Fraser River Estuary Study
Water Quality

Municipal Effluents

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ABSTRACT

An investigation into domestic sewage discharged directly to the Fraser River and Sturgeon Bank within the Fraser River Estuary study area in the period 1970 to 1979 was undertaken. Each treated discharge was addressed from the viewpoint of relevant objectives, conditions of permits which may apply, and applicable wastewater treatment technology. Each discharge was assessed according to monitoring data related to the discharge.

All discharges of raw sewage, excepting combined sewer overflows and sewage treatment plant bypasses, will have been eliminated from receiving waters in the study area by the end of 1980. As well, all sewage will receive as a minimum primary treatment.

The three largest sewage treatment plants within the study area are operated by the Greater Vancouver Sewerage and Drainage District (GVS & DD). Due to possible hydraulic overloading, a detailed engineering assessment of the present primary facilities at the Iona STP is required immediately.

The GVS & DD should prepare a timetable outlining steps to be taken to upgrade the effluent quality at the three sewage treatment plants to meet level "AA" of the objectives with respect to acute toxicity. As a means to this end, a source control program is recommended.

It is recommended that the 1979 effluent monitoring program at the three plants be continued, and that a special study related to chlorinated organics formed in injection water be undertaken. As well, a groundwater monitoring program adjacent to sludge storage facilities is recommended. Studies to measure the timing and volumes of combined sewer overflows and sewage treatment bypasses are recommended.

It is further recommended that the diversion of sewage from the secondary treatment plants at Maple Ridge and Pitt Meadows to Annacis be deferred until secondary treatment of the Annacis effluent is provided.

Note: R.T. Cain, P.Eng. left the employ of the Ministry of Environment in February 1979 to join McMillan Bloedel Ltd.

PREFACE

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

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

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

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

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

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

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

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

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

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

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1. INTRODUCTION

With some exceptions, wastewater cannot be legally discharged to the environment unless a pollution control permit allowing the discharge has been issued. The permits are issued by the Pollution Control Branch (PCB), using objectives established from public hearings held by the Pollution Control Board. The functions of the PCB in this respect were placed under the authority of the Waste Management Branch in late 1979.

Swain has described elsewhere(1) the direct discharges of domestic sewage into the Fraser River from industrial complexes and miscellaneous small operations. This report will describe the major discharges of effluent from municipal sewage systems entering water bodies within the study area and will discuss related data, but will not take the environmental impact of these discharges into account. The impact of these discharges has been discussed in other reports in this series(13)(23). Possible methods of improving effluent quality are examined.

The data base reviewed covers the period from 1972 to December 1979. Most of the data have been extracted from the files of the PCB, the files of the Greater Vancouver Sewerage and Drainage District (GVS & DD), or from the computerized data storage and retrieval system operated by the Ministry of Environment. Not necessarily all chemical parameters analyzed at an operation have been included. Data included are those which the authors feel can help in an overall understanding of the effect of municipal effluents on the receiving water quality.

The data in this report may vary slightly from those presented in other background reports or in the summary report of this study. This is due to overlapping stages of preparation for the different reports, however the overall content and conclusions are not affected.

2. BACKGROUND INFORMATION

This chapter presents an historical summary of major engineering reports which have been responsible, in part, for the development of the sewerage systems serving the majority of the study area. As well, the processes by which the effluents are regulated are addressed.

2.1 Evolution of the Municipal Sewerage Systems

2.1.1 The Lea Report(2)

Mr. R.S. Lea was commissioned in May of 1911 by the Committee of the Greater Vancouver Joint Sewerage and Drainage System (composed of representatives of the City of Vancouver, the Municipalities of Point Grey, South Vancouver and Burnaby). Mr. Lea was to prepare a scheme for a comprehensive sewerage and drainage system for the area.

The Lea Report was submitted to the Committee in February 1913. The report formed the basis for the design and construction of sewerage and drainage facilities in the area until 1953. The report proposed sewage disposal by dispersion and dilution, but noted that sewage treatment might be required for sewage discharged to the Fraser River.

The report led to the establishment of the Vancouver and District Joint Sewerage and Drainage Board (VDJS & DB) for the administration of "An Act Providing a Joint Sewerage and Drainage System for the City of Vancouver and Adjoining Districts" (proclaimed March 1914). One recommendation of the report was not implemented. The recommendation was that separate domestic sewage and storm sewage systems be used in areas draining to English Bay and False Creek.

2.1.2 The Rawn Report(3)

The VDJS & DB was composed of the City of Vancouver, the Municipality of Burnaby, and the City of New Westminster in 1949 when consultants were commissioned to review the Lea Report. The consultants were also to recommend a revised plan for sewerage and drainage in a considerable portion of the Lower

Mainland. Many of the areas to be studied for the purposes of the report were outside of the then district boundaries. The Rawn Report was submitted in September 1953. One of its recommendations was for the construction of a high rate primary sewage treatment plant at Iona Island (see Figure 1).

The VDJS & DB was replaced by the Greater Vancouver Sewerage and Drainage District (GVS & DD) in 1956. The GVS & DD was charged with implementing recommendations of the Rawn Report. Membership of the initial GVS & DD has grown to include the cities of Port Moody, North Vancouver, New Westminster, Port Coquitlam, White Rock, and Langley; the Districts of Coquitlam, West Vancouver, North Vancouver, Surrey, Delta, and Fraser Mills; and the Township of Richmond.

The GVS & DD is responsible for the construction, maintenance, operation, and administration of major sewerage and drainage facilities. These sewerage and drainage facilities handle all municipal-type sewage within the GVS & DD. Local sewerage works within the area which carry sewage to the GVS & DD sewerage works are the responsibility of the City, District or Township in which these are located.

2.1.3 Updating the Rawn Report

A report published in January 1969[4] recommended the establishment of three major areas (Figure 2: Fraser, Vancouver, Richmond) within the study area (total of four within the GVS & DD with North Vancouver). The report outlined plans for sewerage works in each of the Fraser, Vancouver, and Richmond Sewerage areas, including the establishment of major trunk collection systems, new sewage treatment works at Lulu and Annacis Islands, and additional sewage treatment works at the Iona Island sewage treatment plant.

2.2 Regulation of Effluents

2.2.1 Pollution Control Permits

Municipal effluents are discharged to surface waters following conditions of a pollution control permit. These permits are issued under the authority of the Director of Pollution Control, who administers the Pollution

Control Act.

The permits contain, amongst other matters, limits on effluent volume and contaminant concentrations. These limits are usually based upon provincial objectives[5] which have been issued by the Pollution Control Board. The requirements for wastewater monitoring of a particular discharge are based upon the volume of sewage being discharged, the dilution provided by the receiving water, as well as the type and location of receiving water. The permit holder is normally directed to undertake surveillance monitoring regarding volumes discharged and contaminant limits. The permit also generally outlines treatment works which may be undertaken.

2.2.2 Development of Pollution Control Objectives

The Pollution Control Board sponsored one public inquiry in which testimony was presented by interested parties and reviewed by a panel held to be knowledgeable in various related disciplines. As a result of the inquiry, a series of objectives was developed relating to various municipal-type waste discharges. In all of the objectives, specific requirements are set as a result of an evaluation of sensitivity of the environment, state-of-the art, and economic considerations. The objectives are to be periodically reviewed in light of experience and further knowledge.

All new discharges are to meet level "AA" objectives. Existing discharges which do not meet level "AA" are to be upgraded. Upgrading will be to interim level "BB", where appropriate, and then to level "AA". The timing involved in upgrading is determined by the Director of Pollution Control, with due regard to the quality and use of the environment at each particular location.

No specific regulations have been filed under the Federal Fisheries Act related to municipal-type sewage discharges, however general provisions of the Act would be applicable.

3. IONA ISLAND SEWAGE TREATMENT PLANT (PE 23)

The Iona Island sewage treatment plant (STP) is located on Iona Island at the mouth of the North Arm of the Fraser River (see Figure 1). It was built in the period of 1961 to 1963, expanded in 1972 and 1973, and again in 1978 to 1979.

Effluent from the plant is discharged into an open channel which extends from the shoreline, across the intertidal foreshore of Sturgeon Banks, to the Strait of Georgia. The channel is uncovered at low tide but covered at high tide by marine water. A jetty borders the north side of the channel.

The plant receives flows from the Vancouver Sewerage Area (see Figure 2). This sewerage area encompasses the City of Vancouver, the University of British Columbia and Endowment Lands, Vancouver Airport, and a small part of Burnaby. This area covers approximately 14 400 hectares and contains an estimated population of 475 000. The population is projected to increase to 640 000 by the year 2021. The area is serviced to a large degree by combined sewers which can carry domestic sewage, stormwater and industrial wastewater.

In an attempt to identify industrial discharges within the City of Vancouver, and to determine the effect of these discharges on effluent quality, the City of Vancouver and the Environmental Protection Service (EPS) carried out an investigation during 1977[6][38]. Based upon water consumptions at various industries, the food industry discharged 41.1% of the wastewaters discharged by industry to the sewerage system, the wood and wood products industries 16.3%, the metal industries 9.9%, printers and photographers 9.2%, the chemical industries 9.1%, plastics industries 5.1%, and other miscellaneous industries 9.3%. Chemical industry operations discharged 61% of the sludge generated by industry, service industries 13.9%, and metal industry operations 12.7%.

3.1 Plant Design

The Iona Island STP provides primary treatment for the sewage. This is accomplished through a process which includes mechanical screening, comminution, grit removal, pre-aeration, and sedimentation. Facilities are also available to permit the pre-chlorination of the sewage, although records indicate that this has not occurred since 1973. Disinfection facilities, in the form of chlorination equipment and a chlorine contact tank, permit the disinfection of the effluent from May through September on a yearly basis. Dechlorination of the effluent is not carried out. Accumulated sludge passes through thickeners, and is treated in four anaerobic sludge digesters.

The plant design is based upon a population equivalent of 640 000 persons, a loading of 39 700 kilograms per day (kg/d) of biochemical oxygen demand (BOD_5), and a loading of 44 500 kg/d of suspended solids. The actual 1979 loadings were 64 800 kg/d of BOD_5 and 54 600 kg/d of suspended solids.

The design removal efficiencies are 35% for BOD_5 and 60% for suspended solids. During 1979, actual removal efficiencies were 36% for BOD_5 and 51% for suspended solids.

The peak flow rate at which the primary sedimentation tanks are used is 942 000 cubic metres per day (m^3/d). The raw sewage pumps have a maximum rated capacity of 2 080 000 m^3/d. However, flows greater than 942 000 m^3/d, which are attributable to stormwater being mixed with domestic sewage, are diverted from the sedimentation tanks, and are screened and degritted before entering the chlorine detention pond. These diverted flows are then discharged to Sturgeon Banks. Flows cannot exceed 1 530 000 m^3/d, since the incoming sewers are only designed to carry that volume of sewage.

3.2 Pollution Control Permit

Pollution control permit PE 23 was issued for the plant in April 1958. The latest amendment, which did not alter permit limits was in January 1979. The permit limits are listed in Table 1. The permit restricts the average daily effluent discharge rate to 318 000 m^3/d, the pH to within the range of 6.7 to 7.3 pH units, the BOD_5 to a concentration of 100 mg/L, and the suspended solids concentration to 70 mg/L. The limits for BOD_5 and suspended solids in pollution control permit PE 23 are more stringent than level "BB" of the Objectives, although not as stringent as level "AA". However, these limits were issued prior to the adoption of the Municipal Objectives in 1975, and have not been changed to conform to the Objectives.

A summary of the compliance of the effluent quality with PE 23 is included in Table 2. This table indicates that the suspended solids concentrations in the effluent have met the permit limit for approximately 90% of the analyses. However BOD_5 concentrations met permit limits for only 55% of the measurements, while after 1977, flow met the limits for less than 10% of the measurements. The pH of the effluent met permit limits for approximately 70% of the measurements.

3.3 Effluent Characteristics

The primary treatment facilities at the plant have not been expanded since 1973. The effluent monitoring data have been summarized in Table 3. Monthly removal efficiencies for BOD_5 and suspended solids to the end of 1977 have been presented graphically in Figure 3. Graphs presenting the percent removal of suspended solids for 1979 as a function of temperature, flow, and initial suspended solids concentrations have been presented in Figure A-1 of Appendix A.

The GVS & DD indicated in August 1980 that flow measurements (and subsequently calculated loadings) at the Iona STP may have been overestimated by as much as 30% since 1977, due to problems with the measuring devices[37]. Loadings quoted hereafter have not been corrected for the possible 30% error.

The average suspended solids loading to the receiving water was 24 000 kg/d during 1979. This was an increase of nearly 30% over the 1977 loading. (The year 1977 was the last one referred to in the Summary Report[7]). Yearly mean concentrations of suspended solids in the effluent have fluctuated only 8 mg/L during the eight year period of plant operation.

The main design function for primary treatment plants is the removal of suspended solids. The removal of suspended solids in most years reached its highest degree of efficiency during August. During that month, a mean suspended solids reduction of 70% was reached which compares to a design level of 60%. This high removal efficiency was due in part to low flows of stormwater. However, the suspended solids removal efficiency averaged only 56% during 1979.

The percentage removal of suspended solids at the Iona STP during 1979 was statistically analyzed by means of a multiple linear regression with the three factors - temperature, flow, and the initial concentration of suspended solids (see Appendix A). The three factors had a multiple correlation coefficient of 0.70, and thus directly influenced approximately 50% of overall removal efficiencies.

The loading of BOD_5 in the primary treated effluent to Sturgeon Banks was 41 700 kg/d during 1979, an increase from 1977 of less than 3%. The yearly average BOD_5 concentration in the effluent has fluctuated over a range of 31 mg/L during the eight years of plant operation.

The BOD_5 removal efficiency reached 35% during 1979. The greatest BOD_5 removal efficiency during the plant's operation occurred in 1978 when it reached 38%. The mean values of BOD_5 removal efficiency for specific months in the five year period from 1973-1977 were approximately constant from May through September. The mean removal efficiency during those months was 35%, which is also the design efficiency. The maximum removal efficiencies for BOD_5 and suspended solids correspond to the time of year at which the smallest effluent discharge rate occurs, that is to say the period when little stormwater enters the plant resulting in better sedimentation.

Dissolved oxygen concentrations in the plant influent ranged from less than 0.1 mg/L to 5.7 mg/L in 1979. Sulphide concentrations were less than 0.06 mg/L. Dissolved oxygen concentrations in the plant effluent ranged from 2.2 mg/L to 7.0 mg/L.

The mean concentration of all metals in the effluent was less than 0.2 mg/L except iron, boron (1979 mean concentration of 0.2 mg/L), and aluminum (1979 mean concentration of 0.9 mg/L). The concentrations of all metals except iron met level "AA" of the Objectives. Iron concentrations met level "BB".

Removal efficiencies during 1977 for metals with concentrations above detection levels varied from 20% for zinc to 60% for copper. Measured loadings during 1979 of the more toxic metals ranged from about 20 kg/d for lead to 55 kg/d for zinc. During the same year, for less toxic metals, the loading of iron was 150 kg/d, the loading of aluminum was 400 kg/d, while the loading of boron was 90 kg/d.

The loading of Kjeldahl nitrogen in the primary treated effluent to Sturgeon Banks during 1979 was 8 400 kg/d. This represents an increase of 60% over the average loading discharged during 1977. The loading of total phosphorus was 1 335 kg/d during 1979. This is an increase of 38% over the 1977 loading.

Several constituents in the effluent were at concentrations below detection limits during 1979. These included arsenic, barium, cobalt, cyanide, mercury, molybdenum, selenium, silver, sulphide and tin.

Geometric monthly mean total coliform contents in the effluent have been calculated for 1977, and are included in Table 4. The data indicate that the coliform contents were reduced from approximately 2 000 000 MPN/100 mL when the effluent was not disinfected, to approximately 200 MPN/100 mL when effluent disinfection was taking place.

Geometric mean loadings of total coliforms for 1977 were also calculated. This was done in order that different coliform loading sources within the study area might be compared. Further discussion of these results has been presented by Churchland[8].

Bioassays were performed during 1976 by the International Pacific Salmon Fisheries Commission (IPSFC) and the EPS. The test conducted by the IPSFC was based upon the average over three weeks of continuous flow tests with sockeye salmon before chlorination of the effluent. The test indicated a 96 hour LC_{50} of 45% (42% based upon mean mortality). This result is similar to acute toxicities measured at four primary treatment plants near San Francisco[9] and one plant near Seattle[10]. The two EPS static tests utilized rainbow trout as the test species with samples which were aerated before the bioassays were conducted. The mean 96-hour LC_{50} was 51%.

B.C. Research performed monthly bioassays for the GVS & DD during 1978 and 1979. The static tests were carried out on grab samples using rainbow trout as the test species. During 1978, all 96-hour LC_{50} values were reported as greater than 100%. The mean 96-hour LC_{50} during 1979 was lowered to greater than 98%, and the values ranged from 86.2% to greater than 100%. These tests indicate that the effluent toxicity consistently meets level "BB" of the Objectives, which contrasts with both the EPS and IPSFC tests.

In reviewing the acute toxicity studies performed, Singleton[(11)] indicated the toxicity in the Iona effluent had been partly attributed to anionic surfactants, un-ionized ammonia, and possibly copper.

Cain, Clark and Zorkin[(12)] carried out a survey of trace organics in selected discharges within the study area during 1978. Two effluent samples indicated concentrations of pentachlorophenol of 1.2 μg/L and 1.3 μg/L, and concentrations of 2,3,4,6-tetrachlorophenol of 0.9 μg/L and 0.7 μg/L. A third analysis indicated concentrations of 6 μg/L of pentachlorophenol and 30 μg/L of tetrachlorophenol. Trace organics measured in the effluent were fatty acids (100 μg/L of hexadecanoic acid and 200 μg/L of octadecanoic acid); phthalate esters (20 μg/L of dibutyl-, 2 μg/L of diethyl-, 50 μg/L of dimethyliso-, and 10 μg/L of dimethyl); caffeine (10 μg/L); steroids (70 μg/L of each of cholesterol and coprostanol); and chlorinated hydrocarbons (0.004 μg/L of hexachlorobenzene and 0.3 μg/L of polychlorinated biphenyls).

Stancil[(13)] has reported a degraded zone adjacent to the Iona STP outfall. The degradation, which is becoming more widespread, affects the dissolved oxygen, phosphorus, and nitrogen in the water column, as well as nitrogen, phosphorus, organic carbon, and metals in the sediments. Metal contents of biota have risen, and the sediments adjacent to the outfall are of a much finer composition than those originally present. There are also increased suspended solids concentrations in the water column adjacent to the outfall.

3.4 Sludge

The quantity of solids removed in the primary treatment process since 1976 has averaged 30 tonnes/day (t/d). This sludge is digested in four anaerobic digesters and is stored on site. An average of 500 m^3/d of sludge at a solids concentration of 6% to 7% has, since 1976, been sent to the digesters after passing through thickeners. These values for sludge volumes are of the same order as measured at primary treatment plants in Ontario[14], where sludge volumes were measured as being 1.78 m^3 sludge for every 1 000 m^3 of wastewater treated.

All the digested sludge is stored in lagoons. There are four storage lagoons, each with sufficient capacity for approximately five years of sludge. There is sufficient land available for four additional lagoons. One lagoon has been emptied and the dried sludge provided to a composting company. Leachate from the lagoons is not treated further. No monitoring of the groundwater quality adjacent to the lagoons is carried out.

Analyses of metals in the sludge from the Iona Island STP are presented in Table 5. These values are lower than the median values reported by the Environmental Protection Agency (EPA)[15][16] (Table 17) for metals in anaerobically digested sludge from treatment plants in selected U.S. cities.

Other contaminants removed during treatment, and which pass through the digesters, are present in the sludge. Two analyses of the sludge for the presence of polychlorinated biphenyls indicated concentrations of 1.1 ppm and 1.9 ppm, based upon the wet weight of the sludge. However, an analysis of the sludge for the presence of polychlorinated biphenyls by B.C. Research indicated a concentration of less than 0.1 ppm. These data indicate that either methods of sampling the sludge are extremely critical, analytical techniques are inadequate, or that there are large variations in sludge quality.

The PCB analyzed the sludge on one occasion during 1979 as part of a program of analyzing sludges in British Columbia. The results, included in Table 16 and based upon the wet weight of the sludge, indicated 13 300 mg/kg of iron, 966 mg/kg of copper, 912 mg/kg of zinc, 142 mg/kg of chromium, 29 mg/kg of nickel, 7 mg/kg of cadmium, and 6.7 mg/kg of aluminum in the sludge.

4. ANNACIS ISLAND SEWAGE TREATMENT PLANT (PE 387)

The Annacis Island STP is located on Annacis Island (see Figure 1). It started treating sewage in July 1975. Effluent from the plant is discharged via a submerged diffuser system which extends to approximately the midpoint of Annieville Channel in the Main Arm.

The plant receives flows from the Fraser Sewerage Area (see Figure 2). This sewerage area encompasses all or parts of Delta, Surrey, Richmond, New Westminster, Port Coquitlam, Coquitlam, Vancouver, Burnaby, Langley, Port Moody, and White Rock. It covers an area of 46 000 hectares and contains an estimated population of 397 000. The area is serviced by separate sanitary and storm sewer systems except for New Westminster and parts of Burnaby, which have combined storm and sanitary sewers.

A survey carried out by the GVS & DD(17) indicated that industrial wastewater contributes 20% of the average daily flow in the Fraser Sewerage area. It also indicated that 35% of the industrial flow originated from food processing operations, 32% from wood products operations, and 14% from petroleum industry operations. The remaining 19% was discharged by a large number of small firms.

4.1 Plant Design

This facility provides primary treatment of the sewage. This is accomplished through a process which includes mechanical screening, pre-aeration, and sedimentation. Provision has been made to permit pre-chlorination of the influent to the plant.

