be the removal and disposal of sludge.

The effect of this treatment on river water quality can be estimated in only the most general terms. Assuming that the loadings from untreated storm water are one half those from primary treated municipal effluents, and that storm water treatment removes 50 percent of contaminants, the total loading to the river will decrease by about 17 percent. If in addition to storm water treatment the municipal effluents underwent secondary treatment, the total loadings to the river would decrease by nearly 40 percent. These conclusions are tentative because the data for storm water contributions are very uncertain. Whether source control of storm water, discussed in Section 10.2.2, would be effective compared to storage and treatment is not known.

10.3 Control of Sources Discharging to Sewer

In Section 10.1, we discussed secondary treatment as a method of improving the quality of municipal effluent. Another method is to reduce the load of contaminants discharged to the sewer. In practice, this means the control of industries connected to sewer. The volume of industrial effluent varies from 9 to 20 percent of municipal effluent, depending on the sewerage area. In Chapter 6, we described the diversity of industry in the study area. It contributes contaminants ranging from heavy metals to organic compounds. In this section, we discuss the need for source control, methods that can be used, and the effects that can be expected.

10.3.1 Source of Toxicants in Municipal Sewage

Toxic compounds in municipal sewage can come from industrial effluents, from domestic effluent discharged mainly from residential areas, from the water itself or from the water distribution system. To compare the contribution of each of these sources, we prepared a rough estimate of the heavy metals contributed to the Annacis plant (Table 19).

The loadings from metal industries to the sewer were estimated from the survey prepared by the Greater Vancouver Regional District[6]. The data are very approximate, but indicate that these industries contribute at least 20 to 30 percent of the heavy metals entering the Annacis plant.

The loadings from a typical residential area were obtained from analyses of influent to the White Rock sewage treatment plant[24]. This plant received no industrial effluent (White Rock sewage was diverted from Boundary Bay to the Annacis plant in April 1977). These data indicate that domestic sewage from residential areas contributes from 10 to 50 percent of heavy metals entering Annacis.

The quantity of heavy metals in the water supply was estimated from an average analysis of water sampled from the three main watersheds (Seymour, Capilano and Coquitlam)[25]. The results show that water entering the distribution system contributes about 1 to 10 percent of the heavy metals going to Annacis. The water is acidic (average pH = 6.2) and can therefore be expected to dissolve metals such as copper, iron, lead and zinc from the distribution system. For example, copper at the consumer's tap has been found to be as high as 1 mg/L for hot water, and around 0.1 mg/L for cold water[25]. The corrosion effect is, in part, responsible for some of the heavy metals in domestic sewage.

This rough analysis suggests that up to half of the heavy metals in municipal effluent may come from domestic sources, and the remainder probably comes from industrial sources. To extend this conclusion to other toxic materials would be rather speculative because of lack of data. Bioassays carried out on municipal effluent entering the White Rock plant showed no acute toxicity[24]. Similar data for industrial effluents discharged to sewer showed moderate to high toxicity (Chapters 5 and 6). On this basis, we can expect industry's contribution of toxic compounds to municipal effluent to be important.

10.3.2 Benefits of Source Control

A reduction of toxic contaminants discharged by industry to sewers, including heavy metals and organics such as cyanide and phenols etc., would have several benefits. The most important would be a reduction of contaminants in primary treated effluent, now discharged by the three main treatment plants. The amount of this reduction is difficult to predict with certainty. Assuming complete elimination of industrial toxicants, our analysis on heavy metals (Section 10.3.1) suggests that the load in municipal effluents would be halved. This effect would be approximately equivalent to that of secondary treatment (Section 10.1.1). Although such a result is not possible in practice, we can expect the effect of source control to perhaps approach that of secondary treatment for toxic contaminants.

Source control will also reduce shock loads, or surges in the concentration of contaminants to the treatment plants. The presence of these surges is shown, to some extent, by the range in daily average concentrations in the plant effluent (Table 3). The sudden introduction of high contaminant concentrations to the sewer may cause short term toxicity problems in the river. The need for this type of control will become even more important should biological secondary treatment be installed at the treatment plants. Shock loads can upset these plants by poisoning bacteria in the activated sludge. These problems are recognized in the U.S., where pretreatment standards are being set up, on a national basis, to protect the environment and publicly owned treatment works[21].

10.3.3 Technical Considerations and Methods of Source Control

The U.S. Environmental Protection Agency recognizes 129 known priority pollutants[21], which might be present in municipal effluent. Compounds on this list have been identified, or are suspected to be carcinogenic, mutagenic, teratogenic or toxic to aquatic life. Thirteen heavy metals are included in the list. These metals are present in municipal effluent in mainly an insoluble form, and at higher concentrations than organic compounds. Some of the organic compounds on the list were found in the treatment plant effluents at very low concentrations[9]. The extent to which source control will reduce the discharge of toxic contaminants is difficult to ascertain. The discussion in the previous two sections suggests that up to half of the heavy metals, and certain other toxicants, may be removed from municipal effluent by a source control program.

In order to establish such a program on a uniform basis, guidelines are required on limits of contaminants that can be discharged to sewer. A comparison of guidelines is drawn up in Table 20. These include the limits now imposed by the Greater Vancouver Regional District, some median values for limits from a survey of sewer ordinances in the U.S., and standards proposed for the metal plating industry by the U.S. Environmental Protection Agency. We have also included the range of provincial objectives which apply to certain effluents discharged directly to fresh water. These are naturally more restrictive than limits for discharges to municipal sewers.

Using the data in Table 20 we have suggested limits for a number of contaminants discharged to municipal sewers. The suggested limits are about 20 to 40 times less restrictive than provincial objectives. These factors are proposed assuming there is a dilution of industrial contaminants with general municipal sewage of 20 to 1. They are also in keeping with limits proposed elsewhere. The result of this exercise shows that most of the limits required by the Greater Vancouver Regional District are in keeping with provincial objectives and other sewer ordinances. Some limits, such as for cadmium, chromium, lead and nickel, should probably be set somewhat lower. We have suggested limits for a number of contaminants not dealt with by the Regional District, although the suggested list is by no means complete.

Several means of achieving the suggested limits for discharges to sewer are available. The methods can be divided into in-plant controls and effluent pretreatment. In-plant controls have been used successfully in several industries, and often result in savings to the industry, as well as in a reduction in pollution. One of the most important measures is reduction of water use. This can be done by avoiding leaks at hoses and valves, controlling cooling systems, preventing accidental overflows and controlling washing procedures. Recycling waste streams within a plant can also reduce water use and can lead to higher product recovery. Other in-plant measures include the recovery of by-products, which might otherwise be wasted, the substitution of toxic materials with non-toxic materials in the process, the blending of waste streams, the equalization of waste flows over time and the segregation of waste and uncontaminated streams.

Effluent pretreatment often produces toxic sludges (Chapter 6), which must be disposed of. Some methods of sludge disposal are discussed in Section 10.1.2, for secondary treatment. Sludges from the pretreatment of industrial effluents contain higher concentrations of toxic materials, so that the disposal problem is more difficult. Certain sludges can be recycled, for example fats can be sent to a rendering plant or metal hydroxides to a smelter. Incineration is possible in some cases, although the vaporization of metals and the production of toxic gases from organics may require extensive emission controls.

The disposal of industrial sludges in landfills is probably the most common method used in the study area. This procedure can cause problems if it is not carried out properly. Organic waste in landfills is oxidized by bacteria to organic acids. The acids are then decomposed by methane-forming bacteria. The result is that the organic acids dissolve heavy metals in the sludge to form a toxic leachate. This leachate can wash out PCB's and other organic toxicants in the landfill. The solution is to use a segregated landfill for industrial sludges, excluding organic wastes[21]. In this type of landfill, the sludge is placed in layers, about 1 m thick, covered with about 6 cm of limestone to prevent lowering of pH, and then covered with up to 1 m of earth. The landfill must be above the groundwater table. Leachate is monitored, and treated if necessary. Sulphides must be excluded to prevent the formation of sulphuric acid, which might leach toxic materials.

The discussion demonstrates the need to set up proper sludge disposal facilities as part of a source control program. There is also a need to dispose of certain liquid wastes, generated by industry, which cannot be sewered or treated. These include waste oils and solvents, acid wastes such as pickling liquor, and a variety of organic wastes. Since the rise in oil prices, the recycling of used crank case oil has become established in the region. This material is therefore not believed to present a problem for the future[6]. Other wastes are trucked to disposal facilities in the U.S., but this procedure does not constitute a long term solution. The remaining wastes are probably disposed of at landfill sites, in a manner which is likely to create toxic leachates. Since techniques exist for dealing with most of these wastes, a system to treat them on an area-wide basis will be required.

10.3.4 Administrative Considerations

Under existing legislation, each municipality may control the discharges into its sewers. The control is exercised by regulations incorporated into the municipal plumbing bylaws (Chapter 6). The Greater Vancouver Regional District is responsible to the Province, through pollution control permits, for the discharge of treated municipal effluent to the river and estuary. However, the Regional District has no direct control over inputs into the sewer, although it is accountable for the final effluent discharged to the environment.

The degree of control exercised by municipalities varies over the region. The City of Vancouver is the only municipality in the study area that operates a laboratory, and carries out a regular schedule of sampling and inspection. Their program has been quite successful, but may have resulted in certain industries relocating to areas where regulations and enforcement are less stringent. Although industries locating in new premises can usually be controlled with existing bylaws, regulations that would apply uniformly to the whole district are needed for proper control of wastes, now discharging via the sewer system to the Fraser River. These regulations would include the following elements.

a) Effluent Guidelines

Limits are required on toxic compounds, and other materials discharged to the sewer. The list suggested in Table 20 could be used as a starting point. If large volumes are being discharged from a particular source, more stringent limits may be needed, in order to reduce the total load to the treatment plants. For very small volumes, less strict limits may be practical. Limits on the total volume of effluent that can be discharged should be negotiated with the discharger.

b) Monitoring

A monitoring program should be set up for all major discharges to the sewer. The type of sample, frequency of sampling and parameters to be measured would be decided on an individual basis. Measurement of effluent flow rate should be a part of all programs.

Monitoring may be carried out either by the industry or by the regulating agency, or by both. In any case, readily accessible sampling points should be provided.

c) Inspection

The inspection of industrial plants and pollution control works is normally tied in with the monitoring program. Inspections ensure that pollution control equipment is being properly maintained and operated, and that accidental spills will not happen. These inspections should be part of an effective enforcement program.

d) Data Analysis

Staff with a knowledge of engineering and chemistry should assess monitoring data and programs. The overall contaminant loadings to the regional treatment plants should be calculated. This continuing assessment will enable recommendations for corrective action or changes in programs to be made.

Monitoring and assessment has been estimated to require from 0.5 to 2 staff members per 40 000 m^3/d of municipal effluent(21). This is equivalent to between 7 and 30 people for the study area.

e) Disposal of Sludges and Liquid Wastes

A system to deal with toxic sludges and liquid wastes should be an integral part of source control regulations. A landfill for the safe disposal of toxic sludges must be set up. The landfill would be tied into facilities which may be required to treat and dispose of liquid wastes, including very toxic substances such as polychlorinated biphenyls.

Legislation incorporating the above concepts must be established. The administration of the legislation would probably best be carried out by the Regional District. However, the authority to administer the legislation could be delegated to municipalities in cases where the facility and staff are already in place. Some advantages of municipal involvement are their good knowledge of the sewerage system and local industries, the need to work closely with other municipal departments (plumbing, electrical, fire, etc.) and their ability to respond quickly in an emergency (such as gasoline or fuel oil spills). Regardless of the level at which the regulations are enforced, they should be uniform for the study area, and should allow corrective action to be taken for the benefit of the whole region.

10.4 Disposal of Leachate From Landfills

The composition and estimated flow rate of leachate from the five major landfills in the study area are described in Chapter 7. The total volume of leachate discharged daily to the river from the sites averages about 14 500 m^3/d (Table 25). Current plans for leachate disposal are to direct leachates from Burns Bog (50 percent of total) and Port Mann (6 percent of total) to the Annacis Island treatment plant, and to pretreat leachate from Richmond (34 percent of total) before direct discharge to the Main Arm. Leachate from Braid Street (8 percent of total) is currently pumped, via the sewer, to the Annacis treatment plant.

Although the total volume of leachate is relatively small (less than 10 percent of the Annacis plant discharge) certain contaminants are present at concentrations higher than those usually found in municipal sewage. The main contaminants are: ammonia nitrogen (30 to 90 mg/L average), iron (5 to 43 mg/L average), manganese (0.5 to 5 mg/L average) and chemical oxygen demand (250 to 840 mg/L average). Static bioassays show that landfill leachates are somewhat more acutely toxic to fish than primary treated municipal effluent. This result is probably due to the much higher concentration of ammonia in the leachates. Certain toxic organic contaminants are assumed to be present in the leachates, although the concentration and character of these contaminants have not been documented.

The characteristics of the leachates are such that direct discharge to the river could cause localized degradation of water quality. Leachate can therefore either be treated before discharge to the river, or discharged to the sewer, with or without pretreatment. The current Provincial Municipal Objectives[4] do not contain specific objectives for leachates discharged to receiving water, although there are general objectives for receiving water. As a first estimate it is reasonable to expect that the leachate should meet at least level BB, and possibly level AA, applicable to municipal effluent[4]. Although these objectives do not specify ammonia concentrations, their criteria for effluent toxicity will effectively regulate ammonia content of the leachate.

In order for leachate to meet municipal objectives, it will need to undergo a form of secondary treatment. Secondary treatment using the activated sludge process may be appropriate (Table 18). However, tests on actual leachates and engineering studies would be required in choosing a process, because little is known about treatment of landfill leachates. Such tests are now being carried out on leachate from the Richmond landfill.

If landfill leachate from the study area is discharged to the sewer, as planned, the main impact will be at the Annacis treatment plant, from leachate discharged by the Burns Bog landfill. The main contaminant in the leachate is ammonia (90 mg/L, average ammonia nitrogen). Assuming the ammonia nitrogen content of Annacis effluent is 12 mg/L (Table 3), the effect of adding Burns bog leachate would be to raise this concentration in the effluent to about 15.3 mg/L.

Data presented in the water quality report[27] indicate that safe conditions for fish will exist (0.02 mg/L or less un-ionized ammonia nitrogen) at an ammonia nitrogen concentration in the river of up to 0.2 mg/L, under average river pH and temperature conditions. Since the minimum dilution of Annacis effluent, around the outfall, is about 100 to 1 (Section 3.4), the ammonia nitrogen concentration in the river will usually not exceed 0.2 mg/L, and will create no hazard to fish. At high slack tide, effluent dilutions as low as 3 to 1 may occur right above the outfall, resulting in an ammonia nitrogen concentration in the river of about 5 mg/L. Since this condition would occur for only short periods (up to 12 hours), and in a very localized area (immediately over the diffuser), it is unlikely to be hazardous to fish.

