Fraser River Estuary Study
Water Quality

Stormwater Discharges

K.D. Ferguson
and
K.J. Hall

Vancouver, British Columbia
December, 1979

Government of Canada

Province of British Columbia

Canadian Cataloguing in Publication Data

Ferguson, K. D., 1952-
Stormwater discharges.

(Fraser River estuary study, water quality)

Background report to the Fraser River estuary study of the Fraser River Estuary Study Steering Committee.
Bibliography: p.
Includes bibliographical references.
ISBN 0-7719-8305-0

1. Urban runoff - British Columbia - Greater Vancouver Regional District. 2. Storm sewers - British Columbia - Greater Vancouver Regional District. 3. Sewage disposal in rivers, lakes, etc. - British Columbia - Fraser River. 4. Water quality - British Columbia - Fraser River - Measurement. I. Hall, K. J., 1940- . II. British Columbia. III. Canada. IV. Title. V. Series.

TD665.F47 628.1'682 C80-092043-0

PREFACE

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

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

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

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

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

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

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

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

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

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

ABSTRACT

An assessment was made of the pollutant load from stormwater discharges in the Greater Vancouver Regional District (GVRD) to the lower Fraser River/Estuary, aspects of the stormwater collection, treatment, and disposal practices in the region which require further research and stormwater management policy questions which must be addressed by local municipal, regional district and pollution control regulatory agencies. Stormwater pollutant loadings were based on literature-reported average pollutant concentrations since very few monitoring programs have been conducted in the region. A stormwater monitoring program should be implemented to obtain data that may be used to calculate representative stormwater pollutant loadings. These measurements would provide information in support of developing the most appropriate overall strategy for stormwater management and the level of protection from pollution from this source that can be effectively provided to the Fraser River/Estuary.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BOD_5	5 day biochemical oxygen demand
COD	chemical oxygen demand
DO	dissolved oxygen
EPA	Environmental Protection Agency (U.S.A.)
EPS	Environmental Protection Service (Canada)
FR	filterable residues
GVRD	Greater Vancouver Regional District*
GVSDD	Greater Vancouver Sewerage and Drainage District*
ha	hectare
IWD	Inland Waters Directorate
kg	kilograms
lb/d	pounds per day
l/sec	litres per second
m	metres
m^3	cubic metres per day
MF	membrane filtration
mgd	million gallons (Imperial) per day
mg/l	milligrams per litre
ml	millilitres
MPN/100 ml	most probable number per 100 millilitres
NFR	non-filterable residue (suspended solids)
NH_3-N	ammonia nitrogen
NO_2-N	nitrite nitrogen
NO_3-N	nitrate nitrogen
Org-N	organic nitrogen
Ortho-PO_4	phosphorus as orthophosphate
PBB	polybrominated biphenyls

---

* In this report the GVRD designation is used to represent the land surface of municipalities comprising the Greater Vancouver Regional District, while the GVSDD designation is used to represent the regional district governmental organization.

PCB	polychlorinated biphenyls
PCB (provincial)	Provincial Pollution Control Branch
PCT	polychlorinated terphenyls
ppb	parts per billion
ppm	parts per million
SM	settleable matter
TAlk	total alkalinity
$TDPO_4$	phosphorus as total dissolved phosphate
TFR	total fixed residue
TIC	total inorganic carbon
TKN	total kjeldahl nitrogen
TN	total nitrogen
TOC	total organic carbon
TP	phosphorus as total phosphorus
TPO_4	phosphorus as total phosphate
TR	total residue
TVR	total volatile residue
µg/l	micrograms per litre
WIB	Water Investigations Branch

SUMMARY

Sewers have been used by man for centuries to carry wastewater. Separate storm, sanitary, and combined sewers are all commonly found in North American cities. In the GVRD, the older parts of the region such as Vancouver and portions of Burnaby and New Westminster use combined sewers. In total, there are over 100 separate stormwater discharges and 12 combined sewer overflows from the region to the lower Fraser River/Estuary.

From studies conducted in other cities of North America it is clear that stormwater is not as pure as once thought. In fact, stormwaters are often highly contaminated. Air pollution, fertilizers and pesticides used in residential and agricultural areas, animal fecal matter, and even normal street surface accumulations of dust and dirt are the main sources of pollutants to urban runoff. As such, a study of the water quality of the lower Fraser River/Estuary and of pollution sources to the receiving water would not be complete without an examination of stormwater discharges.

Very few stormwater monitoring programs have been conducted in the GVRD to date and none of a comprehensive nature. The data available give little indication of the average composition of stormwater in the region. Only Still Creek has been sampled extensively and data show that the stream contains significant heavy metals, PCB's and fecal coliform concentrations. Urban runoff and discharges from plating industries and sanitary sewers were identified as sources of contamination to that stream. Very little monitoring has been conducted of other storm drainage systems in the region.

As a result of the lack of local monitoring data and an incomplete understanding of the transport of pollutants through the natural system, stormwater pollutant loading calculations are only approximate. Calculations show that stormwater discharges could be a significant source of pollutants to the Fraser River/Estuary.

Other methods than those used for this report to calculate stormwater pollutant loads are available and these may be more accurate when calibrated with monitoring data.

Stormwater management techniques have been developed to reduce the intensity of urban runoff and improve its quality. Their application in other cities of North America has been in the reduction of the incidences of combined sewer overflow - as an alternative to sewer separation. Source control methods and stormwater holding ponds are the only techniques which have been used for stormwater management in separate sewer areas.

About 80% of the Iona Island sewerage area is served by combined sewers whereby both sanitary sewage and stormwater are collected and treated prior to discharge. Computer analysis using a model developed by Charles Howard and Associates Ltd. suggests that about 40 to 50% stormwater pollutant control is achieved in this area although incidences of combined sewage overflow are known to occur from the collection system.

Stormwater ponds were identified as the least cost alternatives for the Annacis and Lulu Island sewerage areas. For example, it was estimated that 50% NFR removal from stormwater could be achieved in the Annacis and Lulu sewerage areas at a cost of $26 000 000 and $8 500 000 respectively. The alternative of source controls, such as frequent street sweeping and catch basin cleaning, was not evaluated in the present analysis but should be in future studies.

CONCLUSIONS

1. Extensive areas of the GVRD are serviced by combined sewers although sewer separation is continuing. Officials in all GVRD municipalities are aware of the potential pollution aspects of stormwater but control measures are rarely designed into the system. The City of Vancouver makes limited use of first flush separators as a means to manage stormwater. The effectiveness of these is not known.

2. It has been demonstrated in other cities of North America that stormwater can be highly contaminated, particularly in NFR and fecal coliforms. In some cities, especially those employing a high degree of sanitary sewage treatment, sewer separation is not the best or most cost effective method to improve receiving water quality.

3. Data are available from other cities in North America and the analysis presented here was based on some of these data. The limited local data appears to be similar and the analytical procedures used to assess stormwater pollutant loadings elsewhere are likely applicable in the GVRD.

4. Stormwater pollutant loadings calculated to date have been rough estimates only, based on literature reported data. For the calculation presented in this report, physical characteristics of individual catchments and some factors which may affect stormwater quality were not taken into account. The pollutant loadings presented are not believed to be accurate enough for detailed planning decisions.

5. Computer simulation methods which will provide more accurate stormwater pollutant loadings are available but could not be implemented within the scope of the present overview study. In conjunction with data gathered in a monitoring program, these methods could provide loadings to be used for planning purposes.

6. The implementation of stormwater management techniques to reduce stormwater pollutant loadings in North America is not extensive. Preliminary results have shown that stormwater ponds in particular are effective in controlling stormwater pollution in separate sewer areas. Other stormwater management techniques such as watershed storage have been used to reduce combined sewer overflows and may be more effective in reducing pollution than sewer separation. The various sewer system alternatives are shown in Figure 6 (Page 45).

7. The present analysis suggests that significant stormwater pollutant control for the Iona sewerage area is currently being accomplished in the existing combined sewer system. Continued sewer separation in the sewerage area without implementation of stormwater management techniques may result in an increased pollutant load to the Fraser River/Estuary. The pollutant loads from combined sewer overflows, treated sewage and storm sewers must be compared in order to establish the most cost effective method to reduce the total input of pollutants to the receiving waters, should this be deemed necessary.

8. Stormwater ponds appear to be the most cost effective means to control stormwater pollution in the Annacis and Lulu sewerage areas. Natural ponding occurs now during high tides when flood gates are closed and some degree of sedimentation may be achieved at these times.

9. Little is known about the specific impact of stormwater discharges on the Fraser River/Estuary, however, it is believed that stormwater contributes significantly to the overall pollutant loading. The quantity of pollutants from this source will increase as the region becomes more urbanized unless stormwater management techniques are instituted.

RECOMMENDATIONS

1. Stormwater pollutant loadings should be compared to those from combined sewer overflows in order to assess the efficacy of sewer separation in the region. Based on this comparison, pollution control and economic benefits may be realized by suspension of sewer separation in favour of retention of combined sewage with appropriate overflow controls.

2. A stormwater monitoring program should be conducted in the GVRD to obtain data which may be used with an appropriate model to calculate more accurate pollutant loadings. A suggested monitoring program is outlined in Appendix VI of this report.

3. If receiving water quality information indicates that the water quality of the Fraser River/Estuary is being degraded or may be degraded in the future to the extent that the resource is affected, then a comprehensive approach must be taken to identify all significant sources of pollution and recommend methods to minimize the pollution. Stormwater pollutant loadings presented in this report suggest that stormwater may be a significant source of some pollutants, and therefore, must be considered in such studies.

4. Information regarding modern stormwater management techniques should be brought to the attention of municipal officials in the GVRD. The implementation of these techniques could reduce stormwater pollution and collection system costs although further studies are required. Several manuals have been prepared on this subject and the techniques described should be assessed for their applicability to the GVRD.

5. The effectiveness of the City of Vancouver's first flush separators should be investigated to determine their applicability as stormwater control methods. A proposed monitoring program is outlined in Appendix VI. Based upon the results of this study, the possibility of more extensive applications of these separators could be evaluated.

6. Receiving water monitoring should be conducted in the immediate vicinity of selected stormwater discharges to determine their effect on the Fraser River water quality.

7. Monitoring programs designed to determine the stormwater pollutant loading should include inter-rainfall event sampling since studies conducted in the GVRD (11) indicate that substantial quantities of pollutants may be discharged during those periods.

8. An estimate of pollutant loading from combined sewage overflows should be made based upon data collected to date and supplemented by additional data as needed. A possible monitoring program designed to gain this additional data is outlined in Appendix VI.

1 INTRODUCTION

Sewers have been used by man to carry water since ancient times. However, until the early nineteenth century these sewers were used for the conveyance of stormwater only. Human excreta were first carried in London sewers in 1815, in Boston sewers in 1833, and in Paris sewers in 1880 (1). In that era, raw wastewater was discharged directly to receiving waters.

It was not until the late nineteenth and early twentieth centuries that wastewater treatment was developed. As pollution of receiving waters and environmental concern increased, the use of treatment systems became widespread and their complexity increased. Many cities found that their combined sewer systems were not compatible with proposed or existing treatment systems. High wet weather flows often reduced pollutant removal efficiencies through the overloading of sedimentation tanks and clarifiers and "washout" of secondary aeration tanks. Overflows of combined sewage also occurred from the collection system itself. In some cases, very large capacity trunk sewers and treatment plants would have been required to carry and treat the unusually large wet weather combined sewage flows. Many cities were faced with three choices:

1) build very large and expensive treatment facilities and sewers to carry and treat all the combined sewage;
2) build smaller and less costly treatment facilities and sewers but allow the combined sewer overflows to occur;
3) separate the storm and sanitary collection system, treat the sanitary sewage before discharge, and discharge the untreated stormwater directly.

Most North American cities adopted the latter approach for newly developed areas and followed the second approach for existing core areas. Some sewers were separated in the core areas to reduce the incidences of combined sewage overflow. Construction of twin sewer systems was expensive and disruptive to city structures. The problem came into focus before a 1963 United States Senate subcommittee investigating water pollution. The cost of national sewer separation in the U.S. was estimated to be up to 48 billion dollars (2). It was recommended that realistic estimates of costs be developed and alternative methods of wastewater control be investigated (3).

In 1965, the U.S. Congress authorized a Research, Development, and Demonstration Program to find lower cost alternatives to sewer separation. It was largely through studies initiated under this EPA program that stormwater was found to contain significant pollutant concentrations (4).

In 1970, an EPA sponsored study of the District of Columbia's stormwater problem recommended that the sewer separation program there be abandoned and that pollution abatement programs for both combined and separate sewerage areas be developed (subject to confirming studies) (5). An EPA sponsored study in Tulsa, Oklahoma (6) showed that stormwater contributed about 20% of the BOD_5, 31% of the COD, 85% of the NFR, 31% of the org-N, and 4% of the soluble ortho-PO_4 total annual load entering the study areas' receiving streams.

In England, a water management study of the Thames River Basin (7) identified problems related to NFR in stormwater and combined sewer overflows. Urban runoff including sewage bypasses were found to be critical sources of organic wastes to the Thames River from Chatham, Stratford, and London. About 80% of the annual TP contribution from Stratford originated from sewage bypasses, urban runoff and minor point sources.

In Canada, studies initiated under the Canada-Ontario Agreement on Great Lakes water quality have identified a number of stormwater-related problems (8). Excessive bacterial counts and algae growth were attributed to combined sewer overflows into Toronto Harbour and

Collingwood Harbour. Sediments which were considered to be reservoirs of nutrients, heavy metals, and PCB's were found to accumulate in the Toronto Central Waterfront harbour area from the Don River and urban drainage. Road salt carried in storm sewers and streams account for 20% to 40% of the total Cl input to Lake Ontario.

The bacteriological water quality deterioration of the Rideau River (Ottawa) has been attributed to surface runoff following urbanization of the area (3).

Shellfish growing water quality surveys conducted by the EPS in coastal areas of British Columbia have often reported significant bacteriological levels in stormwater. Shellfish growing waters have been closed to harvesting based on high receiving water fecal coliform concentrations resulting from these contaminated stormwater discharges.

Bioassays and chemical analyses were performed on grab samples obtained from 11 storm sewers in Prince George and 10 in Kamloops during a 1973 EPS study (9, 10). Of the 23 bioassays conducted on the Prince George samples, 16 exhibited acute toxicity and 4 of the 30 Kamloops samples exhibited acute toxicity. The report suggested that industrial wastes were present in the Prince George stormwater.