The plant effluent is disinfected using chlorine from May through September, and is dechlorinated during that time using sulphur dioxide. A surface mixer is utilized at the end of the chlorine contact tank to ensure the adequate mixing of the sulphur dioxide with the effluent.

Sludge which is removed during the treatment process is thickened and subsequently treated in two anaerobic digesters. The digested sludge is then stored in sand dyked storage lagoons. Two additional sludge digesters are being constructed during 1980.

The plant design is based upon an initial population equivalent of 490 000 persons (1986 estimate), with an ultimate design population equivalent of 1 172 000 (estimate for year 2021). The plant was initially designed for a BOD_5 loading of 48 900 kg/d and a suspended solids loading of 61 050 kg/d. The actual 1979 plant loadings were 41 800 kg/d of BOD_5 and 42 400 kg/d of suspended solids. The assumed loading reductions used in the design were 35% for BOD_5 and 60% for suspended solids.

The design peak dry weather flow rate is 379 000 m^3/d, although the design average dry weather flow is only 245 000 m^3/d. The ultimate design dry weather flow is 585 000 m^3/d. The raw sewage pumps have a maximum rated capacity of 881 000 m^3/d.

The initial plant design capacity is the capacity presently built into the plant and is based upon 1986 projections, although influent pumping and screening are designed for ultimate flows. However, this design capacity could be exceeded before 1986 should flows and/or concentrations greater than projected be conveyed to the plant. References to ultimate design capacity relate to increased treatment capabilities which are not built at the present time, but which have been projected as being adequate to provide primary treatment during the period 1986 to 2021.

4.2 Pollution Control Permit

Pollution control permit PE 387 was issued in March 1971 for discharges from the plant which was at the time unbuilt. The latest amendment to the permit was in January 1979. The permit limits are included in Table 1.

The permit restricts the effluent discharge rate to 586 000 m^3/d, the BOD_5 concentration to 130 mg/L, and the suspended solids concentration to 100 mg/L. The limits prescribed for BOD_5 and suspended solids are equivalent to, or more stringent than, level "BB" of the Objectives. To achieve level "AA" of the Objectives, secondary treatment of the effluent would be required.

A summary of the compliance of effluent quality with PE 387 is included in Table 2. This table indicates that flow met the permit limit 100% of the time, and suspended solids concentrations met the limit on over 95% of the 1979 analyses. The BOD_5 in the effluent met the permit limit on only 30% of the 1979 analyses.

4.3 Effluent Characteristics

The effluent monitoring data have been summarized in Table 6. The monthly removal efficiencies for BOD_5 and suspended solids, from plant start-up to December 1977, have been presented graphically in Figure 4. Graphs for the percent removal of suspended solids for 1979 as a function of temperature, flow, and the initial suspended solids concentrations have been presented in Figure A-2 of Appendix A.

The suspended solids loading to the river was 14 200 kg/d during 1979. This represents an increase of 32% over the loading discharged during 1977. When compared to the effluent design loading, the 1979 loading is 58% of the design loading.

The average suspended solids concentration in the effluent increased from 52 mg/L in 1975 to 74 mg/L during 1979. These increases are due, in part, to increased flows between 1975 and 1979, which reduce the retention time of the sewage in the plant and subsequently affect effluent quality. Another factor is that the strength of the influent sewage is increasing.

The removal efficiency for suspended solids reached its maximum during the July through September period. During these months, a 70% reduction of suspended solids occurred. This compares to a design level of 60%, which is not met during five months of the year.

The percentage removal of suspended solids at the Annacis STP during 1979 was statistically analyzed in Appendix A using a multiple linear regression with the factors temperature, flow, and the initial concentration of suspended solids. The three factors had a multiple correlation coefficient of 0.68, and thus directly influenced approximately 46% of overall removal efficiencies.

The BOD_5 loading to the river was 30 100 kg/d during 1979. This represents a loading increase over 1977 levels of 39%. However, the 1979 plant loading rates are at only 86% of design.

The maximum BOD_5 removal (37%) occurred during September, and the highest yearly BOD_5 removal efficiencies were recorded for the July through September period. The design removal efficiency of 35% is usually met in September.

The average concentrations of COD in the effluent have increased from 163 mg/L during 1975 to 321 mg/L in 1979. The COD loading increased from 24 000 kg/d in 1975 to 61 600 kg/d in 1979.

Septic conditions have been noted in the influent to the Annacis plant. During 1979, sulphide concentrations as high as 0.8 mg/L, and dissolved oxygen concentrations of less than 0.1 mg/L have been recorded. These septic conditions will affect the dissolved oxygen content of the plant effluent, and in fact, dissolved oxygen concentrations as low as 1.8 mg/L have been recorded in the effluent (mean concentration 3.2 mg/L).

The mean concentration of all metals in the effluent was less than 0.2 mg/L except for iron, boron (1979 mean concentration of 0.3 mg/L) and aluminum (1979 mean concentration of 1.0 mg/L). The concentrations of all metals except iron consistently met level "AA" of the Objectives. The concentration of iron consistently met level "BB".

During 1977, removal efficiencies for metals with concentrations above detection limits were fairly consistent, ranging from 21% removal of lead to 30% removal of copper. The loadings to the river recorded in 1979 for toxic metals ranged from about 6 kg/d for lead to 31 kg/d of zinc. Aluminum, boron, and iron are less toxic than many metals. The 1979 loading rates were 190 kg/d, 60 kg/d and 140 kg/d respectively.

The 1979 loading of Kjeldahl nitrogen to the river was 4 600 kg/d. The 1979 loading of total phosphorus was 845 kg/d. These represent increases over 1977 loading rates of 22% for Kjeldahl nitrogen and 14% for total phosphorus.

Analyses for several constituents in the effluent indicated that concentrations were below detection limits during 1979. Constituents in this group included arsenic, barium, cobalt, cyanide, mercury, molybdenum, nickel, selenium, silver, sulphide and tin.

Geometric monthly mean total coliform values in the effluent have been calculated for 1977. These values, included in Table 7, indicate that total coliform values were reduced from values of approximately 9 000 000 MPN/100 mL during periods when the effluent was not being chlorinated, to approximately 800 MPN/100 mL during periods when the effluent was being chlorinated. Geometric mean loadings of total coliforms have also been calculated in order that Churchland[8] might compare different coliform sources.

Bioassays performed on the effluent have been summarized by Singleton[11]. Tests have been performed by the EPS, B.C. Research, and the IPSFC. Static tests, using 24-hour composite samples, were performed by both the EPS and the IPSFC during 1976. The mean 96-hour LC_{50} values were 68% and 38%, respectively. However, the EPS samples were aerated for 18 hours before the tests were commenced. Tests performed by the IPSFC using continuous flow bioassays over a nine week period indicated a 96-hour LC_{50} of 26%. Fifteen static tests carried out between 1976 and 1978 by B.C. Research using grab samples indicated a mean 96-hour LC_{50} of 92.8%, and a range of values from 43% to greater than 100%.

In November 1979, after chlorination had ceased for the year, continuous flow and static bioassays of 24-hour composite samples were conducted by IPSFC at Annacis Island treatment plant in the same manner as in 1976. In addition, static bioassays of grab samples were conducted. For 45 of 47 bioassays at 75% effluent, mortalities were 100% in 96 hours. The 96-hour LC_{50} ranged from 18 to 30% in continuous flow bioassays in 1979, with the most toxic effluents occurring during dry weather flow. In no case did effluent meet a 96-hour LC_{50} equal to 75%, the level "BB" objective.

B.C. Research performed monthly bioassays during 1978 and 1979 for the GVS & DD on grab samples of the Annacis effluent[11]. The 1978 mean 96-hour LC_{50} was 84%, for a range of values from 52.3% to greater than 100%. The effluent became more lethal during 1979 when the mean 96-hour LC_{50} was 77%, with a range of values from 50% to greater than 100%. These ranges of values do not consistently meet level "BB" of the Objectives.

In reviewing the bioassays performed, Singleton[11] indicated that the toxicity in the Annacis effluent could be attributed to anionic surfactants, cyanide, and possibly un-ionized ammonia.

Cain, Clark and Zorkin[12] carried out a survey of trace organics in selected discharges within the study area during 1978. Samples of effluent were collected on two occasions. The samples contained 2,4,6-trichlorophenol (0.7 µg/L and 1.2 µg/L), pentachlorophenol (1.2 µg/L and 4.5 µg/L), and 2,3,4,6-tetrachlorophenol (13.2 µg/L and 28.8 µg/L). Trace quantities of 2,3,6-trimethylphenol and 4-chloromethylphenol were found in one sample.

A third effluent sample, analyzed for additional trace constituents, indicated a level of 270 µg/L of hexadecanoic acid, 2 µg/L of dibutylphthalate, 4 µg/L of diethylphthalate, 20 µg/L of caffeine, 90 µg/L of coprostanol, 110 µg/L of cholesterol, 9 µg/L each of pentachlorophenol and tetrachlorophenol, 0.006 µg/L of hexachlorobenzene and 0.24 µg/L of polychlorinated biphenyls.

Atwater[19] has reported that leachate from the Burns Bog landfill is to be diverted to the Annacis STP. The 1979 diluted leachate flow rate represents 1.4% of the 1979 effluent flow rate from (and assumed influent flow rate to) the Annacis STP. The very approximate 1979 leachate loadings to the Annacis STP, calculated by Atwater[19], are less than 1.4% of the Annacis STP effluent loadings except for zinc (2.6%), Kjeldahl nitrogen (4.6%), and iron (11.5%).

4.4 Sludge

The quantity of solids removed in the primary treatment process has averaged 20 t/d since 1976. The sludge is concentrated in thickeners, digested in anaerobic digesters, and subsequently stored on site. Overflow from the sludge thickeners is returned to the pre-aeration tanks. Leachates from the lagoon are not collected or treated further. Supernatant from the lagoons is returned to the pre-aeration tanks, as necessary. No monitoring of groundwater quality adjacent to the lagoons takes place.

An average of 400 m^3/d of sludge was sent to the anaerobic digesters during 1979. This value is similar to the quantities reported in the 1978 studies carried out in Ontario, which indicated sludge volumes of 1.78 m^3 for every 1 000 m^3 of wastewater treated[14].

There are presently three storage lagoons at the Annacis site, two already full. The third lagoon may have sufficient capacity to store sludge until 1985. The GVS & DD is presently studying alternate methods and locations of sludge disposal, including the possibility of excavating sludge from the two existing but filled lagoons, and re-using their capacities. However, no decision related to the ultimate disposal of the presently lagooned sludge has been made.

Analyses of metals contents in sludge from the Annacis Island STP have been presented in Table 8. These values are lower than the median values reported by EPA[15,16] (Table 17) for metals in anaerobically digested sludge from treatment plants in selected cities in the USA.

The PCB analyzed the sludge on one occasion during 1979 as part of a program of analyzing sludges in British Columbia. The results, included in Table 16 and based upon the wet weight of the sludge, indicated 8 700 mg/kg of iron, 1 070 mg/kg of zinc, 992 mg/kg of copper, 157 mg/kg of chromium, 32 mg/kg of nickel, 5 mg/kg of cadmium, and 4.4 mg/kg of aluminum in the sludge.

4.5 Non-Technical Considerations

Controversy has persisted regarding the location of this facility and the degree of treatment that it should provide since before its construction. On December 7, 1972 the Lieutenant Governor in Council instructed the Pollution Control Board to review its policy with respect to primary treatment of municipal sewage discharges entering the Lower Fraser River, and to establish a new policy requiring secondary treatment at Annacis. On December 12, 1972, the Pollution Control Board amended its policy to comply with these instructions.

Pollution control permit PE 387 had required, when issued on March 3, 1971, that primary treatment be provided at Annacis. On February 22, 1973, the Director of the PCB, in keeping with the new Board policy, amended PE 387 so that secondary treatment was required at Annacis.

The GVS & DD appealed the conditions of the amended permit which required secondary treatment, to the Cabinet in June 1974. The basis of the GVS & DD appeal was that there were no technical grounds on which to base a requirement for secondary treatment. On April 21, 1975, a Committee of the Cabinet allowed the appeal. However, the Committee of the Cabinet also instructed that a Technical Committee under the Chairmanship of the Environment and Land Use Committee (ELUC) Secretariat be established with a four-fold responsibility. The responsibilities were to assess alternative secondary treatment methods, to present a fool-proof means of dechlorination, to consider the possibility of harmful effects of secondary treatment upon the nutrient chain, and to suggest alternatives which would lead to a better control of toxic materials entering the sewage systems.

The report issued by the ELUC Secretariat[20] made two major recommendations. One recommendation called for the pilot testing of chemical, physical-chemical, and biological secondary treatment processes at Annacis. The second recommendation called for the immediate implementation of a source control program for all major discharges of toxic substances to the sewerage system. The Director of the PCB ordered the GVS & DD, by letter dated February 4, 1977, to implement a program of obtaining information on the generation, transportation, and disposal of hazardous and toxic wastes within the GVRD. An April 4, 1977 amendment to PE 387 directed the GVS & DD to expand the source control program over the entire region so as to reduce the disposal of toxic materials directly into municipal sewers, and to provide a schedule to locate and control such sources. The GVS & DD contend they do not have the legal authority to implement an adequate source control program. As well, the GVS & DD was to implement pilot testing to determine the most cost effective treatment alternative for secondary treatment at the facility.

The GVS & DD completed the survey to identify and characterize toxic and hazardous wastes and submitted a report to the PCB in November 1978[17].

A pilot testing program related to treatment alternatives has not been undertaken. The GVS & DD did not wish to proceed until required effluent standards were defined, since effluent characteristics would vary from process to process. These matters were the subject of a public inquiry held by the Pollution Control Board in February of 1980. The Pollution Control Board had not finalized its recommendations upon completion of this background report.

5. LULU ISLAND SEWAGE TREATMENT PLANT (PE 233)

Lulu Island is geographically separated from the remainder of Greater Vancouver by the North, Middle, and Main Arms of the Fraser River. The island, which is dyked, is a reclaimed river delta. The central portion of the island consists largely of peat bogs which restrict industrial and residential activities to the eastern and western extremities. The western population centre, consisting of residential and light industrial development, is independently served by the Lulu STP.

The Lulu Island STP is located at the south-western edge of Lulu Island (see Figure 1). It started treating sewage in January 1973. Effluent from the plant is discharged via a submerged diffuser into the Main Arm, upstream from Steveston Island.

The plant receives flows from the Richmond Sewerage Area (see Figure 2). This sewerage area encompasses most of the developed areas of Richmond. It contains an area of 5 300 hectares and an estimated population of 96 000, approximately 60 000 of whom are served by the treatment plant. The sewerage area is serviced by separate storm and sanitary sewer systems.

A survey carried out by the GVS & DD(17) indicated that industrial wastewater contributed 9% of the average daily flow into the sewerage area. An estimated 70% of this flow originates from food processing operations. The remaining percentage of the flow is discharged by a large number of small operations. However, 78.8% of sludges and spent chemicals generated by the metal products industries in the study area (excluding the City of Vancouver), originates on Lulu Island.

5.1 Plant Design

The Lulu Island STP provides primary treatment of the sewage. This is accomplished through a process which includes prechlorination, comminution, pre-aeration, and sedimentation. The effluent was disinfected using chlorine and a contact tank from May through September after 1977, and was dechlorinated. Sludge removed in the treatment process was incinerated and the ash and stack particulates were landfilled on site. The sludge incinerator was also designed to use waste oils, solvents, and other select combustible liquids as auxiliary fuels.

The plant design was based upon an initial population equivalent of 96 000, with space available on site to expand the facility to treat wastes from a population equivalent of 141 000. The initial plant design BOD_5 loading was 15 900 kg/d and the suspended solids loading was 19 500 kg/d. The 1979 influent loading rates were 6 500 kg/d of BOD_5 and 6 600 kg/d of suspended solids. The assumed reductions used in the design were 35% for BOD_5 and 60% for suspended solids.

The average dry weather flow rate used in the initial plant design was 61 200 m^3/d. The ultimate average dry weather capacity, available upon construction of the second phase of the plant, will be 132 000 m^3/d. The raw sewage pumps have a maximum rated capacity of 168 000 m^3/d. This capacity will be increased by 162 000 m^3/d in the construction of the second phase.

According to the initial design figures, the effluent could contribute a loading to the river of 10 300 kg/d of BOD_5 and 7 800 kg/d of suspended solids.

5.2 Pollution Control Permit

Pollution control permit PE 233 was issued in June 1968 to cover the discharge of raw sewage. It required that the GVS & DD provide primary treatment and post chlorination of the effluent by January 1, 1975. The permit was amended in March 1971 to allow the installation of primary treatment facilities. The latest permit amendment was in January 1979.

The permit limits are included in Table 1. The permit conditions restrict the flow to 133 000 m^3/d, the BOD_5 concentration to 169 mg/L, and the suspended solids concentration to 128 mg/L. The limits for BOD_5 are not as stringent as those required for level "BB" of the Objectives. However, the suspended solids limit is equivalent to the level "BB" objectives.

A summary of effluent compliance with the limits of PE 233 is included in Table 2. It indicates 100% compliance during the period between 1975 and 1979 for flow and suspended solids. The compliance of BOD_5 has decreased from 100% during 1976, to only 45% during 1979.

5.3 Effluent Characteristics

The effluent monitoring data have been summarized in Table 9. The operational performance of the facility, as indicated by the monthly removal efficiencies for BOD_5 and suspended solids, has been presented graphically in Figure 5. Graphs for the percent removal of suspended solids for 1979 as a function of temperature, flow, and the initial suspended solids concentration have been presented in Figure A-3 of Appendix A.

The suspended solids loading to the river was 1 800 kg/d during 1979. The concentration of suspended solids in the effluent has decreased yearly since 1973. This may have been caused by the fact that as flows increase the probability of septic conditions producing floating sewage, is decreased.

The removal efficiency for suspended solids reaches its maximum for the months of May through October. During those months, a mean reduction of approximately 70% is achieved. This compares to a design level of 60%, which is almost always met.

The percentage removal of suspended solids at the Lulu STP during 1979 was statistically correlated in Appendix A, using a multiple linear regression, with factors temperature, flow, and the initial concentration of suspended solids. The three factors had a multiple correlation coefficient of 0.70, and thus directly influenced approximately 50% of overall removal efficiencies.

The BOD_5 loading to the river was 4 500 kg/d during 1979. This represents an increase of 32% over 1977 loadings. The BOD_5 concentrations in the effluent have increased yearly since 1973. No pattern throughout the year related to removal efficiencies is apparent, due probably to the lack of influence of stormwater on the plant.

The average dissolved oxygen concentration in the effluent was 1.8 mg/L during 1979, with a range of concentrations from 0.5 mg/L to 2.7 mg/L. These values were affected by the influent dissolved oxygen concentrations which ranged from less than 0.1 mg/L to 0.5 mg/L. Sulphide concentrations in the influent ranged from 0.1 mg/L to 3.1 mg/L (mean of 1.2 mg/L). Similar values have also been recorded during other years.

The mean concentrations of certain toxic metals in the effluent were frequently greater than 0.2 mg/L. This was the case for copper (mean concentration of 0.33 mg/L in 1975), zinc (mean concentration of 0.54 mg/L in 1978), and total chromium (mean concentration of 0.21 mg/L in 1979). It is believed that these concentrations result from metal plating plants discharging wastes to this treatment plant. The concentration of all metals except iron, lead, and chromium consistently met level "AA" of the Objectives. The concentrations of iron and chromium consistently met level "BB". Mean lead concentrations did not meet level "BB", possibly due to the fact that three battery plants discharge effluent to the sewerage system within this sewerage area.

Less toxic metals at concentrations greater than 0.2 mg/L were boron (0.44 mg/L) and aluminum (1.3 mg/L). Removal efficiencies varied during 1977 from 18% for iron to 29% for lead. Measured loadings during 1979 varied from 0.1 kg/d of cadmium to 10 kg/d of zinc.

Loadings of 860 kg/d of Kjeldahl nitrogen and 150 kg/d of total phosphorus were discharged by the Lulu STP during 1979. Increases over 1978 loadings were 13% for Kjeldahl nitrogen and 18% for total phosphorus.

Arsenic, barium, cobalt, molybdenum, selenium, silver, sulphide, and tin were not present in concentrations above detection limits in 1979.

Geometric monthly mean total coliform values in the effluent have been calculated for 1977. These values, included in Table 10, indicate that total coliform values are reduced from approximately 37 000 000 MPN/100 mL during periods when the effluent is not being disinfected, to approximately 200 MPN/100 mL during periods when the effluent is being disinfected. The effluent was chlorinated continuously from the commencement of wastewater treatment in

January 1973 until September 1977. Thereafter the effluent has been chlorinated from May through September. Geometric mean loadings of total coliforms have also been calculated in order that Churchland[8] might compare different sources of coliforms.

Bioassays performed on the effluent have been summarized by Singleton[11]. Continuous flow tests were conducted by the IPSFC during both 1974 and 1975, using sockeye salmon as the test species. Nine 96-hour LC_{50} bioassays were performed in 1974, on primary treated effluent prior to chlorination. These tests indicated a mean 96-hour LC_{50} of 21% with a range of values from 17% to 25%. Six bioassays on dechlorinated effluent during 1975 indicated a range of 96-hour LC_{50} values from 16% to 40%, with a mean value estimated by Singleton[11] to be 25%.

B.C. Research performed monthly 96-hour LC_{50} acute toxicity tests on the Lulu effluent for the GVS & DD during 1978 and 1979. Using rainbow trout, grab samples, and a static bioassay test procedure, the mean 96-hour LC_{50} value during 1978 was 65% and the range was from 41% to 84%. The 1979 mean 96-hour LC_{50} decreased to 61% and the range was 25% to 84%. Acute toxicity data obtained since 1974 indicate the effluent consistently failed to meet level "BB of the Objectives.