Landfill leachates discharged to the sewer will be subject to existing controls (Section 6.4). Most of the contaminants in leachates are at levels which will meet existing and suggested limits (Table 20) for discharges to sewers. For example, Burns Bog leachate contains iron (6.2 mg/L average) and manganese (0.46 mg/L average) within the limits. The COD of this leachate (250 mg/L average) is within the generally accepted range for BOD_5 discharged to sewer (400 to 600 mg/L). No limits exist for ammonia nitrogen. Although this parameter is unlikely to be a problem in the immediate future, control is needed to prevent a rapid increase of concentration in the primary effluent. A limit for dicharges to sewer, in the order of 20 to 30 mg/L, should keep concentrations of ammonia nitrogen in line with those encountered in municipal sewage. Such a limit would mean that most landfill leachates would require some pretreatment, probably involving aeration, before discharge to sewer.

If landfill leachate is added to the sewer, then certain toxic organic compounds, which are assumed to be present in leachate at low concentrations, will also be added. Some of these compounds may precipitate or be adsorbed onto suspended matter during primary treatment, and thereby be removed with the primary sludge. Certain compounds may be chemically altered by chlorination-dechlorination, which is carried out during the summer. This process may render the compounds more toxic. The extent to which any of these processes occur and their effect on final effluent toxicity are difficult to assess. More information on the types of compounds present and their behaviour during primary treatment is required.

The question of whether landfill leachates should be treated then discharged to the river, or pretreated and discharged to the sewer is likely to be answered by engineering and economic feasibility. In either case, we can impose adequate limits to control known contaminants, such as ammonia and heavy metals. The problem of eliminating trace organic contaminants, and preventing the formation of more toxic compounds through disinfection, must be solved whether the leachates are treated separately, or sewered and treated with municipal effluent.

11. CONCLUSIONS AND RECOMMENDATIONS

11.1 Main Conclusions

Sources of contaminants in the Lower Fraser River can be grouped into four categories. These are: municipal effluents, storm water, direct industrial discharges and landfill leachates. The total volume of all discharges is, on average, nearly two million cubic metres per day. About 50 percent of this total is estimated to be storm water, 30 percent is municipal effluents, 18 percent is direct industrial discharges, and less than 2 percent is landfill leachates.

Descriptions of these discharges, and of their effect on water quality and aquatic biota, are summarized in this report. The effect of the discharges on the environment of the lower Fraser river is not always clear. Our knowledge is variable and incomplete, and it is often difficult to relate contaminant sources with environmental effects. For example, far more information has been collected on municipal effluents and water chemistry, than on industrial effluents and aquatic biota, while our knowledge of storm water is based mostly on calculations. From an analysis of all the information we can draw the following main conclusions.

11.1.1 General Water Quality of the River

Most water quality parameters in the river are not measurably changed by the major discharges. However, measurable changes may occur in dilution zones, and there is concern over the additive effect of these zones.

Dissolved oxygen is at or near saturation in all reaches of the river. At the bottom of certain sloughs and backwaters the dissolved oxygen drops to a point where aquatic life could be endangered in localized areas. These problems are probably caused by poor flushing action, aggravated by log storage, runoff and leachates from landfilled material.

The suspended solids load and turbidity are higher than in most other rivers in the Province. This is a natural condition and the contribution of discharges in the study area to the suspended solids load is minor. The organic nature of suspended solids in sewage causes localized toxicity problems in deposition areas, such as Iona. Nutrients are present in a wide range of concentrations, but at times reach those of highly productive areas. The high turbidity can seasonally limit algal growth in the river. The effect of nutrient discharges in the study area on the productivity of the Strait of Georgia is uncertain.

The overall concentration of ammonia in the river is well below levels toxic to aquatic life. This situation is unlikely to change in the near future, except in the dilution zone of the Annacis discharge, under certain critical river flow conditions. The concentrations of heavy metals in the river are generally below acute toxicity criteria. The levels of copper and zinc exceed some criteria. Since a large proportion of these metals is associated with the suspended solids, the metals are not believed to contribute significantly to acute toxicity.

During the summer, when the municipal effluents are chlorinated, the fecal coliform levels are high enough to close bathing beaches on the river, but usually low enough to allow use of river water for irrigation. In the summer the fecal coliform counts are within Provincial standards at bathing beaches in the outer estuary. Levels are higher in the University area than in the Tsawwassen area.

The fecal coliform level is too high to allow harvesting of molluscan shellfish in any part of the study area. The criterion for shellfish is so strict, and the sources of coliform contamination so diffuse, that this situation is unlikely to change in the future. There is some evidence that the Fraser River may affect molluscan shellfish growing waters in the Gulf Islands. In the winter, when there is no chlorination of municipal effluents, the fecal coliform levels in the river increase markedly.

11.1.2 Acute Toxicity of the Annacis Effluent

The Annacis treatment plant handles about 30 percent of all municipal effluents discharged in the study area. Excluding the Iona effluent, which is discharged to Sturgeon Bank, the Annacis effluent constitutes over 90 percent of municipal effluents discharged to the river.

Values for the acute toxicity of the effluent to fish vary according to the method used. However, even in an extreme case, the overall toxicity outside the mixing zone is not an immediate problem in the river because of the large dilution that takes place. Under certain tidal conditions the dilution near the diffuser can be within the acutely toxic range. The situation can change in the future, as the effluent flow increases. When Annacis reaches its maximum capacity (projected for the year 2020), lower safe limits may be approached in the river, at minimum river flow and at present effluent toxicity levels. This prediction does not include the possible toxic effects of storm water and other discharges.

The toxicity of the Annacis effluent is believed due to a variety of compounds such as ammonia, surface active agents, sulphides, cyanide and phenols. Heavy metals, and a range of organic contaminants, are also believed to contribute to acute toxicity. Some of these compounds come from domestic sewage and some from industrial effluents.

Industry accounts for about 20 percent of the effluent flow entering the Annacis plant. The food industry is the largest contributor in this category and its effluent is not generally cumulatively toxic. However, heavy metals and organic contaminants are discharged to sewers by the wood products and metal products industries, and to a lesser extent by the petroleum and miscellaneous industries. More industries are connecting to the municipal sewer, instead of discharging to surface waters. This trend could increase the toxicity of the municipal effluent in the future.

11.1.3 Storm Water and Landfill Leachates

There are nearly 200 storm water outfalls and ditches in the study area, most of which discharge to the river. On average, the concentration of contaminants is lower in storm water than in municipal effluents. However, higher concentrations can occur for short periods in the first flush of a storm. The load of contaminants from storm water is variable, but appears to be in the range of one half to twice the load from Annacis, depending on the parameter. The effect may be diffuse since it is spread over many outfalls.

Storm water is a potential source of heavy metals and organic contaminants, which are entrained in sediments from streets and other surfaces. It may also be an important source of fecal coliforms.

Landfill leachates are a source of ammonia, toxicity and organic contaminants. Although loadings to the river are small compared to those from municipal effluents and storm water, the effect of diverting the leachates to the Annacis plant is not clear. The level of certain organic contaminants in the leachates may be lowered by primary treatment. However, increases in ammonia concentration and the formation, at certain times, of chlorinated organic compounds may render the Annacis effluent more toxic.

Leachates from woodwaste dumps have degraded certain small tributaries and backwaters.

11.1.4 Sublethal and Cumulative Effects on Aquatic Biota

The sublethal effects of contaminants from municipal effluents and storm water are very difficult to measure directly in the river. Heavy metals, especially mercury, copper and zinc, accumulate in sediments and invertebrates in the river. The level of accumulation is above natural background levels but well below polluted conditions. All values for fish are within accepted food criteria, except for mercury in certain resident fish.

Organic contaminants, such as polychlorinated biphenyls, pesticides and pentachlorophenol, also accumulate in sediments and biota to some degree. Levels are still quite low, except adjacent to known sources discharging directly to the river.

11.1.5 Effect of the Iona Effluent on Sturgeon Bank

The Iona treatment plant handles about 65 percent of all municipal effluents discharged in the study area. It discharges primary treated effluent to Sturgeon Bank.

The effluent causes degradation and eutrophication in an area extending about 3 km from the outfall across the Bank. The effects of eutrophication extend to certain birds and mammals in the food web. Effects on water quality and aquatic biota are fairly well documented.

The effluent causes a lowering of dissolved oxygen, sometimes below critical levels, and a localized increase in nutrient concentrations. These effects, plus the discharge of particulate matter, either eliminate or limit aquatic life in the degraded area. There is an accumulation of copper and zinc in clams near the outfall to fairly high levels. Mercury is accumulated to high levels in clams and crabs from the outfall area. There is also evidence that organic contaminants, such as polychlorinated biphenyls, accumulate in crabs among other species.

There is an indication that the zone of degradation is increasing, probably as a result of increases in effluent volumes discharged. Although the degraded area is small compared to the total area of the Bank, contaminated mobile organisms will spread over a wider area.

11.1.6 Industrial Effluents Discharged Directly to the River

There are over 100 outfalls discharging industrial effluents to the river. Nearly half of these outfalls are located on the North Arm, where about half of the effluent volume is discharged.

Over 70 percent of the effluent volume comes from the forest industry. The impact of these discharges is either localized or negligible. Certain metal products industries are discharging high loads of heavy metals and there are a few point sources of toxic organic contaminants.

The situation on direct industrial discharges is variable, as industries close, expand or connect to municipal sewers.

11.1.7 Control Measures and Their Effect on Water Quality

Municipal effluents and storm water are the largest source of contaminants to the river. Landfills and most direct industrial discharges are of less importance. Although a detailed discussion of control measures is beyond the scope of this report, a general discussion of established techniques is given to put recommendations on control measures in perspective.

Conventional biological treatment, using the activated sludge process, is a proven way of reducing the acute toxicity of municipal effluents. Secondary treatment at Annacis and Lulu will reduce the total loading of most contaminants to the river by about 20 to 25 percent, and fecal coliform levels in the effluents by 90 percent. Treatment of storm water, using in-line settling ponds, could improve the overall contaminant removal to about 40 percent of the total load.

The acute toxicity of secondary effluent is nearly nil and is about 25 percent of primary effluent toxicity . The microbial quality of secondary effluent is improved over primary. However, secondary treatment will double the amount of sludge now generated by primary treatment. The total cost of installing secondary treatment at the three main plants would be about $48 million, at 1979 prices. The acquisition of land and of sludge disposal facilities would be extra. The annual cost of operating the three main primary plants was about $2.9 million in 1979. The additional cost of operating secondary treatment would be about $2.9 million per year, at 1979 values. The total cost of installing storm water settling ponds in the study area is tentatively estimated to be about $35 million.

Source control, which is the control of effluents discharged to sewer, is not carried out over much of the region. A complete source control program will limit the amount of contaminants entering the primary treatment plants. The effect would be roughly equivalent to the removal of heavy metals and certain other substances by secondary treatment. If secondary treatment is installed, source control is needed to reduce surges in the concentration of contaminants entering the treatment plant, and to thereby protect the operation of the plant.

Source control for industry can be achieved by limiting water use and recycling waste streams. It can also be done by pretreatment of effluents before their discharge to sewer. Toxic sludges arising from pretreatment of effluents will require safe disposal. A source control program cannot proceed without special facilities for disposal of toxic sludges and toxic liquid wastes generated by industry. These sludges and wastes cannot be sewered or disposed of in existing sanitary landfills.

11.2 Summary of Recommendations

The following recommendations are based upon the information and analyses presented in preceding chapters. The recommendations represent the technical views of the members of the water quality work group. They do not reflect necessarily the policy of government agencies to which work group members belong. The recommendations are designed to protect water quality and to provide direction to those planning the future of the estuary.

The recommendations we propose are of two types: action on control measures, and monitoring programs to establish the best control measures needed in the near future. The recommendations are presented briefly here, together with some estimated implementation dates. A flowchart summarizing the recommendations is shown in Figure 7.

11.2.1 Recommended Control Measures

This section describes actions that can be started immediately to control discharges in the study area.

a) Source Control

A source control program is required to reduce the toxicity of municipal effluents. Such a program will limit the amounts of toxic contaminants discharged by industry to municipal sewers, and eliminate illegal connections to storm sewers. We recommend that such a program be implemented immediately over the Greater Vancouver Regional District (GVRD).

The need for new legislation and administration of existing legislation must be investigated to give the GVRD the power to institute source control on a uniform basis in the region. We recommend that high priority be given to such an investigation. The administration of suitable legislation could be delegated to municipalities.

Source control could be in effect by the early 1980's. It must be in place before secondary treatment of municipal effluent, in order to protect the operation of secondary treatment plants.

b) Disposal of Sludge and Hazardous Wastes

We recommend that a facility to dispose of toxic sludges, solvents and toxic liquid wastes be set up in the region. Such a facility will be needed to deal with sludges generated from the pretreatment of industrial discharges to municipal sewer. It is therefore an integral part of the source control program.

Many wastes could be disposed of in a secure landfill, which should be located as close to the industrial sector as technically and socially feasible. A basic facility should be operational by the early 1980's, when source control takes effect. There should be storage space for those contaminants requiring more elaborate disposal methods. The development of such methods, which may include treatment, recovery and incineration, will require more time.

c) More Advanced Treatment at the Iona Plant

If a decision is made to rehabilitate the degraded area of Sturgeon Bank, and to prevent further degradation, more advanced treatment must be installed at Iona. This could be in the form of conventional secondary treatment, such as the activated sludge process, physical-chemical treatment or a long sea outfall.

A decision on whether to proceed with secondary treatment must weigh the cost of the project against the benefits of rehabilitation. The costs involve at least $26 million in capital expenditure, and an additional $1.5 million per year in operating costs. The benefits include restoration of water quality and aquatic biota to their natural state in the degraded area, a reduction in fecal coliform contamination on the Banks and adjacent areas, and a reduction in the spread of contaminated aquatic organisms.

An economic and engineering feasibility study would be required first. This would be followed by a pilot plant study, if this is deemed necessary. A decision on the best type of treatment could be reached in the early 1980's, and installation of the works could be completed by the mid 1980's.

d) Control of Industrial Effluents Discharging Directly to the River

In Chapter 5 we name two plants where action is required to improve effluent quality discharged to the river. These include one metal processing plant and one forest industry plant. The metal processing plant should be upgraded to meet level A of the Provincial Objectives. The forest industry plant needs to reduce effluent toxicity and to improve effluent clarification, to prevent the discharge of sludge containing polychlorinated biphenyls.

In general, industrial discharges to the river should be monitored more regularly. Samples of industrial effluents should be checked for those toxic contaminants most likely to be present. The discharge of high pH effluents (above 8.5) should not be allowed.

e) Investigation of Accidental and Unregulated Discharges

Accidental spills and unregulated discharges have affected habitat and caused fish kills, especially in tributary streams and backwaters. The location of illegal dumps that affect water quality is not always immediately known. We recommend immediate investigation and documentation of these problems, so that regulatory agencies can take corrective action.

11.2.2 Recommended Monitoring Programs

More information is required to make decisions on certain important issues, such as storm water control, further treatment at the Annacis plant and treatment of landfill leachates. Specific programs to collect the information are summarized in this section.

Analysis of program results should lead to decisions, by the mid 1980's, on the type of control required next. Possible outcomes could be a form of storm water control and more advanced treatment at Annacis by the late 1980's to early 1990's. The timing of such future control measures will depend not only on program results, but also on the effect of source control and other measures, to be phased in by the early 1980's.

More details on the specific programs summarized here are given in the relevant background reports[7, 10, 15, 27, 28, 31].

a) Storm Water Monitoring

A one year program is proposed to characterize storm water, and to estimate more accurately its contribution to contaminant loadings to the river. At least three catchment areas would be selected, which are typical of industrial, commercial and residential districts in the area.