Recognizing that stormwater can contribute significant pollutant loads to receiving waters, a study of the lower Fraser River/Estuary water quality would not be complete without an assessment of the stormwater discharges from the GVRD.

The purpose of this report is to:

1) examine the stormwater collection systems in the lower Fraser River/Estuary drainage area and to identify the discharge points,
2) review the literature on urban stormwater quality and compare reported values to those obtained from monitoring programs conducted in the GVRD;

3) present estimated stormwater pollutant loadings from the study area to the lower Fraser River/ Estuary;
4) review the literature on stormwater pollutant control methods and present estimated control costs for the GVRD; and
5) identify areas of insufficient data base.

The goal of this report and others in this series is to provide information that will assist the environmental protection agencies to establish policy and program priorities so as to preserve the ecological integrity of the Fraser River/Estuary system. Important recommendations, conclusions and other observations presented in the other Fraser River/ Estuary series stormwater reports (11, 56) are summarized here.

2 REVIEW OF RUNOFF PATTERNS

Sewer system construction in the lower mainland has followed the North American pattern. Older sections of the region including New Westminster, the majority of Vancouver, and parts of Burnaby are serviced by combined sewers. Newer areas are serviced by separate systems.

In the combined areas, stormwater and sanitary sewage is usually directed to the sewage treatment plants. During heavy rainfall when runoff is high, combined overflows of stormwater and sanitary sewage may occur through a number of emergency outfalls located along Burrard Inlet, False Creek, and the lower Fraser River/Estuary. Sub-surface collection systems are used exclusively in these areas.

In the separate sewered areas, natural water courses are utilized for stormwater transport wherever possible. Where there are no natural water courses, stormwater is either collected by conventional sub-surface systems and discharged to the receiving water through pipes, or collected and transported in open ditches. Much of Coquitlam and Burnaby use conventional sub-surface collection systems, while most of Surrey, Delta, Richmond, Maple Ridge, Pitt Meadows, and Port Coquitlam use ditches.

The location of storm drains, natural water courses and emergency combined sewer overflows which discharge to the lower Fraser River are shown in Figure 1. Many outfalls are fitted with flood boxes to prevent the inflow of saltwater into the collection system during high tides. About 70% of the storm sewer discharges in the study area are influenced by tidal reversal of river flow (11). Some stormwater from Surrey, Delta, Richmond, and Port Coquitlam flows by gravity to the dykes, located along the Fraser River where it is then pumped to the receiving water.

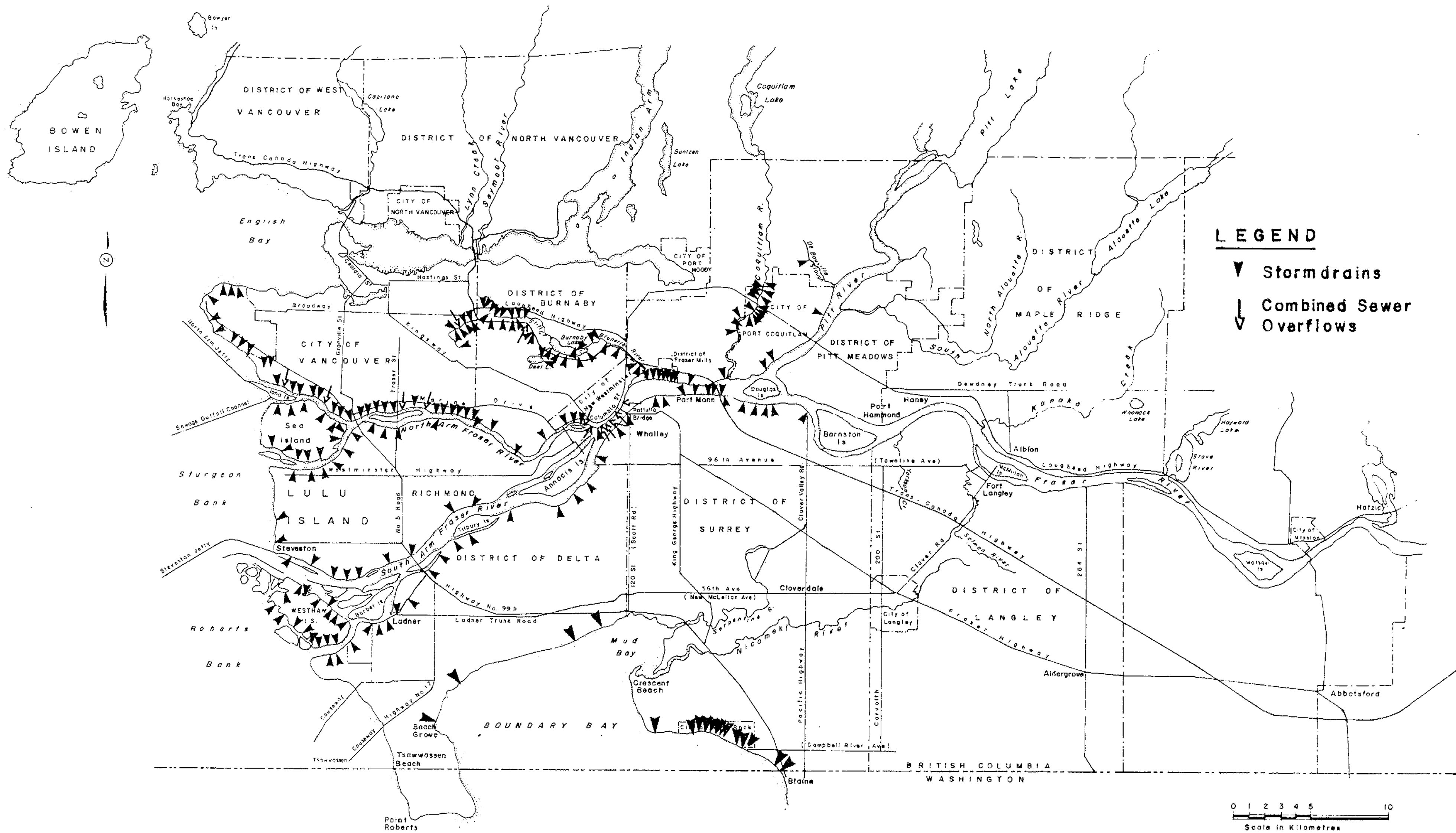


FIGURE I LOCATION OF STORMWATER AND COMBINED SEWER OVERFLOW DISCHARGES TO THE LOWER FRASER RIVER / ESTUARY (II)

A registry (56) of all known stormwater discharges to the lower Fraser River/Estuary has been prepared recently by the provincial Ministry of Environment. Photographs and descriptions of each stormdrain are included in that report.

A portion of downtown Vancouver is serviced by a "hybrid" system wherein connections were constructed between select stormwater and sanitary manholes. This allows the first flow (flush) of stormwater to enter the sanitary sewers and be treated at the Iona sewage treatment plant prior to discharge (12).

There are also several major streams tributary to the lower Fraser River which carry stormwater from the study area. These include the Brunette River, Coquitlam River, Pitt River, North and South Alouette River (tributary to the Pitt River), Kanaka Creek, Salmon River, Yorkson Creek, and Still Creek (tributary to the Brunette River). Pollutant loads in some of these streams include stormwater inputs from the study area and runoff from the upstream watershed. Stream flow monitoring stations operated by the IWD of Environment Canada are generally not located close enough to stream mouths to include all stormwater entering the streams from the study area.

No other stormwater flows are regularly recorded for sub-surface or open-ditch stormwater collection conduits. Both the GVSDD and the City of Vancouver have measured flows in some combined sewers. Also, some flow data could be generated by timing stormwater pumps in those municipalities which have them.

Stormwater collection systems in the GVRD are usually designed according to the Rational Method (13). It may be expressed as:

$$Q = CiA$$

where: Q - is the peak runoff rate.
A - is the tributary drainage area.
i - is the rainfall intensity.
C - is an empirical runoff coefficient.

The rainfall intensity selected for design is usually based upon intensity-frequency-duration curves prepared for the region. The design intensity is defined as the average rainfall intensity for a duration equal to the time of concentration for a selected rainfall frequency. The time of concentration is the time for runoff from the furthest point in the catchment to reach the study point. The selected rainfall frequency or return period used by municipalities in the GVRD is usually 5 or 10 years.

All municipalities in the GVRD except Surrey and Richmond use the Rational Method for storm sewer design. Drainage studies conducted for Surrey and Richmond have used Clark's Instantaneous Hydrograph and Schneiders Unit Hydrograph respectively for runoff modelling purposes. Combined sewers in the False Creek area of Vancouver are currently being studied by the City of Vancouver with the assistance of Dorsch Consultants Ltd. (12). Combined sewage quantity and some quality data have been obtained in that study. Some stormwater flow data was obtained for a limited period in Surrey to calibrate their hydrograph model.

Typical literature reported runoff coefficients are used to estimate the percentage of precipitation which converts to runoff in those municipalities which use the Rational Method for stormsewer design. The actual coefficient used may be adjusted from the average literature reported value for the land use under study depending on the designer's experience and knowledge of the specific catchment.

Quantities of runoff in the GVRD are dependent upon the quantity of rainfall. Lines linking points of equal annual precipitation (isohyets) in the region are shown in Figure 2. Average annual precipitation varies from about 1200 mm/yr in Delta to 2500 mm/yr in West Vancouver. Quantities of precipitation also vary significantly across the larger municipalities. A total of 38 precipitation recording stations are located in the region as shown in Figure 2 and Table 1.

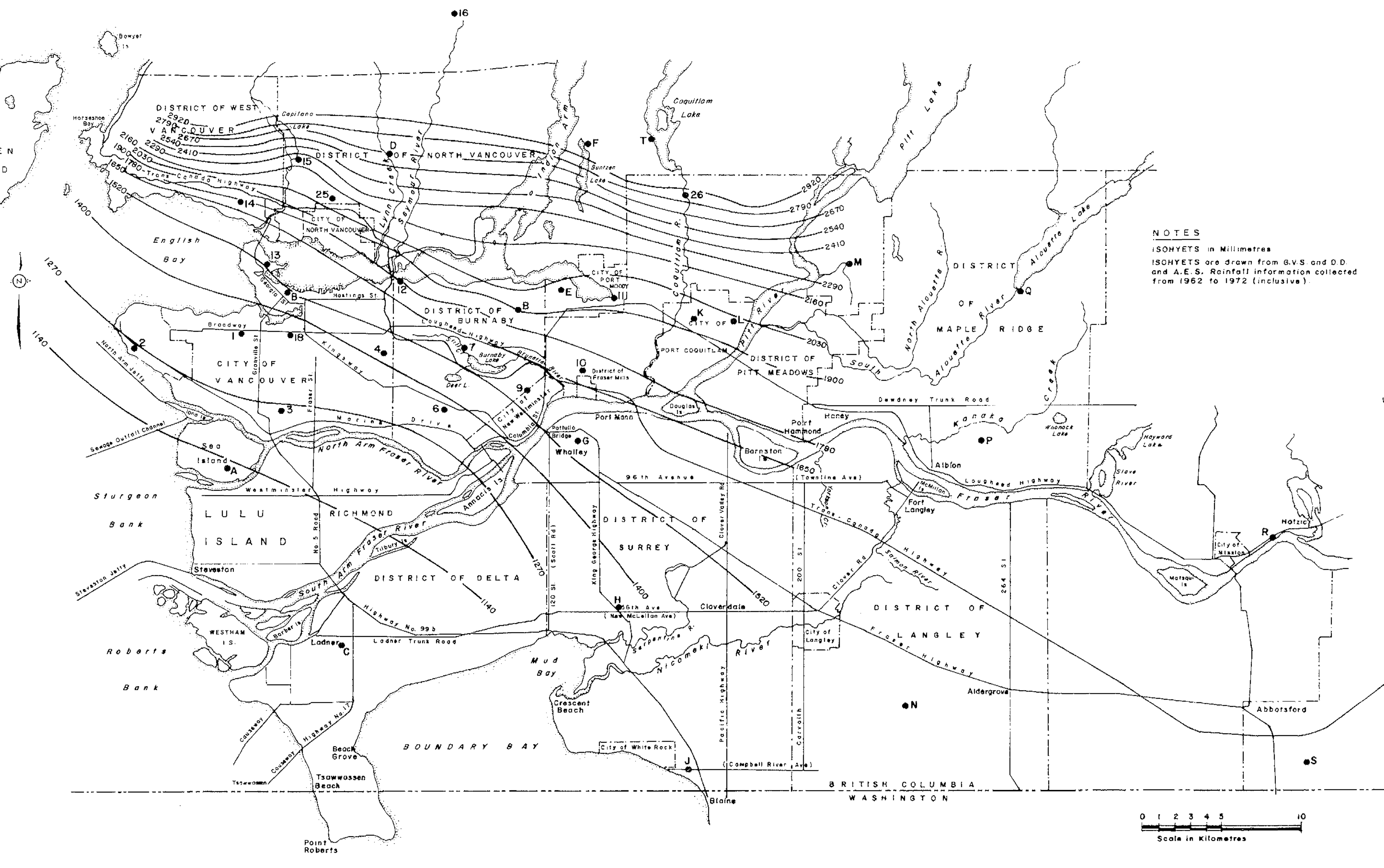


FIGURE 2 ISOHYETS IN THE GVRD (14)

TABLE 1 RAIN GAUGES IN THE GVRD (14)

Station Name	Station Designation	Latitude	Longitude
Atmospheric Environment Service Rain Gauges			
Vancouver International Airport	A	49° 11'	123° 10'
Vancouver P.M.O.	B	49° 17'	123° 07'
Delta Ladner East	C	49° 05'	123° 04'
North Vancouver, Lynn Creek	D	49° 22'	123° 02'
Port Moody Gulf Oil Refinery	E	49° 17'	122° 53'
Buntzen Lake	F	49° 23'	122° 51'
Surrey Kwantlen Park	G	49° 12'	122° 52'
Surrey Municipal Hall	H	49° 06'	122° 50'
White Rock S.T.P.	J	49° 01'	122° 46'
Port Coquitlam City Yard	K	49° 16'	122° 46'
Port Coquitlam, Prairie Road	L	49° 16'	122° 44'
Pitt Polder	M	49° 18'	122° 38'
Langley Lochiel	N	49° 03'	122° 35'
Haney Microwave	P	49° 12'	122° 31'
Alouette Lake	Q	49° 17'	122° 29'
Mission West Abbey	R	49° 09'	122° 16'
Huntington Vye Road	S	49° 01'	122° 14'
B.C. Hydro-Coquitlam Lake	T	49° 22'	122° 48'
U.B.C. - Plant Science Bldg.	U	49° 15'	123° 15'
GVSDD Rain Gauges			
GVSDD Head Office	1	49° 16'	123° 09'
U.B.C. - Plant Science Bldg.	2	49° 15'	123° 15'
Sir Winston Churchill H.S.	3	49° 13'	123° 07'
Renfrew Elementary School	4	49° 15'	123° 02'
McPherson Park Junior Sec.	6	49° 13'	122° 59'
Burnaby Central-Sperling P.S.	7	49° 15'	122° 58'
Trans Mtn. Burnaby Term.	8	49° 16'	122° 55'
Westburnco Reservoir	9	49° 14'	122° 54'
Coquitlam Municipal Hall	10	49° 14'	122° 52'
Pt. Moody S.P.S.	11	49° 17'	123° 50'
Vancouver Heights Reserv.	12	49° 17'	123° 01'
Stanley Park Yard Office	13	49° 18'	123° 08'
West Vancouver Municipal Hall	14	49° 20'	123° 10'
Cleveland Dam, Caretaker's House	15	49° 22'	123° 06'
Seymour Falls Dam	16	49° 26'	122° 58'
Vancouver City Hall	18	49° 16'	123° 07'
District of N. Vancouver Mun. Hall	25	49° 20'	123° 05'
Coquitlam Chlorination House	26	49° 20'	122° 46'

3 EXISTING DATA ON STORMWATER QUALITY

3.1 Literature Survey

The potential environmental damage posed by contaminated stormwater discharges has only recently been recognized. Few extensive monitoring programs have been conducted due to the complexity of the stormwater-pollutant system and the cost of monitoring.