In reviewing the acute toxicity studies performed, Singleton[11] indicated that the toxicity of the Lulu effluent could be attributed to un-ionized ammonia, cadmium, copper, cyanide, anionic surfactants, and possibly iron and nitrite.

Cain, Clark and Zorkin[12] carried out a survey of trace constituents in selected discharges within the study area during 1978. Samples of effluent were collected on two occasions. The samples both contained pentachlorophenol (1.0 μg/L and 3.0 μg/L), 2,3,4,6-tetrachlorophenol (0.5 μg/L and 1.7 μg/L), and trace quantities of 2,4,5- and 2,4,6-trichlorophenol. One of the samples also contained a trace of 3,4,5-trichlorophenol.

A third effluent sample, analyzed for additional trace constituents, indicated a level of 5 000 μg/L of octadecanoic acid, 3 000 μg/L of hexadecanoic acid, 110 μg/L of tetradecanoic acid, 40 μg/L of eicosanoic acid, 40 μg/L of diethylphthalate, 60 μg/L of caffeine, 450 μg/L of coprostanol, 400 μg/L of cholesterol, 8 μg/L of pentachlorophenol, 1 μg/L of tetrachlorophenol, 0.13 μg/L of polychlorinated biphenyls, and 0.005 μg/L of hexachlorobenzene.

5.4 Sludge

The quantity of solids removed in the primary treatment process has averaged 3.8 t/d since 1976. These solids are burned in a fluidized bed incinerator following thickening, conditioning, and centrifuging. Two wet scrubbers recover ash suspended in the flue gas.

An estimated eighty percent of the ash is landfilled. The remaining twenty percent is discharged to the chlorine contact tank where it is mixed with the effluent. Overflow from the thickener returns to the pre-aeration tanks.

The PCB analyzed the sludge on one occasion during 1979 as part of a program of analyzing municipal sludges in British Columbia. The results, included in Table 16 and based upon the wet weight of the sludge, indicated 4 600 mg/kg of iron, 1 850 mg/kg of zinc, 959 mg/kg of copper, 906 mg/kg of chromium, 83 mg/kg of nickel, 29 mg/kg of cadmium, and 3 mg/kg of aluminum in the sludge.

6. LADNER LAGOON (PE 64)

The Ladner sewage lagoon is located north of the Town of Ladner. It started treating sewage in 1964. Effluent is discharged towards Ladner Marsh. This is to discontinue late in 1980 when the sewage will be diverted to the Annacis STP.

The facility receives flows from an area of approximately 125 hectares in and around Ladner. The sewerage area contains an estimated 4 000 people. The lagoon design was based upon an ultimate population of 5 500.

6.1 Pollution Control Permit

Pollution control permit PE 64 was issued in February 1963 and amended in November 1968 to increase the limit for flow. The limits of PE 64 are included in Table 1. It allows the discharge of 1 364 m^3/d of sewage into the river. The BOD_5 concentration is limited to 30 mg/L, and the suspended solids concentration to 50 mg/L.

The permit limits are more stringent than level "AA" of the objectives. The limits were exceeded on approximately twenty percent of the occasions when the effluent was sampled. The median pH value exceeded the range of values allowed pursuant to PE 64 about 50% of the time.

6.2 Effluent Characteristics

The effluent monitoring data have been summarized in Table 11. The mean discharge rate was estimated to be 850 m^3/d. The mean concentration of BOD_5 was 20 mg/L, and of suspended solids 34 mg/L. The median fecal coliform value was about 1 300 MPN/100 mL.

7. LANGLEY SEWAGE TREATMENT PLANT (PE 4339)

The Langley STP started operating in 1977 and discharges to the Main Stem of the Fraser River (Figure 1). The plant receives flows from the West Langley area with a 1980 estimated population of 1 000. The industrialized section of northwest Langley is also connected to the plant.

7.1 Plant Design

The plant has been designed to function as an aerated lagoon until flows greater than 910 m^3/d are reached. At that time, the facility will be modified to function as an extended aeration plant. Chlorination and dechlorination facilities are located on site.

The plant was initially designed, and will be operated, for an influent loading of 180 kg/d of both BOD_5 and suspended solids. The BOD_5 design loading rate for the high rate system is 16 $kg/d/m^3$.

7.2 Pollution Control Permit

Pollution control permit PE 4339 was issued in October 1976. The limits of the permit are included in Table 1. The permit restricts the BOD_5 to a concentration of 45 mg/L, the suspended solids to a concentration of 60 mg/L, and the flow to 41 000 m^3/d. The limits are equivalent to level "AA" of the objectives for the ultimate discharge rate.

No data have been recorded for the quality of this effluent. The flows during 1980 were estimated by the Langley Engineering Department to be approximately 300 m^3/d.

8. MAPLE RIDGE SEWAGE TREATMENT PLANT (PE 77)

The Maple Ridge STP discharges into the Main Stem of the Fraser River (Figure 1). The sewage is treated in an activated sludge secondary treatment plant which began operations in March 1974.

The plant receives flows from the District of Maple Ridge, which includes the townships of Hammond and Haney. The sewerage area encompasses approximately 500 hectares (see Figure 2).

The municipality is exploring the possibility of diverting the sewage to the Annacis STP as opposed to constructing a new plant and continuing to provide secondary treatment to the sewage. The present plant is close to capacity and can probably not be expanded using activated sludge to handle future flows due to constraints at the site. However, the feasibility of other processes such as the CIL deep shaft have not been investigated.

8.1 Plant Design

The Maple Ridge plant provides secondary treatment of the sewage. This is accomplished through a process which includes comminution, grit removal, aeration, and clarification. The effluent is disinfected using chlorine. Sludge is digested aerobically but is discharged with the effluent.

The plant is designed on the basis of a loading to the aeration tank of 2 100 kg/d of BOD_5 and 2 400 kg/d of suspended solids. Retention in the 1 050 m^3 aeration tank is 3.35 hours, while the overflow rate from the 900 m^3 clarifier is 20.4 $m^3/m^2/d$. The retention time in the chlorine tank at the design flow of 7 600 m^3/d is one hour, although this retention time is reduced to 24 minutes at the peak flow rate of 18 900 m^3/d.

8.2 Pollution Control Permit

Pollution control permit PE 77 was issued for the discharge in September 1963. The latest amendment to the permit was in November 1978. The permit limits are included in Table 1.

The permit restricts the effluent discharge rate to 7 600 m^3/d, the concentration of BOD_5 to 130 mg/L before July 1, 1979 and 45 mg/L after that date, and the concentration of suspended solids to 130 mg/L before July 1979 and 60 mg/L after that date. The limits of PE 77 for the post-July 1979 period are more stringent than level "AA" of the Objectives.

A summary of the monitoring data has been included as Table 12. It indicates that the pre-1979 limits were met.

8.3 Effluent Characteristics

The mean concentrations for the period of record were 49 mg/L of BOD_5 and 42 mg/L of suspended solids. The median fecal coliform value was 24 000 MPN/100 mL.

The municipality has estimated that the 1977 average dry weather flow was 5 300 m^3/d, with an average peak flow of 10 600 m^3/d, and an average minimum daily flow of 1 800 m^3/d.

8.4 Sludge

Sludge is digested aerobically. Historically, the digested sludge has been discharged with the effluent. Sludge disposal facilities were to be completed before June 30, 1979.

The PCB carried out a survey of the quality of numerous municipal sludges throughout British Columbia during 1979. The results, included in Table 16 and based upon a wet weight, revealed 7 700 mg/kg of iron, 2 000 mg/kg of copper, 694 mg/kg of zinc, 25 mg/kg of chromium, 13 mg/kg of nickel, 6 mg/kg of cadmium, and 4 mg/kg of aluminum in the sludge.

9. PITT MEADOWS SEWAGE TREATMENT PLANT (PE 378)

The Pitt Meadows STP came into operation in April 1973. The effluent is discharged through a gravity line to the Main Stem of the Fraser River. The location of the discharge is indicated in Figure 1.

The plant receives flows from a commercial and residential area which contains a population of approximately 4 000. Anticipated population growths have required the District of Pitt Meadows to consider expansion of the plant. The District is also considering the diversion of sewage to the Annacis STP.

9.1 Plant Design

The Pitt Meadows STP provides secondary treatment to the sewage. This is accomplished through a process which includes comminution, treatment in an extended aeration plant, and post chlorination. Sludge drying beds are also available on site.

The plant design is based upon a population equivalent of 4 000 persons, a BOD_5 loading of 300 kg/d, and a minimum overflow rate from the settling tank of 29.4 $m^3/m^2/d$. The design capacity of each of the sludge drying beds is approximately 885 m^3. Underflow from the sludge drying beds is treated in the plant prior to discharge.

9.2 Pollution Control Permit

Pollution control permit PE 378 was issued for the plant on January 8, 1971, although the plant was not operational until April 1973. The permit limits are included in Table 1. The permit restricts the effluent discharge rate to 1 500 m^3/d, the BOD_5 concentration to 75 mg/L, and the suspended solids concentration to 100 mg/L.

The limits prescribed for BOD_5 and suspended solids, based upon the dilution available, are equivalent to, or more restrictive than, level "AA" of the Objectives.

A summary of the compliance of the quality of the effluent with PE 378 is included in Table 2. This table indicates 100% compliance for concentrations of BOD_5 and suspended solids on those occasions when sampling was carried out.

9.3 Effluent Characteristics

The effluent monitoring data are summarized in Table 13. The concentrations of BOD_5 and suspended solids in the effluent are comparable to concentrations expected from a properly designed and operated extended aeration plant. Kjeldahl nitrogen concentrations ranged from 7 mg/L to 19 mg/L, while total phosphorus concentrations ranged from 6.6 to 7.4 mg/L. No analyses for metals have been carried out.

The PCB have estimated that the approximate average flow has ranged from 600 m^3/d in 1975 to 1 300 m^3/d in 1979.

9.4 Sludge

No information on sludge quantities is available. As well, it is not known if the drying beds have ever been emptied. Based upon the volumes cited by Metcalf and Eddy, it is estimated that the sludge volumes generated have ranged from 4 m^3/d in 1975 to 9 m^3/d in 1979[(39)]. Sludge storage facilities are to be reviewed as a part of the proposed plant expansion.

The PCB carried out a survey of the quality of numerous municipal sludges throughout British Columbia during 1979. The results, included in Table 16 and given on a wet weight basis, revealed 4 900 mg/kg of iron, 1 100 mg/kg of copper, 654 mg/kg of zinc, 20 mg/kg of chromium, 12 mg/kg of nickel, 6 mg/kg of cadmium, and 2.7 mg/kg of aluminum in the sludge.

10. OVERVIEW OF MUNICIPAL DISCHARGES

The three largest sewage treatment plants within the study area are Iona, Annacis and Lulu. These plants are operated by the GVS & DD and serve an estimated population of 953 000. The plants provide primary treatment and, on average, discharged 662 000 m^3/d of effluent during 1979.

The treatment plants operated in Maple Ridge, Ladner, Pitt Meadows, and Langley serve an estimated population of only 35 000. These plants provide secondary treatment to the wastes.

Flow and loading figures which follow do not allow for the possible 30% error in flow measurements recorded at the Iona STP since 1977 (see Section 3.3 of this report).

10.1 Flow

The estimated flow of treated domestic sewage to the study area in 1979 was 668 000 m^3/d. Of this total, 66% was discharged from the Iona STP, 29% was discharged from the Annacis STP, 4% from the Lulu STP, and approximately 1% in total from the Langley STP, the Pitt Meadows STP, the Maple Ridge STP, and the Ladner Lagoon.

An extensive monitoring data base exists for the GVS & DD discharges. Due to the existence of this data base, the large percentage of total flow handled by the GVS & DD plants, and the fact that secondary treatment is carried out at the other plants, only those effluents discharged by the GVS & DD will be discussed.

10.2 Sewage Treatment Plant Influents

Sewage flows are composed of domestic sewage, and varying amounts of industrial wastewater and stormwater. Industrial wastewater accounts for 20% of the flow in the Fraser Sewerage Area, 9% of the flow in the Richmond Sewerage Area, and an estimated 10% of the flow in the Vancouver Sewerage Area. The food industry discharged the largest proportion of the industrial wastewater in the three sewerage areas.

The influent loading of BOD_5 and suspended solids at the Iona STP exceeded design levels during 1979 by 63% and 22% respectively. The loadings to the Annacis STP were between 70% and 80% of design, while those entering the Lulu STP were less than 50% of design.

The lowest dissolved oxygen concentrations in an influent were recorded at the Lulu STP where the maximum concentration during 1979 was only 0.5 mg/L. Although dissolved oxygen concentrations as low or less than 0.1 mg/L were recorded at all of the plants, the highest influent dissolved oxygen concentration during 1979 was recorded at the Iona STP (5.7 mg/L).

The presence of dissolved sulphide was not detected at the Iona STP during 1979. Values of dissolved sulphide as high as 0.8 mg/L were recorded during 1979 at the Annacis STP, while values of 3.1 mg/L were recorded at the Lulu STP. The presence of sulphide in influent sewage could result from septic conditions. These conditions are more common in newly developed areas of a sewerage district in which systems have a high capacity, hence high retention time. This can cause anaerobic conditions and sulphide formation.

10.3 Effluent Characteristics

10.3.1 Suspended Solids

A total of 40 000 kg/d of suspended solids was discharged during 1979 from the three major sewage treatment plants. The Iona STP discharged 60% of the total, the Annacis STP 35%, and the Lulu STP 5%.

Information prepared for the Environment and Land Use Committee Secretariat[20] indicated suspended solids removal efficiencies of between 60% and 79% may be achieved at primary treatment plants. These removal efficiencies seem high in light of removal efficiencies quoted by Imhoff and Fair[21]. They indicated removal efficiencies of 45% for weak sewage, which had suspended solids concentrations less than 100 mg/L, and 65% for strong sewage which had initial suspended solids concentrations of 300 mg/L. The design removal efficiency of GVS & DD plants is 60%. During 1979, removal efficiencies of 73% were recorded at Lulu, 67% at Annacis, but only 56% at Iona. These removal efficiencies relate inversely to the percentage of stormwater entering each plant.

The addition of activated sludge secondary treatment would increase the suspended solids removal to a range of 70% to 90%. Assuming an 80% reduction is achieved, the 1979 suspended solids loading to the study area from the three plants would be reduced from the existing 40 000 kg/d to 18 700 kg/d, a loading reduction of 53% over present conditions. A loading reduction of 52% would be realized with secondary treatment provided at only the Annacis STP and the Iona STP. A zone of degradation which is expanding in terms of area affected by metals has been observed adjacent to the Iona effluent channel[13]. It has been suggested that these metals are associated with the suspended solids[13]. Presumably, reductions in suspended solids concentrations would also help in controlling the expanding area of degradation.

10.3.2 Oxygen and Biochemical Oxygen Demand

Dissolved oxygen concentrations in the effluents during 1979 ranged from a mean value of 1.8 mg/L at the Lulu STP to 4.2 mg/L at Iona. The low dissolved oxygen concentration in the Lulu STP effluent was accompanied by high sulphide concentrations. These conditions are the result of the low ratio of actual flow to design flow which increases the retention time within the collection system, thereby causing anaerobic conditions and sulphide formation.

A total of 76 300 kg/d of BOD_5 was discharged to the study area during 1979. Nearly 55% of this originated from the Iona STP, nearly 40% from the Annacis STP and 6% from the Lulu STP.

The three plants removed nearly 36 800 kg/d of BOD_5 from the sewage during 1979. This represents a 32% BOD_5 reduction. Removal efficiencies were 35% at Iona, 28% at Annacis, and 30% at Lulu. The design efficiency for BOD_5 removal at all plants is 35%.

The primary treatment of sewage removes suspended solids and oxygen demanding substances associated with suspended solids. In particular it removes between 30% and 40% of the influent BOD_5[20]. The removal efficiencies at Annacis and Lulu were near or below the bottom of this range.

The application of secondary treatment, in the form of activated sludge, would increase BOD_5 removals to a range of 70% to 90%[20]. Assuming that an 80% reduction was achieved, the BOD_5 would be reduced from the 1979 loading of 76 300 kg/d to 22 000 kg/d, a reduction of 71%. The effect of converting the largest treatment plants to secondary treatment first, and maintaining the Lulu STP as a primary treatment facility, would be to bring about a reduction in the amount of BOD_5 discharged of approximately 67%.

10.3.3 Phosphorus

A total of 2 335 kg/d of total phosphorus was discharged from the three sewage treatment plants during 1979. Nearly 58% of this was discharged from the Iona STP, 36.5% was discharged from Annacis, and only 6.5% from Lulu.

Primary treatment can reduce phosphorus levels by an estimated 10%[20]. The application of secondary treatment, in the form of activated sludge, would increase the removal to between 25% and 30%. Assuming 27.5% removal with primary and secondary treatment, the application of secondary treatment would reduce phosphorus loadings from the present 2 335 kg/d to 1 880 kg/d, a loading reduction of approximately 20%. Secondary treatment at Lulu Island would have little effect on the overall loading reduction.

10.3.4 Nitrogen

A total of 13 900 kg/d of Kjeldahl nitrogen was discharged from the three major plants during 1979. The Iona STP discharged 61% of this total, the Annacis STP discharged 33%, while the Lulu STP discharged 6%.

Primary treatment can reduce total nitrogen levels in sewage by 25%[20]. The addition of activated sludge treatment would increase this to a range of 20% to 40%. Assuming that total and Kjeldahl nitrogen loading reductions are similar, and a removal efficiency of 30%, the application of secondary treatment would reduce nitrogen loadings from the present 13 900 kg/d to 13 000 kg/d. This represents a loading reduction of only 6.5%.

10.3.5 Metals

It is estimated that during 1979, the three major sewage treatment plants discharged about 100 kg/d of zinc, 40 kg/d of copper, and 30 kg/d of lead. Approximately 300 kg/d of iron was also discharged. The largest quantity of each metal was discharged by the Iona STP.

The Lulu STP consistently discharged the highest concentrations of chromium, copper, lead, nickel and zinc. This is probably because it receives a large volume of wastewater from metal products industries in comparison with its total flow.

The mean concentration of most metals recorded during 1979 at all plants met level "AA" of the Objectives. Exceptions were iron (which met level "BB" at all plants), chromium (which met level "BB" at the Lulu STP), and lead (which exceeded level "BB" at the Lulu STP).

Approximately equal concentrations of boron and aluminum were discharged from the three plants during 1979. Since boron concentrations in the domestic water supply are less than 0.1 mg/L[22], it is speculated that the boron may originate from specialized detergent formulations, soil sterilants, and other miscellaneous commercial sources.

For the metals being discharged in measurable quantities, it has been estimated that primary treatment can remove between 40% and 54% of the lead in the raw sewage, 25% to 45% of the copper, and 19% to 40% of the zinc[20]. Secondary treatment, in the form of activated sludge, with adequate aeration times provided, could result in removal efficiencies of 52% to 90% for lead, 52% to 80% for copper, and 56% to 80% for zinc[20]. Assuming the midpoints of these ranges, the provision of secondary treatment could eliminate an estimated fifty percent of the present metal loadings from sewage treatment plant effluents to the study area.

10.3.6 Acute Toxicity

A comparison of many of the bioassays performed on effluents from the three major sewage plants is difficult since the bioassays differ according to fish species, the type of sample tested, and type of test performed. Since B.C. Research has carried out acute toxicity tests during 1978 and 1979 on the effluents from the three major plants using static tests, rainbow trout, and grab samples, this served as the best inter-plant comparison.

These tests indicated that the Lulu effluent was most toxic. During 1979, its mean 96-hour LC_{50} was 61%. The next most highly lethal effluent was from Annacis. The Iona effluent was the least toxic. The effluents from the three plants would appear to be increasing in toxicity over the years with lower mean 96-hour LC_{50} values during 1979 than in previous years and wider ranges of concentrations which were acutely toxic.

Anionic surfactants and un-ionized ammonia were readily identified as toxic sewage components at the three plants. Values of both un-ionized ammonia(23) and surfactants(24) are not reported to be of concern in the Fraser River. Heavy metals and organic contaminants can also contribute to effluent toxicity.

Singleton(11) has indicated that depending upon the bioassay procedure employed, significantly different results have been reported for 96-hour LC_{50} values. Although the Objectives(5) do not specify the test procedure which is to be employed to determine an effluent's toxicity, as it related to level "AA" or "BB", it is specified that the samples are to be taken prior to chlorination. However, the Objectives(5) do specify that the toxicity tests related to maintaining the receiving water quality are to be performed using a 96-hour LC_{50} static bioassay test procedure. As well, information provided in the Objectives and related to initial monitoring frequencies for effluent discharges, indicates that grab samples should be used.

10.3.7 Trace Constituents

The data reported, which were limited in terms of frequency and numbers of analyses, indicated the presence of chlorinated phenols commonly used in wood preservation. Pentachlorophenol and 2,3,4,6-tetrachlorophenol were detected in all three effluents. Concentrations of pentachlorophenol appeared to decrease throughout the treatment process. Measurable quantities of 2,4,6-trichlorophenol were also recorded in both the influents to, and effluents from some of the plants. As well, trace quantities of 2,4,5-, 2,4,6-, and 3,4,5-trichlorophenol were recorded.

A variety of other organics in trace amounts were identified in all three effluents. These included palmitic acid (hexadcanoic), diethylphthalate, caffeine, cholesterol, coprostanol, hexachlorobenzene, and polychlorinated biphenyls.

10.3.8 Disinfection and Bacteriological Quality

Effluents from the three major sewage treatment plants were chlorinated from May through September. Effluents from Lulu and Annacis were dechlorinated with sulphur dioxide prior to discharge. This process appears to remedy the enhanced toxicity which is associated with residual chlorine.

Chlorine is used as the disinfecting agent at the three plants. Chlorine gas is dissolved in a slipstream of primary treated effluent and is injected into the flow at the head end of the chlorine contact tanks.