Sampling equipment would be set up in an attempt to sample all storms in each catchment area. In practice, we can anticipate that 50 to 60 percent of the storms would be sampled. Sequential grab samples would be taken. These would be analysed for typical parameters such as BOD_5, nutrients, fecal coliforms and heavy metals. The acute toxicity would be measured using fish bioassays. Flow data would also be collected. The data would be interpreted using modelling techniques. The presence of toxic organic contaminants in storm water would be assessed, using gas chromatography-mass spectroscopy on selected samples. The cost of the overall program would be fairly high (at least $100 000 over one year).

Along with this program, assessment of control measures would be needed. This includes preliminary economic and feasibility studies of street sweeping methods, and storage in ponds, on roofs and in sewers.

b) Receiving Water Monitoring

An ongoing surveillance program is proposed, for the Main Stem at Patullo Bridge. The program will establish the loadings of nutrients and certain heavy metals (copper, mercury and zinc) entering the study area, with more certainty than obtained so far. Grab samples would be taken at three equally spaced sites across the river. Samples would be taken weekly during freshet (April to August, inclusive), and monthly the rest of the year.

Field measurements of dissolved oxygen, conductivity, pH and temperature, should be carried out at various points in the river, including sloughs and backwaters. This work would be performed four times a year. Progress reports, interpreting data from the surveillance program and the field measurements, should be prepared at least once a year. Every five years a more extensive one year program, incorporating more sites, would be carried out.

Monitoring of fecal coliforms during the summer (May to September) should continue at bathing beaches. Sites at Tsawwassen could be reduced and those at the University beaches increased. Fecal coliforms should be measured upstream from the main discharges. These data, and those collected from storm water and municipal effluents, will be used to assess coliform inputs to the area. Less frequent monitoring could be carried out in the Main Arm and the North Arm, during the winter. This would establish microbial water quality in the river during the period when municipal effluents are not chlorinated. The data on fecal coliforms should be reviewed annually.

c) Municipal Effluent Monitoring

Data on the influents and effluents should continue to be collected. Flow proportioned composite samples would be analysed, at least once a month, for a wide array of parameters. These include BOD_5, suspended solids, nutrients, toxic compounds such as cyanide, sulphide and phenolics, and heavy metals. All effluents should be regularly monitored for fecal coliforms. The type of toxic organic contaminants present in the effluent would be identified by gas chromatography-mass spectroscopy. Gas chromatography could then be used, once a month, to measure the concentrations of four or five of the most important organic contaminants.

Continuous flow on-line bioassays should be performed, twice a year over a period of several weeks, to measure toxicity variations, since it appears to be a more sensitive bioassay procedure. If possible, tests should be done to measure the presence or absence of stress on fish exposed to varying concentrations of effluent.

d) Annacis Dilution Zone Monitoring

This program will delineate more clearly the effluent plume from the Annacis treatment plant. Results can then be used to estimate the effects of measures, such as source control and the addition of landfill leachates to the treatment plant, on water quality in the zone of influence. The results can also be used to predict the effect on water quality of other major discharges to the river. Dye or tracer studies should be carried out at various river flow conditions. Special attention should be given to worst case conditions, namely high slack tide and low river flow, when there is minimum dilution of effluent.

Algal bioassays should be carried out using river water to dilute effluent. This work will help to assess the effect of sewage on biota, at various levels of contamination in the receiving water.

e) Leachate Diversion Monitoring

The diversion of leachates from Burns Bog and Port Mann landfills to the Annacis plant can be used as case studies. The effect of these diversions should be evaluated through effluent monitoring (section c) and dilution zone monitoring (section d). Of particular interest is the possible formation of toxic compounds through chlorination of organic constituents of leachates.

We recommend that no further diversions of landfill leachates to sewage treatment plants be planned, until the results of this study are known.

f) Aquatic Biota Monitoring

The aquatic biota should be evaluated every five years, starting in the early 1980's. The purpose is to measure the accumulation of heavy metals and organic contaminants.

The program would include sampling of periphyton, invertebrates, sediments and fish. Sampling sites would be selected to provide continuity with sampling done in the past. The costs of sample collection and analysis are much higher than for water quality monitoring. Laboratories carrying out the work should therefore use the same techniques and a high degree of quality control. Analytical techniques that use the smallest sample mass, should be adopted.

g) Special Studies

The following studies, aimed at solving specific problems, are proposed.

- Determination of mercury sources in the study area: mercury has accumulated in sediments and aquatic biota, but specific sources are unknown.

- Identification of compounds responsible for effluent toxicity: this knowledge will help to control the toxicity of municipal effluents.

- Identification of water quality problems in sloughs and tributaries: areas important to salmon can be categorized, and action taken if deemed necessary.

- Evaluation of copper and zinc toxicities in the river: these metals exceed certain water quality criteria. Further work is required on their toxicity and on the form in which they occur.

- Measurements of metals in fish outside the study area: for comparison we need to know the metal content of fish upstream from Hope (Prince George, Lillooet and 100 Mile House areas).

- Evaluation of fecal coliform contamination outside the study area: fecal coliforms transported by the Fraser River may, at times, affect molluscan shellfish in the Gulf Islands and areas of Vancouver Island.

- Measurement of the impact of landfill leachates: more knowledge is needed on the localized impact of leachates on water quality.

- Assessment of laboratory techniques for heavy metal analysis.

- Measurement of primary productivity in the Strait of Georgia: phytoplankton studies will document trends in primary productivity. The effect of nutrients discharged in the study area can then be assessed more clearly.

- Investigation of pathogens in sediments and beach sands: sediments can concentrate pathogens and indicator organisms, and may thus be a health threat on beaches and in dredge material used as fill.

- Chronic toxicity studies of Annacis and other major effluents: these tests will help in the prediction of long term impact of toxicants in the river.

- Study of superchlorination of sewage used as injection water at the sewage treatment plants: the substitution of plain water for sewage, in the dilution of liquid chlorine at the plants, should reduce the formation of toxic chlorinated compounds.