General results of some stormwater monitoring programs conducted in other cities of North America are discussed here while a more detailed discussion appears in Appendix I.

Reported stormwater pollutant concentrations often vary greatly for a number of reasons. For example, higher pollutant concentrations may be expected in the early stages of a storm (first flush), in highly paved or industrialized areas, in response to intense rainfall periods, after prolonged dry periods, and in areas with construction activities. A study conducted in Tulsa, Oklahoma indicated that the greatest variation in quality was for bacteriological and NFR parameters (6).

Typical constituents of urban runoff are shown in Table 2. Pollutants enter stormwaters either directly as pollutants entrained in raindrops or indirectly as matter which is picked up from land wash. Usually the indirect source is more significant. Particulates, as dust and dirt, accumulate on land surfaces at the rate of 170 to 320 tonnes/km^2/year in most cities (15). The accumulation is often directly related to the degree of air pollution and, therefore, industrial areas tend to have greater accumulation rates.

In undeveloped areas, most rainfall infiltrates the soil and adds to groundwater or evaporates. In developed regions, much of the rainfall washes off the impervious areas rapidly, entraining most of the accumulated street matter. This may lead to a first flush effect

TABLE 2 POLLUTANT CHARACTERISTICS OF URBAN RUNOFF (16)

1. Colour causing materials
2. Turbidity
3. Foam causing materials
4. Floating materials
5. Street litter debris
6. Material from street or pavement surface
7. Debris from vacant lands
8. Ice control chemicals
9. Pest control chemicals
10. Fertilizers
11. Animal and bird excreta
12. Lawn or garden litter
13. Household or commercial refuse
14. Air-deposited materials from precipitation
15. Twigs and leaves
16. Paper
17. Plastic materials
18. Tire and vehicular exhaust residue
19. Heavy metals
20. Hazardous material spills
21. Leachates from landfills and illegal dumping of wastes

whereby a high initial flow and pollutant concentration is recorded. Poor or infrequent catch basin cleaning often contributes to the first flush effect by providing a reservoir of matter which is easily carried by runoff. Poor or infrequent street cleaning also contributes to the first flush effect.

Sartor and Boyd (17) in rainfall simulation studies found that 75% to over 95% of the total amount of street surface contaminants were removed during the first hour of rainfall.

The same authors conducted extensive studies of street surface runoff in 12 cities in the U.S. which had populations ranging from 13 200 (Bucyrus Ill.) to 895 000 (Baltimore Md). They found that street surface runoff was highly contaminated and the major constituent was inorganic, mineral-like matter, similar to common sand or silt. Most of the contaminants were found to be in the fine residues fraction of the street surface accumulated matter. The quantity of this matter at any one test site depended upon the elapsed time since the last cleaning by sweeping or rainfall (17).

Studies done in the Castro Valley, California (6) indicated that a high BOD_5 can be expected from the first runoff event in a rainy season or at other times of the year after a significant dry spell.

Typical stormwater is often characterized as having an equal to or greater NFR concentration than untreated sanitary wastewater and a BOD_5 equal to that of secondary treated effluent.

Chlorinated hydrocarbon and organic phosphate compounds analyses conducted on street surface samples from the 12 cities studied by Sartor and Boyd identified dieldrin, DDD, DDT, methoxychlor, aldrin, methyl-parathion, and lindane in some samples. Polychlorinated biphenyls were found in significant quantities in samples from all cities studied. The authors concluded that "there is little question that street surface contaminants warrant serious consideration as a source of receiving water pollution, particularly in cases when such discharges of contaminants coincide with times of low stream flow or poor dispersion" (17).

Most stormwater monitoring studies conducted to date have not calculated total rainfall event pollutant loads, rather average concentrations are usually reported. It is difficult, therefore, to compare results of different studies.

3.2 Stormwater Quality Monitoring in the GVRD

Relative to many other major populated regions of North America, very few stormwater quality monitoring programs have been conducted in the GVRD. With one exception, no flow proportional composite or sequential grab samples have been obtained.* It is clear from the results of monitoring programs elsewhere that composite or sequential samples are required to determine the average concentration of pollutants in stormwater and loadings.

A summary of the monitoring programs conducted to date is presented here while data summaries may be found in Appendix II.

1) 1969-1971 GVSDD Catchbasin sampling (18)

Grab samples were obtained from catchbasins throughout the region by GVSDD and analyzed for total coliforms. Although several high counts were found, the majority of the results were below 2000 MPN/100 ml. No correlation was made between rainfall and coliform concentrations.

2) 1972-1973 Still Creek Study - Westwater (19, 20)

Westwater Research conducted sampling of Still Creek at various locations and of the Brunette River at Braid Street from July to August 1972 and January to June 1973. These data were generated during a study of all the tributaries to the lower Fraser River. The Brunette River showed higher concentrations of Na and Cl than any of the other

---

* This excludes the combined sewage studies conducted by the City of Vancouver.

tributaries. Still Creek was identified as having localized oxygen deficiency, high fecal coliform counts, and high heavy metal concentrations (notably Cu, Pb, Zn, and Fe). Using heavy metal toxicity levels determined by the American Fisheries Society, Still Creek exceeded recommended toxicity criteria for Cu, Pb, and Zn, 53%, 35% and 88% of the time respectively (21). Trace metal inputs to Still Creek were thought to originate from two sources - storm runoff and direct discharge of industrial wastes or illegal sanitary sewer connections.

3) 1973 Still Creek Study - GVSDD (22)

A rather extensive sampling program was conducted by GVSDD of the Still Creek system. Bacteriological and chemical analyses were performed on samples obtained. Results indicated that fecal coliform counts in the Still Creek system increased during wet weather probably as a result of street runoff although illegal sanitary sewer connections to storm sewers and unknown sanitary storm sewer cross-connections were believed to exist in the area. Levels of BOD_5, colour, TN, TP, NFR, TR, and heavy metals substantially increased during the first wet weather after an extended dry period.

At the time of this study, two metal plating operations were discharging wastes to the creek.

4) 1973-1974 Westwater Brunette River - Still Creek Study (23)(54)

A series of stream sediment and street surface material were collected and analyzed for 11 trace metals and 17 chlorinated hydrocarbons. A considerable variation in street surface trace metal concentrations was found for any one land use area. Industrial and commercial areas generally had the greatest trace metal accumulations. However, Pb was the only contaminant which showed significant accumulation in all land use areas except green space. Street surface materials were found to contain from 1.8 to 5.7 times the average levels of Cd, Co, Cr, Cu, Hg, Ni, Pb, and Zn found in the stream sediments.

Chlorinated hydrocarbons found in both stream and street surface samples include p,p'-DDT, p,p'-DDE, p,p'-DDD, alpha chlordane, gamma chlordane, and PCB's. Levels of up to 0.78 ppm dry weight of PCB were found in Still Creek and substantial levels were detected in every sample. Significant concentrations of PCB's were also found in street surface materials with the mean levels of 0.091, 0.05, 0.096 and 0.14 ppm recorded for residential, green space, industrial and commercial land uses, respectively.

Grab samples were also obtained under high and low flow conditions at six stations to assess the importance of rainfall events in the transport of trace metals from street surfaces. At most stations, Cu, Pb, and Zn levels increased during high flows. Manganese concentrations increased during low flows and were thought to originate from groundwater.

5) <u>1974 Westwater Renfrew St. Storm Sewer Sampling</u> (24)

Samples were taken from the Renfrew Street stormwater system which is believed to be free from illegal connections and/or cross-connections with sanitary sewers. The catchment area is a 22 block medium density residential area. The overall study involved sampling of several combined sewer systems but the Renfrew sewer was the only separate storm system.

Grab samples were obtained during a winter rainfall event, two days after the rainfall, and during a summer dry period. Turbidity and trace metal analyses were performed on the samples while flow measurements were made at the time of sampling. Parameters such as Cu, Ni, Pb, Zn and turbidity were all at higher concentrations during the rainstorm compared to after. Iron and Mn concentrations were higher after the rainfall compared to during. In terms of loading, however, all parameters were higher during the rainfall compared to after.

The study (24) concluded that: "Urban stormwater runoff is an important source of Cu, Pb, and Zn. Presumably these materials originate from street surface materials which are flushed into the storm sewers during periods of rainfall. Peak loading rates (in the combined sewers) were found to be as much as 15 times higher than dry average values. The timing of peak stormwater trace metal loads was found to be coincident with the period of maximum rainfall intensity."

6) 1976 EPS-GVRD Storm Sewer Sampling (25)

Grab samples were obtained from 18 storm sewers in the GVRD ranging from the University of British Columbia (UBC) to 88th Avenue and King George Highway in Surrey. Chemical and toxicity analyses were performed on these samples. All samples submitted for bioassays (96 hour LC50) were found to be non-acutely toxic to the test fish (rainbow trout). Results for chemical analyses obtained for this study generally compare closely with those obtained from the Westwater Still Creek survey although comparisons are rather difficult, since up to 24 samples were analyzed for each Still Creek site while only two samples per site were analyzed for the EPS study.

Significant PCB concentrations were detected in all but one of the stormwater samples submitted for analyses. The highest concentration measured was 0.0011 mg/l in a sample obtained from a pond at the British Columbia Institute of Technology.

7) Burnaby Stormwater Bacteriological Sampling (26)

The Municipality of Burnaby has established about 33 stations throughout the municipality for bacteriological analyses. The majority of these are on the Still Creek, Deer Lake, Burnaby Lake, and Brunette River system, however, about eight stations have been established on small streams tributary to the Fraser River. Municipal officials have conducted limited monitoring of these latter stations, generally only about five samples per year. This sampling is part of an ongoing program to identify sources of bacteriological contamination.

Other provincial and municipal health departments in the GVRD have conducted limited stormwater bacteriological sampling. This sampling has been conducted to identify illegal sanitary connections to storm sewers and unknown cross-connections. For this reason and because of the sporadic nature of the sampling and lack of correlation of results with rainfall, the data is of limited value to assess the bacteriological quality of "normal" stormwater.

8) 1978 Provincial WIB and PCB - Stormwater Sampling Program (11, 27)

As part of the Fraser River/Estuary study, the provincial Ministry of the Environment conducted a limited sampling of stormwater in the GVRD from July to November 1978. The location of stormwater discharges to the lower Fraser River/Estuary was a major part of this program. The purpose of the study was not to definitively characterize stormwater quality, but rather to identify pollutants that may be present in stormwater and to develop monitoring techniques - both are necessary pre-requisites for future studies of stormwater quality in the GVRD.

The monitoring program consisted of sampling for chemical and bacteriological constituents, including pesticides (Table 3). All samples were grabs obtained from stormdrain discharges. The results of this study appear in another report (11).

The results of the tidal cycle monitoring are particularly important and are presented in Appendix II of this report. Generally, the results showed that the stormwater discharged to the lower Fraser River at Carrington Street was of poorer quality than the river.

TABLE 3 WIB-PCB STORMWATER SAMPLING PROGRAM (11, 27)

1. Pesticides
   a) stations - 5
   b) samples per station - 2
   c) parameters:

Aldrin	Lindane
Alpha-Chlordane	
Gamma Chlordane	p,p' - DDT
	p,p' - DDD
Hexachlorobenzene (HCB)	p,p' - DDE
Heptachlor	PBBs
	PCBs
Chlorinated Phenols (PCP)	Arochlor
Paraquat	
Methoxy chlor	

2. Chemical Constituents
   a) stations - 34
   b) samples per station - 2 to 3
   c) parameters:

pH	TKN
TAlk	NO_2NO_3
Total Metals (Al, As,	TN
Cr, Cu, Fe, Pb, Mn, Hg,	Oil and Grease
Ni, Mg, Zn)	Phenolics
TOC	TPO_4, $TDPO_4$
TIC	
DO	TR, NFR

   d) physical parameters:

flow	temperature
salinity	conductivity
colour	

3. Coliforms
   a) stations - 38
   b) samples per station - 3
   c) parameters: fecal coliforms

4. Tidal Cycle Sampling
   a) location - stormdrain discharging to Fraser River at Carrington Street
   b) samples - up to 12 samples during cycle
   c) parameters:

flow	TOC
colour	TIC
temperature	Oil and Grease
pH	TKN
conductivity	TN
DO	TPO_4
NFR	Phenolics
Total Metals (Mn, Hg, Ni,	
As, Cr, Pb, Zn, Cu, Fe)	

4 POLLUTANT LOADING FROM SURFACE RUNOFF

Three attempts to estimate the pollutant loading from stormwater to receiving waters in the GVRD are documented here. The first appeared in the February 1973 brief submitted by the GVSDD to the public enquiry on municipal waste disposal (18). The second was presented in a report (June 1973) by M.A. Franson (28) commissioned by the GVSDD Planning Department. The most recent attempt is presented in this report for the first time.

4.1 Stormwater Pollutant Loadings - GVSDD

The GVSDD was not required or expected to include a discussion of urban runoff pollutants in their brief submitted to the public enquiry on municipal waste disposal. However, these analyses points out some important considerations for policy decisions regarding municipal discharges in the region.