Pierce[25] indicated that the chlorine concentration in such injection water is commonly 3 500 ppm. He further indicated that the superchlorination of a secondary municipal effluent (chlorine dose of 1 500 mg/L for one hour) resulted in the formation of 36 chlorinated organic compounds not present in the unchlorinated effluent. It is likely that similar numbers of chlorinated organic compounds are formed at the three sewage plants when effluent is used as the source of the injection water. Furthermore, approximately twice as much chlorine is required to disinfect a primary treated effluent as is required to disinfect a secondary treated effluent to achieve similar residuals after the same contact time.

Disinfection of the effluent lowered geometric mean coliform values in the Iona and Lulu effluents to approximately 200 MPN/100 mL during 1977. The geometric mean total coliform value in the Annacis effluent during the same period was 800 MPN/100 mL. When the effluents were not being chlorinated, geometric mean total coliform values ranged from 2 000 000 MPN/100 mL at the Iona STP to 37 000 000 MPN/100 mL at the Lulu STP.

10.4 Sludge

Sludge is treated utilizing thickeners and anaerobic digesters prior to storage in sludge lagoons at both the Iona STP and Annacis STP, while sludge was incinerated following thickening and centrifuging at the Lulu STP. Overflow from the thickeners was returned to the pre-aeration tanks for further treatment.

The sludge digestion process reduces volatile solids by an estimated 50% according to GVS & DD officials. These solids are converted to water, carbon dioxide and methane. Leachates from the sludge lagoons are not collected or treated further at either plant. No monitoring of the effect of these leachates on groundwater quality is carried out. However, the leachates are likely to contain significant loadings of most parameters.

The largest volume of digested sludge is generated at the Iona STP, although Annacis is nearly equal. Sludge volumes requiring storage or immediate disposal could be reduced through mechanical dewatering or dewatering in lagoons. Dewatering can increase the solids in the sludge to a range of 15% to 30%[26] while removing leachates for further treatment. The implementation of sludge dewatering, ahead of sludge storage may have to be considered in order to reduce sludge volumes should secondary wastewater treatment be installed, since secondary treatment of wastewater with activated sludge can increase sludge volumes by 86%[16]. However, sludge volumes will be dependent upon the type of treatment chosen. This would require a detailed examination of the options for ultimate disposal.

Analyses of sludges from five of the sewage treatment plants within the study area were carried out by the PCB during 1979. In terms of metal contents in the sludges, the Lulu STP had the greatest content of chromium, cadmium, nickel and zinc. The sludge from the Maple Ridge STP contained the greatest content of copper and iron. The sludge from the Iona STP contained the greatest content of aluminum, although the sludges from all of the plants contained very little aluminum.

Sludge from Lulu was incinerated following thickening, conditioning, and centrifuge dewatering. Supernatant from the thickeners was returned to the pre-aeration tank for further treatment. Approximately 20% of the ash in the flue gas of the incinerators which was recovered by the wet scrubbers was discharged with the effluent.

Ultimate sludge disposal methods will have to be investigated by the GVS & DD, particularly if secondary treatment is installed. Techniques for ultimate sludge disposal include incineration, dumping in the ocean, or dumping on land. The application of sewage sludge to land has often been the most feasible method of disposal at other locales, due to environmental and economic considerations[27].

10.5 Effluent Monitoring

The GVS & DD monitors both influents and effluents at all the sewage treatment plants on a regular basis. Several analyses are generally performed daily on composite samples. These include tests for suspended solids, turbidity, chloride, and total solids. Other analyses are performed approximately two out of every three days due to the nature of the analyses and the need for personnel to perform the analyses immediately. These include tests for specific conductivity, dissolved oxygen, fecal coliform, COD, temperature, and chlorine residual. Analyses of BOD_5 are performed approximately one in every three days owing to the scheduling requirements inherent in this analysis. Analyses not related directly to process controls are performed monthly. These include oil and grease, phenols, acute toxicity, metals, cyanide, sulphide, nutrients, sulphate, alkalinity, methyl blue active substances, and fluoride.

11. UNTREATED DISCHARGES

Untreated discharges consist of stormwater discharges, raw sewage discharges, combined sewer overflows and sewage treatment plant bypasses. Stormwater discharges within the study area have been discussed elsewhere[30]. Combined sewer systems have been constructed in Vancouver, New Westminster, and parts of Burnaby. Combined sewers carry stormwater as well as municipal-type sewage. Overflows occur within combined sewer systems at predetermined locations when pipe capacities are exceeded. Combined sewer overflows occur along the North Arm and the Main Stem of the river within the study area, and within Burrard Inlet outside of the study area. Therefore all of the collected sewage does not necessarily arrive at the treatment plant.

As well, all of the sewage arriving from the collection system does not necessarily pass through the sewage treatment plant. If the quantity of sewage which reaches the plant is greater than can be handled by the plant, portions of the flow will be bypassed around the plant. These sewage bypasses occur at plants receiving flows from combined sewer systems.

Specifics related to raw sewage discharges, combined sewer overflows, and sewage treatment plant bypasses are discussed in further detail in the following sections.

11.1 Combined Sewer Overflows

Regulators within a combined sewer system are set so that excessive flows, which enter the system during storms, overflow to a receiving water. This prevents overloading of the sewage plant and localized flooding due to the backing up of water in the sewer.

Combined sewer overflows occur during or after storm events. Their frequency of occurrence is a function of rainfall patterns. These overflows occur at discrete points and contain contaminants found in stormwater and municipal sewage.

There are 21 locations of combined sewer overflows along the Main Stem and the North Arm. These overflow points have been indicated in Figure 6. It has been estimated by the GVS & DD that the total volume of these overflows ranges from 5 900 m^3 during the May through September period to 17 100 m^3 during the October through April period. This represents 0.01% of the total sewage discharged to the study area in 1979, however these volumes are discharged over a period of several hours.

The estimated volume discharged from individual or groups of locations, is indicated in Table 14. These estimates are based upon work carried out in Vancouver's West End. They indicate that winter overflow volumes are twice those of summer. Another factor included in the estimate is that pipe capacities are from eight to ten times the average dry weather storm flow plus municipal sewage flow. There are no measurements of the actual frequency or volume of overflows diverted within the study area.

The United States Environmental Protection Agency (EPA)[28] has indicated that total nitrogen and total phosphorus concentrations in overflows are generally less than those found in secondary treated effluents. Total nitrogen concentrations in overflows range from 3 mg/L to 16 mg/L compared to 30 mg/L in secondary treated effluents. Total phosphorus concentrations ranged from 1 mg/L to 11 mg/L, although the majority of the values were less than the 5 mg/L expected in secondary treated effluents.

As expected, the BOD_5 and suspended solids concentrations are reported to be in excess of concentrations generally achieved in secondary treated effluents[28]. Suspended solids concentrations range from 50 mg/L to 250 mg/L. The BOD_5 concentrations range from 70 mg/L to 1 100 mg/L. Based upon the midpoint of these ranges and the total annual estimated flow from overflows to the river, the approximate BOD_5 loading would be 3 500 kg/annum while the approximate suspended solids loading would be 13 800 kg/annum. These estimates are probably quite imprecise.

11.1.1 Application of Pollution Control Objectives

The Pollution Control Objectives for municipal type waste discharges require screening of overflows in excess of certain selected multiples of the dry weather flows depending upon the discharge location. Since the GVS & DD have indicated that pipe capacities are from 8 to 10 times the average dry weather flow, screening of all overflows would permit the overflows to meet level "AA" of the Objectives. The GVS & DD do not provide any treatment to combined sewer overflows.

11.2 Sewage Treatment Plant Bypasses

Sewage bypasses occur at sewage treatment plants if the plant is closed for maintenance (extremely rare occurrence), if a pump failure prevents sewage from entering the plant, or if the flow coming to the plant is in excess of what can be treated. The three major plants have from two to four times the pumping capacity required for design flows.

The GVS & DD has indicated that bypasses occur frequently at the Iona STP, but that neither Lulu nor Annacis have ever been bypassed. This is due to the facts that no stormwater directly enters the sewage system conveying sewage to the Lulu STP, and that combined sewers conveying sewage to Annacis are regulated to overflow at thirteen locations upsystem from the plant (see Figure 6). However, only a portion of the Fraser Sewerage Area (Annacis STP) is serviced with a combined sewer system.

The Iona STP was expanded in 1973. Data presented in Table 15 indicate that bypasses occurred on between 50 and 160 days during the 1970 to 1972 period, and on 58 days during 1979. The actual number of hours during which bypasses occurred were recorded in 1979. Bypasses occurred during seven months for a total of 523 hours during 1979, or 6% of the time.

Sewage flows entering Iona in the range between 942 000 m^3/d (sedimentation tank capacity) and 1 531 000 m^3/d (influent sewer line capacity) are bypassed after passing through the screens and the grit removal chambers.

A continuous overflow of an estimated 70% of the normal sewage flow to the Iona STP was diverted to English Bay and Burrard Inlet from the collection system during the period of March 23 to April 12, 1976. This bypass was required to allow for inspection and repairs of portions of the collection and trunk systems.

Preliminary rainfall data for 1979 for five GVRD stations within the Vancouver Sewerage Area were examined to relate the number of hours of recorded rainfall to the number of hours of bypass at the Iona STP. The GVRD stations examined (numbers 1, 3, 4, 12, and 13) are indicated in Figure 7. Extrapolation of the isohyets, or lines of equal rainfall, revealed that stations 2 and 3 receive virtually the same recorded rainfall, while stations 1 and 18 receive amounts which are within 20 millimetres of each other during a year.

The GVRD use tipping bucket rain gauges to record rainfall. These instruments record on a chart the times when 0.01 inch (0.254 millimetres) of rainfall has accumulated in the bucket. It is difficult to determine the number of hours of rainfall from these charts. The GVRD data however do indicate the number of hours during which multiples of 0.254 millimetres of rainfall have accumulated.

Since it is doubtful that 0.254 millimetres of rainfall could produce enough runoff to require flow bypasses at Iona STP, those hours during which only 0.254 millimetres of rainfall accumulated were disregarded when examining the data. This approach revealed that 636 hours of rainfall were recorded at station 3, 650 hours at station 1, 732 hours at station 4, 721 hours at station 13, and 756 hours at station 12, for an arithmetic average of 699 hours over the entire sewerage area during which there were 0.508 millimetres and more rainfall.

Since sewage was bypassed at Iona during 523 hours in 1979, flows were bypassed during 523 of the 699 hours when 0.508 millimetres or more rainfall was recorded. This represents approximately 75% of those rainfall events.

11.2.1 Application of Pollution Control Objectives

Bypasses around sewage treatment plants are considered in the same context as overflows from combined sewer systems in the Objectives. As noted, bypasses of sewage at the Iona STP, in the range between 942 000 m^3/d and 1 532 000 m^3/d, are screened and the grit is removed. Thus these portions of the bypasses meet the Objectives.

11.3 Raw Sewage Discharges

The Annacis Island STP was the last of the three major sewage treatment facilities to begin operation when it came on-line in 1975. Thus, raw sewage discharges were eliminated from the river within the study area at all locations except at the Deas Island outfall.

The discharge of comminuted raw sewage at the Deas Island outfall is allowed pursuant to pollution control permit PE 187. The GVS & DD anticipates that this discharge will be discontinued sometime during 1980 when the flow is diverted to the Annacis STP. It has been estimated that the volume of this discharge ranges between 7 700 m^3/d and 9 100 m^3/d.

12. HIGHER LEVELS OF TREATMENT

The quality of wastewater discharged from the sewage system can be improved by several methods. These include control of wastewater sources discharging toxic substances or abnormally high levels of suspended solids or BOD_5 into the sewer system (source control), the treatment and/or elimination of combined sewer overflows, and the provision of secondary or higher levels of treatment at the sewage treatment plants (upgrading).

12.1 Source Control

Source control programs have been used for many years throughout North America as a means of protecting sewerage systems. Such programs can have the added benefit of reducing contaminant loadings to receiving streams. Winnipeg is one of the larger centres in Canada which has undertaken such a program.

The establishment of a viable source control program requires that the legal authority to develop, administer, and enforce the program, rests with the same agency. The granting of this authority at a senior level would preclude operations moving to areas within the GVRD which did not enforce the source control program. It would enable the responsible agency to ensure uniformity and continuity, to levy charges against an operation when certain minimum levels in the wastewater were not met, and to require that monitoring programs be carried out by an operation.

The first step which must be undertaken in the establishment of a source control program is the compilation of a list of industrial and commercial contributors to the sewer system. A list has been prepared by the GVS & DD[17].

Secondly, the operations identified on the list must be classified as being of major or minor significance. This classification will be based upon the toxic properties of the wastewater, its volume, and/or loading of certain contaminants. The classification procedure requires detailed analyses of each operation's wastewater.

An integral part of any source control program would have to be the availability of a facility for the disposal of sludges and waste chemicals generated by individual operations. Controls will be required to ensure that trucked wastes are taken to such a facility. Such a facility will be required since many of the sludges will be toxic, and may contain high concentrations of metals and organic contaminants. It might be associated with a facility for the storage and destruction of hazardous wastes.

Once a source control program is established and operating as designed, problems caused by dumping potent wastes will be reduced. This is especially important if conventional secondary treatment is installed at the sewage treatment plants since high concentrations of some potent or inappropriate wastes can upset the treatment process.

12.2 Treatment or Elimination of Combined Sewer Overflows

Overflows from combined sewers can be either treated or eliminated. Combined sewer overflows can be eliminated through the construction of separate storm and sanitary sewer systems in new areas. In older established areas, the separation of sewers is costly. In certain instances, it may not be practical or desirable. The separation of sewers may lead to an increase in the stormwater pollutant loading. An EPA survey(29) of 16 cities which had separated storm from sanitary sewers placed the average 1964 cost at $30 700 per hectare. However, other control strategies exist.

One such strategy is that of combined sewer flushing. The purpose is to resuspend sanitary sewage solids which have settled in the sewer pipes and to transport them to the sewage treatment plant before a storm event causes them to overflow. The EPA(28) has indicated that the effectiveness of such a program can result in 18% to 32% BOD_5 removal from combined sewer overflows. Such a program is undertaken within the combined sewers of the City of Vancouver on a limited basis.

A second strategy, referenced in the background report(30) on stormwater discharges within the study area, applies to street cleaning. Street cleaning can remove accumulations of street surface contaminants which would otherwise be carried into the sewer system, possibly overflowing. This strategy can remove from 2% to 11% of the BOD_5[28]. Other applicable strategies apply to the collection system itself.

One such collection system strategy applies to regular maintenance of the system. This program includes correcting malfunctions, unblocking clogged lines, optimizing regulator functions and locating unused in-line storage. In-line storage is accomplished using regulators to distribute and contain storm flows within the system, and thus reduce peak flows. Such a program can reduce but may not eliminate all overflows. The City of Vancouver is presently studying the possibility of using in-line storage[34].

Storage can also be provided outside of the sewer system, either at points where overflows occur, or near the sewage treatment plant. This latter location for a storage area is a preferred locality, since such storage areas provide flow equalization. This option may be particularly attractive when secondary treatment becomes desirable for environmental or other reasons.

Another strategy is to eliminate stormwater discharges such as roof, foundation, air conditioning and yard drains to combined systems. The estimated average 1964 cost of such a program was $7 875/hectare[29] for seven cities studied in the United States.

Overflows can be treated by several methods. These methods, which can approximate primary treatment, include screening with coarse and fine screens, sedimentation, filtration, and swirl and helical concentrators. Disinfection may also be carried out. Other advanced methods can also be utilized. However, these should probably not be considered until the sewage treatment plants are upgraded, since the loading impact of the combined sewer overflows is not known. Further information on these methods is presented in Appendix V of the stormwater report[30].

12.3 Upgrading Sewage Treatment Plants

Secondary treatment is the next treatment process which can be added to that in existence at the three major plants. Although normally considered as being biological in nature, secondary treatment could take the form of physical-chemical treatment. Physical-chemical treatment as a large scale secondary treatment process has not been widely used for an application involving large flows and small quantities of troublesome constituents which are otherwise controllable. Its use may not be particularly attractive in Greater Vancouver and consequently, it will not be considered in this discussion. Biological secondary treatment of large sewage flows has generally taken the form of activated sludge. The principles and variations of the activated sludge process, are discussed elsewhere[31].

Loading reductions possible with secondary treatment are discussed in Chapter 10. Lowered effluent toxicities would be associated with these reductions. In fact, literature reviews have indicated that effluent toxicity may be lowered to meet level "AA" objectives with activated sludge treatment[32,33]. This is of primary importance. The GVS & DD has compiled preliminary design data for a step aeration process at the Annacis STP[34]. The data indicate that such a process, based upon a retention time of four hours, will cost between 80% and 100% of the cost of the primary treatment plant. Operating and maintenance costs would be double the present primary treatment costs.

The Iona STP has been constructed in three stages. The first stage was constructed in 1961 to 1963 for $6 600 000. The second stage cost $3 600 000 in 1972 to 1973, while the last stage cost $3 400 000 in 1978 to 1979. The Engineering News Record (ENR) cost index brings this total cost in 1979 to $33 000 000. Secondary treatment, using the 80% cost estimate, could cost $26 400 000.

Similarly, the 1974 cost of $14 900 000 for the construction of the Annacis STP, when updated to mid-1979 using the ENR cost index, becomes $22 500 000. The cost of secondary treatment at Annacis, using the 80% cost estimate, would be $18 000 000.

The cost of construction of the Lulu STP in 1972 was $4 600 000. Updating to mid-1979 values using the ENR cost index brings this cost to $8 000 000. Assuming that secondary treatment construction costs 80% of this, the cost in mid-1979 to provide step aeration with a four hour retention time at Lulu would be $6 400 000.

If the cost of secondary treatment was actually 100% of the cost of primary, the cost at the three plants would rise from the estimated $50 800 000 to $63 500 000. These costs are approximate. Detailed design would have to be completed to obtain more accurate cost estimates. As well, sludge handling, and land acquisition, have not been allowed for. The accuracy of these cost estimates, particularly those based on pre-1970 costs, is not expected to be reliable. The accuracy of indexing costs to a current base dollar increases with more recent data[35].

Tertiary treatment is usually not considered an additional treatment module and consequently post-secondary treatment may be a better description. The objective of post-secondary treatment is to remove one or more troublesome constituents prior to discharge to a fragile receiving medium. Such is the case for the use of chlorination and dechlorination, or the application of nutrient removal prior to discharging to small streams or lakes. There is no obvious reason for requiring nutrient removal in discharges entering the Fraser River in the study area[23]. Chlorination and dechlorination is being carried out at Lulu and Annacis, while chlorination alone is being carried out at Iona.

13. CONCLUSIONS

The survey of industrial discharges entering the municipal sewage system within the GVRD indicated that industry accounted for 20% of the sewage in the Fraser Sewerage Area and 9% in the Richmond Sewerage Area. This survey did not identify all industrial discharges within the Vancouver Sewerage Area. However, the City of Vancouver and the EPS have done this in a report to the PCB.

All discharges of raw sewage, excepting combined sewer overflows and sewage treatment plant bypasses, will have been eliminated by the end of 1980. However, the majority of raw sewage discharges had been eliminated by June 1977, with the exception of the Deas Island outfall. Municipal sewage being discharged within the study area will receive primary treatment as a minimum by the end of 1980.

The largest volume of effluent is generated from the Iona STP, even when the possible 30% error in flow measurements recorded at the Iona STP since 1977 is taken into account. The plant is hydraulically overloaded and does not meet design specifications with respect to removal efficiencies for BOD_5 and suspended solids.

The Annacis STP contributes nearly 30% of the municipal sewage discharged within the study area. This percentage will increase as the Fraser Sewerage Area develops.

During 1979, the loadings of BOD_5 and suspended solids to the Annacis STP were approximately 70% to 80% of design loadings. The preliminary design of the plant anticipated that increasing the primary capacity would be required by approximately 1986. This does not seem unreasonable in light of present loadings, and the fact that the Deas Island discharge as well as landfill leachates will be diverted to the plant during 1980.

The loadings on the Lulu STP were less than 50% of the design loadings. The primary capacity at this plant should be satisfactory for many years to come.

Many contaminants were not present in detectable concentrations in the effluents of the three major plants during 1979. These included arsenic, barium, cobalt, molybdenum, nickel, selenium, silver, sulphide and tin. In addition, cyanide and mercury concentrations at the Iona STP and Annacis STP were below detection limits. The concentrations of most metals in the effluents from the three plants met either level "AA" or level "BB" of the Objectives with the exception of the lead concentration at Lulu, which consistently did not meet these levels.

The effect of stormwater on treatment plant suspended solids removal efficiencies is markedly different between plants. The largest volume of stormwater enters the Iona STP, which experienced the lowest suspended solids reduction during 1979. The Lulu STP, receives no stormwater and experienced the greatest suspended solids reduction. Plant performances were also influenced by the actual loadings relative to design loading.

Low dissolved oxygen concentrations in the effluent, as well as septic conditions in the plant influents, will likely continue at the Lulu STP until actual flows are closer to design flows. However, septic conditions in the influent may also result from the sewage experiencing long detention times in a collection system laid at extremely flat grades. This may continue even when design flows are reached in the collection system.

The effluents from the three major sewage treatment plants have shown increased acute toxicity between 1978 and 1979 as measured in bioassay tests performed for the GVS & DD by B.C. Research. Effluent toxicities at Lulu and Annacis consistently do not meet level "BB" of the Objectives.

No test procedure to perform bioassays is outlined in the Objectives. However, to remain consistent with test specifications for receiving waters, grab samples taken prior to chlorination could be used in 96-hour LC_{50} static bioassays, or an acceptable standard method prescribed in the Pollution Control Objectives.

The limits prescribed for suspended solids and BOD_5 for Annacis and Iona are equal to or more stringent than level "BB" of the Objectives. At Lulu, the limit for suspended solids meets level "BB" of the Objectives, but the limit for BOD_5 is not as stringent.