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FIGURE 1

LOCATION OF THE MAIN MUNICIPAL TREATMENT PLANTS AND LANDFILL SITES

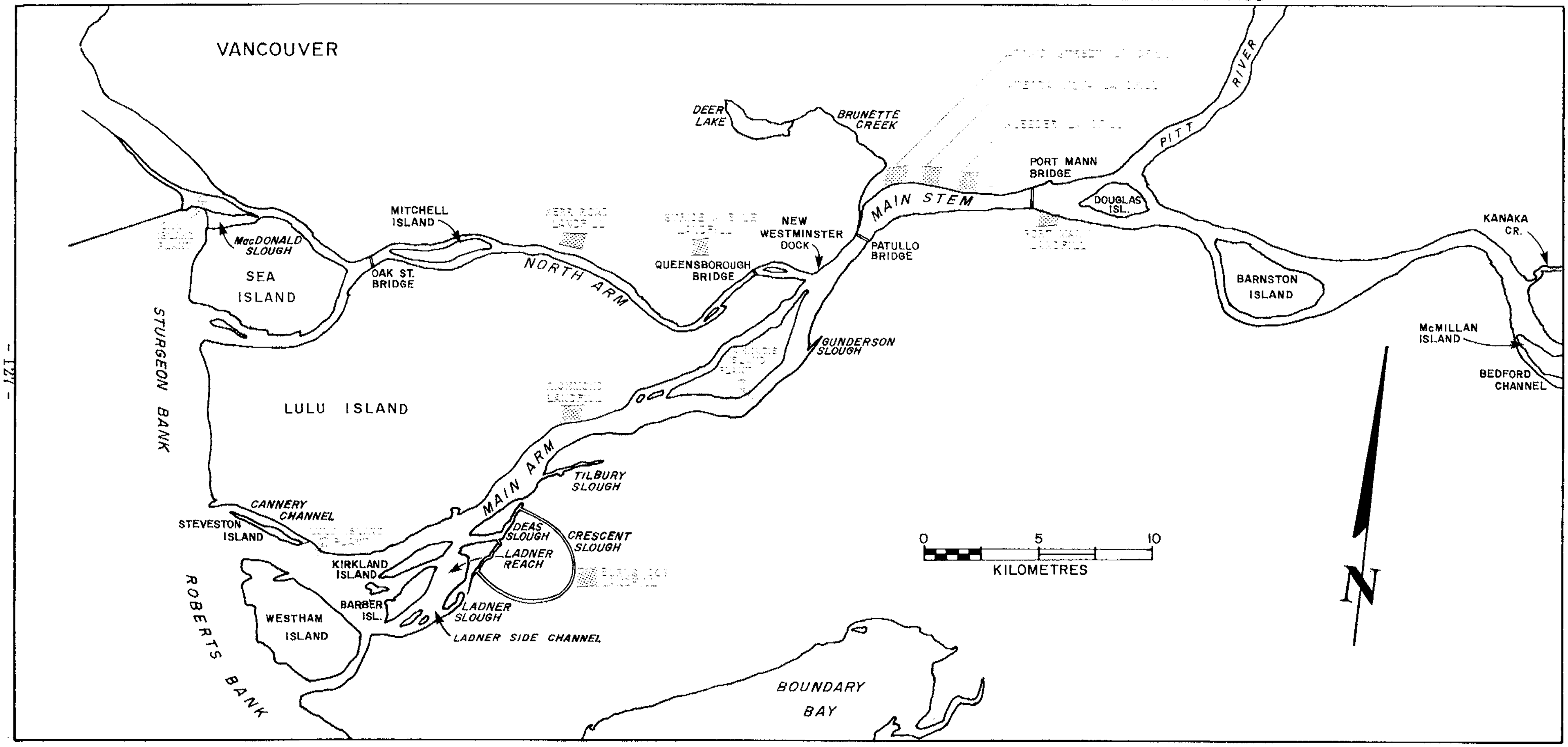


FIGURE 2

SEWERAGE AREAS OF THE MAIN TREATMENT PLANTS

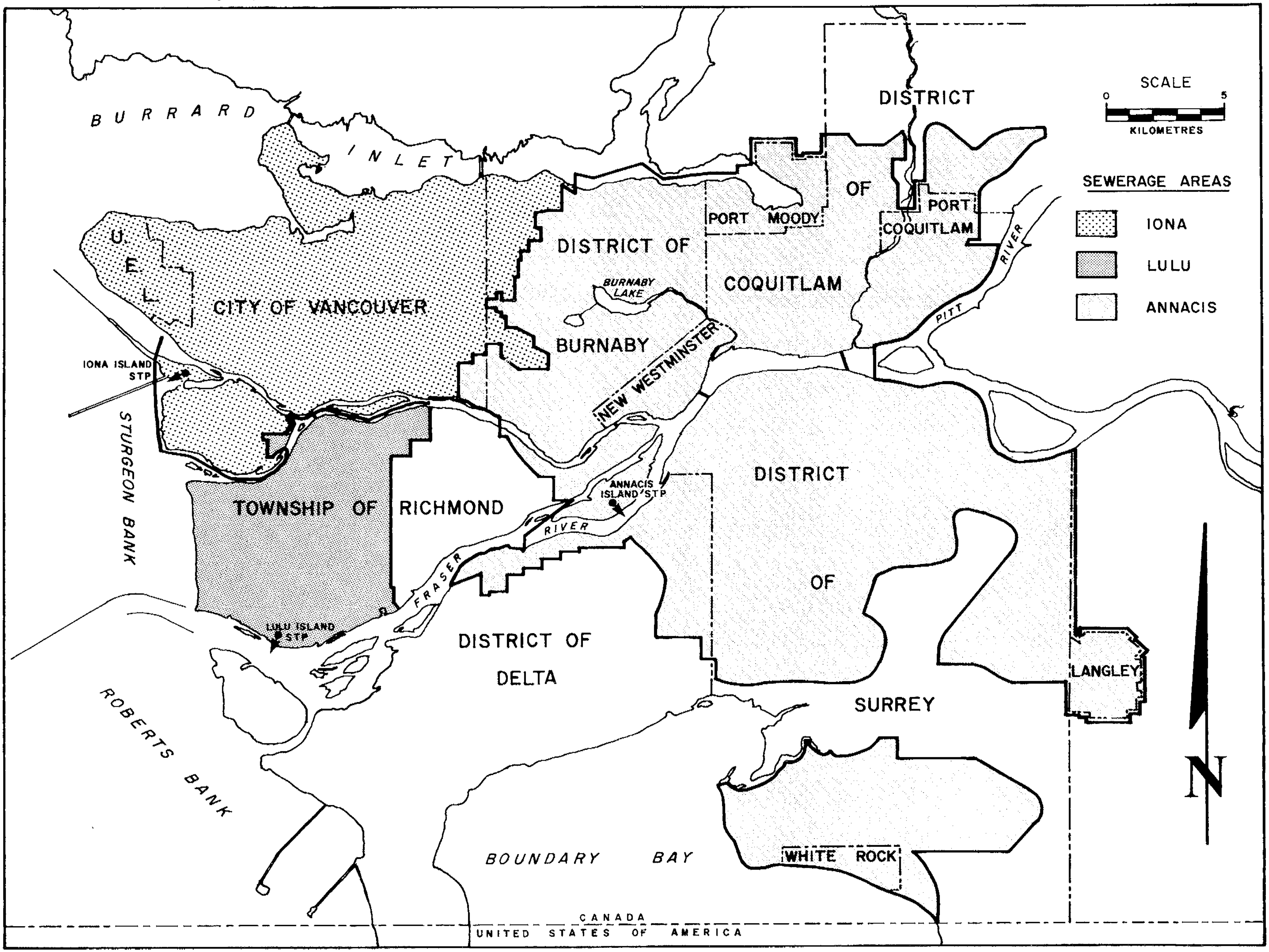


FIGURE 3

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

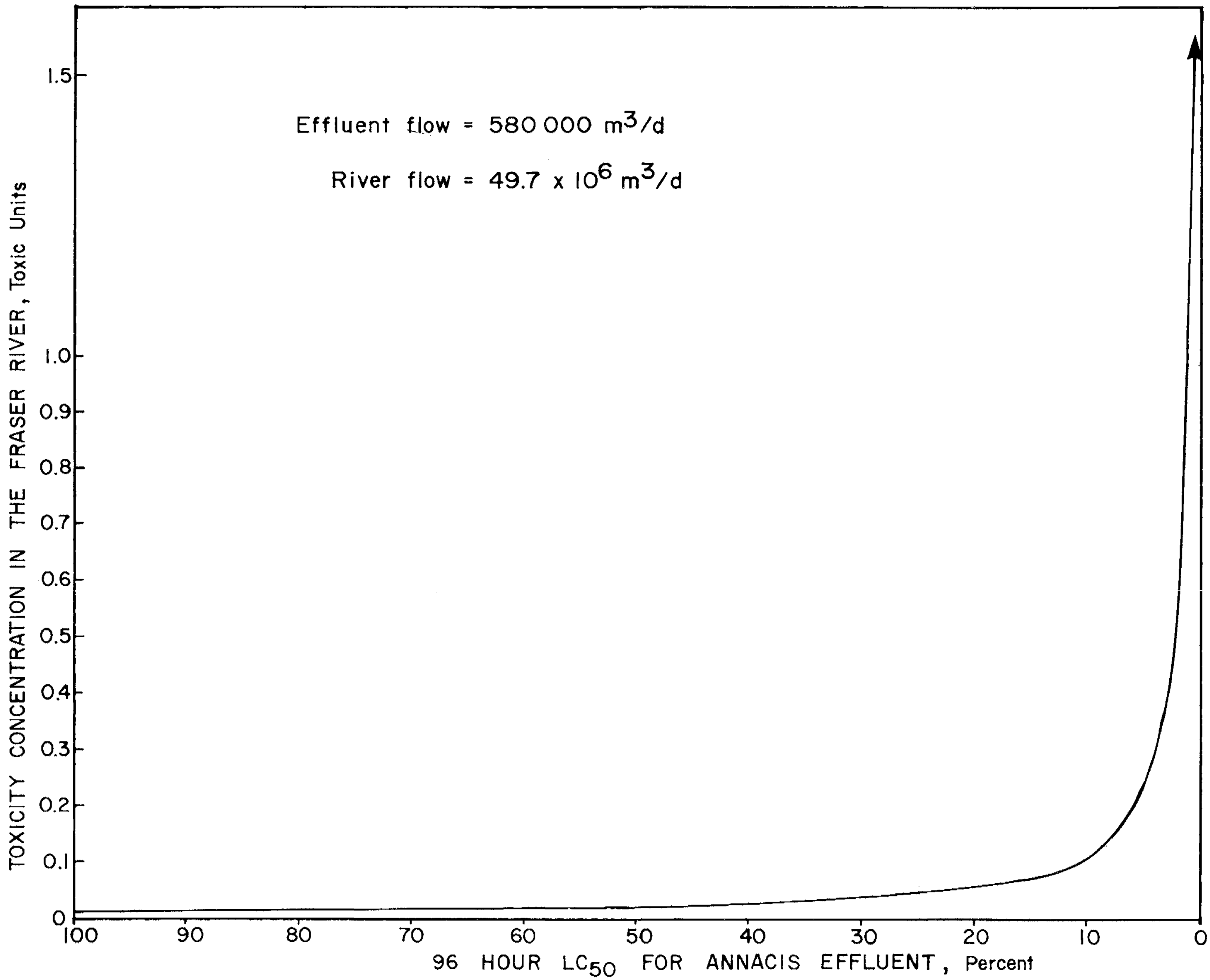


FIGURE 4

LOCATION OF STORM SEWER OUTFALLS

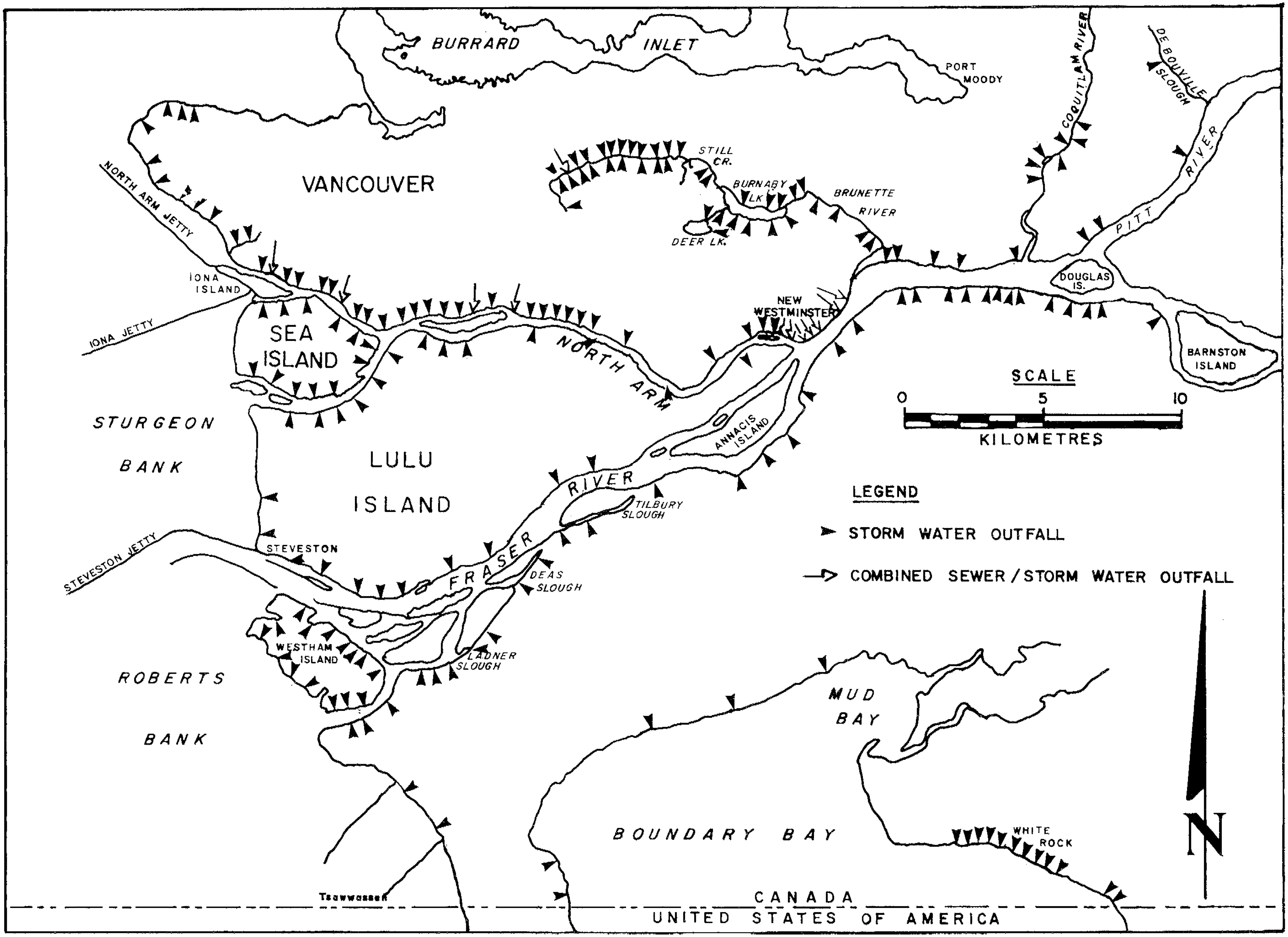


FIGURE 5

LOCATION OF THE MAIN INDUSTRIES DISCHARGING TO THE FRASER RIVER BETWEEN 1970 AND 1978

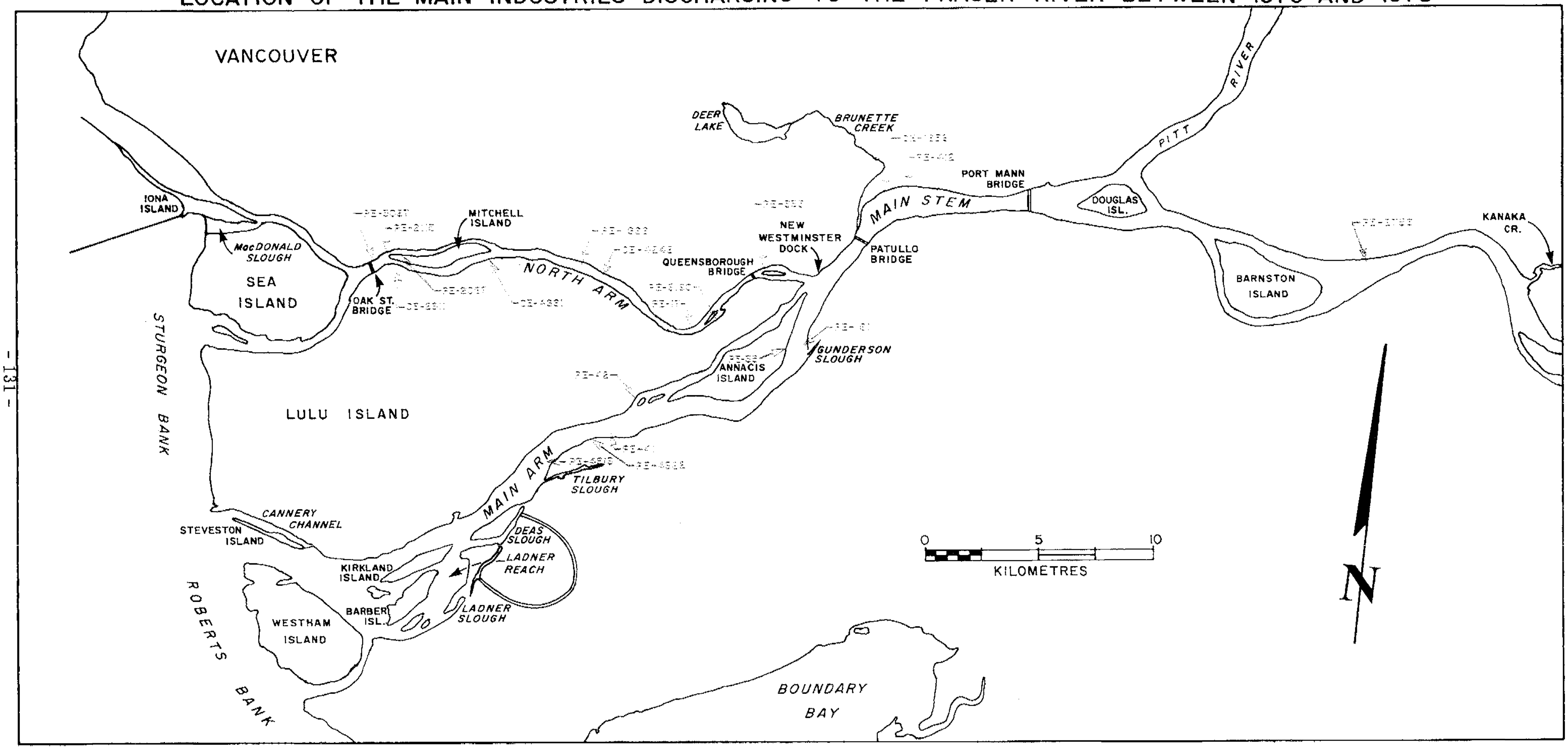


FIGURE 6

LOCATION OF REACHES INTO WHICH SAMPLING SITES ARE GROUPED

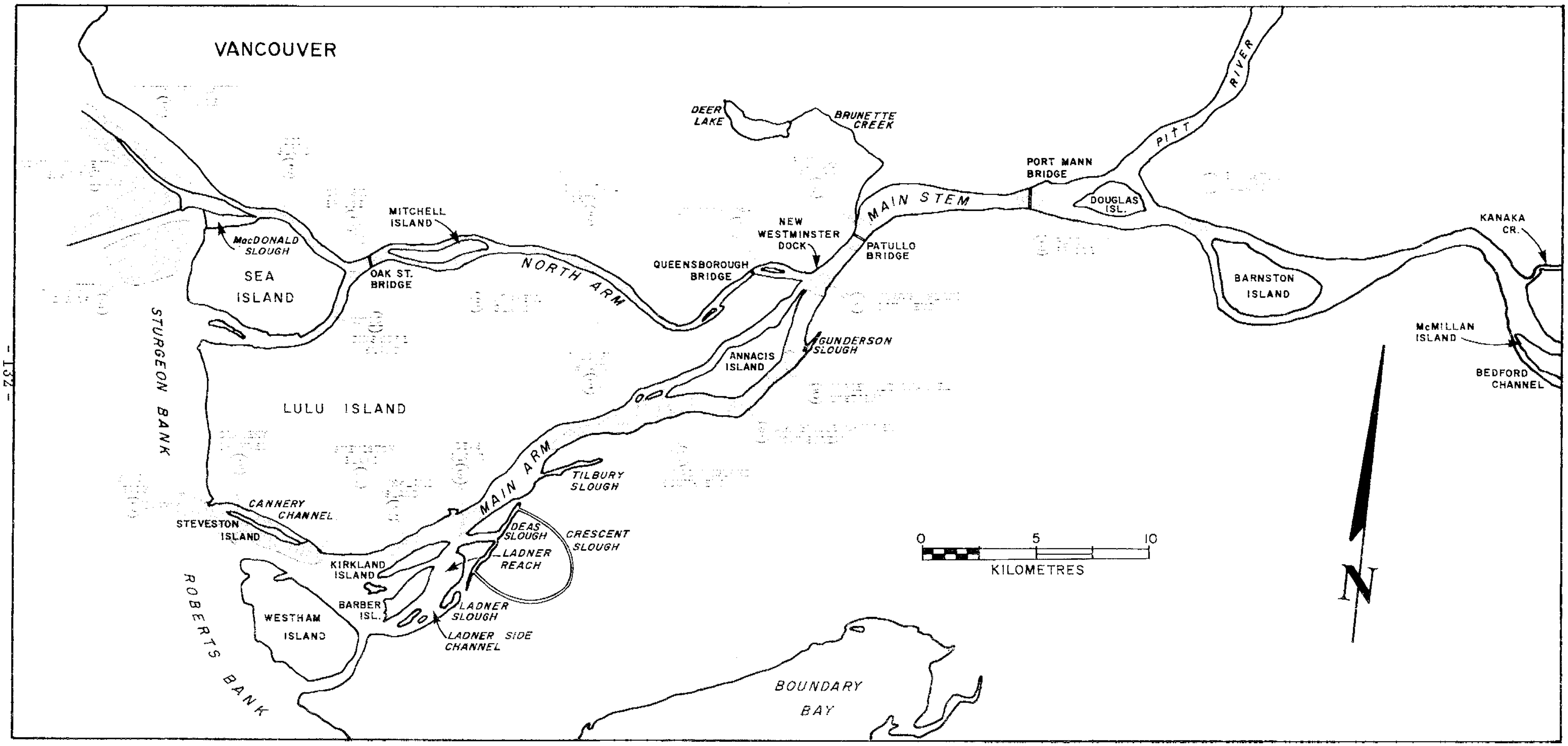
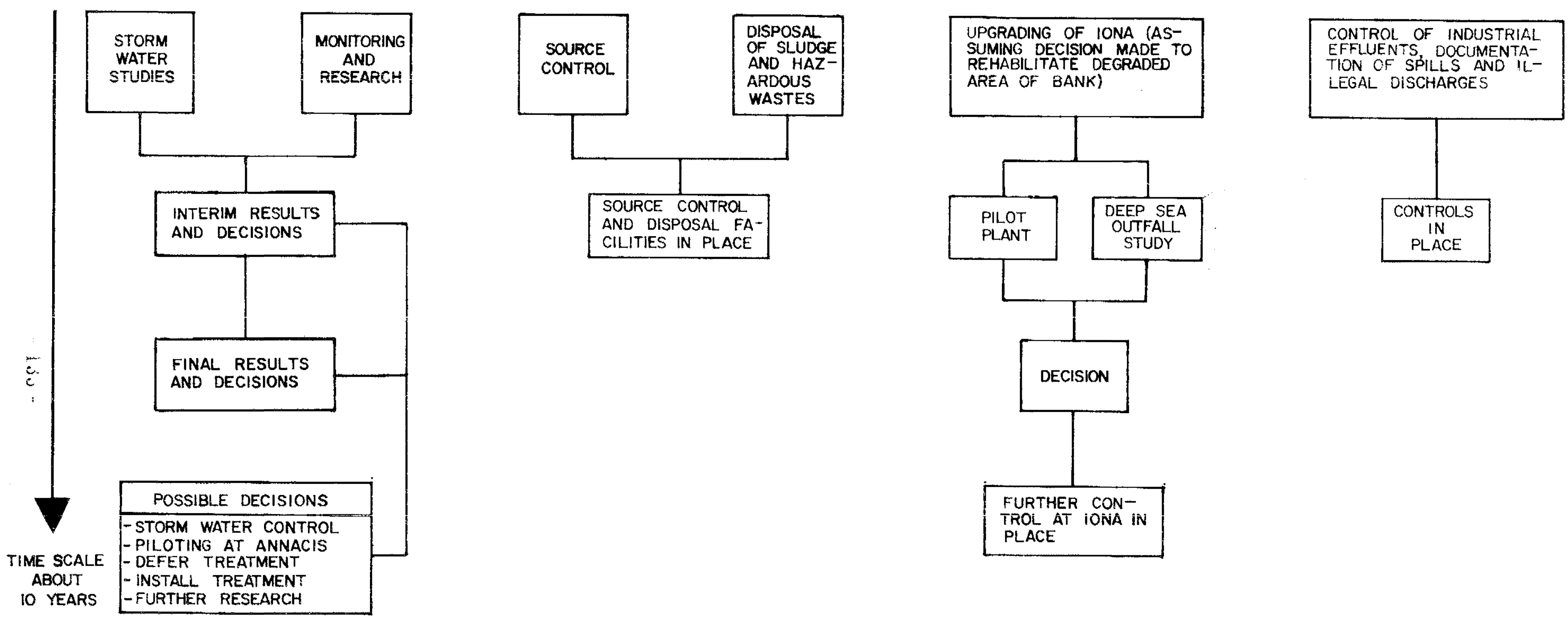


FIGURE 7

FLOW CHART SUMMARIZING THE WATER QUALITY RECOMMENDATIONS



<u>NOTE</u> MAJOR ERRORS IN INTERPRETATION WILL BE MADE IF THIS CHART IS CONSIDERED WITHOUT REFERENCE TO CHAPTER II.