The stormwater pollutant loadings calculated by the GVSDD are based upon an EPA report (17) which presented data gathered in 12 American cities. In that report, street runoff pollutant rates were presented for a hypothetical city based upon data gathered in actual studies in the municipalities (Table 4). These results show that the runoff from the first hour of a moderate-to-heavy storm would contribute more pollutants than would the city's sanitary system during the same period of time.

The GVSDD used these loading rates and assumed that there were 50 hours of moderate to heavy rainstorms during the summer months to arrive at summer stormwater pollutant loadings (Table 5). These loadings were then compared to the quantity of pollutants lost through summer combined sewer overflows on the North Slope of Burrard Peninsula. The authors concluded that:

TABLE 4 CALCULATED QUANTITIES OF POLLUTANTS THAT WOULD ENTER THE RECEIVING WATERS OF A HYPOTHETICAL CITY (17)

City Characteristics:

Population.......................................100 000 persons
Total land area..................................57 km^2
Land use distribution
  residential....................................75%
  commercial.....................................5%
  industrial.....................................20%
Streets (tributary to receiving waters)..............644 curb kilometres
Wastewater flow..................................54 000 m^3/day

Characteristics	Street Runoff Following a 1-hr Storm (kg/hr)	Raw Wastewater (kg/hr)	Secondary Plant Effluent (kg/hr)
SM plus NFR	254 000	590	54
BOD_5	2 500	500	50
COD	5 900	540	54
TKN	400	95	9
TPO_4	200	23	1
Total coliforms (organism/hr)	4000×10^{10}	$460\ 000 \times 10^{10}$	4.6×10^{10}

TABLE 5 GVSDD CALCULATED SUMMER POLLUTANT LOADS (18)

Parameter	Contaminant loading street surface runoff (50 hours) (in 5 months) (kg)	Contaminant loading combined sewage overflows (raw sanitary sewage) (0.085% for 5 months) (kg)	Contaminants from combined sewer overflow as a percentage of contaminants from surface runoff (%)
Residues	13 000 000	1700	0.134
BOD_5	130 000	1400	1.13
COD	295 000	1100	0.53
Coliform	$2x10^{15}$ organisms	$1.32x10^{15}$ organisms	66.0
TKN	20 000	270	1.37
TPO_4	10 000	66	0.66
Zn	13 000	1.1	0.018
Cu	6 000	0.22	0.012
Pb	5 200	0.17	0.003
Ni	450	0.05	0.012
Hg	650	0.35	0.53
Cr	1 000	0.22	0.02

1) combined sewer overflows were minor sources of pollution in the Greater Vancouver Area when diversion capacities greater than peak dry weather flow are provided;

2) there is evidence indicating that surface drainage from urban areas contains significant pollutant loadings and that there is little information regarding stormwater discharges in urban areas in British Columbia and research should be initiated by the Pollution Control Authority;

3) the volume of surface drainage from urban areas is so large as to preclude treatment but that effort should be directed towards location of discharge of urban drainage so that effect on public health, recreation and fish resources will be minimized.

4.2 Stormwater Pollutant Loadings - M.A. Franson

The purpose of the report on environmental quality in Greater Vancouver by M.A. Franson was to provide the residents of the area with an overview of environmental quality rather than to present a detailed technical analysis of pollution in the region. As such, the calculation of stormwater pollutant loadings from the GVRD to receiving waters is not expected to be accurate. The results provide data for comparison purposes.

Stormwater NFR and BOD_5 loads were calculated for the years 1973, 1986, and 2000 using estimated urbanized land areas, average yearly rainfall for the region, runoff coefficients, and average pollutant concentrations (250 mg/l NFR and 40 mg/l BOD_5) as shown in Table 6. Runoff coefficients were assumed to increase in the future because of more intensive use of urbanized land.

Pollutant loads from the region's sewage treatment plants were calculated for the same years using average raw sewage pollutant concentrations (250 mg/l NFR and 150 mg/l BOD_5), flows provided by

TABLE 6 WATER POLLUTANT DISCHARGES IN STORMWATER (28)

Year	Estimated Urbanized Land Area (ha)	Rainfall (mm/yr)	Runoff Coefficient*	Runoff (kg/yr) x10^9	Pollution Discharge** (million kg/yr)	
					NFR	BOD_5
1973	30 500	1270	0.4	145	36	6
1986	38 500	1270	0.45	219	55	9
2000	47 600	1270	0.5	302	76	12

* 0.4 value typical of present residential development. Increases reflect more intensive use of urbanized land.

** Based on values intermediate between those for combined and separate wastewater: 250 mg/l NFR and 40 mg/l BOD_5.

the GVSDD, and average pollutant removal efficiencies for primary and secondary wastewater treatment (65% NFR and 35% BOD_5 for primary; 90% NFR and 85% BOD_5 for secondary) as shown in Table 7.

The annual quantities of NFR and BOD_5 from urban runoff and treated domestic sewage discharges were compared as shown in Figure 3. This data indicates that stormwater contributions are a major source of NFR compared to domestic dischares and that their importance will grow. Contributions of BOD_5 from stormwater will be significantly less than from domestic discharges. Franson concluded that "pollutant loadings from stormwater, domestic sewage, and industrial effluents were of a similar order of magnitude and, therefore, concentration on control of any one aspect to the exclusion of others would lead to only comparatively minor gains in the reduction of pollution to the regions' receiving waters".

4.3 Stormwater Pollutant Loadings

Stormwater pollutant loadings to the lower Fraser River/Estuary were calculated for this report. The method used was similar to that employed by Franson, but an attempt was made to consider some of the physical aspects of the GVRD. Basically, the method involved calculating the quantity of urban runoff using the proportion of each of five land use groups in each member municipality of the GVRD, average annual precipitation for each municipality, and runoff coefficients for each land use group. Pollutant loadings were calculated using the quantity of urban runoff from each land use group and literature reported average stormwater pollutant concentrations for each land use. The results of the analysis are shown in Tables 8 and 9, while a detailed account is given in Appendix III.

No average stormwater pollutant concentrations have been generated from monitoring programs conducted in the GVRD and, therefore, except for trace metals, literature-reported values were used for these

TABLE 7 WATER POLLUTANT DISCHARGES FROM DOMESTIC SOURCES (28)

Year	Treatment Received	Flow		Influent Pollutants* (million kg/yr)		Effluent Pollutants* (million kg/yr)	
		(m^3/sec)	(kg/yr)*	NFR	BOD_5	NFR	BOD_5
1973	None	1.7	54	13	8	13	8
	Primary	3.5	108	27	16	10	10
	Secondary	0	0	0	0	0	0
	Total	5.2	162	40	24	23	18
1986	None	0	0	0	0	0	0
	Primary	6.0	180	47	29	16	19
	Secondary	2.8	89	22	13	2	2
	Total	8.8	278	69	42	18	21
2000	None	0	0	0	0	0	0
	Primary	8.0	251	63	38	22	24
	Secondary	4.5	142	35	21	4	3
	Total	12.5	392	98	59	26	27

Based on 250 mg/l (by weight) NFR and 150 mg/l BOD_5.

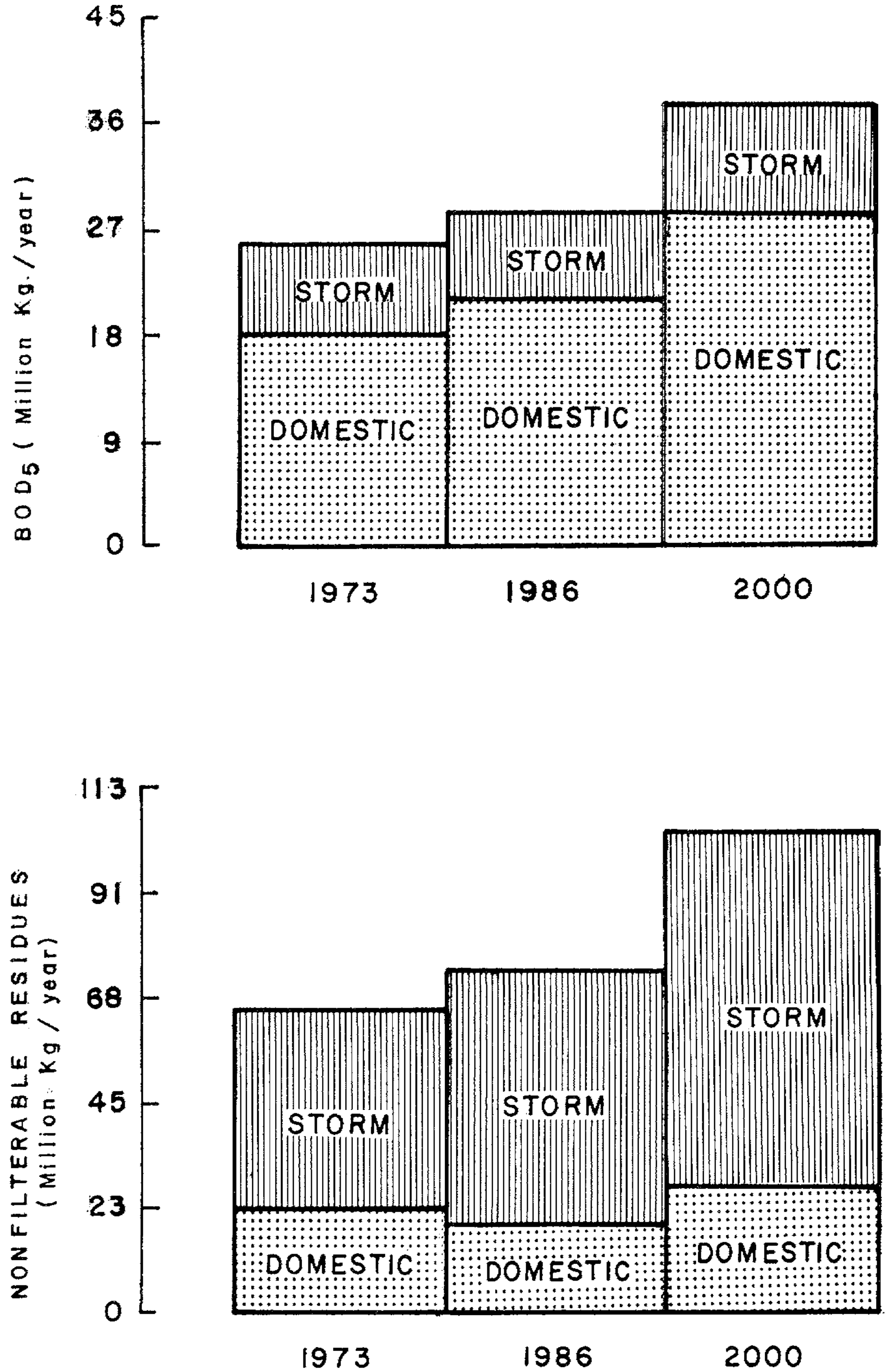


FIGURE 3 BOD_5 AND NONFILTERABLE RESIDUES DISCHARGED TO GVRD RECEIVING WATERS (28)

TABLE 8 POLLUTANT LOADINGS FROM SURFACE RUNOFF IN THE GVRD DISCHARGING TO LOWER FRASER RIVER/ESTUARY

Parameter	Unit Loading kg/day*
BOD_5	14 800
TN	1240
TP	390
Total Coliforms	600×10^{12}
Fecal Coliforms	560×10^{11}
Cu	12
Fe	200
Mn	18
Ni	1.6
Pb	30
Zn	14

*Except fecal and total coliforms number/day values are rounded off.

TABLE 9 POLLUTANT LOAD FROM SURFACE RUNOFF BY MUNICIPALITY

Municipality	BOD_5	TN	TP	Total Coliforms	Fecal Coliforms	Cu	Fe	Mn	Ni	Pb	Zn
	-----	-----	-----	-----	kg/day	-----	-----	-----	-----	-----	-----
Burnaby	2800	210	60	109×10^{12}	106×10^{11}	1.8	32	2.9	0.27	5.9	2.1
Coquitlam	2400	220	53	121	88	1.7	46	2.7	0.27	4.9	1.9
Delta	1300	150	106	58	54	1.6	26	1.9	0.19	2.6	2.0
New Westminster	700	50	17	25	27	0.6	7	0.8	0.07	1.5	0.6
Port Coquitlam	600	50	13	26	23	0.4	8	0.7	0.06	1.4	0.6
Port Moody	40	3	1	1	2	0.01	0.3	0.03	0.003	0.08	0.01
Richmond	3100	280	64	124	120	3.6	43	4.3	0.43	6.2	4.7
Surrey	1700	130	36	64	67	1.2	19	2.4	0.17	3.6	1.4
Vancouver	2000	140	41	72	76	1.0	19	1.8	0.15	4.2	1.0
UEL	60	8	1	4	2	0.04	2	0.07	0.008	0.1	0.03

All values in kg/day except total and fecal coliforms which are numbers/day.
Some values are rounded off compared to values shown in Appendix III.

calculations. It is not known if these literature values are close to the actual local average stormwater pollutant concentrations. Trace metal concentrations were determined from the studies conducted by Westwater in Still Creek (Section 3.2). Also, this analysis does not take into account some factors which are believed to affect stormwater quality including antecedent dry periods, storm patterns, storm intensities and runoff volume.

The method of calculating runoff quality is also an approximation since the runoff coefficient is not constant throughout a storm and varies from storm to storm depending upon the antecedent moisture, storm pattern, frequency, and intensity. Storage at the surface and in the pipes or channels and the changing rate of runoff contribution from a catchment area are also not considered.

The area which was assumed (from topography maps) to drain to the Fraser River/Estuary may not exactly correspond to the actual drainage system. Stormwater collected in the combined sewerage areas of Vancouver, New Westminster, and Burnaby were included in the stormwater loading calculation. Since most of this stormwater is treated before discharge, the pollutant loadings for those municipalities with combined sewers would be lower than shown here. Complete removal of these loadings should result in only about an 11% reduction in the total loadings shown in Table 8.

It is not known what effect flood boxes have on the stormwater pollutant concentrations. During high tides, flood boxes on stormdrain outfalls are usually closed - preventing discharge of the runoff. Under certain tidal conditions, the stormwater may be stored up to eight hours before discharge. Some solids would be expected to settle during this holding period and may not be reentrained in the waters during discharge. Subsequent flows could carry this bed load into the receiving waters.

For these calculations, the annual quantity of stormwater from the study area was averaged to a daily rate. Stormwater discharges are highly irregular and the daily loading levels calculated here would likely be exceeded by some storms. In dry periods, there would be little discharge of stormwater from most stormdrains although groundwater contributions can be significant (11).