The effluent quality of the three major plants generally met the suspended solids limits. However, BOD_5 concentrations only met permit limits on 55% of samplings at Iona, and less than 50% at Lulu and Annacis. These limits will only be met consistently through the provision of secondary treatment. The zone of degradation near the Iona channel is becoming more widespread. There are no monitoring data related to the Lulu and Annacis outfalls to indicate the extent of any zones of degradation.

The prescribed limits for BOD_5 and suspended solids at the Ladner Lagoon, the Langley STP, the Maple Ridge STP, and the Pitt Meadows STP are equal to or more stringent than level "AA" of the Objectives.

The application of secondary treatment at the three major sewage treatment plants, assuming that steps were taken to prevent shock loadings to the plants or surges which could wash out the biological floc, could reduce the 1979 suspended solids loading by 50%, the BOD_5 loading by 70%, loadings of metals by 50%, total phosphorus loadings by 30%, and nitrogen loadings by 7%. The additional treatment could be expected to reduce effluent toxicity to meet level "AA" of the Objectives.

The implementation of a source control program would help to control substances which cannot easily be removed with either primary or secondary treatment. Such a program would also prevent slug loadings of toxic substances which may upset biological secondary treatment plants and create a hazard in the receiving water. However, a source control program would also require that a sludge handling facility be established to handle the variety of sludges which would be generated. The disposal of hazardous wastes is a problem which must be considered concurrently.

The provision of secondary treatment could increase the volume of sludge generated by 86%. Although sludge digester capacities would have to be increased to handle these volumes, sludge storage problems could be partially rectified through the implementation of sludge dewatering. Sludge dewatering facilities might be constructed by modifying the sludge storage lagoons. However, the disposal of the dry sludge would still have to be undertaken.

Until such time as secondary treatment is provided at Annacis, it is difficult to justify, for other than administrative or financial reasons, the diversion of effluents which presently pass through secondary treatment facilities, such as from Ladner and Maple Ridge, to a facility providing only primary treatment. A secondary treatment facility, when overloaded, can continue to produce an effluent of better quality, relative to what can be achieved from a primary treatment facility. However, an overloaded plant would have to be upgraded eventually.

The use of effluent as injection water for the chlorination process promotes the formation of chlorinated organics in the effluent. However, the fate of these compounds and their effect on the receiving water is not known once the injection water has recombined with the main sewage effluent stream. Many of the trace organics analyzed in the effluents from the major sewage treatment plants were also found in the plant influents, but the referenced study was not exhaustive.

The chlorination of the effluents has reduced geometric mean total coliform levels, during the May through September period, to the range of 200 MPN/100 mL to 800 MPN/100 mL.

Sewage treatment plant bypasses have occurred approximately six percent of the time at the Iona STP. However, the volumes of sewage involved in these bypasses is not known.

The treatment of combined sewer overflows, based upon the available data, would not seem to be an immediate concern, since the estimated flows account for only 0.01% of the sewage entering the study area. However, the local effects of such overflows have not been studied in any great detail.

Monitoring of the influents and effluents from Iona, Annacis, and Lulu is more extensive than is required for day to day control. Nevertheless, the data will be valuable for future decision making.

14. RECOMMENDATIONS

The following recommendations are based upon factors such as the present quality of municipal sewage discharges within the study area, the relationship of the Objectives of the Pollution Control Board to that quality and existing pollution control permits dealing with the discharges, as well as the status of knowledge related to specific aspects of municipal sewage discharges within the study area. The economic implications of these recommendations have not been considered. These recommendations may be modified in importance when taken into account with discussions and recommendations made in other background reports prepared by and for the Water Quality Work Group of the Fraser River Estuary Study. The integration of these reports has taken place in the final Summary Report of the Water Quality Work Group.

(1) A detailed engineering assessment of the present primary treatment facilities at the Iona STP should be undertaken immediately with the view to possibly adding capacity or changing the discharge location. This assessment should outline maintenance procedures to ensure that flow measurements at the Iona STP specifically, but at all of the plants generally, are recorded accurately.

(2) The GVS & DD should improve effluent quality from the Lulu STP so that the acute toxicity of the effluent, as a minimum, consistently meets level "BB" of the Objectives using a 96-hour LC_{50} static bioassay test on a grab sample taken prior to chlorination. As well, the GVS & DD should prepare a timetable to upgrade all three plants so that the effluents meet level "AA" toxicity objectives.

(3) The GVS & DD should undertake steps to ensure that any BOD_5 limits outlined in their permits are consistently met. This will either necessitate the provision of secondary treatment facilities, or a review of permits to bring BOD_5 limits into line with BOD_5 concentrations which can be expected in a properly designed and operated plant.

(4) Further treatment at Iona STP may be needed in view of the effect of the effluent on a localized area of Sturgeon Bank. Monitoring is recommended at Annacis and Lulu STP's so that the need for further treatment in the future can be assessed.

(5) The GVS & DD should maintain the effluent monitoring program utilized during 1979. In addition, compounds identified as possible problems should be measured to determine their concentration in the effluents.

(6) The GVS & DD should continue its program of monthly bioassay sampling of the effluents from Iona, Annacis and Lulu. The tests used should continue to be 96-hour LC_{50} static bioassays on grab samples of effluent, unless other bioassay methods are issued in revised Pollution Control Board Objectives.

(7) Sludge disposal methods presently being utilized by the GVS & DD should be reviewed by GVS & DD with a view to reducing sludge storage requirements and providing sites for the ultimate disposal of the sludge.

(8) An investigation of chlorinated organics formed in injection water during the chlorination process and their fate in the receiving environment should be carried out to determine if the primary treated sewage used as injection water should be replaced by fresh water.

(9) The GVS & DD should install groundwater monitoring wells adjacent to the sludge storage facilities, as well as develop a groundwater monitoring program at these locations, which will determine the quality of groundwater adjacent to the storage facilities. This program might necessitate that surface waters near the storage facilities be monitored if the groundwaters are severely contaminated.

(10) A source control program within the GVRD should be undertaken immediately. This will necessitate that the legal authority is given to one agency to carry out such a program. The provision of a sludge disposal facility for toxic sludges is required in order to implement such a program.

(11) Studies should be undertaken to determine the frequency and duration of combined sewer overflows, as well as to determine what localized effects these overflows have on the receiving water.

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A special note of thanks is made to Ms. Wendy Bergerud, who wrote section A-2 on the multiple linear regression analysis, performed the analysis, and who asked the questions to generate the thoughts expressed in section A-3.

FIGURE 1.
LOCATION OF MUNICIPAL SEWAGE DISCHARGES

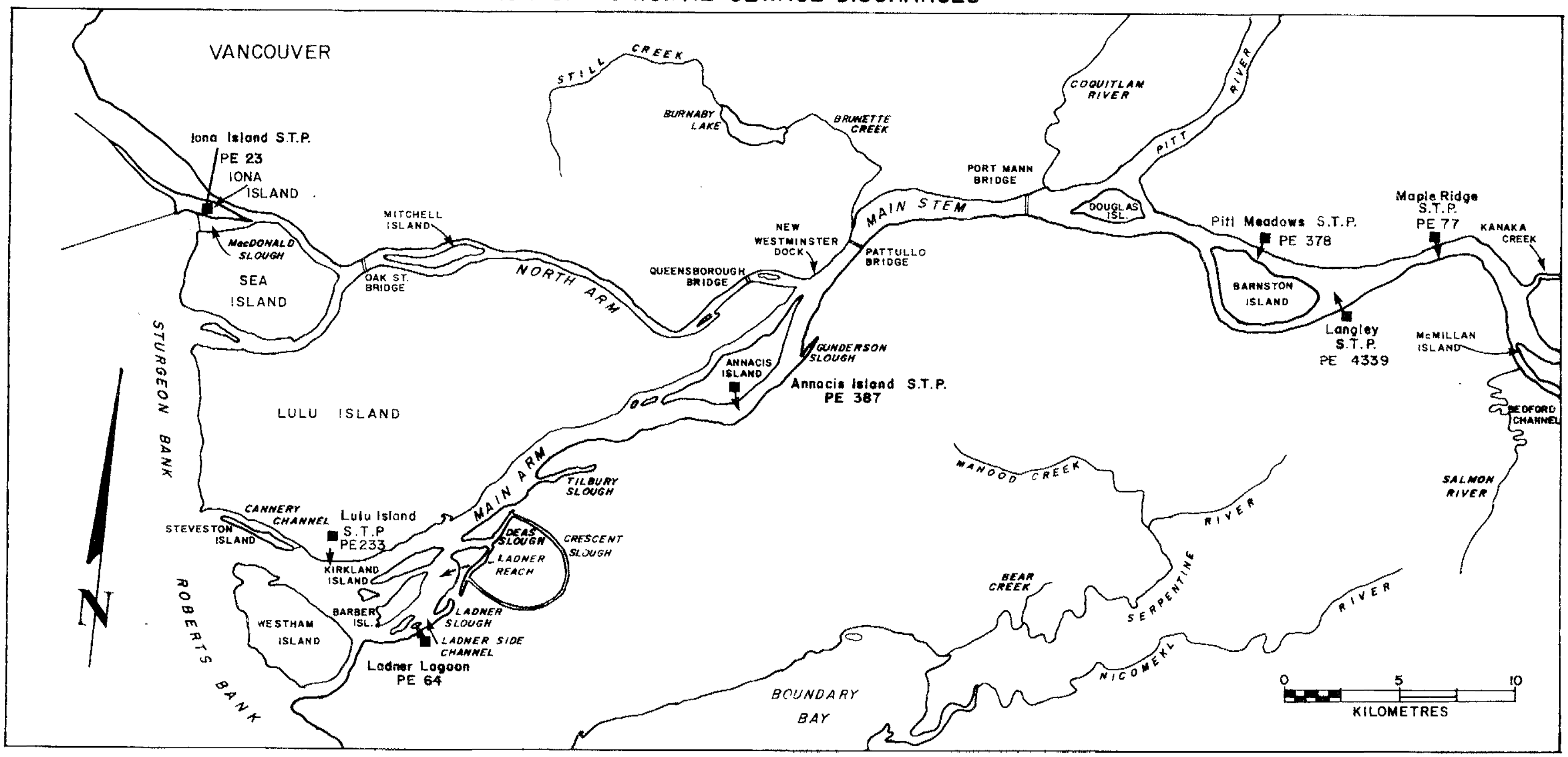


FIGURE 2.
LOCATION OF MAJOR SEWERAGE AREAS WITHIN THE STUDY AREA.

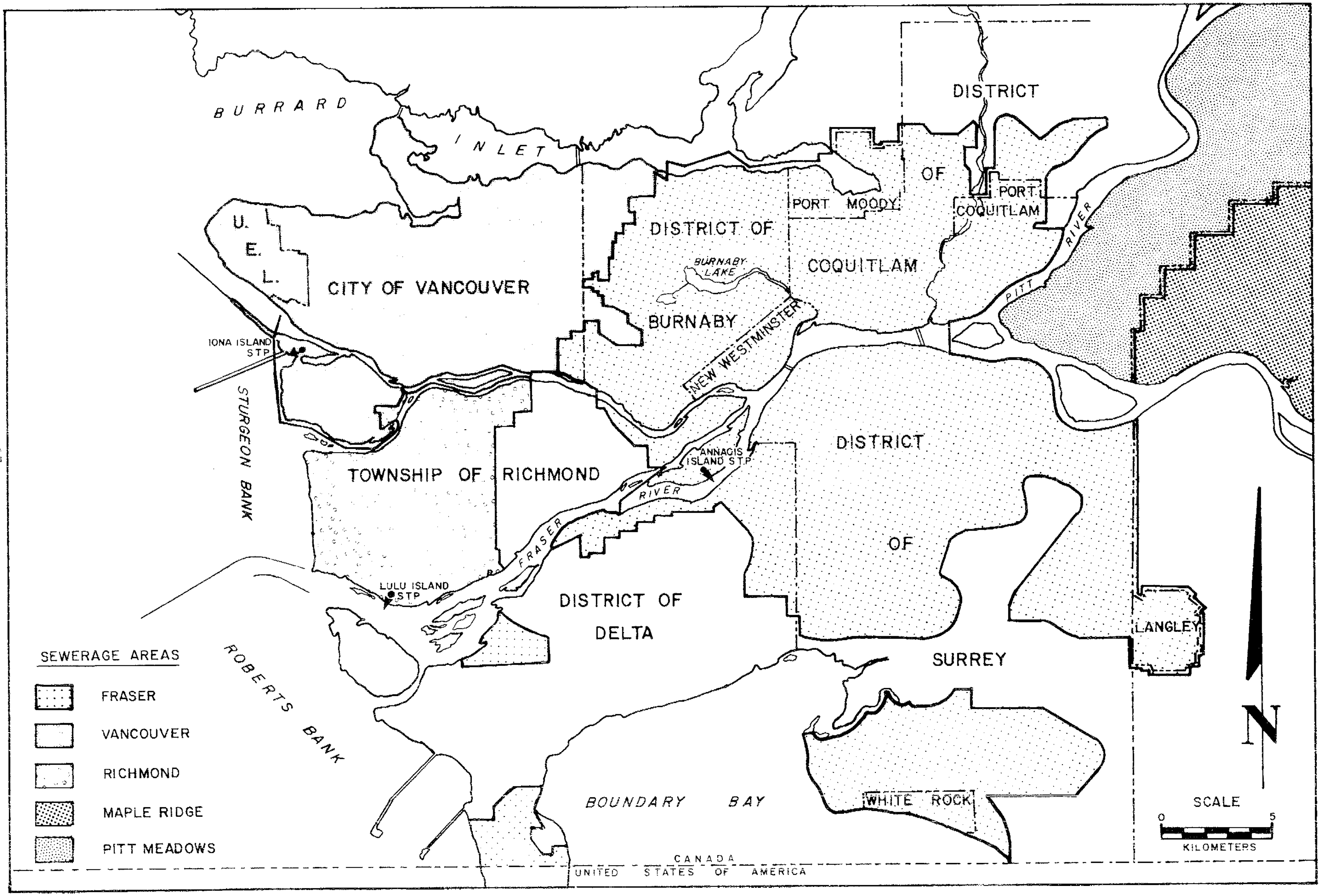


FIGURE 3.
IONA ISLAND S.T.P. – OPERATIONAL PATTERNS, JANUARY 1973 TO DECEMBER 1977.

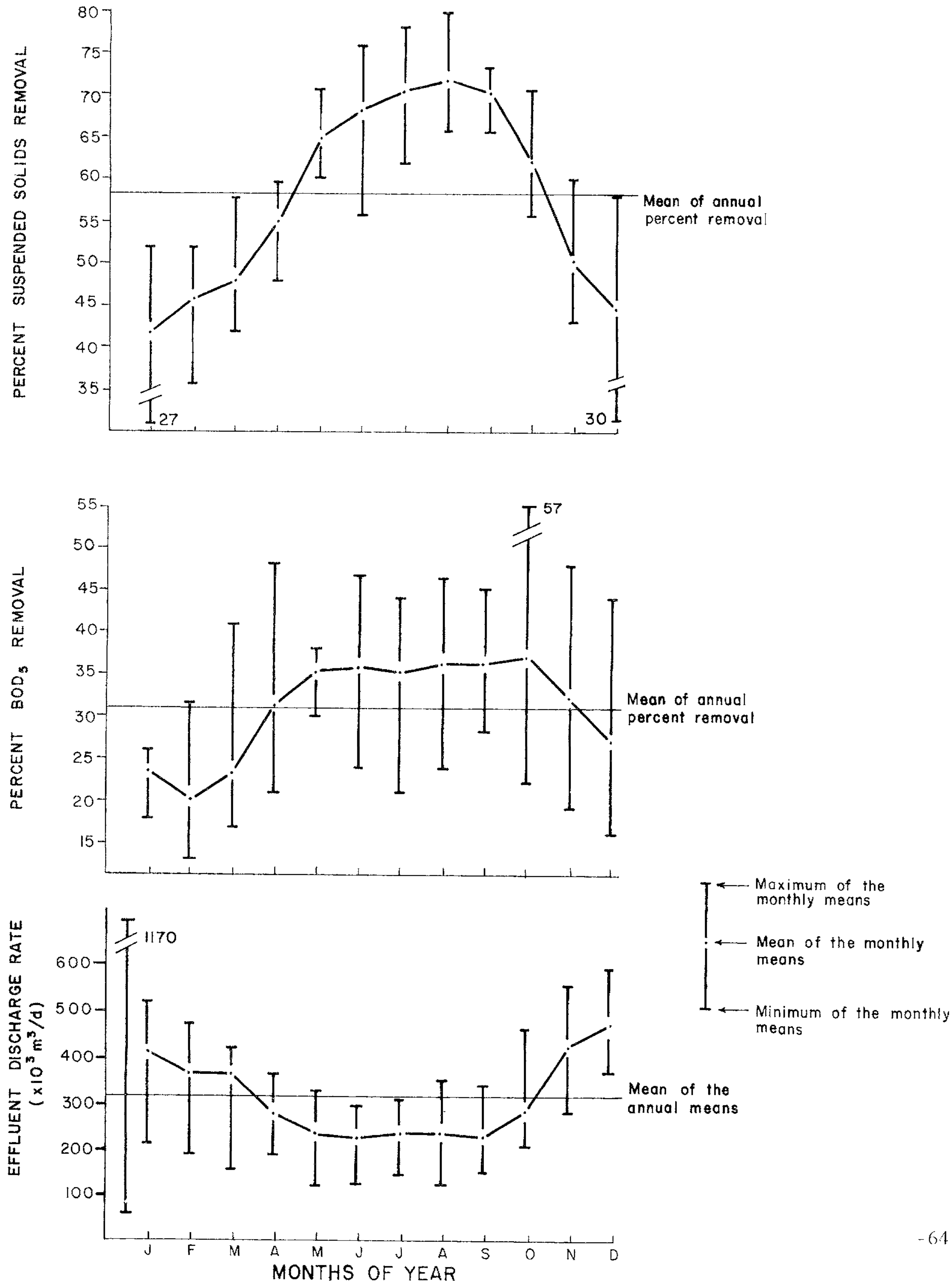


FIGURE 4
ANNACIS ISLAND S.T.P. - OPERATIONAL PATTERNS, SEPTEMBER 1975 TO DECEMBER 1977

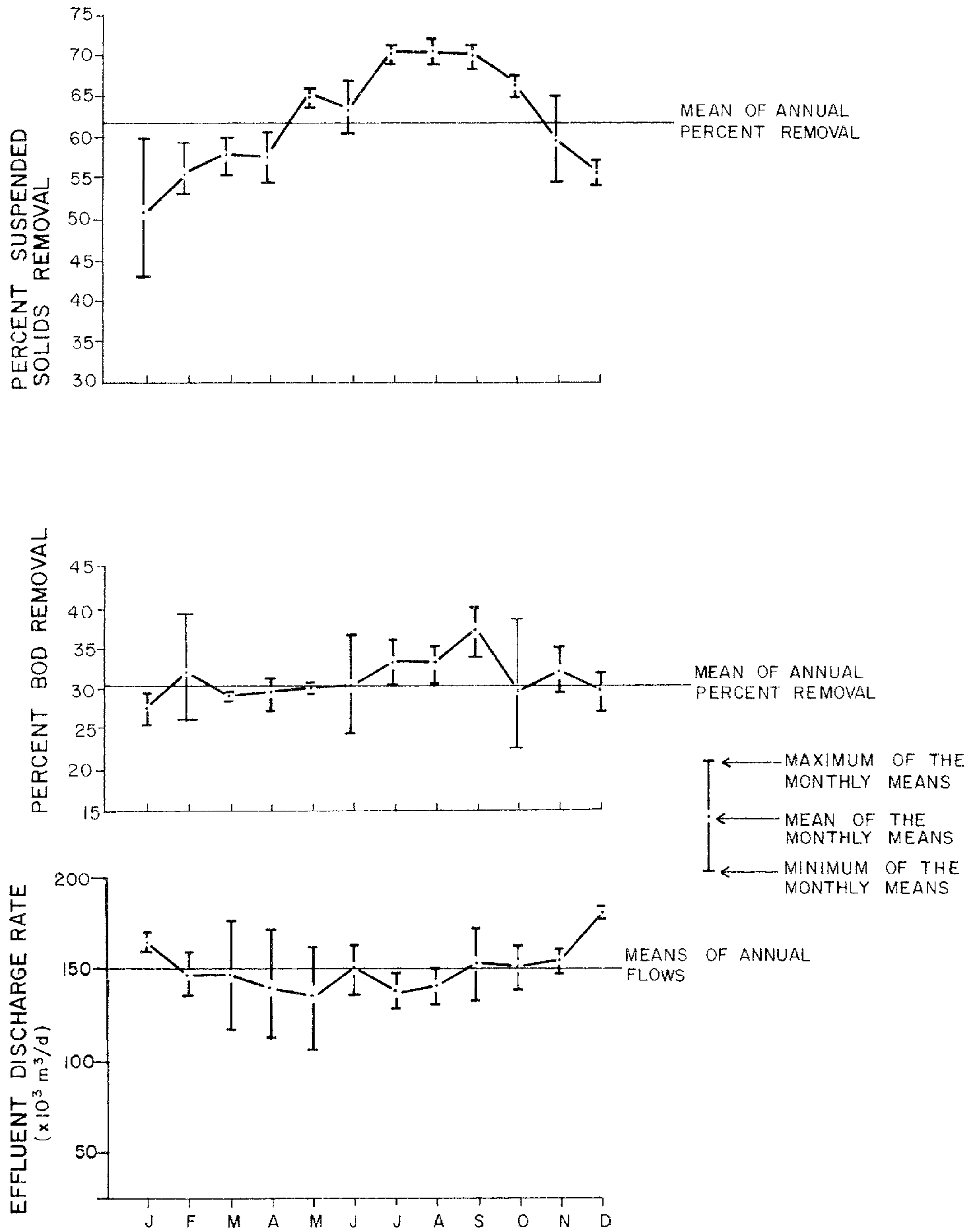


FIGURE 5
LULU ISLAND S.T.P. - OPERATIONAL PATTERNS, JANUARY 1973 TO DECEMBER 1977.