TABLE 1

SUMMARY OF POLLUTION CONTROL PERMIT CONDITIONS FOR THE THREE MAIN SEWAGE TREATMENT PLANTS

Parameter	Plant	Annacis Island	Iona Island	Lulu Island
Aluminum, Total	mg/L	4.0		
Arsenic, Total	mg/L	0.25		
Barium, Dissolved	mg/L	1.0		
BOD_5	mg/L	130	100	169
Boron, Dissolved	mg/L	5.0		
Cadmium, Dissolved	mg/L	0.01		
Chromium, Total	mg/L	0.3		
Cobalt, Dissolved	mg/L	0.5		
Copper, Dissolved	mg/L	0.5		
Cyanide, Total	mg/L	0.5		
Flow	m^3/d	586 000	318 200	132 500
Iron, Dissolved	mg/L	1.0		
Lead, Dissolved	mg/L	0.1		
Manganese, Dissolved	mg/L	0.5		
Mercury, Total	mg/L	0.002		
Molybdenum, Total	mg/L	0.5		
Nickel, Dissolved	mg/L	0.5		
Oil and Grease	mg/L	30		
pH		6.5-8.5	6.7-7.3	
Phenol	mg/L	0.4		
Selenium, Total	mg/L	0.1		
Silver, Total	mg/L	1.0		
Sulphide, Dissolved	mg/L	1.0		
Suspended Solids	mg/L	100	70	128
Tin, Total	mg/L	10		
Toxicity, 96 h LC_{50}	%	75		
Zinc, Total	mg/L	5.0		

Note: Values for parameters other than BOD_5, flow, pH and suspended solids are not imposed limits, but are used for comparison in administering the permit.

TABLE 2

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

	Dye	Effluent			
		At Average Flow in 1977	At Average Flow in 1986	At Maximum Instantaneous Flow 1975-1976	At Average Flow in 2021
No. of Diffusers in Use Discharge Rate m^3/s	1 0.11	9 1.9	18 2.8	1 3.8	18 6.8
Dilution Near the Outfall For Release on Ebb Tide, Returning on Flood Tide	x 840	x 440	x 600	x 24	x 240
Dilution 140 m Upstream From the Outfall	x 530	x 280	x 380	x 15	x 160
Dilution Over the Outfall at High Slack Tide	x 5	x 3	x 4	Nil	x 1.5
Minimum Dilution at the Edge of the Initial Dilution Zone	x 300	x 160	x 212	x 9	x 90

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

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

TABLE 3

SUMMARY OF EFFLUENT CHARACTERISTICS FROM THE THREE MAIN SEWAGE TREATMENT PLANTS

Parameter \ Plant		Iona Mean	Iona Range	Iona No. of Values	Annacis Mean	Annacis Range	Annacis No. of Values	Lulu Mean	Lulu Range	Lulu No. of Values
BOD_5	mg/L									
	1972	77	18-144	136						
	1973	74	25-140	123				113	55-220	131
	1974	79	20-211	110				138	63-233	164
	1975	100	19-222	143	96	48-221	63	124	51-500	151
	1976	87	40-173	73	122	55-220	121	134	55-169	207
	1977	105	24-187	125	88	47-219	142	142	67-224	133
Cadmium, Total	mg/L									
	1972	< 0.01	<0.01-0.15	347						
	1973							<0.02	<0.01-0.12	328
	1974							<0.021	<0.01-0.04	66
	1975	< 0.013	<0.01-0.01	43				<0.01	<0.006-0.033	56
	1976	< 0.012	<0.01-0.01	55	< 0.002	< 0.0005-0.0022	53	<0.01	<0.01-0.01	51
	1977	< 0.007	<0.005-0.01	54	< 0.005		61	<0.01	<0.005-0.02	59
Chromium, Total	mg/L									
	1972	< 0.01	< 0.01-2.2							
	1973							<0.18	< 0.1-1.5	328
	1974							<0.19	<0.08-2.13	91
	1975	< 0.15	<0.07-0.32	44				<0.86	<0.07-11.9	56
	1976	< 0.07	<0.07-0.074	55	0.03	0.006-0.067	52	<0.09	<0.07-0.14	51
	1977	< 0.06	0.02-0.09	62	0.07	0.011-0.83	37	<0.13	<0.06-0.23	59

TABLE 3 (CONTINUED)

SUMMARY OF EFFLUENT CHARACTERISTICS FROM THE THREE MAIN SEWAGE TREATMENT PLANTS

Parameter	Plant	Iona Mean	Iona Range	Iona No. of Values	Annacis Mean	Annacis Range	Annacis No. of Values	Lulu Mean	Lulu Range	Lulu No. of Values
Copper, Total	mg/L									
	1972	0.18	0.07-0.38	305						
	1973							0.24	0.05-1.18	327
	1974							0.24	0.10-1.1	110
	1975	0.18	0.09-0.37	44				0.33	0.07-1.0	56
	1976	0.16	0.10-0.21	55	0.15	0.08-0.28	52	0.22	0.15-0.37	51
	1977	0.20	0.12-0.29	54	0.13	0.04-0.29	61	0.18	0.14-0.23	59
Flow	$m^3/d \times 10^3$									
	1972	323	145-936	365						
	1973	318	135-991	365				11.5	8.2-40.5	365
	1974	377	157-1 160	365				12.7	7.3-25.5	365
	1975	383	188-960	365	148	105-189	365	15.8	11.8-40.5	365
	1976	321	173-715	365	136	101-179	365	18.5	12.3-28.2	365
	1977	387	160-946	365	166	136-199	365	21.6	13.6-42.3	365
Iron, Total	mg/L									
	1972	1.10	0.4-2.5	347						
	1973							3.80	0.1-9.7	329
	1974							3.30	2.0-4.3	110
	1975	1.17	0.69-1.69	44				3.13	2.3-5.5	56
	1976	1.00	0.66-1.6	55	1.09	0.51-1.8	52	2.87	2.2-3.7	46
	1977	0.96	0.68-1.5	54	1.22	0.87-1.64	61	2.93	2.4-3.2	62

TABLE 3 (CONTINUED)

SUMMARY OF EFFLUENT CHARACTERISTICS FROM THE THREE MAIN SEWAGE TREATMENT PLANTS

Parameters	Plant	Iona			Annacis			Lulu		
		Mean	Range	No. of Values	Mean	Range	No. of Values	Mean	Range	No. of Values
Lead, Total	mg/L									
	1972	<0.2	<0.2-4.3	347						
	1973							<0.2	<0.2-4.2	329
	1974							<0.2	<0.13-2.1	113
	1975	<0.2		44				<0.2		56
	1976	0.10	0.017-0.20	54	0.020	0.001-0.097	44	0.10	0.01-0.20	51
	1977	0.067	0.02-0.11	54	0.030	0.005-0.125	61	0.12	0.02-0.24	59
Nickel, Total	mg/L									
	1972	<0.1	<0.1-0.6	347						
	1973							<0.34	<0.1-1.1	329
	1974							<0.37	0.09-6.92	96
	1975	0.09	<0.07-0.19	44				<0.23	<0.07-3.08	56
	1976	<0.07		55	0.08	0.03-0.45	53	0.13	<0.07-0.27	51
	1977	0.06	<0.01-0.07	54		0.01-0.19	61	0.17	<0.07-0.32	59
Nitrogen, Ammonia	mg/L									
	1973							19.9		6
	1976				12.8		8			
	1977	7.0		7	11.4		10	21.7		7
Nitrogen, Kjeldahl	mg/L									
	1973							34.4		6
	1976				26.9		9			
	1977	14.4		7	21.8		11	35.7		7

TABLE 3 (CONTINUED)

SUMMARY OF EFFLUENT CHARACTERISTICS FROM THE THREE MAIN SEWAGE TREATMENT PLANTS

Parameters	Plant	Iona			Annacis			Lulu		
		Mean	Range	No. of Values	Mean	Range	No. of Values	Mean	Range	No. of Values
pH										
	1972	7.2	6.4-9.8	248						
	1973	7.3	6.4-10.0	229				6.9	6.3-7.1	208
	1974	7.0	6.1-8.3	237				6.8	6.6-7.1	238
	1975	7.2	5.4-11.8	240	7.1	6.5-7.4	81	6.8	6.0-7.7	243
	1976	7.3	6.2-9.4	235	6.8	6.2-7.4	231	6.8	6.6-8.9	241
	1977	7.1	6.4-8.2	241	6.6	6.2-7.1	179	6.7	6.4-7.1	246
Phosphorus, Total	mg/L									
	1973							7.6		7
	1976				4.9		10			
	1977	2.6		7	4.2		11	6.1		7
Suspended Solids	mg/L									
	1972	48	16-195	351						
	1973	51	18-250	339				91	49-256	337
	1974	46	10-117	345				90	42-202	353
	1975	49	22-199	352	52	20-108	201	82	33-387	356
	1976	50	19-110	348	56	19-132	548	80	51-117	351
	1977	48	15-166	252	65	29-141	448	81	52-102	267
Zinc, Total	mg/L									
	1972	0.18	0.05-1.69	347						
	1973							0.29	0.04-0.93	329
	1974							0.18	0.10-0.56	111
	1975	0.17	0.10-0.25	44				0.18	0.10-0.53	56
	1976	0.13	0.10-0.18	55	0.16	0.07-0.34	52	0.26	0.20-0.36	51
	1977	0.11	0.04-0.18	54	0.21	0.08-2.29	36	0.42	0.20-0.68	59

Note: Metal concentrations measured as extractable metal were assumed to equal total metal.

TABLE 4

TOTAL COLIFORM COUNTS FOR 1977 IN EFFLUENTS FROM THE THREE MAIN SEWAGE TREATMENT PLANTS

	Monthly Geometric Mean MPN/100 mL		
	Iona	Annacis	Lulu
January	2 132 700	1 591	2 937
February	2 603 100	30 403	13 495
March	3 095 200	7 004	51 275
April	2 678 300	3 609	29 341
May	1 212	3 130	4 909
June	257	2 402	1 456
July	148	841	229
August	170	1 221	1 640
September	200	975	1 181
October	2 341 400	1 844 900	632 090
November	3 226 300		37 367 000
December	2 273 300	9 169 100	25 393 000

TABLE 5

ANALYSIS OF DIGESTED SEWAGE SLUDGE

	Iona Average Concentration ppm Dry Weight		Annacis Average concentration ppm Dry Weight	
	Jan. 1976-March 1977	1978	1976	1977
Cadmium	8.2		5.5	6.0
Copper	610		680	690
Chromium	95		120	180
Iron	7 000		5 700	6 400
Lead	470		200	260
Manganese	150		120	120
Mercury				0.5
Nickel	32		31	43
PCB	27	<0.01		
Zinc	530		650	710

Note: Metal values averaged from monthly analyses; PCB values based on single analysis.

TABLE 6

SUMMARY OF BIOASSAY RESULTS OBTAINED WITH SEWAGE TREATMENT PLANT EFFLUENT

Plant	96 h LC_{50}, % Mean	Range	Type of Bioassay	Number of Bioassays	Fish Used	Year, Effluent Type	Agency
	93	43-100	Static, Grab Samples	15	Rainbow Trout	1976, 1977, 1978 Dechlorinated	B.C. Research
	68	51-78	Static, 24-Hour Composite Samples	3	Rainbow Trout	1976 Dechlorinated	Environmental Protection Service (EPS)
Annacis	38		Static, 24-Hour Composite Samples	1 Tests at 72 Concentrations	Sockeye Salmon	1976 Dechlorinated	International Pacific Salmon Fisheries Commission (IPSFC)
	26		Continuous Flow	1 Tests at 104 Concentrations	Sockeye Salmon	1976 Dechlorinated	
	90	24-100	Static, 24-Hour Composite Samples	20	Coho Salmon	1971, 1972 Chlorinated	EPS
Iona	51	44-58	Static, 24-Hour Composite Samples	2	Rainbow Trout	1976 Chlorinated	
	45		Continuous Flow	1	Sockeye Salmon	1976 Non-Chlorinated	IPSFC
Lulu	25	10-40	Continuous Flow	6	Sockeye Salmon	1975 Dechlorinated	IPSFC

TABLE 7

ESTIMATED VOLUME OF STORM WATER RUNOFF AND OF CONTAMINANTS IN RUNOFF, BASED ON RAINFALL AND LITERATURE VALUES

Parameter \ Source	Ferguson and Hall[15]		Franson[16]	
Total Land Area km^2	492		305	
Average Runoff Volume m^3/d	700 000		400 000	
Average Concentration and Load	mg/L	kg/d	mg/L	kg/d
BOD_5	3-29	14 800	40	16 000
Copper	0.003-0.049	12		
Iron	0.255-0.375	200		
Lead	0.003-0.061	30		
Nickel	0.001-0.005	1.6		
Nitrogen	1-2	1 240		
Phosphorus	0.1-0.6	390		
Suspended Solids			250	100 000
Zinc	0.003-0.068	14		
	MPN/100 mL	No./d		
Total Coliform	30 000-100 000	604×10^{12}		
Fecal Coliform	600-11 000	565×10^{11}		