As recorded at Vancouver International Airport (VIA) from 1941-1970, there has been an annual average of 156 days with measurable rain (52). Assuming that runoff occurs on these days only, the loading values shown in Tables 8 and 9 could be multiplied by 365/156, or 2.3. The mean volume of rain on these days ranges from 4.6 mm/day in June and July to 7.9/mm/day in December (Table 10).

If it is assumed that stormwater pollutant concentrations are constant, then the total loadings are proportional to the daily rainfall. The average annual daily rainfall as recorded at VIA is:

$$\frac{1017 \text{ mm}}{156 \text{ days}} = 6.5 \text{ mm/day}$$

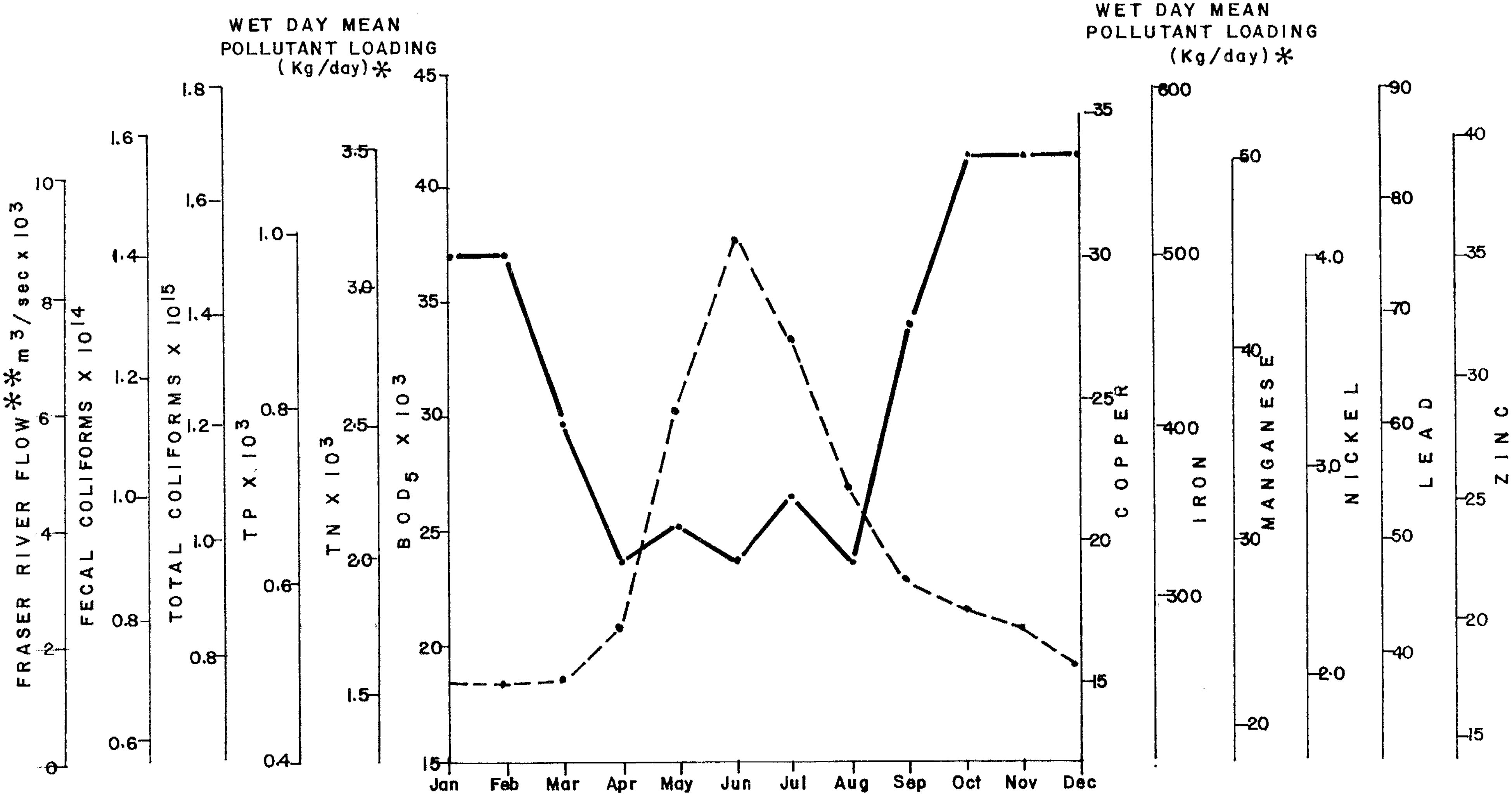
The ratio between this average and the actual monthly wet day rain volumes are shown in Table 10. These values multiplied by 2.3 give the multipliers to determine the monthly variation in wet day pollutant loadings. That is:

$$\text{Wet day pollutant loadings} = \frac{\text{mean monthly rain per wet day}}{\text{mean annual rain per wet day}} \times 2.3 \times \text{daily pollutant loadings (Table 8)}$$

The results of this calculation are shown in Figure 4. When averaged over an entire year the daily stormwater BOD_5 loading, for example, is 14 800 kg/day. However, on the average wet day in December the loading may be 41 400 kg/day.

TABLE 10 ANALYSIS OF MONTHLY RAINFALL CHARACTERISTICS

No. of days with measurable rain	Jan 17	Feb 15	Mar 15	Apr 13	May 10	June 10	July 6	Aug 8	Sept 9	Oct 16	Nov 18	Dec 19
Mean monthly rainfall (mm)	125	109	89	61	47	45	30	37	61	122	139	151
Mean rain per wet day (mm)	7.4	7.4	5.8	4.6	4.8	4.6	5.1	4.6	6.8	7.6	7.6	7.9
Mean monthly rain/wet day / Mean annual rain/wet day	1.1	1.1	0.89	0.70	0.74	0.70	0.78	0.70	1.0	1.2	1.2	1.2
Daily multiplier	2.5	2.5	2.0	1.6	1.7	1.6	1.8	1.6	2.3	2.8	2.8	2.8
Monthly multiplier	42	38	30	21	17	16	11	13	21	45	50	53



LEGEND

——— Monthly Mean Pollutant Loadings

– – – – Fraser River Flow

NOTE

* Except Total and Fecal Coliforms - number/day

** As recorded at Mission (Historical Stream Flow Summary to 1976, IWD, Environment Canada, 1977)

FIGURE 4 MONTHLY VARIATION IN MEAN POLLUTANT LOADINGS

The underlying assumption in this analysis (that stormwater pollutant concentrations are constant) is likely in error, particularly if pollutant accumulation rates are related to antecedent dry weather periods. The magnitude of this error is not known and should be addressed in future monitoring studies.

Pollutant loadings for summer months, for example, may be significantly different since infrequent lower volume summer storms with long antecedent dry weather periods may result in as great or greater loadings than more frequent higher volume winter storms. However, the loadings in Figure 4 show what may be a "shock load" effect. Stormwater pollutants reach the river "instantaneously" while river flow is controlled by snow-melt in the watershed. This is illustrated in Figure 4 where the maximum input of stormwater pollutants may be in the winter when river flows and dilution are at a minimum.

4.4 Some Other Methods to Calculate Stormwater Pollutant Loadings

Methods to calculate stormwater pollutant loadings range from the use of the simple Rational Method and average pollutant concentrations to complex computer models such as the EPA's Stormwater Management Model (SWMM). Computer models have been developed to provide hydrologic, water quality and pollutant loading information, or combination of these, as shown in Table 11. Most of the models have been developed for collection system and treatment works design - many are too complex and expensive to use for planning purposes. A detailed discussion of each of these models is beyond the scope of this report, however, three methods will be discussed here. The use of these, in combination with data obtained from a stormwater monitoring program, should provide more accurate pollutant loadings that could be used for planning purposes in the GVRD.

Model Origin	Model Abbreviation	Multiple Catchment Inflows	Dry Weather Flow	Input of Several Hyetographs	Snowmelt	Runoff from Impervious Areas	Runoff from Previous Areas	Water Balance between Storms	Flow Routing in Sewers	Upstream and Down-stream Flow Control	Surcharging and Pressure Flow	Diversions	Pumping Station	Storage	Prints Stage	Prints Velocities	Dry Weather Quality	Stormwater Quality	Quality Routing	Sedimentation and Scour	Quality Reactions	Wastewater Treatment	Quality Balance between Storms	Receiving Water Flow Simulation	Receiving Water Quality Simulation	Continuous Simulation	Can choose Time Interval	Design Computations	Real-Time Control	Applied to Real Problems	Computer Program available
Hydrocomp	HSP	●	●	●	●	●	●	●	●	●		●		●	●	●	●	●	●		●		●	●	●	●	●		●	●	
EM Protection Agency	SWMM	●	●	●		●	●	●	●	●	●	●	●	●			●	●	●	●	●	●		●	●	●	●	●		●	●
Ontario MOE	CSWMM	●	●	●	●	●	●		●	●		●	●	●			●	●	●	●	●	●		●	●		●	●		●	●
Dorsch Consult	HVM-QQS	●	●	●		●	●	●	●	●	●	●		●	●	●	●	●	●		●	●	●	●	●	●	●			●	
Watermation	CSM	●	●	●		●	●		●	●	●	●	●	●	●	●	●	●	●			●					●	●	●	●	
Water Resources Engineers	Storm Sewer	●	●	●		●	●		●	●	●	●	●	●	●	●	●	●	●		●			●	●		●			●	
Battelle Northwest	BNW	●	●	●		●	●		●		●	●		●	●	●	●	●	●			●					●	●	●	●	●
City of Chicago	CHM-RPM	●	●	●		●	●	●	●		●	●				●	●	●				●		●		●	●	●		●	●
Sogreath	Caredas	●	●			●	●		●	●	●	●	●	●	●	●			●					●	●		●			●	
Seattle Metro	CATAD	●	●	●		●	●	●	●	●	●	●	●	●	●												●		●	●	●
Mit-Resource Analysis	MITCAT	●	●	●	●	●	●		●		●	●		●	●	●								●			●			●	
Norwegian Water Res.	NIVA	●	●						●	●	●	●	●	●			●	●	●			●				●	●	●			
University of Illinois	ISS	●	●		●	●	●		●	●		●	●	●	●	●											●	●			●
Chicago Sanitary District	FSP	●	●	●	●	●	●	●	●					●	●									●		●	●			●	●
CH2M - Hill	SAM	●	●	●		●	●	●	●		●	●	●		●												●				
Corps of Engineers	STORM		●		●	●	●	●				●		●			●	●			●		●	●		●				●	●
Illinois State	Illudas	●	●	●		●	●		●							●											●	●		●	●
Minneapolis St. Paul	UROM - 9	●	●	●		●	●		●			●															●		●	●	●
University of Massachusetts		●	●			●		●	●	●					●	●										●					●
British Road Research Lab	RRL	●	●	●		●			●															●			●			●	●
Colorado State University		●	●			●			●	●					●	●															●
Wilsey and Ham	WH - I	●				●	●		●																		●	●		●	
University of Cincinnati	U CUR	●				●	●		●															●			●				●
University of Nebraska	HYDRA	●		●		●	●		●																		●				
Queens University	QUUR M	●				●	●		●																						

TABLE II MODEL COMPARISONS

4.4.1 Metro Seattle's 'Desk Top' Method. This method has been developed by Metro Seattle (29) to calculate stormwater pollutant loadings and has been used for that purpose in the study of two lakes in the region (30, 31). The method attempts to take into account pollutant accumulation and wash-off rates. Pollutant accumulation rates may be determined by monitoring programs conducted in the region and are expressed as pollutant mass/area/dry-day. Wash-off rates are assumed to be related to the volume of runoff - a technique developed by Metcalf and Eddy for EPA's Storm Water Management Model (SWMM) (30). The method may be divided into five calculations.

1) mass of pollutants accumulated on surface = watershed area x accumulation rate.
2) volume of runoff = volume of storm x runoff coefficient.
3) percent pollutant mass washed off surfaces is determined from relationship developed for SWMM (Figure 5).
4) pollutant mass washed off = percent washed off x mass accumulated.
5) annual loading from this volume of storm = mass washed off by storm x annual number of storms of this size.

By these calculations, the mass of pollutants generated by a selected storm are determined. Several storms are selected to simulate the precipitation pattern in the region. The advantages of this method include:

a) it is simple;
b) only hand calculators are required;
c) the method takes into account a number of factors which are believed to affect stormwater quality including antecedent conditions, accumulation and washoff rates.