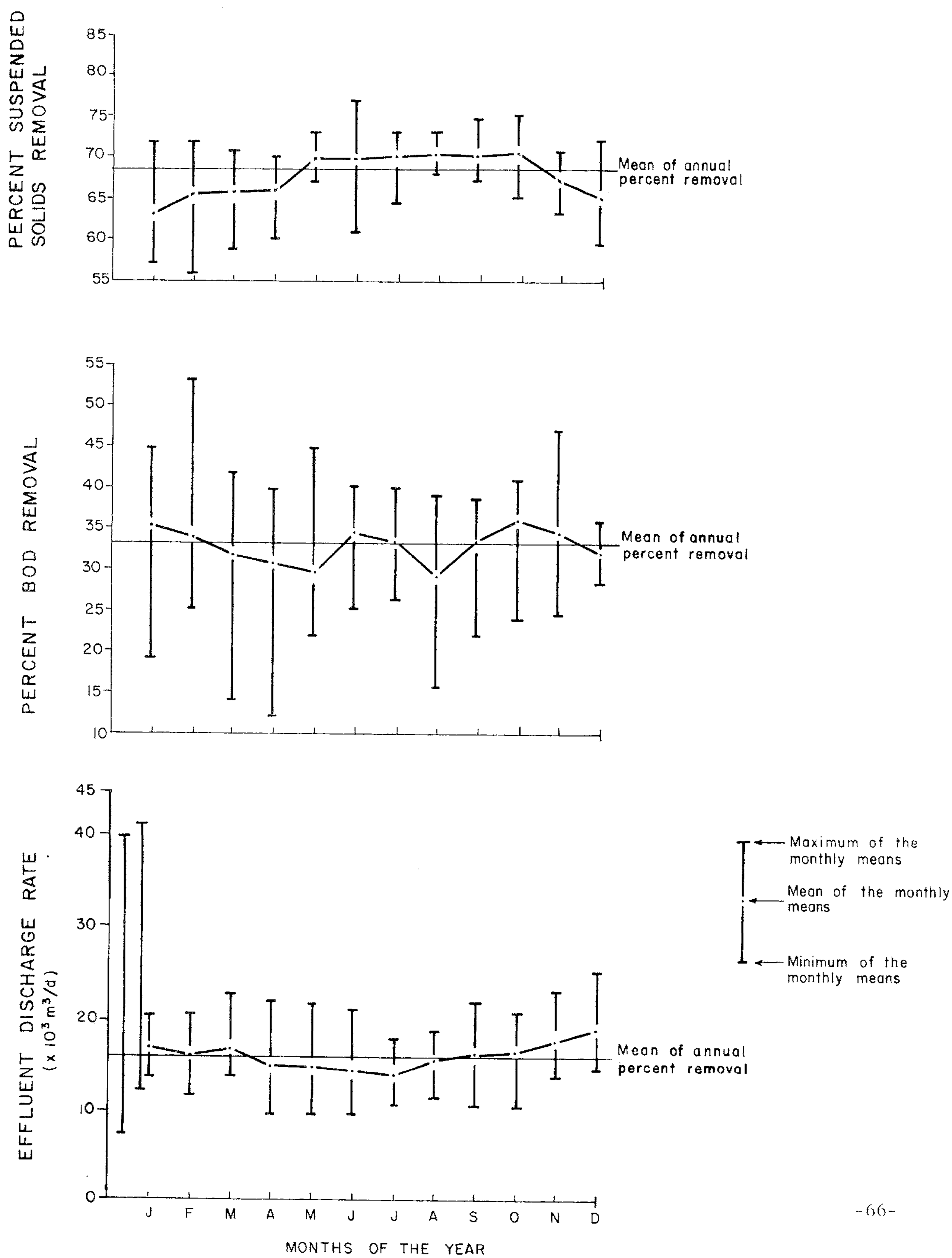


FIGURE 6
LOCATION OF COMBINED SEWER OVERFLOWS.

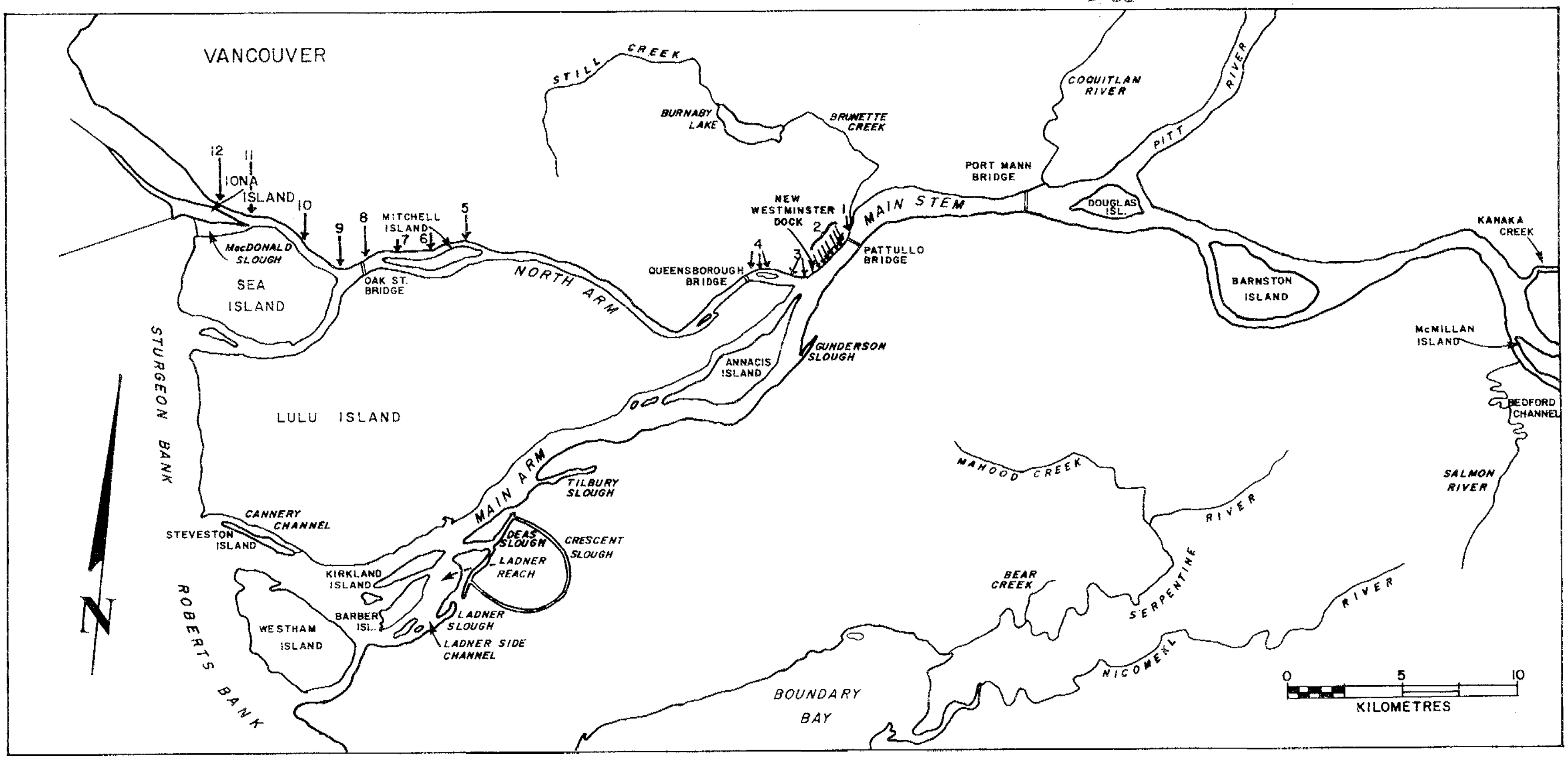
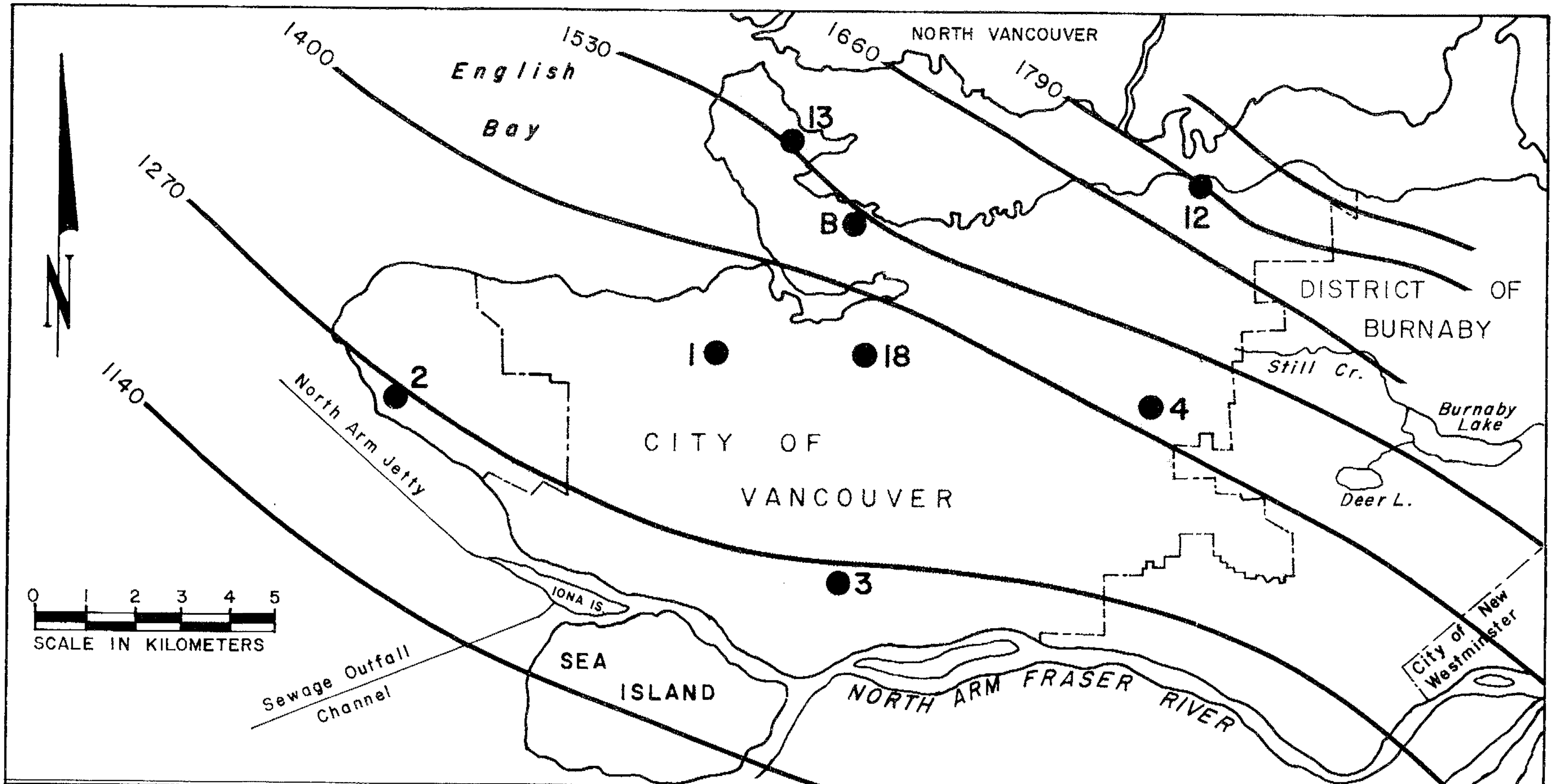


FIGURE 7

ISOHYETS AND RAIN GAUGES — VANCOUVER SEWERAGE AREA.



NOTES

ISOHYETS IN MILLIMETERS.

ISOHYETS ARE DRAWN FROM GREATER VANCOUVER SEWAGE AND DRAINAGE DISTRICT AND ATMOSPHERIC ENVIRONMENT SERVICE RAINFALL INFORMATION COLLECTED FROM 1962 to 1972 (INCLUSIVE).

☐ APPROXIMATE LOCATION OF VANCOUVER SEWERAGE AREA

RAINFALL STATION IDENTIFICATION

1 ·G.V.R.D. HEAD OFFICE (G.V.S. and D.D.)
2 ·U.B.C.- PLANT SCIENCE BUILDING (G.V.S. and D.D.)
3 ·SIR WINSTON CHURCHILL HIGH SCHOOL (G.V.S and D.D.)
4 ·RENFREW ELEMENTARY SCHOOL (G.V.S. and D.D.)
12 ·VANCOUVER HEIGHTS RESERV. (G.V.S and D.D.)
13 ·STANLEY PARK YARD OFFICE (G.V.S. and D.D.)
18 ·VANCOUVER CITY HALL (G.V.S. and D.D.)
B ·VANCOUVER P.M.O. (A.E.S.)

TABLE 1

PERMIT LIMITS

Permit \ Parameter	BOD_5 (mg/L)	Suspended Solids (mg/L)	pH	Flow (m^3/d)
PE 23 Iona Island	100	70	6.7-7.3	318 226
PE 64 Ladner Lagoon	30	50	6.5-7.5	1 364
PE 77 Maple Ridge	130/45*	130/60*	-	7 590
PE 187 Deas Island**	200	160	-	9 092
PE 233 Lulu Island	169	128	-	132 518
PE 378 Pitt Meadows	75	100	-	1 520
PE 387 Annacis Island	130	100	-	586 000
PE 4339 Langley	45	60	-	41 000

\- No limit.

* Lower limits effective July 1979.

** 1967 Limits - more restrictive limits for secondary treatment plant issued May 12, 1976.

TABLE 2

SUMMARY

PERMIT COMPLIANCE

Permit	Year	Percent Compliance			
		BOD_5	Suspended Solids	pH	Flow
PE 23 Iona STP	1975	53	92	57	54
	1976	46	92	73	61
	1977	47	93	69	36
	1978	-	-	-	9.3
	1979	55	86	67	6.6
PE 77 Maple Ridge	1974	100	100	-	-
	1975	100	100	-	-
	1976	100	-	-	-
	1977	100	100	-	75
	1978	100	100	-	100
PE 233 Lulu STP	1975	95	100	-	100
	1976	100	100	-	100
	1977	80	100	-	100
	1978	-	-	-	100
	1979	45	100	-	100
PE 378 Pitt Meadows	1973	100	100	-	-
	1974	100	100	-	-
	1975	100	100	-	-
	1976	100	100	-	-
	1977	100	100	-	-
	1978	-	-	-	-
PE 387 Annacis STP	1976	62	99.8	-	100
	1977	41	97.5	-	100
	1978	-	-	-	100
	1979	29.6	96.3	-	100

- No limit, or data unavailable.

TABLE 3

IONA STP

EFFLUENT MONITORING DATA SUMMARY

Parameter	No. of Values	Period of Record	Values* (mg/L)			Loading (kg/d)	% Removal
			Max.	Mean	Min.		
pH	248	1972	9.8	7.1**	6.4	-	-
	229	1973	10.	7.1**	6.4	-	-
	237	1974	8.3	7.1**	6.1	-	-
	216	1975	8.0	7.05**	6.5	-	-
	235	1976	7.6	7.2**	6.9	-	-
	233	1977	8.2	7.1**	6.4	-	-
	242	1978	8.7	7.0**	5.8	-	-
	226	1979	8.1	-	5.3	-	-
Suspended Solids	351	1972	195	48	16	15 500	57
	341	1973	250	52	18	16 500	55
	345	1974	117	46	10	17 500	60
	359	1975	69	49	32	19 000	59
	335	1976	70	50	33	16 000	62
	329	1977	166	48	15	18 500	61
	340	1978	102	46	15	19 600	64
	348	1979	178	54	16	24 000	56
BOD_5	136	1972	144	78	18	25 000	29
	123	1973	140	74	25	23 500	31
	119	1974	211	80	20	30 000	35
	133	1975	152	100	42	38 500	29
	123	1976	124	87	50	30 700	29
	126	1977	187	105	24	41 000	30
	112	1978	161	86	40	36 600	38
	119	1979	170	94	36	41 700	35
Flow (x 10^3 m^3/d)	366	1972	937	323	146	-	-
	346	1973	991	318	135	-	-
	365	1974	1 161	377	157	-	-
	365	1975	960	383	188	-	-
	358	1976	715	320	173	-	-
	364	1977	946	387	160	-	-
	365	1978	765	426	260	-	-
	365	1979	1 068	445	209	-	-

TABLE 3 (CONTINUED)

IONA STP

EFFLUENT MONITORING DATA SUMMARY

Parameter	No. of Values	Period of Record	Values* (mg/L)			Loading (kg/d)	% Removal
			Max.	Mean	Min.		
COD	63	1975	228	142	53	54 400	-
	218	1976	226	187	135	59 800	-
	220	1977	187	163	123	63 100	-
	228	1978	262	151	52	64 300	-
	234	1979	367	164	53	73 000	-
Total Phosphorus	10	1977	3.8	2.5	1.1	970	-
	12	1978	3.5	2.6	1.2	1 100	-
	12	1979	4	3	1	1 335	-
Kjeldahl Nitrogen	10	1977	18	13.6	5	5 250	-
	12	1978	26	16	8	6 810	-
	12	1979	25	19	6	8 450	-
Total Aluminum	12	1978	1.8	0.8	0.4	340	-
	12	1979	1.2	0.9	0.5	400	-
Diss. Boron	12	1978	0.34	0.23	0.13	98	-
	12	1979	0.27	0.20	0.03	89	-
Total Chromium	347	1972	2.2	<0.1	<0.1	-	-
	43	1975	0.32	0.15	0.07	58	-
	55	1976	0.074	0.07	0.07	23	-
	10	1977	0.08	0.03	0.02	12	-
	12	1978	0.08	-	<0.05	-	-
	12	1979	0.09	-	<0.05	-	-
Total Copper (Diss.† in 1978 and 1979)	325	1972	0.38	0.18	0.07	-	11
	43	1975	0.37	0.18	0.09	70	45
	55	1976	0.21	0.16	0.10	53	52
	54	1977	0.29	0.19	0.12	78	58
	12	1978	0.25	-	<0.04	-	-
	12	1979	0.18	0.06	<0.04	27	-
Total Iron (Diss.† in 1978 and 1979)	347	1972	2.5	1.1	0.4	360	12
	43	1975	1.7	1.2	0.7	450	33
	55	1976	1.6	1.0	0.7	320	31
	54	1977	1.5	0.93	0.7	360	26
	12	1978	0.6	0.38	0.10	160	-
	12	1979	0.52	0.34	0.14	150	-

TABLE 3 (CONTINUED)

IONA STP

EFFLUENT MONITORING DATA SUMMARY

Parameter	No. of Values	Period of Record	Values (mg/L)			Loading (kg/d)	% Removal
			Max.	Mean	Min.		
Total Lead	347	1972	4.3	<0.2	<0.2	-	11
	55	1976	0.2	0.10	0.017	33	24
	10	1977	0.12	0.06	0.02	26	50
	12	1978	0.05	0.02	0.005	9	-
	12	1979	0.10	0.04	0.02	18	-
Total Nickel (Diss.† in 1978 and 1979)	347	1972	0.6	<0.1	<0.1	-	-
	43	1975	0.19	0.09	<0.07	35	-
	55	1976	0.07	<0.07	<0.07	-	-
	54	1977	<0.07	-	<0.01	-	-
	12	1978	<0.05	<0.05	<0.05	-	-
	12	1979	<0.05	<0.05	<0.05	-	-
Total Zinc	347	1972	1.69	0.18	0.05	58	29
	43	1975	0.25	0.17	0.10	65	17
	55	1976	0.18	0.13	0.10	42	34
	54	1977	0.36	0.12	0.04	44	21
	12	1978	0.72	0.17	0.09	72	-
	12	1979	0.32	0.12	0.06	53	-

* All values in mg/L except pH and flow

** Median

\- No measurement or calculation

† Only dissolved analyses performed for copper, iron and nickel in 1978 and 1979

TABLE 4

BACTERIOLOGICAL DATA SUMMARY

IONA ISLAND STP

1977

Month	Total Coliform (MPN/100 mL)	Loading (MPN/Day X 10^{12})			
	Geometric Mean	Average	Minimum	Maximum	Geometric Mean
January	2 132 700	10 700	336	25 100	7 326
February	2 603 100	11 300	1 760	44 700	8 836
March	3 095 200	20 900	2.44	170	13 200
April	2 678 300	28 800	36.7	372 000	9 895
May	1 212	601	0.29	18 100	4.2
June	257	1.02	0.09	6.4	0.8
July	148	2.55	0.09	35.3	0.5
August	170	46.3	0.10	736	0.6
September	200	22.1	0.09	753	0.7
October	2 341 400	63 700	0.09	712 000	8 246
November	3 226 300	21 900	4 080	56 100	17 920
December	2 273 300	18 600	96.7	73 200	10 870

TABLE 5

IONA STP

SLUDGE MONITORING DATA SUMMARY

Parameter	Period of Record	No. of Values	mg/kg (Wet Wt.)		
			Max.	Mean	Min.
Cadmium	1976	24	0.45	0.33	0.16
	1977	14	0.52	0.33	0.24
	1978	8	0.5	0.35	0.2
	1979	14	0.4	0.23	0.2
Chromium	1976	24	5.88	3.8	1.73
	1977	16	6.27	4.5	3.7
	1978	8	6.6	5.1	4.3
	1979	14	6.4	4.7	3.5
Copper	1976	24	40.5	24.7	10.1
	1977	16	32.8	25.5	19.0
	1978	8	44.7	29.5	19.8
	1979	14	44.7	32.5	23.0
Iron	1976	24	350	280	218
	1977	16	457	339	215
	1978	8	517	452	390
	1979	14	525	436	296
Lead	1976	24	26	18.8	7.47
	1977	16	38.8	21.4	15.3
	1978	8	27	23.5	20
	1979	14	48	26.2	16
Manganese	1976	22	7.8	6.1	4.7
	1977	16	8.3	6.3	3.7
	1978	8	9.7	8.5	7.4
	1979	14	10.8	7.2	5.3

TABLE 5 (CONTINUED)

IONA STP

SLUDGE MONITORING DATA SUMMARY

Parameter	Period of Record	No. of Values	mg/kg (Wet Wt.)		
			Max.	Mean	Min.
Mercury	1978 1979	8 14	0.20 0.28	0.17 0.16	0.13 0.13
Nickel	1976 1977 1978 1979	24 16 8 14	1.83 1.79 2.1 2.4	1.3 1.3 1.6 1.6	0.66 0.98 1.1 1.1
Zinc	1976 1977 1978 1979	24 16 8 14	32.3 29 29.5 35.6	21.4 22.4 25 26.6	12.4 17.5 17.4 17.8
Percent Solids	1978 1979	6 14	3.6 4.4	3.15 3.0	2.5 1.9
Polychlorinated Biphenyls	Raw Sludge - 1.9 ppm (wet wt.) - 1.1 ppm (wet wt.)				