TABLE 8

VOLUME AND COMPOSITION OF STORM WATER DURING DRY WEATHER FLOW, FROM MEASUREMENTS MADE IN SUMMER, 1978

Parameter	Average Value	
Total Dry Weather Flow	356 000 m^3/d	
	mg/L	kg/d
Arsenic	< 0.0006	< 0.5
Carbon, Organic	16.4	5 840
Chromium, Total	0.007	2.5
Copper, Total	0.011	3.9
Iron, Total	5.46	1 940
Lead, Total	0.016	5.7
Mercury, Total	0.000042	< 0.1
Nickel, Total	0.04	14
Nitrogen, Total	4.61	1 640
Oil and Grease	3.5	1 250
Phenol	0.012	4.3
Phosphorus, Total	0.172	61
Suspended Solids	39.8	14 200
Zinc, total	0.046	16
	MPN/100 mL	No./d
Fecal Coliform	6 200	221×10^{11}

TABLE 9

RESULTS OF MISCELLANEOUS ANALYSES OF STORM WATER AND STREET SEDIMENTS[15]

Parameter \ Data Source		Renfrew Street Sewer, 1974		Sampling of 18 Storm Sewers, 1976		Street Sediments, 1974
		Dry Weather	Wet Weather	Dry Weather	Wet Weather	
Cadmium, Total	mg/L			<0.01	<0.01	
Chromium, Total	mg/L			<0.02	<0.02	
Copper, Total	mg/L	0.001	0.010	<0.01	<0.01	
Cyanide	mg/L			<0.03	<0.03	
Iron, Total	mg/L	0.740	0.350	1.58	2.10	
Lead, Total	mg/L	0.009	0.062	0.037	0.128	
Mercury, Total	mg/L			<0.0002	<0.0002	
Nickel, Total	mg/L	0.001	0.002	<0.05	<0.05	
Phenol	mg/L			<0.03	<0.03	
Zinc, Total	mg/L	0.122	0.166	0.115	0.715	
Polychlorinated Biphenyls:	mg/L			<0.001		
Commercial	ppm dry wt.					0.141
Industrial	ppm dry wt.					0.096
Residential	ppm dry wt.					0.091
Green Space	ppm dry wt.					0.050

TABLE 10

APPROXIMATE CONCENTRATIONS AND LOADINGS OF CONTAMINANTS IN MUNICIPAL EFFLUENTS AND STORM WATER

	Concentrations mg/L			Loadings (kg/d) and Flows (m^3/d)		
	All	Storm Water		All	Storm Water	
	Municipal Effluents	Average From Rainfall	Dry Weather Flow	Municipal Effluents	Average From Rainfall	Dry Weather Flow
BOD_5	92	21		55 000	15 000	
Chromium, Total	0.065		0.007	40		2.5
Copper, Total	0.17	0.017	0.011	100	12	4
Iron, Total	1.09	0.28	5.5	650	200	1 900
Lead, Total	0.103	0.04	0.016	60	30	5.6
Nickel, Total	0.08	0.002	0.04	50	1.6	14
Phosphorus, Total	3.9	0.57	0.17	2 300	400	60
Suspended Solids	52	40*	40	31 000	28 000	14 000
Zinc, Total	0.16	0.02	0.05	100	14	17
Average Flow				600 000 380 000 From Iona	700 000	350 000

* Assumed Value

TABLE 11

THE APPROXIMATE DISTRIBUTION AND FLOW OF INDUSTRIAL EFFLUENTS DISCHARGED DIRECTLY TO THE FRASER RIVER FROM 1970 TO 1978

Reach / Effluent Type	Main Stem			Main Arm			North Arm			Overall		
	No. of Out-Falls	Flow m^3/d	% of Flow	No. of Out-Falls	Flow m^3/d	% of Flow	No. of Out-Falls	Flow m^3/d	% of Flow	No. of Out-Falls	Flow m^3/d	% of Flow
Municipal	12	1 100	1.0	6	210	0.2	5	30	<0.1	23	1 340	0.4
Uncontaminated Cooling Water	3	150	0.1	4	18 700	18.9	14	13 630	8.3	21	32 480	8.6
Forest	6	106 300	93.3	2	3 200	3.2	16	122 000	74.5	24	231 500	61.4
Food	2	450	0.4	8	3 450	3.5	3	1 370	0.8	14	5 270	1.4
Metals	1	130	0.1	2	330	0.3	6	26 630	16.3	9	27 090	7.2
Cement	1	4 550	4.0	6	1 390	1.4	0	0	0	7	5 940	1.6
Miscellaneous	5	1 240	1.1	4	71 760	72.5	1	10	0.1	10	73 010	19.4
Total	31	113 920	100.0	32	99 040	100.0	45	163 670	100.0	108	376 630	100.0
% of Total Flow		30			26			44			100	

TABLE 12

DATA SUMMARIES FOR THE MAIN INDUSTRIES DISCHARGING TO THE FRASER RIVER FROM 1970 TO 1978

Reach	Company	Pollution Control Permit No.	Type of Operation	Effluent Flow m^3/d	Effluent Flow % of Total To Reach	Discharge Point	Monitoring Data or Permit Information
Main Stem	Crown Zellerbach Canada Ltd., Fraser Mills	PE-412	Sawmill	53 400	47	Between Port Mann and Patullo Bridges	S.S. = 89 mg/L (mean 1973-1978) = 39-293 mg/L (Range of Annual Means) BOD_5 = 10 mg/L (Mean 1973-1978)
	B.C. Forest Products Ltd., Hammond Mill	PE-2756	Sawmill	45 800	40	Upstream From Barnston Island	S.S. = 530 mg/L (Mean 1975-1978) = 85-1 236 mg/L (Range of Annual Means) BOD_5 = 58 mg/L (Mean 1975-1978) = 10-116 mg/L (Range of Annual Means)
	Canadian Forest Products Ltd., New Westminster	CE-1656 Diverted to Annacis S.T.P. Dec. 1976	Hardboard and Plywood Mill	6 800	6	Upstream From Confluence With Brunette River	S.S. = 515 mg/L BOD_5 = 1 420 mg/L Phenolics = 1.9 mg/L (Permit Application Data)
Main Arm	Dow Chemical of Canada Ltd., Tilbury Island	PE-41	Phenol Plant	66 000	67	From Tilbury Island	Cooling Water + 160 m^3/d Process Effluent. Phenol in Total Effluent = 0.014 mg/L (Mean 1975-1978) = 0.003-0.026 mg/L (Range of Annual Means)
	Genstar Ltd., Tilbury Island	PE-4513	Cement Plant	18 200	18	From Tilbury Island	Uncontaminated Cooling Water

TABLE 12 (CONTINUED)

DATA SUMMARIES FOR THE MAIN INDUSTRIES DISCHARGING TO THE FRASER RIVER FROM 1970 TO 1978

Reach	Company	Pollution Control Permit No.	Type of Operation	Effluent Flow m^3/d	Effluent Flow % of Total To Reach	Discharge Point	Monitoring Data or Permit Information
Main Arm	Western Peat Moss Ltd., Delta	PE-4382	Peat Moss Processing	5 500	5.5	To Ground off Tilbury Island	Effluent Exfiltrates to River
	M.B. Ltd., Island Paper Mills Division	PE-35 Diverted To Annacis STP, October 1978	Fine Paper Mill	3 050	3	From South Side of Annacis Island	S.S. = 187 mg/L (Mean 1965-1978) = 160-216 mg/L (Range of Annual Means) BOD_5 = 157 mg/L (Mean 1965-1978) = 105-178 mg/L (Range of Annual Means)
	Lafarge Canada Ltd., Richmond	PE-42	Cement Plant	1 230	1.2	Opposite Lions Island, Downstream From Annacis Island	S.S. = 1 208 mg/L (Mean 1965-1978) = 618-1 604 mg/L (Range of Annual Means) BOD_5 = 32 mg/L (Mean 1965-1978) Tot. Pb = 0.42 mg/L (Mean 1965-1977) Tot. Zn = 0.17 mg/L (Mean 1965-1978) Tot. K = 751 mg/L (Mean 1965-1978)

TABLE 12 (CONTINUED)

DATA SUMMARIES FOR THE MAIN INDUSTRIES DISCHARGING TO THE FRASER RIVER FROM 1970 TO 1978

Reach	Company	Pollution Control Permit No.	Type of Operation	Effluent Flow m^3/d	Effluent Flow %of Total To Reach	Discharge Point	Monitoring Data or Permit Information
Main Arm	Titan Steel and Wire Co. Ltd., Surrey	PE-161	Metal Finishing Plant	270 Process Effluent	0.3	To the River Near Gunderson Slough	Tot. Fe = 633 mg/L (Mean 1965-1978) = 127-1 570 mg/L (Range of Annual Means) Tot. Pb = 7.0 mg/L (Mean 1965-1978) = 0.17-27.4 mg/L (Range of Annual Means) Tot. Zn = 4.6 mg/L (Mean 1965-1978) = 0.8-10.3 mg/L (Range of Annual Means
				460 Cooling Water	0.5	To Gunderson Slough	Tot. Fe = 0.79 mg/L (Mean 1975-1977) Tot. Pb = 0.03 mg/L (Mean 1975-1977) Tot. Zn = 0.28 mg/L (Mean 1975-1977)
North Arm	M.B. Ltd., Canadian White Pine Division	PE-1666	Sawmill	73 000	45	Mid-Way Between Queensborough and Oak Street Bridges	pH = 7.7 Oil and grease = 2.2 mg/L (From 1 sample in 1978)

TABLE 12 (CONTINUED)

DATA SUMMARIES FOR THE MAIN INDUSTRIES DISCHARGING TO THE FRASER RIVER FROM 1970 TO 1978

Reach	Company	Pollution Control Permit No.	Type of Operation	Effluent Flow m^3/d	Effluent Flow % of Total To Reach	Discharge Point	Monitoring Data or Permit Information
	Western Canada Steel Ltd., Richmond	PE-2087	Steel Rolling Mill	25 000	15	From North Side of Twigg Island	Diss. Fe = 0.6 mg/L (Mean 1975-1978) = 0.2-1.3 mg/L (Range of Annual Means) Tot. Fe = 11.4 mg/L (One Value 1975) Diss. Zn = 0.02 mg/L (Mean 1975-1978) = 0.02-0.04 mg/L (Range of Annual Means)
North Arm	Belkin Paper-board Ltd., Burnaby	PE-17	Paper Board Mill	16 400	10	Downstream From Queensborough Bridge	S.S. = 700 mg/L (Mean 1965-1978) = 426-1 092 mg/L (Range of Annual Means) BOD_5 = 207 mg/L (Mean 1965-1978) = 149-345 mg/L (Range of Annual Means) Tot. Zn = 2.7 mg/L (Mean of 3 Values 1965-1973) PCB's = 0.0024 mg/L (Mean of 4 Samples 1979)
	Canadian Forest Products Ltd., Eburne Division	PE-2115	Sawmill	9 200	6	Between Mitchell Island and Oak Street Bridge	All 3 Hydraulic Debarkers Changed to Mechanical Type in 1974 and 1975. S.S. = 23 mg/L (1 sample 1975)

TABLE 12 (CONTINUED)

DATA SUMMARIES FOR THE MAIN INDUSTRIES DISCHARGING TO THE FRASER RIVER FROM 1970 TO 1978

Reach	Company	Pollution Control Permit No.	Type of Operation	Effluent Flow m^3/d	Effluent Flow % of Total To Reach	Discharge Point	Monitoring Data or Permit Information
North Arm	Scott Paper Ltd., New Westminster	PE-335-02	Paper Mill	8 900	5.5	Upstream From Queensborough Bridge	S.S. = 110 mg/L (Permit Limit) BOD_5 = 140 mg/L (Mean 1965-1978) = 108-216 mg/L (Range of Annual Means)
		PE-335-01 Diverted to Annacis S.T.P. Aug. 1977	Groundwood Mill	1 930	1.2		S.S. = 266 mg/L (Mean 1974-1976) BOD_5 = 252 mg/L (Mean 1974-1976)
	Rayonier Canada (B.C.) Ltd., Vancouver	PE-3087 Plant Closed April 1976	Bark Extraction Plant	6 800 Extraction Plant Effluent + Cooling Water	4.1	Between Mitchell Island and Oak Street Bridge	No Monitoring Data. Possible Contaminants are: S.S., BOD_5, Bisulphite and Certain Heavy Metals (Cr, Cu, Fe, Zn)
				5 500 Drier and Evaporation Plant Effluent	3.4		
	M.B. Ltd., Vancouver Plywood Division	CE-4248	Plywood & Specialty Board Plant	2 350	1.5	Between Queensborough and Oak Street Bridges	Cooling Water, Probably Uncontaminated

TABLE 12 (CONTINUED)

DATA SUMMARIES FOR THE MAIN INDUSTRIES DISCHARGING TO THE FRASER RIVER FROM 1970 TO 1978

Reach	Company	Pollution Control Permit No.	Type of Operation	Effluent Flow m^3/d	Effluent Flow % of Total To Reach	Discharge Point	Monitoring Data or Permit Information
North Arm	Tree Island Steel Co. Ltd., New Westminster	PE-3190	Metal Finishing Plant	800 Process Water	0.5	From South Side of Tree Island	Tot. Fe = 73 mg/L (Mean 1976-1978) = 13-109 mg/L (Range of Annual Means) Tot. Pb = 4.8 mg/L (Mean 1976-1978) = 0.4-9.3 mg/L (Range of Annual Means) Tot. Zn = 26 mg/L (Mean 1976-1978) = 5-37 mg/L (Range of Annual Means)
				800 Cooling Water	0.5		Tot. Pb = 0.26 mg/L (Mean of 3 Values 1977-1978) Tot. Zn = 65 mg/L (Mean of 3 Values 1977-1978)
	Varta Batteries Ltd., Richmond	CE-4661 Process Effluent Diverted to Lulu S.T.P., Aug. 1977	Battery Manufacturer	30	0.02	From Richmond, Opposite East Tip of Mitchell Island (No. 6 Road)	No Monitoring Data Available. Cooling Water Only Discharged After Aug. 1977.

TABLE 12 (CONTINUED)

DATA SUMMARIES FOR THE MAIN INDUSTRIES DISCHARGING TO THE FRASER RIVER FROM 1970 TO 1978

Reach	Company	Pollution Control Permit No.	Type of Operation	Effluent Flow m^3/d	Effluent Flow % of Total To Reach	Discharge Point	Monitoring Data or Permit Information
North Arm	Metalex Products Ltd., Richmond	CE-2311 Diverted to Lulu S.T.P. Jan. 1976	Lead Smelter	14	0.01	From Richmond, Opposite Twigg Island (No. 5 Road)	Tot. Fe = 9.3 mg/L (Average of 2 Values 1970-1973) Tot. Pb = 7.5 mg/L (Average of 5 Values 1970-1973 = 2.5-13.5 mg/L (Range of Values) pH = 1.7-6.5 (Range of 5 Values)

TABLE 13

ESTIMATES OF EFFLUENT VOLUME DISCHARGED BY INDUSTRY TO MUNICIPAL SEWERS[6, 20]

Industry Type	Average Effluent Volume m^3/d			
	Iona Sewerage Area	Annacis Sewerage Area	Lulu Sewerage Area	Total
Metal	3 472	4 583	386	8 441
Printing and Photography	3 165	47	48	3 260
Food	14 741	11 475	1 289	27 505
Chemical	3 116	281	91	3 488
Paint	66	5	0.9	71.9
Plastics	1 741	4.5	45	1 790.5
Textiles	59	2.3	36	97.3
Electrical	46	36		82
Wood	5 597	10 678		16 275
Rubber		45		45
Petroleum*	2 450	5 540		7 990
Dry Cleaning	351			351
Automotive	186	19		205
Miscellaneous	2 497	965		3 462
Total	37 487	33 680.8	1 895.9	73 063.7

* These flows were estimated from the provincial data base EQUIS.