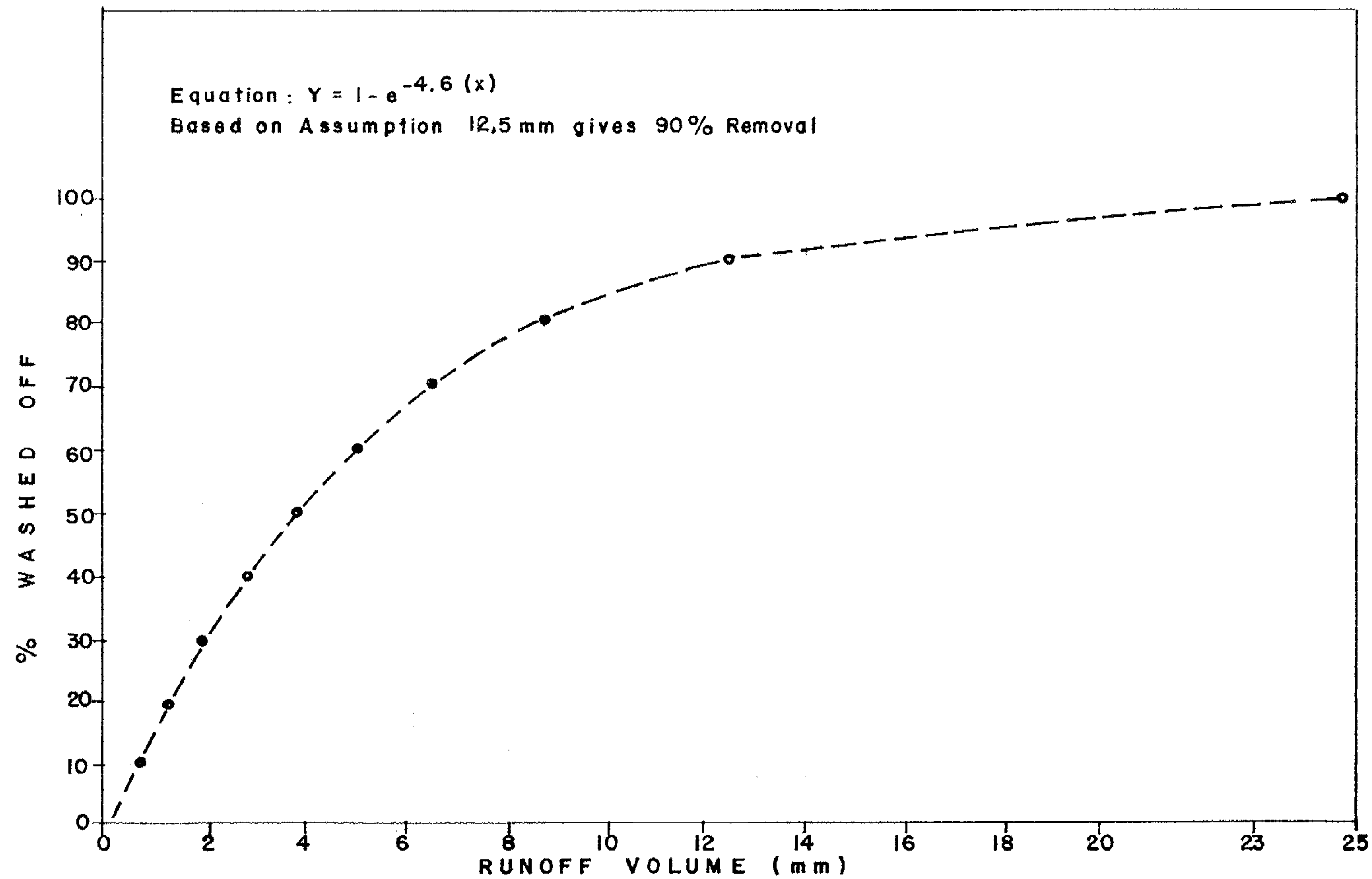


FIGURE 5 PERCENT OF POLLUTANT WASHED OFF AS A FUNCTION OF VOLUME OF RUNOFF (30)

The disadvantages of this method include:

a) only selective storms are considered and these may not be critical events from a stormwater quality viewpoint;
b) incomplete wash-off and residual build-up are assumed to offset each other;
c) depression storage and other hydrologic factors are lumped into the runoff coefficient;
d) the method is difficult to calibrate and verify.

4.4.2 U.S. Army Corp of Engineers' Storage, Treatment, Overflow, Runoff Model (STORM) (33). STORM allows the calculation of both stormwater quantity and quality. The program considers the properties of storm duration and intensity, storm spacing, and storage capacity of the stormwater system. In the model, pollutants are assumed to accumulate on the catchment area at a constant rate since the preceding rain event (similar to the Metro Seattle method). The amount of pollutants washed from the land surface is related to the intensity of rainfall, rate of runoff, and the pollutant accumulation rate. Runoff quantity may be calculated using either a coefficient method (Rational), the U.S. Soil Conservation Service (SCS) Curve Number Technique, or a combination of the two. The SCS method assumes a curvilinear relationship between accumulated runoff and accumulated rainfall. It attempts to take into account depression storage, interception, infiltration, and soil moisture capacity (33).

STORM may also be used to calculate the frequency, quantity, and quality of overflows from a combined sewerage area. The input data needed for STORM includes:

a) hourly rainfall;
b) area of drainage basin;
c) percent of each of five land use groups of the total drainage basin area;

d) average percent imperviousness of each land use group;

e) runoff coefficients for pervious and impervious areas;

f) depression storage available on impervious areas;

g) daily pollutant accumulation rates for each land use group.

The advantages of this method are:

a) it is a non-proprietary model;

b) it is a relatively simple method yet generates the required information needed for planning purposes by estimating annual pollutant loads, defining critical events, and assessing the long term impacts of urbanization;

c) it is a continuous simulation model using continuous hourly precipitation data, although it may also be used for single events;

d) the model may be calibrated and verified-although with some difficulty;

e) it has been used by others (13) to generate annual stormwater pollutant loads on a city-wide basis for Ontario communities;

f) the model is available in Canada through the Ontario Ministry of the Environment.

The disadvantages include:

a) a large scale digital computer is required;

b) input magnetic tape precipitation data may not be available, necessitating a great deal of input data processing;

c) the basic assumptions of the model may not be valid for the catchment under consideration (e.g., pollutants may not accumulate linearly with antecedent dry days).

4.4.3 Charles Howard and Associates Ltd. Statistical-Analytical Method (CHA) (34, 35). This method was developed by CHA as a means to estimate stormwater treatment costs and was used for this study for that purpose (Section 5.2.1). A detailed discussion of the technique may be found in Appendix IV. Reportedly (36) the technique could be readily adapted to calculate stormwater pollutant loadings for the GVRD once the relationship between pollutant accumulation and antecedent dry days, and wash-off rate and runoff volume are known. These relationships must be determined from a monitoring program. The advantages of this technique are:

a) the method reportedly (37) has an accuracy that is comparable to STORM for calculating runoff volumes;
b) the technique is suitable for desktop computers,
c) the technique is flexible and could be adapted to reflect the pollutant accumulation and wash-off rates derived from the study area.

The disadvantages of the method include:

a) precipitation data for only four stations in the GVRD are in a form that can be immediately used (although data from other stations in the region could be reduced);
b) the model cannot be verified for single events since it provides only statistical results;
c) the model assumes that quality and quantity are in constant proportions.

It is difficult to assess the relative accuracy of these models. Generally, they are only as accurate as the quality of input information and the ability of the operator to perceive the physical factors of the study area that affect stormwater loadings. The models described here illustrate some of the techniques available to assess stormwater pollutant loadings; a thorough analysis is required to determine the best appropriate model for the GVRD system.

4.5 Total Stormwater Pollutant Loadings

Thus far, this report has considered the pollutant loading from what may be termed wet weather stormwater. Other studies in North America have followed this approach. Results from recent sampling conducted in the GVRD by the WIB-PCB indicate that storm drains may contribute significant quanitites of pollutants during dry periods. That sampling program was outlined in Section 3.2 (Page 16) of this report and the results are discussed in detail in another report (11) published in the Fraser River/Estuary series.

Dry weather stormsewer pollutant loadings were calculated by multiplying mean concentrations by instantaneous flows determined during that study. Several storm drains exhibited high fecal coliform counts (2 drains 240 000/100 ml and 5 drains between 24 000/100 ml and 240 000/100 ml). These levels are likely indicative of sanitary cross-connections to the storm drains and therefore may not represent typical stormsewer discharge composition. However, if the sampled storm drain set are representative of the total stormwater inputs, then these loadings show what actually is discharged to the Fraser River/Estuary. Accordingly, these stations were included in the calculations of mean bacteriological and chemical dry weather pollutant loadings.

The results of this analysis are shown in Table 12 while the total input of pollutants from stormsewers is presented in Table 13. It appears that dry weather stormsewer discharges may be a significant source of pollutants relative to wet weather inputs particularly TN, Fe, Pb, Mn, Ni, and Zn. The data base for dry weather stormsewer discharges is very small and calculated pollutant loadings are only approximate.

TABLE 12 DRY WEATHER STORMWATER MEAN POLLUTANT CONCENTRATION AND LOADING

Parameter	Mean Concentration (mg/l)*	Mean Loading (kg/d)
pH	7.23	
TR	1 270	450 000
NFR	33	11 700
TP	0.242	86.1
NH_3	0.75	267
NO_3-N	0.62	221
NO_2-N	0.020	7.1
Organic N	1.07	381
TN	3.08	1 100
TOC	16.5	5 870
TIC	31.6	11 200
Phenol	0.010	3.6
Al	0.59	210
As	0.0006	0.21
Cr	0.008	2.8
Cu	0.017	6.0
Hg	0.051	18.1
Fe	5.16	1 800
Mn	0.45	160
Ni	$<$0.01	$<$3.6
Pb	0.094	33.5
Zn	0.068	24.2

*except Hg - ug/l.

TABLE 13 WET AND DRY WEATHER STORMSEWER POLLUTANT LOADINGS

Parameter	Wet Weather Stormwater		Dry Weather Discharges		Total Stormsewer Loading kg/d*
	kg/d*	(%)**	kg/d*	(%)**	
Flow	695 000	(66)	356 000	(34)	1 050 000
BOD_5	14 800				14 800
TN	1 200	(43)	1 100	(48)	2 300
TP	400	(87)	86	(17)	486
Total Coliform	6.0×10^{14}				6.0×10^{14}
Fecal Coliform	5.6×10^{13}	(95)	2.6×10^{12}	(5)	5.9×10^{13}
Copper	12.0	(75)	6.0	(33)	18
Iron	200.0	(10)	1 800	(90)	2 000
Manganese	18.0	(10)	160	(90)	180
Nickel	2.0	(12)	<3.6	(<64)	<5.6
Lead	30.0	(83)	33.5	(52)	64
Zinc	14.0	(47)	24.2	(64)	38

* except flow - m^3/day, and total and fecal coliforms - number per day.
** percentage of total stormsewer discharge.
*** some values have been updated since publication of the Water Quality Work Group Summary Report.

5 STORMWATER MANAGEMENT

Stormwater management techniques were originally developed to reduce or control stormwater flow and thereby reduce combined sewer overflows or flooding. Recently, treatment and source control systems have been examined as a means to reduce the stormwater pollutant loadings. Many of the management techniques can be applied to both combined and separate sewerage areas. The effectiveness and cost of the methods, particularly treatment devices, for separate stormwater systems has not been well documented.

Stormwater management and combined sewer storage and treatment techniques may be applied to combined sewer areas to reduce overflows without increasing pollution from stormwater, contrary to sewer separation. In addition, these techniques may be less costly than sewer separation. Full scale combined sewer overflow storage and treatment demonstrations are important to note since this technology may be adapted to separate stormwater systems in the future should they be deemed effective. A discussion of these demonstrations are included in Appendix V.

The various sewer system alternatives are illustrated in Figure 6.

5.1 Management Techniques

Stormwater management techniques generally fall into three categories:

1) source controls,
2) storage and treatment,
3) combination of above.

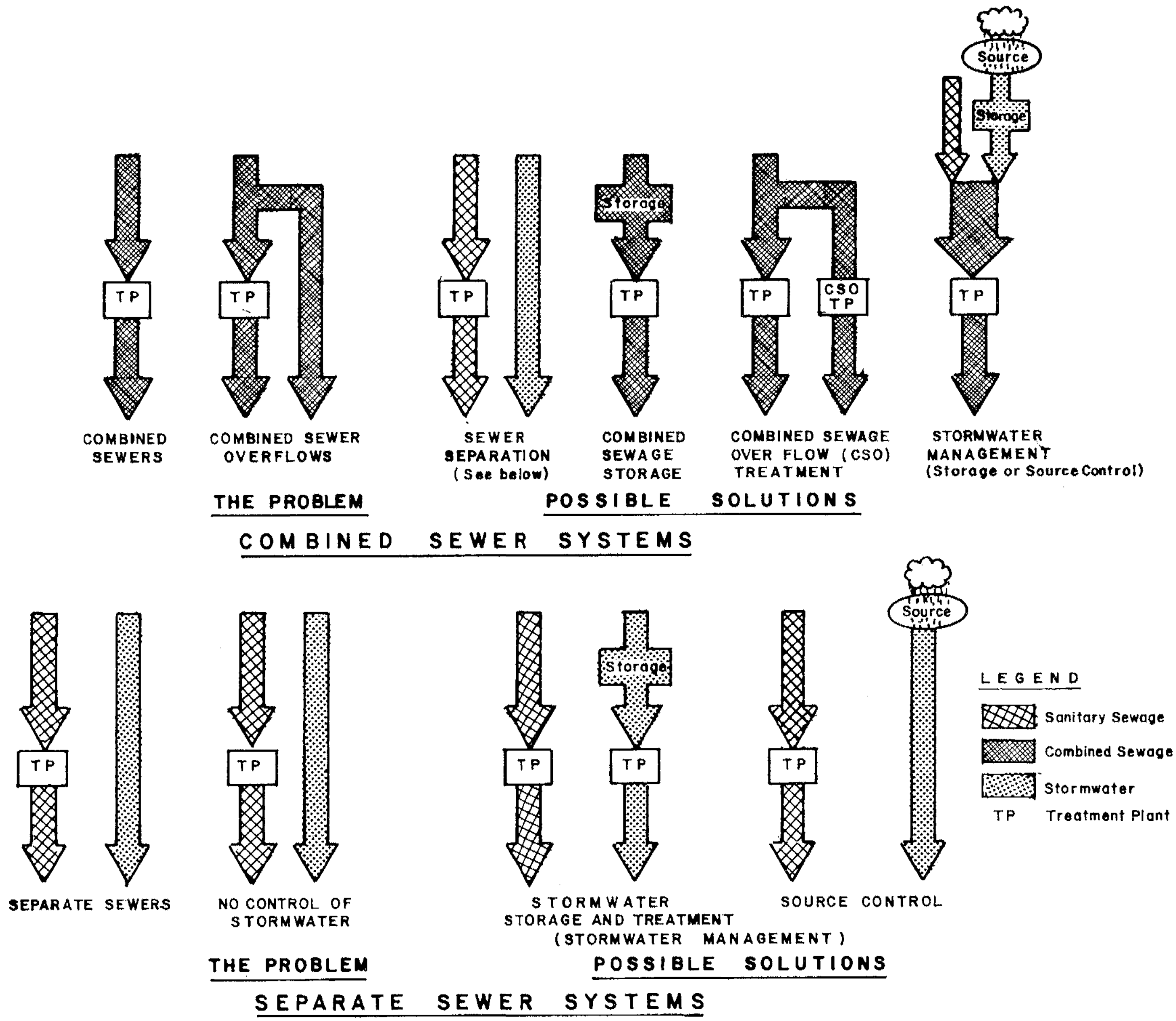


FIGURE 6 SEWER SYSTEM ALTERNATIVES

5.1.1 Source Controls. Source controls may include methods to reduce stormwater volumes or pollutant concentrations. Methods for reducing the quantity and/or rate of urban runoff at source include (38, 39):

1) roof storage;
2) porous pavements;
3) seepage basins, pits, trenches, wells and ditches;
4) tile fields.

Methods for improving the quality of urban runoff include (39):

1) decreasing air pollution and dustfall;
2) erosion control during the construction of buildings and highways;
3) improved street sweeping practices;
4) removal of lead compounds from gasoline;
5) improved methods for deicing pavements;
6) catchbasin cleaning.