TABLE 6

ANNACIS STP

EFFLUENT MONITORING DATA SUMMARY

Parameter	No. of Values	Period of Record	Values* (mg/L)			Loading kg/d	% Removal
			Max.	Mean	Min.		
pH	71	1975	7.3	7.1**	6.8	-	-
	239	1976	7.3	6.8**	6.5	-	-
	233	1977	7.1	6.6**	6.2	-	-
	236	1978	7.6	6.9**	6.2	-	-
	243	1979	6.9	6.6**	6.4	-	-
Suspended Solids	108	1975	67	52	35	7 700	55
	329	1976	70	56	41	8 000	63
	362	1977	141	65	29	10 800	64
	354	1978	126	67	38	11 800	62
	327	1979	137	74	17	14 200	67
BOD_5	38	1975	164	96	56	14 300	29
	228	1976	164	122	71	16 600	32
	129	1977	219	135	47	21 700	32
	117	1978	230	141	72	24 800	28
	116	1979	240	157	86	30 100	28
Flow (x 10^3 m^3/d)	122	1975	190	149	105	-	-
	366	1976	179	136	101	-	-
	365	1977	199	166	136	-	-
	365	1978	396	176	88	-	-
	365	1979	564	192	129	-	-
COD	61	1975	215	163	117	24 000	-
	182	1976	278	226	162	31 000	-
	220	1977	304	273	219	45 300	-
	194	1978	427	297	145	52 300	-
	208	1979	600	321	157	61 600	-
Total Aluminum	12	1978	1.2	0.7	0.3	123	-
	12	1979	1.8	1.0	0.7	192	-
Diss. Boron	12	1978	0.7	-	0.1	-	-
	12	1979	0.45	0.31	<0.05	59.5	-
Diss. Cadmium	52	1976	0.0022	0.002	0.0005	0.26	-
	12	1978	0.008	-	<0.0005	-	-
	12	1979	0.0015	0.0005	<0.0005	-	-
Total Chromium	52	1976	0.05	0.03	0.013	3.7	-
	12	1977	0.11	0.07	0.015	12	-
	12	1978	0.20	-	<0.05	-	-
	12	1979	0.10	0.07	<0.05	13.4	-

TABLE 6 (CONTINUED)

ANNACIS STP

EFFLUENT MONITORING DATA SUMMARY

Parameter	No. of Values	Period of Record	Values* (mg/L)			Loading kg/d	% Removal
			Max.	Mean	Min.		
Total Copper (Diss.† in 1978 and 1979)	52 61 12 12	1976 1977 1978 1979	0.19 0.29 0.06 0.14	0.15 0.13 - 0.06	0.11 0.04 <0.04 <0.04	21 22 - 12	23 30 - -
Total Iron (Diss.† in 1978 and 1979)	52 61 12 12	1976 1977 1978 1979	1.31 1.64 1.05 2.40	1.09 1.22 0.65 0.74	0.71 0.87 0.30 0.26	150 200 115 140	38 25 - -
Total Lead	52 12 12 12	1976 1977 1978 1979	0.037 0.10 0.05 0.05	0.02 0.04 0.02 0.03	0.007 <0.02 0.005 0.010	2.8 6.6 3.5 5.8	26 21 - -
Total Mercury	12 12	1978 1979	0.0007 <0.0005	<0.0005 <0.0005	<0.0005 <0.0005	- -	- -
Total Nickel (Diss.† in 1978 and 1979)	52 61 12 12	1976 1977 1978 1979	0.088 0.19 0.10 0.18	0.08 - - <0.05	0.07 <0.01 <0.05 <0.05	11 - - -	- - - -
Total Zinc	52 12 12 12	1976 1977 1978 1979	0.21 0.38 0.52 0.26	0.16 0.17 0.18 0.16	0.10 0.11 0.10 0.12	21 28 32 31	21 24 - -
Total Phosphorus	- 10 12 12	1976 1977 1978 1979	6.0 6.7 6.6 5.5	4.2 4.1 4.4 4.4	2.3 2.6 2.6 2.0	570 680 775 845	- - - -
Kjeldahl Nitrogen	- 10 12 12	1976 1977 1978 1979	30 29 31 31	25.5 20.5 24 24	22 15 15 12	3 500 3 400 4 225 4 600	- - - -

* All values are in mg/L except pH and flow

** Median

\- No measurement or calculation

† Only dissolved analyses performed for copper, iron, and nickel in 1978 and 1979

TABLE 7

BACTERIOLOGICAL DATA SUMMARY

ANNACIS ISLAND STP

1977

	Total Coliform (MPN/100 mL)	Loading (MPN/Day X 10^{12})			
Month	Geometric Mean	Average	Geometric Mean	Minimum	Maximum
January	1 591	7.38	2.54	0.13	46.2
February	30 403	1 140	45.7	1.07	4 260
March	7 004	713	12.3	0.36	4 370
April	3 609	15.5	6.22	0.41	74.3
May	3 130	11.2	5.12	0.07	72.2
June	2 402	5.42	3.99	1.25	18.9
July	841	2.55	1.24	0.12	16.4
August	1 221	6.49	1.84	0.30	37.0
September	975	47.7	1.67	0.41	710
October	1 844 900	69 900	3 000	0.26	513 000
November	No Data				
December	9 169 100	22 600	17 160	4 070	57 800

TABLE 8

ANNACIS STP

SLUDGE MONITORING DATA SUMMARY

Parameter	Period of Record	No. of Values	mg/kg (Wet Wt.)		
			Max.	Mean	Min.
Cadmium	1976	24	0.30	0.22	0.15
	1977	16	0.41	0.24	0.12
	1978	8	0.70	0.33	0.12
	1979	12	0.2	0.13	0.1
Chromium	1976	24	8.65	4.7	1.57
	1977	16	11.7	7.2	5.4
	1978	8	10	7.3	5.4
	1979	12	6.5	5.2	4.8
Copper	1976	24	42.8	27.3	13.5
	1977	16	35.8	27.7	22
	1978	8	27.9	24.7	19.8
	1979	12	28.1	24.5	21.1
Iron	1976	24	285	230	175
	1977	16	366	255	128
	1978	8	335	277	230
	1979	12	290	259	220
Lead	1976	24	11.1	8.1	4.5
	1977	16	15.4	10.5	7.4
	1978	8	21	15	10
	1979	12	14	12	8.5
Manganese	1976	23	7.23	5	4.05
	1977	16	7.31	4.9	2.95
	1978	8	6.6	5.45	4.3
	1979	12	5.8	4.81	4.4
Mercury	1977	4	0.10	0.08	0.07
	1978	8	0.17	0.14	0.12
	1979	12	0.17	0.12	0.08
Nickel	1976	24	2.25	1.26	0.6
	1977	16	2.6	1.73	1.4
	1978	8	2.5	1.8	1.1
	1979	12	1.6	1.4	1.2
Zinc	1976	24	43.	25.9	10.5
	1977	16	45.5	28.5	16.8
	1978	8	48.8	37.1	26.7
	1979	12	38.2	27.6	20.2
Percent Solids	1977	16	4.3	3.4	3.1
	1978	8	4.6	3.5	2.9
	1979	12	3.5	2.8	2.2

TABLE 9

LULU STP

EFFLUENT MONITORING DATA SUMMARY

Parameter	No. of Values	Period of Record	Values* (mg/L)			Loading (kg/d)	% Removal
			Max.	Mean	Min.		
pH	208	1973	7.1	7.0**	6.3	-	-
	238	1974	7.1	6.9**	6.6	-	-
	241	1975	6.9	6.8**	6.6	-	-
	240	1976	6.9	6.8**	6.6	-	-
	244	1977	7.1	6.8**	6.4	-	-
	230	1978	7.4	6.6**	5.9	-	-
	243	1979	7.0	6.7**	6.4	-	-
Suspended Solids	337	1973	256	91	49	1 000	64
	353	1974	202	90	42	1 100	70
	353	1975	95	82	68	1 300	70
	348	1976	94	80	67	1 500	68
	357	1977	102	81	52	1 700	70
	361	1978	84	78	43	1 700	66
	355	1979	109	71	40	1 800	73
BOD_5	131	1973	220	113	55	1 300	27
	166	1974	233	138	63	1 800	35
	127	1975	157	124	81	2 000	36
	214	1976	157	134	107	2 500	35
	133	1977	224	142	67	3 100	32
	117	1978	176	168	73	3 700	33
	130	1979	290	178	130	4 500	30
Flow (x 10^3 m^3/d)	357	1973	40.5	11.5	8.2	-	-
	364	1974	25.5	12.7	7.3	-	-
	364	1975	40.5	15.8	11.8	-	-
	366	1976	28.2	18.5	12.3	-	-
	364	1977	42.3	21.6	13.6	-	-
	365	1978	32.7	22.4	8.2	-	-
	365	1979	41.4	25.2	15.9	-	-
COD	75	1975	337	273	115	4 300	-
	219	1976	352	274	76	5 100	-
	236	1977	333	285	250	6 200	-
	246	1978	541	273	97	6 100	-
	240	1979	482	293	165	7 400	-
Total Aluminum	12	1978	1.7	0.9	0.2	20.2	-
	12	1979	3.4	1.3	0.7	32.8	-
Diss. Boron	12	1978	0.69	0.47	0.35	10.5	-
	12	1979	0.52	0.44	0.08	11.1	-
Diss. Cadmium	9	1977	0.02	0.011	0.005	0.24	-
	12	1978	0.009	-	<0.0005	-	-
	12	1979	0.016	0.0045	0.0010	0.11	-

TABLE 9 (CONTINUED)

LULU STP

EFFLUENT MONITORING DATA SUMMARY

Parameter	No. of Values	Period of Record	Values* (mg/L)			Loading (kg/d)	% Removal
			Max.	Mean	Min.		
Total Chromium	56	1976	0.14	0.09	0.07	1.7	-
	9	1977	0.33	0.20	0.066	4.3	-
	12	1978	0.35	0.19	0.09	4.3	-
	12	1979	0.49	0.21	0.12	5.3	-
Total Copper (Diss.† in 1978 and 1979)	334	1973	1.18	0.24	0.05	2.8	32
	73	1974	1.1	0.24	0.10	3.0	14
	57	1975	1.0	0.33	0.07	5.2	10
	56	1976	0.37	0.22	0.15	4.1	20
	61	1977	0.23	0.18	0.14	3.9	22
	12	1978	0.07	-	<0.04	-	-
	12	1979	0.17	0.06	<0.04	1.5	-
Total Iron (Diss.† in 1978 and 1979)	334	1973	9.7	3.8	0.1	44	34
	73	1974	4.3	3.3	2.0	42	30
	57	1975	5.5	3.1	2.3	50	26
	56	1976	3.7	2.9	2.2	53	18
	61	1977	3.2	2.9	2.4	63	18
	12	1978	2.3	1.4	0.75	31	-
	12	1979	1.2	0.94	0.68	24	-
Total Lead	56	1976	0.2	0.10	0.01	1.8	13
	9	1977	0.3	0.2	0.066	4.3	29
	12	1978	0.3	0.17	0.015	3.8	-
	12	1979	0.40	0.15	0.02	3.8	-
Total Nickel (Diss.† in 1978 and 1979)	56	1976	0.27	0.13	<0.07	2.3	-
	61	1977	0.32	0.18	<0.07	3.9	-
	12	1978	0.22	0.11	0.06	2.5	-
	12	1979	0.22	0.13	<0.05	3.3	-
Total Zinc	57	1975	0.53	0.18	0.10	2.8	29
	56	1976	0.36	0.26	0.20	4.8	23
	9	1977	0.91	0.56	0.27	12.1	24
	12	1978	1.05	0.54	0.34	12.1	-
	12	1979	0.70	0.41	0.24	10.3	-
Total Phosphorus	12	1978	7.0	5.8	4.2	130	-
	12	1979	7.1	6.1	5.7	154	-
Kjeldahl Nitrogen	12	1978	36	34	27	760	-
	12	1979	39	34	31	860	-

* All values are expressed in mg/L except pH and flow

** Median value

- No measurement or calculation

† Only dissolved analyses performed for copper, iron and nickel in 1978 and 1979

TABLE 10

BACTERIOLOGICAL DATA SUMMARY

LULU ISLAND STP

1977

Month	Total Coliform (MPN/100 mL)	Loading (MPN/Day X 10^{12})			
	Geometric Mean	Average	Minimum	Maximum	Geometric Mean
January	2 937	1.87	0.09	23.5	0.6
February	13 495	10.4	0.06	50.2	2.7
March	51 275	28.6	0.44	282.1	11.9
April	29 341	15.1	0.52	55.7	6.5
May	4 909	8.7	0.007	53.5	1.1
June	1 456	3.25	0.007	53.5	0.3
July	229	0.11	0.005	0.84	0.04
August	1 640	9.7	0.005	54.6	0.3
September	1 181	3.8	0.007	42.9	0.3
October	632 090	8 060	0.02	54 600	132.3
November	37 367 000	13 900	743	61 200	8 161
December	25 393 000	8 260	2 240	29 000	6 470

TABLE 11

LADNER LAGOON

EFFLUENT MONITORING DATA SUMMARY

Parameter	No. of Values	Period of Record	Values* (mg/L)		
			Max.	Mean	Min.
pH	3	1972	8.3	8.1**	7.5
	5	1973	7.9	7.5**	7.3
	4	1974	7.9	7.5**	7.1
	2	1975	7.9	7.7**	7.5
	2	1976	7.3	7.3**	7.2
	2	1977	7.8	-	7.7
	4	1978	7.9	7.6**	7.1
Suspended Solids	3	1972	52	38	18.6
	4	1973	69	41	15.6
	4	1974	84	38	13
	2	1975	30	19	7
	2	1978	35	23	11
BOD_5	3	1972	33	22	<10
	4	1973	19	14	<10
	4	1974	30	20	11
	2	1975	36	23	10
	2	1976	37	24	11
	2	1977	25	-	<10
	2	1978	63	37	11
Nitrate	3	1972-1973	0.36	0.22	0.07
Nitrite	3	1972-1973	0.39	0.17	0.02
Fecal Coliform	2	1975-1976	>24 000	1 300**	500

* All values are expressed as mg/L except pH and fecal coliform (MPN/100 mL)

** Median

\- Too few data to state mean

TABLE 12

MAPLE RIDGE STP

EFFLUENT MONITORING DATA SUMMARY

Parameter	No. of Values	Period of Record	Values* (mg/L)		
			Max.	Mean	Min.
pH	1	1974	7.1	-	-
	6	1975	7.5	7.2**	7.1
	2	1976	7.2	-	7.1
	2	1977	7.0	-	6.9
	2	1978	7.1	-	7.1
Suspended Solids	1	1974	70	-	-
	6	1975	76	46	22
	2	1976	37	-	20
	6	1977	34	25	9
	14	1978	34	20	10
BOD_5	1	1974	51	-	-
	6	1975	59	41	17
	3	1976	67	63	58
	6	1977	52	33	14
	14	1978	56	26	14
Kjeldahl Nitrogen	1	1974	30	-	-
	6	1975	33	24	7
	1	1976	14	-	-
	2	1977	11	10	9
	2	1978	13	12.5	12
Total Phosphorus	3	1976	4.8	4.4	3.9
	4	1977	5.4	4.8	4.4
	2	1978	4.0	3.9	3.9
Fecal Coliform	4	1975	160 000	24 000**	>24 000
	1	1976	16 000	-	-
	2	1977	>240 000	-	35 000
	2	1978	92 000	-	54 000

* All values are expressed as mg/L except pH and fecal coliform (MPN/100 mL)

** Median

\- Too few data

TABLE 13

PITT MEADOWS STP

EFFLUENT MONITORING DATA SUMMARY

Parameter	No. of Values	Period of Record	Values* (mg/L)		
			Max.	Mean	Min.
pH	2	1973	6.3	-	5.1
	3	1974	4.6	4.4**	4.4
	3	1975	7.2	4.5**	4.1
	2	1976	6.8	-	6.7
	3	1977	7.2	6.6**	6.6
	2	1978	7.5	-	7.2
Suspended Solids	2	1973	30	18.5	7
	3	1974	72	49	36
	3	1975	76	38	14
	2	1976	85	51	16
	1	1977	33	-	-
	2	1978	35	32.5	30
Kjeldahl Nitrogen	1	1974	10	-	-
	1	1975	7	-	-
	1	1976	8	-	-
	1	1977	13	-	-
	1	1978	19	-	-
BOD_5	2	1973	15	-	<10
	3	1974	12	<10**	<10
	3	1975	13	<10**	<10
	2	1976	36	-	<10
	1	1977	<10	-	-
	2	1978	14	13.5	13
Total Phosphorus	1	1974	6.6	-	-
	1	1976	7.4	-	-
Fecal Coliform	1	1974	<2 000	-	-
	2	1975	24 000	-	<20
	1	1977	200	-	-
	2	1978	35 000	-	200

* All values are expressed as mg/L except pH and fecal coliform (MPN/100 mL).

** Median

\- Too few data

TABLE 14

COMBINED SEWER OVERFLOW DATA

Map Location	Overflow: Frequency (times/season)		Overflow: Volume (m^3/season)		Comments
	S	W	S	W	
1	6	18	1 000	3 000	Front St. near B.C. Penitentiary - 750 metres upstream from Pattullo Bridge. (Annacis)
2	6	18	900	2 700	From 10th St. to 1st St. - Seven overflows downstream from Pattullo Bridge - Main Stem. (Annacis)
3	6	18	300	1 000	From 3rd Ave. to 10th Street - Two overflows upstream from Poplar Island. (Annacis)
4	6	18	700	2 200	From 16th St. to 20th St. - Three overflows at Poplar Island. (Annacis)
5	6	18	950	2 900	Kent Ave. N. and Borden - Adjacent to Mitchell Island.
6	6	18	600	1 800	Fraser St. Bridge - 75 metres west of bridge.
7	6	18	600	1 800	Manitoba St. - Opposite Eburne Island.
8	3	6	100	200	Shaughnessy St. - 75 meters upstream from Oak St. Bridge.
9	3	6	70	140	Hudson St. - 700 metres downstream from Oak St. Bridge.
10	3	6	300	600	Argus Drive.
11	3	6	140	300	MacDonald St. - opposite Woods Island.
12	3	6	200	450	Point Grey Golf and Country Club.
	Total		5 860	17 090	

NOTE: All flows are normally to the Iona STP except where noted as going to the Annacis STP.

S = May through September.

W = October through April.

Source: B. Talbot, Senior Assistant Engineer, GVS & DD.

TABLE 15

IONA ISLAND STP

HOURS OF BYPASS

	1970	1971	1972	1979
January	6	19	21	8
February	4	19	13	5
March	6	19	22	6
April	6	16	11	-
May	2	4	3	-
June	2	7	-	-
July	3	3	-	-
August	-	2	-	-
September	-	8	-	4
October	-	14	5	10
November	4	25	-	7
December	18	21		18
Total	51	157	75	58
			Total Hours	523
			% of Year	6%

NOTE: ONLY sewage in EXCESS of plant capacity bypassed.

\- No Bypasses

TABLE 16

SLUDGE ANALYSES

POLLUTION CONTROL BRANCH SURVEY

1979

	Iona STP	Annacis STP	Lulu STP	Maple Ridge	Pitt Meadows
Aluminum	6.7	4.4	3	4.1	2.7
Cadmium	7	5	29	6	6
Chromium	142	157	906	25	20
Copper	966	992	959	2 000	1 100
Iron	13 300	8 700	4 600	7 700	4 900
Nickel	29	32	83	13	12
Zinc	912	1 070	1 850	694	654

NOTE: All data are presented in units of wet weight as mg/kg.

TABLE 17

UNITED STATES EPA ANAEROBIC SLUDGE ANALYSES[16]

Parameter	No. of Values	mg/kg* (Wet Weight)			
		Max.	Median	Mean	Min.
Cadmium	98	3 410	16	106	3
Chromium	94	28 850	1 350	2 070	24
Copper	108	10 100	1 000	1 420	85
Iron (%)	96	15.3	1.2	1.6	0.1
Lead	98	19 730	540	1 640	58
Manganese	81	7 100	280	400	58
Mercury	35	10 600	5	1 100	0.5
Nickel	85	3 520	85	400	2
Zinc	108	27 800	1 890	3 380	108
Percent Solids	-	7	-	-	5

* Except where noted as % (wet weight)

APPENDIX A

EFFECT OF STORMWATER ON PLANT OPERATIONS

A-1. Introduction

A multiple linear regression was used in an attempt to explain the significance of flow, temperature, and the initial concentration of the sewage on suspended solids removals at the three plants. It must be emphasized that the results were based upon data collected during only one year, and that significant conclusions or recommendations cannot be based upon this single set of results. These data have not been presented to suggest changes or to correct deficiencies or underdesign of facilities.