TABLE 14

APPROXIMATE ANALYSIS OF EFFLUENTS DISCHARGED BY INDUSTRY TO MUNICIPAL SEWERS IN THE ANNACIS AND LULU SEWERAGE AREAS

Parameter	Industry Type	Metal	Printing	Food	Chemical	Paint	Wood
BOD	mg/L		36	550-14 100	795-2 000	1 500	150-1 935
Bismuth, Total	mg/L					0.2	
Chromium, Total	mg/L	0.1-8.6				9.3	
Cobalt, Total	mg/L					0.2	
Colour						Strong Tints	300-500
Copper, Total	mg/L	0.35-54.5					
Cyanide, Total	mg/L	1.2-13.0	1.1-2.0			1.6	
Formaldehyde	mg/L				40		
Iron, Total	mg/L	1-15				4.8	
Lead, Total	mg/L	0.2-10.5				77	
Mercury, Total	mg/L					0.045	
Nickel, Total	mg/L	1.8-43.5				0.02	
Nitrogen:							
Ammonia	mg/L		25-162				
Kjeldahl	mg/L		171-467				

TABLE 14 (CONTINUED)

APPROXIMATE ANALYSIS OF EFFLUENTS DISCHARGED BY INDUSTRY TO MUNICIPAL SEWERS IN THE ANNACIS AND LULU SEWERAGE AREAS

Parameter	Industry Type	Metal	Printing	Food	Chemical	Paint	Wood
Oil and Grease	mg/L			48-3 106	243	416-1 000	
Oxygen, Dissolved	mg/L		4.6				
pH		2.7-13.0	9.0-10.6	3.6-12.3	2.1-12.5	5.1-8.0	5.5-9.8
Phenolics	mg/L				16-42	0.036	68
Phosphate	mg/L					5.0	
Solids:							
Dissolved	mg/L		1 329			221-13 356	
Suspended	mg/L		18	52-7 239	270-550	28-7 052	286-1 124
Total	mg/L		1 347	660-34 000			494-3 390
Sulphite	mg/L			10-350			
Surfactants	mg/L					46.8	
Titanium, Total	mg/L					50	
Toxicity, (96 h LC_{50})	%		15-88				40-50
Zinc, Total	mg/L	1.2-2.3				8.9	

TABLE 15

ESTIMATES OF CONTAMINANT LOADINGS FROM INDUSTRY TO MUNICIPAL SEWERS IN THE IONA SEWERAGE AREA

Contaminant \ Industry Type		Metal	Photographic	Paint	Automotive	Textiles	Chemical	Food
Cadmium	kg/d	0.61						
Chromium	kg/d	5.2	0.06	0.00004				
Copper	kg/d	2.4						
Cyanide	kg/d	1.9						
Cyano-complexes	kg/d		2.0					
Lead	kg/d			0.0002				
Mercury	kg/d			0.00009				
Nickel	kg/d	1.7						
Oil and Grease	kg/d				0.68			115
pH			3.4-8.2	6.4-9.6	6.3-11.6	4.9	4.7-6.3	
Silver	kg/d	0.006	0.60					
Suspended Solids	kg/d			0.04	0.23	5.7		136
Zinc	kg/d	1.8		0.0004				

TABLE 16

ESTIMATED FLOWS AND COMPOSITION OF OIL REFINERY EFFLUENTS DISCHARGED TO MUNICIPAL SEWERS

		Chevron Canada Ltd.		Gulf Oil Canada Ltd.		Shell Canada Ltd.	
Pollution Control Permit No.		PE-447		PE-22		PE-449	
Date Process Effluent Diverted to Sewer		June, 1977 To Iona		December, 1974 To Annacis in 1975		December, 1975 To Annacis	
Approximate Flow	m^3/d	2 450		1 440		4 100	
Composition							
Ammonia	mg/L	62.5 7-106	Av. 1965-1977 Range of Annual Average	2.9	Av. of 2 values, 1965-1974	5.4 0.3-13	Av. 1965-1975 Range of Annual Average
BOD_5	mg/L	272 102-464	Av. 1965-1977 Range of Annual Average	106	1 Value	33.6 26-38	Av. 1965-1975 Range of Annual Average
Chromium, Total	mg/L	0.029 0.005-0.058	Av. 1965-1977 Range of Annual Average	0.09	Av. of 2 values, 1965-1974	0.20 0.37-0.11	Av. 1965-1977 Range of Annual Average
Copper, Total	mg/L	1.1 0.1-3.2	Av. 1965-1977 Range of Annual Average	0.005	Av. of 2 values, 1965-1974	0.19 0.09-0.36	Av. 1965-1975 Range of Annual Average

TABLE 16 (CONTINUED)

ESTIMATED FLOWS AND COMPOSITION OF OIL REFINERY EFFLUENTS DISCHARGED TO MUNICIPAL SEWERS

		Chevron Canada Ltd.		Gulf Oil Canada Ltd.		Shell Canada Ltd.	
Composition							
Cyanide	mg/L	0.47 0.02-0.95	Av. 1965-1977 Range of Annual Average	0.01	Av. of 2 values, 1965-1974	0.035 0.03-0.04	Av. 1965-1975 Range of Annual Average
Lead, Total	mg/L	0.32 0.003-1.2	Av. 1965-1977 Range of Annual Average	0.021	Av. of 2 values 1965-1974	0.10 0.08-0.11	Av. 1965-1975 Range of Annual Average
Oil and Grease	mg/L	73.5 35.2-182	Av. 1965-1977 Range of Annual Average	8.1	Av. of 2 values 1965-1974	11.2 9-13	Av. 1965-1975 Range of Annual Leave
Phenol	mg/L	5.4 2-9	Av. 1965-1977 Range of Annual Average	18.5	Av. of 2 values, 1965-1974	1.3 0.5-2.3	Av. 1965-1975 Range of Annual Average
Sulphide	mg/L	211 16-485	Av. 1965-1977 Range of Annual Average	3.95	Av. of 2 values, 1965-1974	0.8 0.2-1.5	Av. 1965-1975 Range of Annual Average
Zinc, Total	mg/L	0.31 0.1-0.9	Av. 1965-1977 Range of Annual Average	0.05	1 Value	0.24 0.23-0.27	Av. 1965-1975 Range of Annual Average

TABLE 17

ESTIMATES OF SLUDGE VOLUME GENERATED BY INDUSTRIES CONNECTED TO SEWER[6,20]

Industry Type	Average Sludge Volume m^3/d			
	Iona Sewerage Area	Annacis Sewerage Area	Lulu Sewerage Area	Total
Metal	1.1	0.5	2.2	3.8
Food	15.2	3	1.9	20.1
Chemical	5.1	7.2	1.5	13.8
Paint	0.2	1.7	0.1	2.0
Electrical		0.1		0.1
Wood	0.5	0.5	0.2	1.2
Petroleum	0.2			0.2
Dry Cleaning	0.2	0.1		0.3
Automotive	0.5			0.5
Miscellaneous	0.2	6.7	1.3	8.2
Total	23.2	19.8	7.2	50.2

TABLE 18

APPROXIMATE EFFECTIVENESS OF SECONDARY TREATMENT USING THE ACTIVATED SLUDGE PROCESS

	Percent Removal								
	Primary				Primary and Secondary				
	For Iona, Annacis and Lulu	Ref. 5	Ref. 21 p. 273	Ref. 8	Ref. 5	Ref. 21 p. 273	Ref. 8	Ref. 21 p. 133	Assumed For Iona, Annacis and Lulu
Arsenic			0			30			30
BOD	32	35			80				80
Cadmium		14	8	60	55	10	80	45	45
Chromium		32	26	55	65	52	79	75	60
Copper	25	35	25	33	66	70	73	82	70
Cyanide			0			40			40
Lead	25	47	24	66	71	46	93	65	50
MBAS					72				70
Mercury			27		71	50		40	45
Nickel		18	6	15	24	9	16	33	10
Nitrogen:									
Total		25			30				30
Ammonia					72				70
PCB	44	50			68				60
Pesticide					25				25
Phenols			37			65			60
Phosphate		10			27				25
Suspended Solids	63	70			80				80
Zinc	25	30	30	54	68	71	77	72	70

TABLE 19

AN ESTIMATE OF HEAVY METALS ENTERING THE SEWER IN THE ANNACIS SEWERAGE AREA

	Estimated Characteristics				Loadings as % of Influent to Annacis		
	Annacis Influent[(a)]	Metal Industry[(b)]	Domestic Sewage[(c)]	Water Supply[(c)]	Metal Industry	Domestic Sewage	Water Supply
Chromium	2.4-184 kg/d	0.5-40 kg/d		<0.001 mg/L 0.2 kg/d	21		0.1-8
Copper	8.8-64 kg/d	1.6-250 kg/d	0.031 mg/L 5.1 kg/d	0.004 mg/L 0.7 kg/d	18-100	8-58	1-8
Iron	192-362 kg/d	4.6-69 kg/d	0.49 mg/L 81.3 kg/d	0.19 mg/L 31.5 kg/d	2.4-19	22-42	9-16
Lead	1.1-27.6 kg/d	0.9-48 kg/d	< 0.1 mg/L 17 kg/d	<0.001 mg/L 0.2 kg/d	82-100	62-100	1-18
Nickel	2.3-42 kg/d	8.3-200 kg/d		<0.001 mg/L 0.2 kg/d	100		0.5-9
Zinc	18-507 kg/d	5.5-10.6 kg/d	0.059 mg/L 9.8 kg/d	0.002 mg/L 0.3 kg/d	2-31	2-53	0.06-2

(a) Based on maximum and minimum Annacis effluent concentrations (Table 3) x $\frac{1}{0.75}$ and 166 000 m^3/d flow.

(b) Based on concentrations in Table 14 and 4 583 m^3/d flow.

(c) Based on 166 000 m^3/d flow.

TABLE 20

GUIDELINES TO EVALUATE LIMITS IN THE CONCENTRATION OF CONTAMINANTS DISCHARGED TO SEWER

Parameter	G.V.R.D. Limits To Sewer 1971	Provincial Objectives For Discharges To Fresh Water			Median Limits To Sewer Ref. 21 p. 112	Proposed EPA Std. For Metal Plating Ref. 21 p. 276	Suggested Limits To Sewer
		Metal Plating 1975	Municipal 1975	Mining 1973			
Aluminum		0.2–0.5 D	2–4 T	0.5–10 D			8 T
Antimony		5 D		0.05–1 D			2 T
Arsenic	1 T	1 D	0.05–0.25 T	0.05–1 D	0.05–1 T		1 T
Barium			0.05–0.25 D				2 T
Boron			1 D				5 T
Cadmium	1 T	0.02–0.1 D	0.005–01 D	0.005–0.02 D	0.1–2 T	0.5 T	0.2 T
Chromium	5 T	0.15–0.6 D	0.1–0.3 T	0.05–0.5 D	5 T	1.6 T	2 T
Cobalt		1–2 D	0.1–0.5 D	0.1–1.0 D			4 T
Copper	2 T	0.1–1 D	0.2–0.5 D	0.05–1 D	1–3 T	2 T	2 T
Cyanide	1 T	0.5–1 T	0.1–0.5 T	0.1–2 T	2 T	0.24 T	1 T
Fluoride		5–15 D	5 D	2.5–15 D			30 T
Iron	10 T	0.5–1 D	0.3–1 D	0.3–5 D			10 T
Lead	2 T	0.2–0.5 D	0.05–0.1 T	0.05–0.5 D	0.1 T	0.4 T	1 T
Manganese		1 D	0.05–0.5 D	0.05–1.5 D			2 T
MBAS			5				25 T
Mercury		0.005 D	0.0006–0.002 T	0.001–0.1 T	0.005 T		0.01 T
Molybdenum		10 D	0.2–0.5 T	0.5–10 D			8 T
Nickel	3 T	1–2 D	0.3–0.5 D	0.03–1 D	1 T	1.8 T	1 T
Oil & Grease	150	10–15	15–30	15			150
Petroleum Prod.	15						15
pH	5.5–9.5	6.5–8.5	6.5–8.5	6–10			5.5–9.5

TABLE 20 (CONTINUED)

GUIDELINES TO EVALUATE LIMITS IN THE CONCENTRATION OF CONTAMINANTS DISCHARGED TO SEWER

Parameters	G.V.R.D. Limits To Sewer 1971	Provincial Objectives For Discharges To Fresh Water			Median Limits To Sewer Ref. 21 p. 112	Proposed EPA Std. For Metal Plating Ref. 21 p. 276	Suggested Limits To Sewer
		Metal Plating 1975	Municipal 1975	Mining 1973			
Phenols	1	0.2-0.5	0.2-0.4		0.5		1
Selenium		0.2-1 D	0.05-0.1 T	0.05-1 D	0.02 T		1 T
Silver		0.05-0.1 D	0.1-1 T	0.1-1 D	0.1 T		2 T
Solids, Susp.	600		40-130	15-150			600
Sulphide			0.5-1 D				5 T
Tin		2-4 D	5-10 T				10 T
Zinc	4 T	0.3-1 D	0.5-5 D	0.5-10 D	5 T	1.5 T	4 T

All values in mg/L except pH.

D = Dissolved.

T = Total.