In recent years, source control methods have received greater attention. There have been extensive tests conducted of the efficiency of street sweeping practices. Broom-type street sweepers have been found to be relatively inefficient in removing fine material smaller than 400 microns (the largest portion of pollutants are associated with the fine solids fraction of street surface contaminants [17]). Vacuum cleaning equipment for municipal street sweeping can remove up to 95% accumulated fine material (38). A study of various alternatives to reduce pollutant loads from St. Thomas, Ontario, to the areas receiving streams concluded that improved street sweeping practices using specialized vacuum-type equipment and elimination of combined sewer overflows by sewer separation would reduce the total wet weather BOD_5 and NFR discharged by about 90% (40). A study of sediment movement in the Scott Run basin in Fairfax County, Virginia, showed that highway construction areas varying from 1% to 10% of the basin area contributed 85% of the sediment (38).

Several methods of source control are to be implemented in a new 73 km^2 community (the Woodlands) north of Houston, Texas, to preserve the natural environment and to minimize stormwater pollution (36). Techniques to be used include:

1) natural grass covered drainage systems,
2) wide shallow swales lined with existing vegetation instead of narrow, deep drainage ditches,
3) flow retarding devices (retention ponds and recharge berms) and erosion control measures,
4) porous pavements,
5) control of fertilizers, pesticides and herbicides.

The estimated cost of the drainage system for this community is expected to be $243/ha compared to $486/ha for a conventional system.

In the GVRD, regulations governing the admission of wastes into sewers have been formulated (41). These regulations state that "no material other than stormwater, unpolluted drainage water and cooling water shall be discharged to storm sewers". Moreover, wastes with certain characteristics are restricted from combined and sanitary sewers. These characteristics include: uncomminuted garbage, temperature greater than 66°C, high grease and other hexane extractable compounds, NFR greater than 600 mg/l, pH lower than 5.5 or higher than 9.5, toxic and poisonous substances among others. Waste such as flammable or explosive liquids, substances capable of restricting flow, substances capable of producing noxious or malodorous gas, radioactive material, or cesspool or septic tank materials must not be discharged to any part of the sewer system.

The District of Coquitlam has enacted a Waterways Protection By-law (No. 1641) (42) which states that no person shall foul, obstruct, or impede the flow of any waterway in the district whether or not it is situated on private property. The District has also established a soil removal by-law (No. 190) which is administered through a permit system (43). This by-law recognizes many of the stormwater management techniques which are available to reduce pollution from construction sites. These include:

a) a limit on maximum slope angles;
b) reclamation of soil removal areas with grass, trees and shrubs;
c) settling basins for drainage from work areas;
d) isolation of work areas from water courses;
e) a limit of 200 mg/l NFR in drainage waters entering water courses;
f) recycling of drainage water wherever possible.

5.1.2 Storage and Treatment. In both stormwater and combined sewer overflow treatment, storage is an important part of the overall system. Without storage, extremely large and expensive treatment facilities would be required to process the irregular stormwater flows.

Storage may be characterized as either in-line or off-line. In-line storage may involve either a series storage-treatment system or storage alone used as a treatment device. In off-line storage, overflows from the collection system are held until capacity is available in the treatment system.

In-line type storage facilities have been used for the treatment of stormwater, reduction in flooding and the creation of recreational lakes. A study of Meadowville (44), a new area of Mississauga, Ontario, concluded that pollutant loads from the 120 ha area would increase after development (BOD_5 29.1 kg/ha, NFR 191.6 kg/ha, TN 11.2 kg/ha, orthophosphate 1.1 kg/ha) compared to pre-development loads (BOD_5 4.5 kg/ha, NFR 38.1 kg/ha, TN 1.1 kg/ha, ortho-PO_4

0.4 kg/ha). Peak flows from the area were expected to increase by a factor of 2 to 5 depending on storm frequency and the total annual runoff was expected to increase from 104 mm/yr to 203 mm/yr. Two dams were proposed for the catchment as part of a connected green belt. It was found that the ponds formed behind these dams would act as effective silting basins. Predicted yields of pollutants passing through the system to a downstream river were BOD_5 1.2 kg/ha, NFR 12.3 kg/ha, TN 7.8 kg/ha, and orthophosphate 0.9 kg/ha. Based upon predictions of pollutant concentrations in the reservoir, a seasonal algae growth was possible. The expected accumulation of residue in the basins was small (average 1.3 mm/yr) due to the large area available for storage. The study also concluded that the basins had a potential to go anaerobic and that a program of regular draw-down and cleaning should be planned. The construction of the in-line detention lake began in 1976.

An in-line stormwater retention pond will be built for a new urban area drained by the Kennedy-Burnett system in the Township of Nepean, Ontario (46). The basin provides storage up to 25 000 m^3 (900 000 ft^3). The system includes a storage reservoir, upstream transport channel, inlet control structure, bypass channel, and trash racks with provision for chlorination and dosing of coagulant chemicals, should they be necessary. The cost of the facility was estimated at $450 000 in July 1977. The settling time was assumed to be at least 24 hours with a drawdown period of 12 hours.

In-line stormwater retention facilities were constructed in Winnipeg for peak flow control as well as public and private use (46). There are six systems in varying stages of development utilizing permanent retention facilities. All systems are integrated within residential subdivisions with varying proportions of public shoreline. Studies of regional drainage areas have shown that systems utilizing stormwater storage can be up to 600% less costly than conventional systems. Studies have been conducted to assess the pollutant removal effectiveness of these ponds, and these results, as well as design characteristics are shown in Table 14.

In-line stormwater ponds have also been proposed to rejuvenate streams by improving water quality, reducing of peak flows (thereby decreasing erosion), and increasing low flows by attenuation. A basin plan has been developed for the Juanita Creek basin (47), an area of about 2590 ha in King County near Seattle, Washington. The plan calls for the establishment of 11 neighbourhood ponds, limited channel improvements, a continuation of existing on-site storage controls, and wet land preservations. The expected cost to the homeowners in the basin is $1 to $2 per month. The system of on-site detention facilities and neighbourhood ponds are expected to effect 70% NFR, 30% BOD, 50% coliforms, 60% TN, and 60% TP removal.

When used as a treatment device, in-line storage is in effect a sedimentation tank. There is presently very little data available to assess the effectiveness of stormwater ponds for treatment purposes, and there is no other well-defined technology which has been demonstrated on a large scale (46).

An EPA sponsored demonstration project of storm sewer discharges was conducted in New Orleans (53). It showed that storm sewer discharges containing excessive coliform bacteria levels were felt to degrade the water quality of Lake Pantchartrain.

Sodium hypochlorite was added to runoff from 16 high-volume storms and more than 20 low-volume storms. A sodium hypochlorite manufacturing plant was constructed to provide the necessary disinfectant. The largest single event treated was 257 400 m^3 of stormwater. Chlorine residuals greater than 0.5 mg/l resulted in 99.99% reduction in coliform concentrations. However, upon cessation of chlorination, significant regrowth of coliforms was noted in the receiving waters.

TABLE 14 CITY OF WINNIPEG STORMWATER PONDS' CHARACTERISTICS (55)

Design Data:

1) minimum of 200 m^2 (5 acres) of water surface;
2) 25 year storm return frequency design;
3) 7:1 side slopes;
4) 1.2 m rise in water depth from normal; water level to design storm;
5) 1.8 m depth under normal water level.

Area and Cost Requirements:

1) water surface and slopes occupy about 6% of service area;
2) about $100 per m^2 ($4000 per acre) for lakes and interconnecting piping;
3) about $10 per m^2 ($400 per acre) for grass maintenance;
4) about $4 per m^2 ($150 per acre) of water surface for algae and weed control.

Percent Annual Treatment Efficiency:

Parameter	Southdale System	Fort Richmond System	Average
NFR	93	85	89
TOC	17	55	36
BOD_5	68	40	54
TKN	14	34	24
TN	80	76	78
TP	47	64	56
Cl	-114*	-597*	-356*
Pb	89	80	84

* A negative treatment efficiency means, that more Cl was monitored going out of the lakes than going into the lakes.

A study of best practicable technology for stormwater treatment is to be conducted in Bellevue, Washington and hopefully this and other research will identify effective systems (48).

5.2 Storage-Treatment Costs

5.2.1 Method of Calculation. The development of costs for the reduction of stormwater pollution is rather difficult since efficiencies and unit costs are not readily available in the literature. Moreover, the effectiveness of source controls on reducing stormwater pollutant loads has been rarely documented.

To determine rough estimates of stormwater pollutant removal costs for the GVRD, a method developed by Charles Howard and Associates Ltd. (34) was used. The method allows the calculation of storage-treatment costs based upon climatic and hydrologic characteristics of the watershed and unit costs for various storage-treatment alternatives. The results of the analysis appear on graphs showing lines of equal pollutant removal efficiency for various storage-treatment alternatives or "isoquants". Costs were calculated for each storage-treatment combination using a unit cost function which allowed for economies of scale. Minimum costs were obtained by comparing the costs for each combination. A summary of the results of the analysis appear here while a more detailed account may be found in Appendix IV.

Costs were calculated on the basis of NFR removal. Although the technique could be applied for other parameters, pollutant removal efficiences for the various storage-treatment alternatives are best documented for NFR. Also, it has been shown by many researchers (Section 3 and Appendix I) that many pollutants are associated with solids in stormwater and, therefore, effective NFR removal would result in significant reductions of other parameters.

For this analysis, the municipalities of the GVRD were assigned to the sewerage areas of the three treatment plants - Iona, Annacis, and Lulu Island as shown in Table 15. This was done for simplicity since the sewerage boundaries do not correspond exactly to the municipal boundaries. Also, the entire Iona sewerage area was assumed to be a combined system while the Annacis and Lulu areas were assumed to be separate.

Some storage-treatment alternatives considered the use of existing treatment plant capacities. The capacity available for processing stored runoff between events was assumed to be used for stormwater treatment at no extra cost and was calculated to be the difference between the design peak wet weather flow (WWF) and dry weather flow (DWF) as shown in Table 16.

Non-filterable Residue removal efficiencies for the three treatment plants were obtained from examination of data obtained during wet weather months (27). Stormwater NFR pollutant removal efficiencies were assumed to be 0.50, 0.60, and 0.63 for the Iona, Annacis, and Lulu sewage treatment plants, respectively.

5.2.2 Storage-Treatment Alternatives. A total of four storage treatment alternatives were considered for each of the three sewerage areas as shown in Table 17. The alternatives involved three types of storage (sedimentation tank, watershed, and stormwater ponds) and five types of treatment (activated sludge, swirl concentrator*, primary treatment, stormwater ponds, and physical-chemical).

Iona - Alternative 1

Sedimentation tank storage is similar to a primary type treatment facility. For this analysis, sedimentation tanks were assumed to be in series with a more advanced treatment device (activated sludge)

---

*For a description of the swirl concentrator see Appendix V.

TABLE 15 GVRD MUNICIPALITIES IN SEWERAGE AREAS

Sewerage Area	Municipality or designated area	Area tributary to Fraser km^2	Weighted Precipitation (mm)*	Weighted Runoff Coefficient*
Iona	University Endowment Lands Vancouver Sea Island	57 (22 mi^2)	1266	0.40
Annacis**	Coquitlam Delta Burnaby New Westminster Port Coquitlam Port Moody Surrey	303 (117 mi^2)	1670	0.34
Lulu	Richmond	130 (51 mi^2)	1140	0.36

* Weighted by area (calculated from data presented in Section 4.3 of this report).

** Other municipalities which are part of the Annacis sewerage area but not considered in this calculation include Langley City and White Rock: and small portions of Vancouver and Richmond which were included in the Iona and Lulu sewerage areas respectively.

TABLE 16 EXCESS TREATMENT CAPACITY AVAILABLE AT GVSDD TREATMENT PLANTS (49)

Treatment Plant	Peak WWF (m^3/d)	DWF (m^3/d)	Capacity for Stormwater Treatment (m^3/d)	Area tributary to Fraser River (km^2)	Capacity per Unit Area ($m^3/d/km^2$)
Iona	1 500 000	320 000	1 200 000	57	21 000
Annacis	880 000	250 000	630 000	303	2 100
Lulu	120 000	59 000	61 000	132	460

TABLE 17 STORAGE - TREATMENT ALTERNATIVES

Sewerage Area	Alternative	Maximum Treatment Efficiency	Existing Capacity ($m^2/d/km^2$)	Cost** Functions (dollars/km^2/yr)
Iona (combined)	(1) Sedimentation Tank Storage	0.50	614*	29 000 $S^{0.75}$
	Activated Sludge Treatment	0.60	0	9 600 $T^{0.80}$
	(2) Watershed Storage	0	0	3 800 $S^{2.0}$
	Activated Sludge Treatment	0.93	0	25 000 $T^{0.80}$
	(3) Watershed Storage	0	0	3 800 $S^{2.0}$
	Swirl Concentrator Treatment	0.40	21 000	1 000 $T^{0.70}$
	(4) Watershed Storage	0	0	3 800 $S^{2.0}$
	Primary Treatment	0.50	21 000	16 000 $T^{0.70}$
Annacis and Lulu (separate)	(1) Stormwater Ponds only	0.60	0	3 800 $S^{1.0}$ 380 $V^{1.0}$
	(2) Watershed Storage	0	0	3 800 $S^{2.0}$
	Primary Treatment	0.60*** 0.63+	2 100*** 463+	16 000 $T^{0.70}$
	(3) Watershed Storage	0	0	3 800 $S^{2.0}$
	Swirl Concentrator	0.20	0	1 000 $T^{0.70}$
	(4) Watershed Storage	0	0	3 800 $S^{2.0}$
	Physical-Chemical Treatment	0.90	0	19 000 $T^{0.75}$

* m^3/km^2
** S - storage (m^3/km^2)
T - treatment ($m^3/day/km^2$)
V - outlet structure ($m^3/day/km^2$)
*** Annacis Sewerage Area
\+ Lulu Sewerage Area

and to be capable of a maximum NFR pollutant removal efficiency equal to the existing primary treatment plant (Iona). Actual removal efficiencies are a function of the runoff residence time. Studies of pollutant removal data for stormwater ponds in Winnipeg suggested use of the function (34):

$$\text{removal efficiency} = 54.4 \log (RT) + 5.63$$

where: RT is the average detention time

This function was used for the calculation of the sedimentation tank NFR removal efficiency and reflects the fact that the tank is not intended as a primary treatment device.

The activated sludge treatment system was assumed to be capable of a maximum NFR removal efficiency of only 0.60 since much of the solids would be removed in the sedimentation tanks.