A-2. Results and Explanation of Multiple Linear Regression

The calculations were done on an IBM 360 computer using the SCATTERGRAM and REGRESSION precedures available in SPSS (Statistical Package for the Social Sciences, see pages 293-300 and pages 320-367, reference A-1). The results of the output are summarized in Figures A-1 to A-3 and Tables A-1 and A-2.

The following discussion assumes that the reader is already familiar with the Pearson correlation coefficient (which will be denoted by r) and simple linear regression analysis (see, for example, references A-2 and A-3).

If the three variables flow (F), initial suspended solids concentration (S) and temperature (T) were independent of each other, then their effect on suspended solids removal (%) could be determined by using separate linear regressions (the results of which are shown in Figures A-1 to A-3, n is the number of values, r is the correlation coefficient and S_{yx} is the standard error of estimate). However F, S and T are not independent as is demonstrated by the non-zero correlation coefficients between F, S and T (and which have been tabulated in Table A-1). Thus it was necessary to use a multiple linear regression analysis.

Multiple linear regression can be viewed as a means of assessing how much of the total variance or variability of % can be explained by the combined effect of F, S and T. It also assesses the effect of one particular variable, for instance F on % with the influence of T and S controlled. It is assumed that % is related to F, S and T by the following equation:

$$\% = a + b_F F + b_S S + b_T T \quad (1)$$

where a = constant

b_F, b_S, b_T = constants called partial regression coefficients

The partial regression coefficients are analogous to the slope in simple linear regression. In the above equation, b_F for example, is the change in % with a change of one unit in flow when T and S are held constant.

To compare the contribution of each variable to the prediction of %, the partial regression coefficients have to be "standardized". This can be done, for instance, by calculating $B_F = b_F\ (S_F/S_\%)$ where B_F is the standardized partial regression coefficient and S_F and $S_\%$ are the standard deviations of F and % (similarly for B_S and B_T). The standardized partial regression coefficients B_F, B_S and B_T are dimensionless quantities, like correlation coefficients, whose values range between -1 and 1. In fact if F, S and T were independent of each other then, for instance, B_F would have the same value as the correlation coefficient between F and % ($r_{F\%}$).

The results of multiple linear regression have the following pattern. The variable which has the highest correlation with % will have the largest regression coefficient. This means that this variable accounts for the largest proportion of the total variance of %. In the case of the Annacis Island STP, T has the largest correlation with % ($r_{T\%} = 0.62$). T therefore has the largest regression coefficient ($B_T = 0.51$). S has the next highest correlation with % ($r_{S\%} = 0.53$) but S is also highly correlated with T ($r_{ST} = 0.47$). This means that some of the variability of % can be jointly accounted for by S and T, and is called here a shared variance. This shared variance is arbitrarily assigned to T since T had the larger correlation with %. Thus this method gives S a smaller regression coefficient ($B_S = 0.34$) than would have been expected for $r_{S\%}$. A similar argument holds for F because F is highly correlated with both T and S ($r_{FT} = -0.57$, and $r_{FS} = -0.54$). The variance of % which F shares with T and S has already been assigned to T or S. Hence the regression coefficient is considerably lower than the correlation coefficient ($B_F = 0.08$ and $r_{F\%} = -0.38$).

The multiple linear regression equation will always reflect this particular pattern of division of %'s variance among the independent variables. Nevertheless, other possible divisions can be studied. In this particular instance, it was expected that F would explain most of the variance of %. To see if this expectation was valid, an hierarchical multiple linear regression was performed. This means that a regression of F and % was performed initially, and then T and S were added to the equation. The final equation with F, S and T is still the same as the multiple regression on all three. The difference in interpretation occurs with the summary table, Table A-2.

The multiple R value in Table A-2 is the correlation coefficient between the predicted values of % (given by the model equation[(1)]) and the actual values of %. It is one indicator of how well the data "fit" the equation. The square of R (R^2) is the fraction of %'s variance which is "explained" by the equation. The R^2 values indicate that at the Annacis Island STP, F itself accounts for 14% of the variance. The addition of T and S accounted for an additional 31%. At the Iona STP, F accounted for 10% of the variance, while T and S accounted for a further 38%. At the Lulu STP, F didn't account for any variance in percent removal while T and S accounted for 48%.

Thus, even when F was given the greatest advantage it accounted for only a small percentage of the total variation in % instead of having the much larger influence anticipated (at least when compared to T and S).

Some conditions in the interpretation are worthy of note:

1. Each equation is only valid for the plant it describes and the operating conditions at the time the data were collected.

2. Each equation is only valid for the range of values used in the analyses. Extrapolations outside that range might yield incorrect answers.

A-3. Influence of Stormwater on Removal Efficiencies

In order to determine the effect that stormwater had upon the operation of the three sewage treatment plants during 1979, multiple linear regressions were performed. The multiple correlation coefficients (R) obtained were 0.68 for the Annacis STP, and 0.70 for both the Lulu STP and the Iona STP. This means that nearly half of the percent removal of suspended solids for each plant can be attributed to these three factors.

The quantity of stormwater entering each plant is markedly different. This fact alters the effect of each factor on the percent removal of suspended solids at the individual plants. The percentage removal of suspended solids and its relationship to each of the three predictor factors is presented graphically in Figures A-1, A-2, and A-3.

The flow entering each plant controls the retention time of the sewage in the sedimentation tanks. However, the flows entering both the Iona STP and the Annacis STP were reduced by combined sewer overflows upsystem from the plants, and at the Iona STP, by plant bypasses. (This control does not alter the influence of the stormwater on other characteristics of the sewage).

Flow had the least direct impact of the three predictor factors on the percentage removal of the suspended solids at the three plants. Although this result may seem unusual, the effect of flow on solids removals is influenced by the design of the sewage collection system and the sewage treatment plants. Thus, the sedimentation tanks handle sewage flows which were anticipated in the plant design. The three plants operate within plant design with respect to retention times in the sedimentation tanks, subsequently reducing the impact and significance of uncontrolled flows.

Stormwater does alter other characteristics of the sewage entering the plants, even if its effect on retention times in the sedimentation tanks is regulated. One such characteristic of the sewage which is altered is the initial concentration of suspended solids. This factor is the most important of the three factors tested in accounting for the percent removal of suspended solids at the Iona STP, and of secondary importance at the Annacis STP and the Lulu STP.

The importance of this factor at the Iona STP may be due to the effect of stormwater on the normal particle size distribution in the sewage. The particle size distribution would be affected by the dilution of sewage by stormwater, by the contribution of solids to the sewage from street runoff, and by the resuspension of particles which had settled within the collection system during normal flow conditions.

The temperature of the influent sewage was the most important of the three factors at the Annacis STP and the Lulu STP. The importance of temperature in the settling rates of solids is shown by Stoke's law[A-5], which defines the settling velocity in terms of gravity, the mass density of the fluid, the size of the particles, and the absolute viscosity of the fluid. Since viscosity is decreased with increasing temperature, settling rates and solids removal are improved at higher temperatures.

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FIGURE A-1

IONA ISLAND STP
RESULTS OF SIMPLE LINEAR REGRESSION
FOR PERCENT REMOVAL OF SUSPENDED SOLIDS
1979

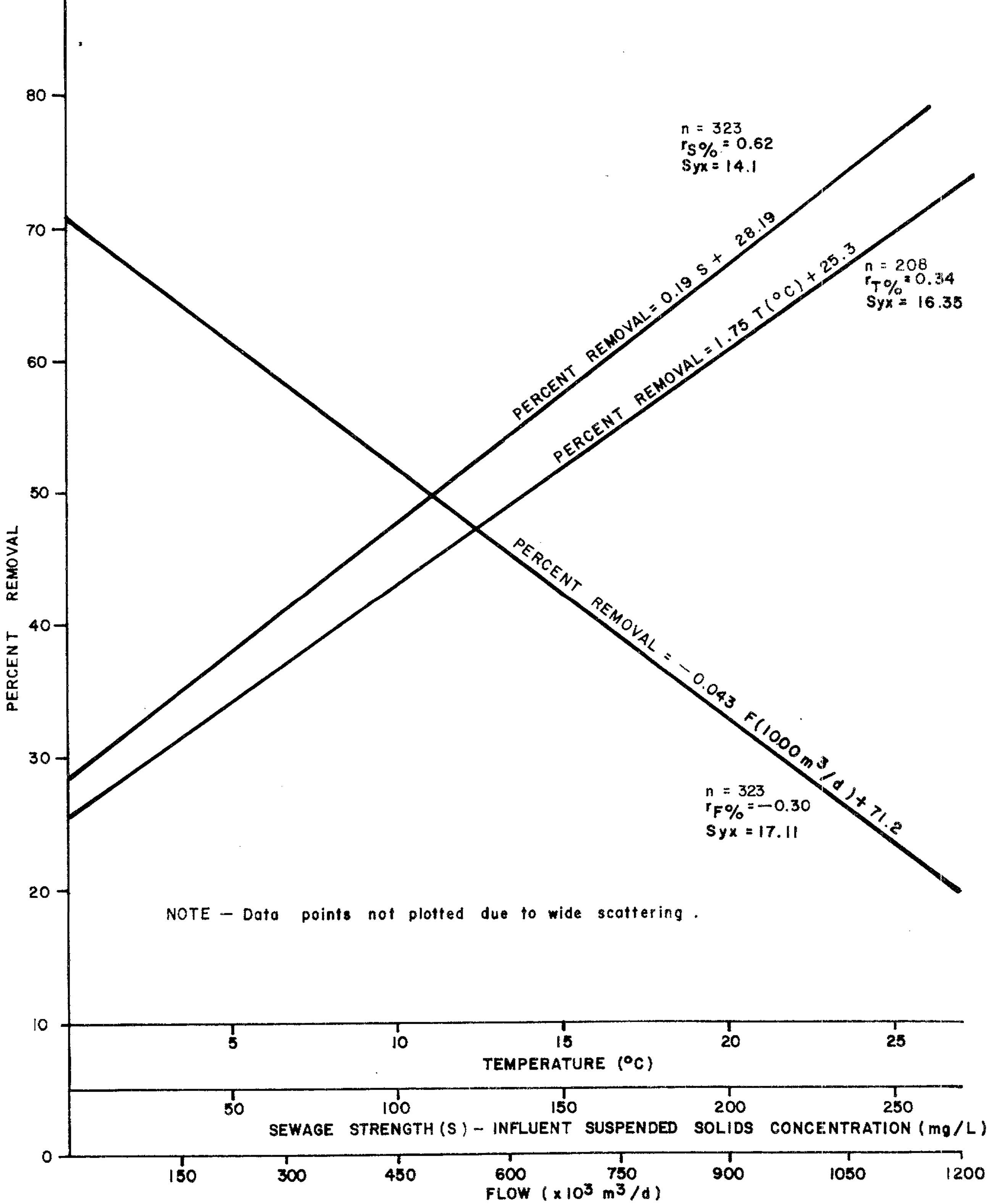

FIGURE A-2

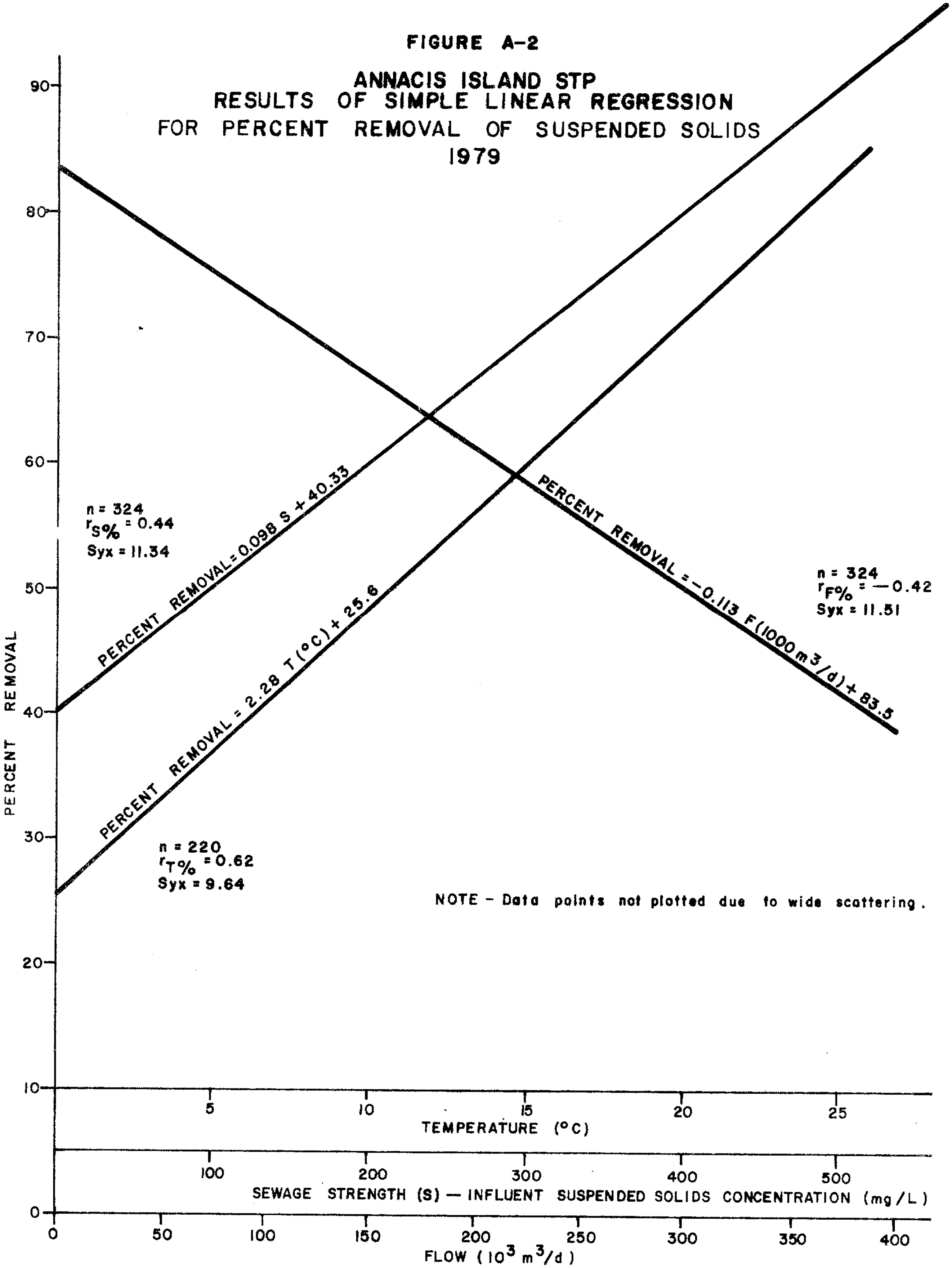
ANNACIS ISLAND STP
RESULTS OF SIMPLE LINEAR REGRESSION
FOR PERCENT REMOVAL OF SUSPENDED SOLIDS
1979
PERCENT REMOVAL
PERCENT REMOVAL = 0.098 S + 40.33
n = 324
rS% = 0.44
Syx = 11.34
PERCENT REMOVAL = 2.28 T(°C) + 25.6
n = 220
rT% = 0.62
Syx = 9.64
PERCENT REMOVAL = −0.113 F(1000 m3/d) + 83.5
n = 324
rF% = −0.42
Syx = 11.51
NOTE - Data points not plotted due to wide scattering.
TEMPERATURE (°C)
SEWAGE STRENGTH (S) — INFLUENT SUSPENDED SOLIDS CONCENTRATION (mg/L)
FLOW (10³ m³/d)

FIGURE A-3

LULU ISLAND STP

RESULTS OF SIMPLE LINEAR REGRESSION FOR PERCENT REMOVAL OF SUSPENDED SOLIDS 1979

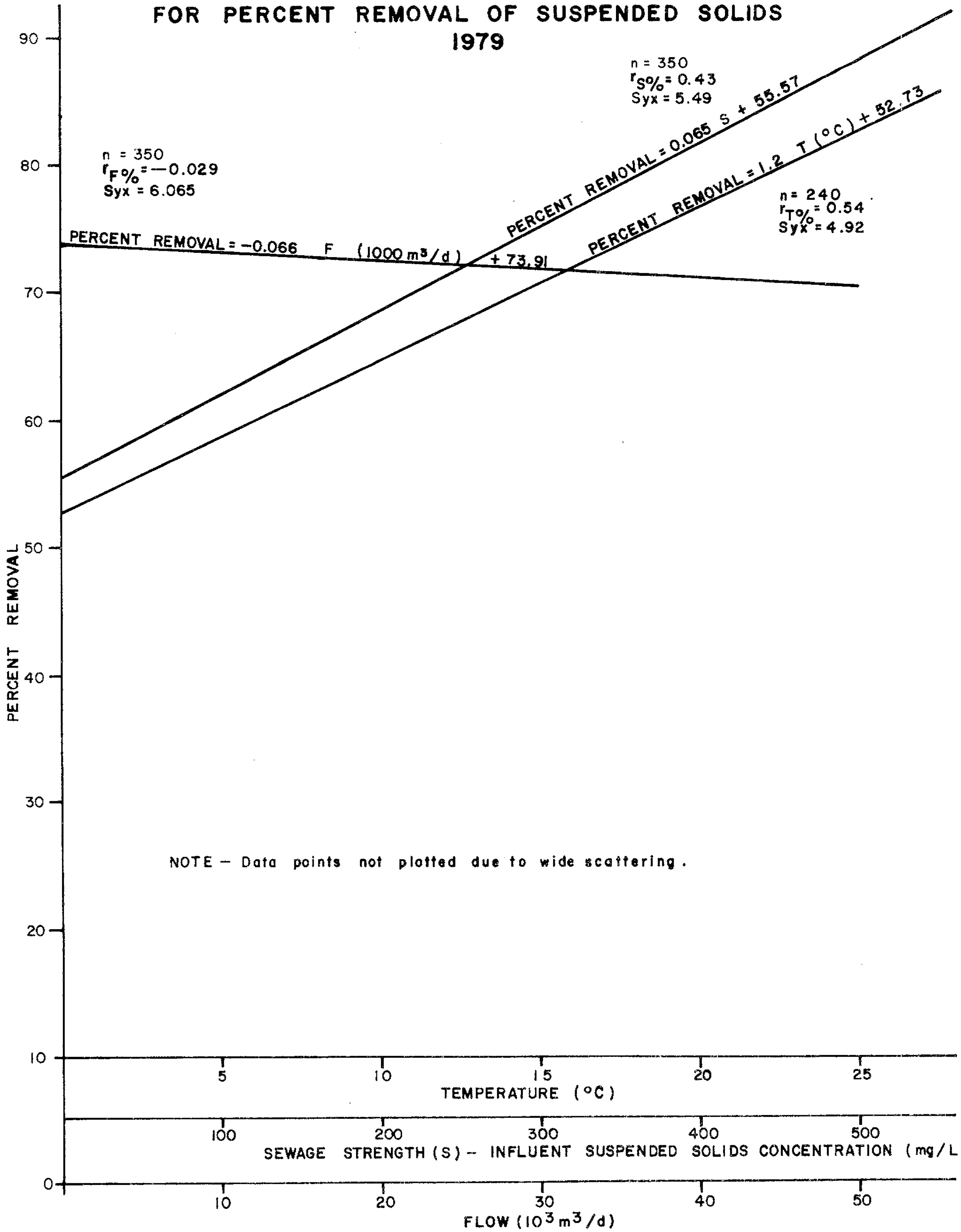

TABLE A-1

SUMMARY OF DATA WITH MEANS, STANDARD DEVIATIONS (S.D.) AND CORRELATION COEFFICIENTS

	Iona STP	Annacis STP	Lulu STP
No. of Values (n)	208	220	240
Percent Removal (%)			
Mean (%)	53.3	62.6	72.6
S.D. (%)	17.4	12.3	5.8
Flow (F)			
Mean (1000 m^3/d)	21.6	9.3	1.25
S.D. (1000 m^3/d)	6.0	2.2	0.11
Suspended Solids (S)			
Mean (mg/L)	135	232	259
S.D. (mg/L)	55	55	30
Temperature (T)			
Mean (^oC)	16	16.25	16.6
S.D. (^oC)	3.4	3.4	2.6
Correlation Coefficients between:			
% and F ($r_{F\%}$)	-0.33*	-0.38*	-0.02
% and S ($r_{S\%}$)	0.67*	0.53*	0.33*
% and T ($r_{T\%}$)	0.34*	0.62*	0.54*
F and S (r_{FS})	-0.31*	-0.57*	-0.18
F and T (r_{FT})	-0.48*	-0.54*	-0.08
S and T (r_{ST})	0.23*	0.47*	-0.17

* Significant correlation at a (individual) probability level of 0.001.

TABLE A-2

REGRESSION COEFFICIENTS FOR THE MULTIPLE REGRESSION

	Iona STP		Annacis STP		Lulu STP	
	Unstandardized	Standardized	Unstandardized	Standardized	Unstandardized	Standardized
Initial Regression						
Flow	0.046	0.33	-0.10	0.38	-0.054	-0.02
Constant (a)	73.86	0	82.26	0	74	0
Multiple R (R^2)	0.33 (10%)		0.38 (14%)		0.02 (.04%)	
Complete Regression						
Flow	-0.0087	-0.06	-0.022	0.08	0.30	0.11
Suspended Solids	0.19	0.62	0.075	0.34	-0.090	0.46
Temperature	0.87	0.17	1.86	0.51	1.39	0.63
Constant (a)	16.91	0	10.76	0	18.72	0
Multiple R (R^2)	0.70 (48%)		0.68 (45%)		0.70 (48%)	