TABLE 21

SUMMARY OF WATER QUALITY DATA FOR ALL REACHES OF THE FRASER RIVER AND ESTUARY, FROM 1970 TO 1978

Parameter		No. of Values	Percentiles 10th	50th	90th
Major Ions and Physical Parameters					
Alkalinity, Total	mg/L	430	36	44.5	54.5
Calcium, Total	mg/L	465	11	14	52
Chloride	mg/L	6 462	2.6	5	5 000
Colour, Apparent	Colour	517	10	19	45
True	Units	370	5	20	40
Conductivity, Specific	µmho/cm	1 663	87	130	16 000
Fluoride	mg/L	105	0.05	0.06	0.24
Hardness	mg/L	816	39	51	676
Magnesium, Dissolved	mg/L	444	1.9	3.0	70
Total	mg/L	545	2.1	3.3	107
pH		2 355	7.2	7.6	7.9
Potassium, Total	mg/L	75	0.6	1.0	33
Sodium, Total	mg/L	532	1.4	3.8	1 420
Solids, Dissolved	mg/L	637	53	81	3 374
Suspended	mg/L	1 265	8	33	118
Sulphate	mg/L	533	5.2	7.5	192
Temperature	°C	6 435	4	10	17
Turbidity	J.T.U.	1 180	5	17	46
Oxygen Consuming Materials and D.O.					
BOD_5	mg/L	345	1	2	6
Carbon, Total Organic	mg/L	922	1	4	7.3
COD	mg/L	227	20	20	48
Oil and Grease	mg/L	108	1	3	7
Oxygen, Dissolved	mg/L	6 670	8.7	10.5	12.7
Volatile Residue of Suspended Solids	mg/L	452	1	4	12
Heavy Metals					
Boron, Dissolved	mg/L	19	0.1	0.2	0.2
Cadmium, Dissolved	mg/L	577	0.0004	0.0005	0.001
Total	mg/L	260	0.0005	0.0007	0.02
Chromium, Dissolved	mg/L	544	0.001	0.005	0.005
Total	mg/L	273	0.005	0.005	0.1
Copper Dissolved	mg/L	602	0.001	0.002	0.005
Total	mg/L	384	0.001	0.005	0.05

TABLE 21 (CONTINUED)

SUMMARY OF WATER QUALITY DATA FOR ALL REACHES OF THE FRASER RIVER AND ESTUARY, FROM 1970 TO 1978

Parameter		No. of Values	Percentiles 10th	50th	90th
Heavy Metals, Continued					
Iron, Dissolved	mg/L	751	0.03	0.10	0.14
Total	mg/L	384	0.3	1.0	3.4
Lead, Dissolved	mg/L	604	0.001	0.001	0.005
Total	mg/L	387	0.001	0.002	0.1
Manganese, Dissolved	mg/L	72	0.003	0.008	0.02
Total	mg/L	322	0.02	0.05	0.10
Mercury, Dissolved	µg/L	187	0.05	0.05	0.05
Total	µg/L	148	0.05	0.05	0.14
Molybdenum, Dissolved	mg/L	11	0.0006	0.0012	0.0063
Total	mg/L	86	0.0005	0.0007	0.0013
Nickel, Dissolved	mg/L	58	0.01	0.01	0.01
Total	mg/L	226	0.01	0.01	0.01
Zinc, Dissolved	mg/L	553	0.002	0.005	0.017
Total	mg/L	414	0.002	0.008	0.03
Other Toxic Compounds					
Arsenic, Total	mg/L	78	0.005	0.005	0.005
Chlorine, Residual	mg/L	43	0.05	0.05	0.05
Cyanide	mg/L	209	0.01	0.01	0.01
Phenolics	mg/L	339	0.001	0.004	0.017
Sulphide	mg/L	236	0.05	0.05	0.32
Surfactants	mg/L	129	0.008	0.03	1.0
Tannin and Lignin	mg/L	220	0.2	0.5	0.8
Nutrients					
Nitrogen, Ammonia	mg/L	874	0.007	0.018	0.05
Nitrate	mg/L	923	0.03	0.08	0.18
Organic	mg/L	229	0.04	0.14	0.23
Phosphorus, Diss. Ortho	mg/L	420	0.003	0.007	0.040
Total	mg/L	1 473	0.008	0.041	0.138
Silica	mg/L	253	3.7	5.4	7.3
Coliforms					
Fecal	MPN/ 100 mL	5 106	40	930	7 500
Total	MPN/ 100 mL	9 342	390	4 300	24 000

TABLE 22

ESTIMATED QUANTITIES OF NUTRIENTS TRANSPORTED BY THE FRASER RIVER AT PATULLO BRIDGE

		Mean Annual Flow m^3/s	Mean Annual Loading t/a		
			Total Nitrogen	Total Phosphorus	Ortho-Phosphorus
1916-1976	10th Percentile (Low Flow Regime)	2 500	20 000	5 000	300
	50th Percentile (Median Flow Regime)	3 400	27 000	7 000	400
	90th Percentile (High Flow Regime)	4 600	37 000	9 000	600
1967	with 95% Confidence Limits	3 200	32 000±15 000	8 000±7 000	500±300
1977	with 95% Confidence Limits	2 600	27 000±11 000	7 000±5 000	400±300

TABLE 23

ESTIMATED QUANTITIES OF NUTRIENTS DISCHARGED TO THE FRASER RIVER IN THE STUDY AREA IN 1977

Source	Tonnes/annum	
	Total Nitrogen	Total Phosphorus
Municipal Effluents	3 700	700
Industrial Effluents	90	9
Landfills	350	1
Storm Sewers	1 000	150
Total	5 140	860

TABLE 24

SUMMARY OF FECAL COLIFORM DATA FOR EACH REACH OF THE FRASER RIVER AND ESTUARY, FROM 1970 TO 1977

River Arm	Reach Number	Year	Geometric Mean Fecal Coliform MPN/100 mL
Main Stem	Mission to Hope	1971-1976	100 - 300
	1	1971-1975	< 500
		1972	< 100
	2	1975-1977	1 000 - 2 000*
	3	1973-1975	1 000 - 1 500
		1976-1977	< 500
	4	1974-1975	1 000 - 4 500*
Main Arm	5	1974-1976	< 1 000
		1977	< 250
	6	1974-1976	1 000 - 2 000
		1977	< 1 000
	7	1973-1975	1 000 - 2 000
		1976-1977	< 1 000
	8	1971-1972	< 1 000
		1973-1974	1 000 - 1 500
		1975-1977	< 1 000
	9	1973-1977	1 000 - 2 000
	10	1970, 1971, 1974, 1976, 1977	< 1 000
		1972, 1973, 1975	1 000 - 3 000
	11	1972-1975	500 - 2 500
		1976-1977	< 1 000
	12	1974-1977	< 500*
	13	1970-1971	< 1 000
		1972-1974	1 000 - 1 500
		1975-1977	< 1 000
North Arm	14	1973-1975	2 000 - 5 000
		1976-1977	< 1 000
	15	1971-1975	1 000 - 4 000
		1976-1977	< 1 000
	16	1973-1976	7 000
		1977	< 1 000
	17	1970-1974	2 000 - 5 000
		1975-1977	< 2 000
	18	1971-1975	2 000 - 6 500
		1976-1977	1 000 - 2 000
	19	1971-1977	500 - 1 500
	20	1971-1976	< 500
	21	1971-1975	1 000 - 4 000
		1976	< 1 000
Middle Arm	22	1971-1975	2 000 - 4 000
		1976	1 000
		1977	< 1 000

* Limited data

TABLE 25

AVERAGE COMPOSITION AND FLOW OF LEACHATE FROM THE MAJOR ACTIVE LANDFILLS

		Richmond	Burns Bog	Braid Street	Leeder	Port Mann
Aluminum	mg/L	0.5	0.39			0.11
Arsenic	mg/L	<0.2	0.01	< 0.01		< 0.15
Barium	mg/L					0.14
Calcium	mg/L			120		160
Cadmium	mg/L	<0.01	0.0003	< 0.004		< 0.01
Carbon, Organic	mg/L	120			40	
Chemical Oxygen Demand	mg/L	700	250	840		500
Chloride	mg/L	300	280	170	36	93
Chromium	mg/L	0.03	0.05	0.04		< 0.015
Copper, Diss.	mg/L		< 0.005			
Tot.	mg/L	<0.02	0.01	< 0.07		
Flow (Estimated)	m^3/d	4 900	7 300	1 200		870
Fluoride	mg/L		0.19			
Iron	mg/L	15	6.2	43	4.9	
Lead	mg/L	<0.01	0.01	0.05		< 0.08
Manganese	mg/L	5	0.46	3.1	0.56	1.6
Mercury	mg/L	<0.1				< 0.1
Nickel	mg/L	<0.2	< 0.01	< 0.13		< 0.08
Nitrogen, NH_3	mg/L	50	90	30	0.3	45
pH		7.2	7.4	6.4	7.1	
Phosphorus, Tot.	mg/L					0.5
Solids, Susp.	mg/L	80		210		90
Tot.	mg/L	3 000		1 700		
Sulphate	mg/L	75		30	8	12
Tannin and Lignin	mg/L		17		36	
Zinc	mg/L	0.3	0.33	0.59		0.32
Estimated Amount of Waste Landfilled Annually	t/a	250 000	230 000	150 000	100 000	40 000

TABLE 26

WATER QUALITY IN CRESCENT SLOUGH, UPSTREAM AND DOWNSTREAM FROM THE DISCHARGE OF LEACHATE FROM BURNS BOG

		Upstream				Downstream			
		Max.	Min.	Mean	No. of Values	Max.	Min.	Mean	No. of Values
Aluminum, Diss.	mg/L	<1	0.03	< 0.28	4	< 1	0.01	0.28	4
Arsenic, Tot.	mg/L	0.014	0	0.009	3	0.012	0	0.008	5
Cadmium, Tot.	mg/L	< 0.0005	0	0.0003	3	0.0005	0	0.0003	3
COD	mg/L	227	49	149	12	334	118	195	12
Chloride	mg/L	432	9	149	12	625	64	292	26
Chromium, Tot.	mg/L	0.017	0	0.008	3	0.02	0	0.01	5
Copper, Tot.	mg/L	0.06	0.01	0.03	3	0.6	0.01	0.04	5
Colour		1 000	100	469	8	1 125	100	570	15
Fluoride	mg/L	0.34	< 0.1	0.16		0.36	0.17	0.23	7
Iron, Tot.	mg/L	9	0.7	6	6	17.5	5.1	9	5
Lead, Tot.	mg/L	0.007	0	0.004	5	0.012	0	0.006	7
Manganese, Tot.	mg/L	0.8	0.4	0.5	6	0.7	0.3	0.5	15
Mercury, Tot.	µg/L	< 1	< 0.05	< 0.3	4	< 1	< 0.05	< 0.3	4
Nickel, Tot.	mg/L	0.03	0.02	0.02	2	0.03	0.02	0.02	2
Nitrogen, NH_3	mg/L	94	0.14	19	13	890	1.6	52	28
Oxygen, Diss.	mg/L	9.6	1.7	4.7	10	7.9	0.03	3.8	22
pH		7.6	6.3	7.0	15	8	4.7	7.2	31
Tannin & Lignin	mg/L	20	7.5	14	5	20	8.4	14.3	7
Zinc, Tot.	mg/L	0.09	0.05	0.07	3	0.08	0.06	0.07	5

TABLE 27

AVERAGE HEAVY METAL CONCENTRATIONS IN SEDIMENTS VALUES IN PPM DRY WEIGHT

	Cadmium	Copper	Iron	Lead	Mercury	Nickel	Zinc
Main Stem	0.10	28	22 900	7.6		43	72
Main Arm	0.07	18	18 300	1.9	0.03	43	44
North Arm	0.03	24	19 500	29	0.03	39	85
Sturgeon Bank		26	24 200	8.6		43	64
Roberts Bank		25	23 500	2.9	0.29	46	54
North of Iona Jetty	0.5	14	15 500	5.5	0.04	31	45
Near Iona Outfall	3.3	172	27 900	145	1.22	47	212
South of Iona Jetty	1.0	43	23 000	28	0.18	42	83
New Westminster	0	31	12 600	162	0.11	31	227
Ladner Side Channel	0.32	53	40 400	21		79	103
Columbia River Downstream From Cominco, Trail	5.3	1 930	189 000	866	2.52		12 600
Illinois River, Illinois	2.0	19		28	27		81
Skeleton Creek, Oklahoma		1.8		3.5			9.2

TABLE 28

AVERAGE HEAVY METAL CONCENTRATIONS IN ALGAE
VALUES IN PPM DRY WEIGHT

	No. of Samples	Cadmium	Copper	Iron	Lead	Mercury	Nickel	Zinc
New Westminster	12	1.7	46	35 200	51	0.14	50	153
Marpole	12	1.7	50	31 000	55	0.09	54	185
Steveston	12	1.2	46		24	0.08	46	94
North Side of Iona Jetty	5	2.0	10	230	<4		4	39
South Side of Iona Jetty	4	4.3	18	590	10		4	122
Swansea Valley, Downstream from Smelter			610	17 600	1 700		490	4 900
Snow Water, Kulusuk, Greenland		1.0	10	7 500			10	20

TABLE 29

AVERAGE HEAVY METAL CONCENTRATIONS IN INVERTEBRATES
VALUES IN PPM DRY WEIGHT
(CONCENTRATION FACTORS IN BRACKETS)

	No. of Samples	Cadmium	Copper	Iron	Lead	Mercury	Nickel	Zinc
Amphipods, Westham Island	3	<3	85	1 270	18	0.05	7	75
Oligochaetes, North Arm	17	<1 (0.7)	16.2 (0.6)	3 560 (0.2)	11 (0.3)	0.47 (4.5)	7 (0.2)	120 (1.0)
Oligochaetes, Main Arm	5	<1 (0.8)	25 (0.6)	3 500 (0.1)	6 (0.4)	0.82 (10.2)	7 (0.2)	106 (1.3)
Chironomid Larvae New Westminster	2		44 (2.2)	2 400 (0.4)				165 (3.7)
Chironomid Larvae Oak Street	4		38 (1.9)	7 400 (1.1)		(0.9) (1.4)		175 (3.3)
Immature Insects, Columbia River Downstream From Cominco, Trail		7.6		383			952	
Oligochaetes, Illinois River, Illinois		1.1	23		17		11	41
Chironomid Larvae, Skeleton Creek, Oklahoma			1.9		1.3			57

Note: Concentration factors reported here are from averaging individual ratios, hence they do not correspond exactly with sediment data reported in Table 27.

TABLE 30

HEAVY METAL CONCENTRATIONS IN MUSCLE TISSUE OF FISH
VALUES IN PPM WET WEIGHT

	No.	Copper Max.	Copper Min.	Copper Mean	Mercury Max.	Mercury Min.	Mercury Mean	Zinc Max.	Zinc Min.	Zinc Mean
White Sturgeon	51	0.97	0.11	0.44	1.28	0.05	0.30	8.6	2.2	4.3
Mountain Whitefish	9	0.85	0.38	0.61	0.29	0.03	0.10	7.2	3.4	4.7
Dolly Varden	28	0.95	0.04	0.47	0.23	0.05	0.11	10.1	3.7	5.4
Cutthroat Trout	29	1.2	0.3	0.59	0.17	0.05	0.09	11.5	3.3	4.6
Rainbow Trout	45	1.02	0.22	0.63	0.31	0.02	0.09	9.3	3.2	4.9
Bridgelip Sucker	3	0.88	0.57	0.71			<0.05	19.4	5.5	10.5
Largescale Sucker	116	1.00	0.10	0.46	0.82	0.05	0.32	15.1	3.1	6.2
Carp	4	0.60	0.26	0.41	0.41	0.22	0.32	4.6	3.1	4.1
Peamouth Chub	125	2.4	0.16	0.74	2.19	0.07	0.31	21	5.9	11.9
Northern Squawfish	90	1.06	0.07	0.60	1.99	0.06	0.68	16.1	3.3	6.5
Redside Shiner	1			0.71			0.09			21.1
Black Crappie	5	0.41	0.36	0.36	0.29	0.13	0.21	7.1	5.2	6.1
Burbot	1			0.78			0.18			5.1
Prickly Sculpin	32	0.74	0.27	0.53	2.19	0.07	0.67	21	5.9	11.9
Chinook Salmon	2	0.70	0.40	0.55	0.03	0.02	0.03	3.2	3.1	3.1
Sockeye Salmon	5	0.80	0.69	0.73	0.05	0.03	0.04	5.2	3.8	4.2
Legislated Levels in Food for Human Consumption		100			0.5*			100		

* The U.S. Environmental Protection Agency has recently increased this level to 1.0 ppm wet weight.