Iona - Alternative 2

Watershed storage involves the use of parking lots, roof tops, and playgrounds as temporary storage sites. The retention period of runoff in such areas must be short and, therefore, no treatment was assumed to take place. In practice, physical and economic constraints may limit the use of this type of storage although no limit was used for this analysis. The cost function is based upon data presented in a 1976 EPA report (50). The activated sludge treatment system used in this alternative was described in Alternative 1.

Iona- Alternative 3

Watershed storage was described in Alternative 2.

The swirl concentrator is a treatment device oriented entirely to solids removal. Swirl concentrators or other similar devices have been used for the treatment of combined sewer overflows (Appendix V) in a number of cities of North America and Europe. For this analysis a maximum of 40% NFR removal efficiency was assumed for the concentrator.

The cost of the unit was obtained from an EPA report (50). It was assumed that the present sewage treatment plant capacity would be used for treatment and the swirl concentrator would be applied to runoff in excess of this volume.

Iona - Alternative 4

Watershed storage was described in Alternative 2.

The primary treatment system was assumed to be an extension of the existing plant. Both existing excess treatment capacity for stormwater treatment and present NFR removal efficiencies were taken into account. The cost function of the sedimentation system used in this alternative was greater than that used for storage in Alternative 1, because as a treatment device, the sedimentation tanks must be large to provide adequate retention times, while as a storage device, the tanks may be smaller as retention for residues removal is not the important design factor.

Annacis - Lulu Alternative 1

Stormwater ponds are being monitored at a number of cities in Canada. Preliminary results show that these ponds may be capable of producing up to 100% NFR removal. As a practical limit, 60% NFR removal was assumed to be the maximum removal efficiency. The pollutant removal function discussed in Iona - Alternative 1 for storage was used for this alternative.

In this application, the stormwater ponds act as both storage and treatment devices.

Annacis - Lulu Alternative 2

This alternative was the same as Iona Alternative 4. Existing excess capacity at the treatment plants were utilized at no additional cost.

Annacis - Lulu Alternative 3

Watershed storage was as discussed in Iona Alternative 2.

The effectiveness of swirl concentrators for separate stormwater has not been well demonstrated. For this analysis, a 20% NFR removal efficiency was assumed for the separate stormwater sewer system.

Annacis - Lulu Alternative 4

Watershed storage was as discussed in Iona Alteranative 2. The physical-chemical treatment system considered in this alternative was a primary type treatment device with the use of chemical coagulant aids. The effectiveness of such a system for stormwater has not been demonstrated. The maximum NFR removal efficiency for this treatment system was assumed to be 0.90.

5.2.3 Alternative Costs. The cost functions used in this analysis were determined by CHA and are based upon data presented in reports from Canada and the U.S. (50, 51, 13) (Table 17). The costs are dependent upon the storage and treatment capacities. Exponents were used to reflect either increased or decreased rate of cost as storage or treatment capacity increases (economies or dis-economies of scale). In general, centralized devices tend to decrease in cost as capacity increases whereas decentralized devices tend to increase in cost. Costs are expressed as annual costs per square kilometer of sewerage area. The interest rate used was eight percent over 20 years, although present worth values are presented for the least cost alternatives.

The results of the calculations are shown in Tables 18 and 19. The analysis indicates that 30% and 40% of the NFR in urban runoff from the Iona sewerage area could be removed with existing treatment capacity. Unfortunately the nature of the computer program and the data made it inconvenient to calculate a 50% isoquant for the watershed storage - primary treatment alternative and, therefore, the cost at this efficiency

TABLE 18 COSTS OF STORAGE - TREATMENT ALTERNATIVES

Sewerage Area		Alternative		Annual Costs for NFR Removal (dollars/km^2)				
		Storage	Treatment	30%	40%	50%	60%	70%
Iona	(1)	Sedimentation Tank	Activated Sludge	8 800	15 000	23 000	32 000	45 000
	(2)	Watershed	Activated Sludge	12 000	18 000	24 000	33 000	43 000
	(3)	Watershed	Swirl* Concentrator	-	-	-	-	-
	(4)	Watershed	Primary	0	0	**	-	-
Annacis	(1)	Ponds	Ponds	3 000	5 800	8 500	**	-
	(2)	Watershed	Primary	11 000	8 800	26 000	50 000	-
	(3)	Watershed	Swirl* Concentrator	-	-	-	-	-
	(4)	Watershed	Physical Chemical	12 000	17 000	22 000	31 000	39 000
Lulu	(1)	Ponds	Ponds	2 700	4 200	6 500	**	-
	(2)	Watershed	Primary	-	17 000	26 000	46 000	-
	(3)	Watershed	Swirl* Concentrator	-	-	-	-	-
	(4)	Watershed	Physical Chemical	10 000	14 000	18 000	26 000	33 000

* Swirl Concentrators were assumed to be capable of a maximum 20% NFR removal.

** Maximum treatment efficiency - alternative must involve complete storage and treatment of runoff (no costs available - see text).

TABLE 19 LEAST COST ALTERNATIVES FOR STORMWATER TREATMENT

Least Cost Alternative for Sewage Area		NFR Removal 30%	40%	50%	60%	70%
Iona (57 km^2)						
Alternative	Storage	Watershed	Watershed	Sedimentation Tank**	Sedimentation Tank	Watershed
	Treatment	Primary	Primary	Activated Sludge	Activated Sludge	Activated Sludge
Annual Costs/unit area*		0	0	\$23 000	\$32 000	\$43 000
Annual Costs (dollars/yr)		0	0	\$1.3 x 10^6	\$1.8 x 10^6	\$2.4 x 10^6
Present Worth (dollars)		0	0	\$13 x 10^6	\$18 x 10^6	\$24 x 10^6
Annacis (303 km^2)						
Alternative	Storage	Ponds	Ponds	Ponds	Watershed***	Watershed
	Treatment	Ponds	Ponds	Ponds	Physical/Chemical	Physical/Chemical
Annual Cost/unit area*		\$3000	\$5800	\$8500	\$31 000	\$39 000
Annual Cost (dollars/yr)		\$909 000	\$1.8 x 10^6	\$2.6 x 10^6	\$9.3 x 10^6	\$12 x 10^6
Present Worth (dollars)		\$9.2 x 10^6	\$18 x 10^6	\$26 x 10^6	\$93 x 10^6	\$120 x10^6
Lulu (132 km^2)						
Alternative	Storage	Ponds	Ponds	Ponds	Watershed***	Watershed
	Treatment	Ponds	Ponds	Ponds	Physical/Chemical	Physical/Chemical
Annual Cost/unit area*		\$2700	\$4200	\$6500	\$26 000	\$33 000
Annual Cost (dollars/yr)		\$360 000	\$560 000	\$860 000	\$3.4 x 10^6	\$4.3 x 10^6
Present Worth (dollars)		\$3.6 x 10^6	\$5.6 x 10^6	\$8.5 x 10^6	\$33 x 10^6	\$42 x10^6

* dollars/km^2/yr at i = 8%, N = 20 years.

** watershed storage - primary treatment may be capable of 50% NFR removal and less costly than the alternative shown (see text).

*** stormwater ponds may be capable of 60% NFR removal and less costly than the alternative shown (see text).

is not known. Physically, this alternative requires that only combined sewage from the area tributary to the Fraser River/Estuary is transferred to the Iona plant for treatment, although the annual costs generated could be applied to the entire sewerage area. Sedimentation tank storage - activated sludge treatment is the least costly alternative for 60% NFR removal, while the watershed storage - activated sludge alternative is the least costly for 70% NFR removal. These alternatives and costs involve treatment of stormwater only, and industrial sewage would continue to be handled by the dry weather treatment plant capacity.

For the Annacis and Lulu sewerage areas tributary to the Fraser River/Estuary, stormwater ponds are the least costly alternative up to minimum 50% NFR removal. The computer program was unable to calculate an isoquant for this alternative at 60% NFR removal efficiency. Watershed storage and physical-chemical treatment would be required for 70% NFR removal.

The watershed storage - primary treatment alternative for Iona and the stormwater ponds alternatives for Annacis and Lulu are physically the easiest alternatives to implement. In effect, much of the Iona sewerage area presently has this system through combined sewerage. However, with continued sewer separation the benefits of stormwater treatment will be lost without the implementation of alternative systems.

Much of the Annacis and Lulu sewerage area utilizes natural streams and open ditches. These are ideal systems for stormwater ponds similar to those used at Juanita Creek and Winnipeg (Section 5.1).

The costs generated in this analysis are only estimates to be used for discussion. They do not represent estimates for engineered facilities in either costs or design. Moreover, costs presented here are based upon studies conducted in the United States and must be updated to local conditions in future studies of stormwater management techniques.

Other than watershed storage, the effectiveness and cost of source controls was not considered in this analysis. It is recognized that source controls may be effective in providing significant stormwater pollution control at considerable less cost than calculated here for storage-treatment methods. It is rather difficult, however, to estimate a cost for these controls for the GVRD since there is little documented information on the subject. Moreover, by the very nature of the problem, cost estimates must be made on a rather detailed site specific basis.

REFERENCES

1. Metcalf and Eddy, Inc., Wastewater Engineering, McGraw-Hill Book Company, (1972).
2. "Retention Basin Control of Combined Sewer Overflows", Springfield Sanitary District, Springfield, Illinois, Environmental Protection Agency, Water Pollution Control Research Series, 11023-08/70, p. 3, (1970).
3. Lager, J.A., and W.G. Smith, Metcalf and Eddy Inc., Urban Stormwater Management and Technology: An Assessment, Environmental Protection Agency, EPA-670/2-74-040, p. 26, (1974).
4. Ibid., p. 30.
5. Ibid., p. 27.
6. Ibid., p. 84.
7. Waller, D.H., "Urban Drainage Problems - An Overview", Modern Concepts in Urban Drainage Conference Proceedings No. 5, Canada-Ontario Agreement on Great Lakes Water Quality, p. 26, (1978).
8. Ibid., p. 30.
9. Sidhu, S.T., A Preliminary Study on Wastewater Characteristics of Prince George Stormwater and Sewage Discharges, Environmental Protection Service, Pacific Region, Manuscript Report EPS 5-PR-75-9, (1975).
10. Sidhu, S.T., A Preliminary Study on Wastewater Characteristics of Kamloops Stormwater Discharges, Environmental Protection Service, Pacific Region, Manuscript Report EPS-75-3, (1975).
11. Clark, M.J.R., and P.K. Krahn, Dry Weather Stormsewer Discharges, 1978. Fraser River Estuary Study - Water Quality, Victoria, (1979).
12. Atwood, J., City of Vancouver Engineering Departments, personal communication.
13. Manual of Practice on Urban Drainage, The Urban Drainage Subcommittee of the Canada-Ontario Agreement on Great Lakes Water Quality, Draft No. 3, pp. 3-12, (1977).

14. Greater Vancouver Sewerage and Drainage District, personal communication.

15. Lager, J.A., W.G. Smith, Metalf and Eddy, p. 88.

16. Manual of Practice on Urban Drainage, p. 5-95.

17. Sartor, J.D., G.B. Boyd, and F.J. Agardy, "Water Pollution Aspects of Street Surface Contaminants", Journal WPCF, Vol. 46, No. 3, 458-467, (1974).

18. "Brief Submitted to the Public Enquiry on Municipal Waste Disposal", Greater Vancovuer Regional District (sic.), Vol. 2, (1973).

19. Benedict, A.H., K.J. Hall, and F.A. Koch, A Preliminary Water Quality Survey of the Lower Fraser River System, Westwater Research Centre, UBC, Vancouver, Technical Report No. 2, (1973).

20. Hall, K.J., F.A. Koch, and I. Yesaki, Further Investigations into Water Quality Conditions in the Lower Fraser River System, Westwater Research Centre, UBC, Vancouver, Technical Report No. 4, (1974).

21. Ibid., p. 53.

22. Vernon, S.A., Still Creek Water Quality Report, Greater Vancouver Sewerage and Drainage District (1974).

23. Garret, C.L., Environmental Contamination by Polychlorinated Biphenyls (PCBs) in British Columbia, Environmental Protection Service, Pacific Region, EPS 8-PR-76-3, (1976).

24. Koch, F.A., K.J. Hall, and I. Yesaki, Toxic Substances in the Westwaters from a Metropolitan Area, Westwater Research Centre, UBC, Vancouver, Technical Report No. 12 (1977).

25. Environmental Protection Service, Pacific Region, unpublished data.

26. Harvey, G., Burnaby Environmental Health, personal communication.

27. Cain, B., Water Investigations Branch, Ministry of the Environment, personal communication.

28. Franson, M.A., Environmental Quality in Greater Vancouver, for Planning Department - Greater Vancouver Regional District, (sic.), Vancouver (1973).

29. Buffo, J., Metro Seattle, personal communication.

30. A Study of the Trophic Status and Recommendations for the Management of Lake Meridian, Metro Seattle, Seattle, Wash. (1978).

31. Water Quality Problems and Alternatives for the Restoration of Lake Ballinger, Metro Seattle, Seattle, Wash., (1977).

32. Perks, A.R., "A Review of Urban Runoff Models", Modern Concepts in Urban Drainage Conference Proceedings No. 5, Canada-Ontario Agreement on Great Lakes Quality, p. 164, (1978).

33. Storage, Treatment, Overflow, Runoff Model "STORM", Hydrologic Engineering Centre, U.S. Army Crops of Engineers, Davis, Calif., 723-S8-L7520 (1976).

34. Flatt, P.E., and C.D.D. Howard, "Preliminary Screening Procedure for Economic Storage-Treatment Trade-Offs in Stormwater Control", International Symposium on Urban Stormwater Management, Lexington, Kentucky, (July 24-27, 1978).

35. Analysis and Use of Urban Rainfall Data in Canada, Charles Howard and Associates, Department of Fisheries and Environment, Water Pollution Control Directorate (August 1978).

36. Howard, C.D.D., Charles Howard and Associates, personal communication.

37. "Storm and Combined Sewer Storage-Treatment Theory Compared to Computer Simulation", Charles Howard and Associates Ltd. for U.S. EPA, Grant No. R805109010, October, 1969.

38. Lager, J.A., and W.G. Smith, Metcalf and Eddy Inc., p.

39. 135-143. Stormwater Management Procedures and Methods, URS Company, p. 000091 (1977).

40. Stormwater Management Technology Systems Demonstration in the City of St. Thomas, James F. MacLaren Limited, for CMHC (1978).

41. "Regulations Pursuant to the Greater Vancouver Sewerage and Drainage District Act Governing the Admission of Wastes Into Sewers", GVRD, (January 1971).

42. "The Corporation of the District of Coquitlam By-law No. 1641" (1969).

43. "District of Coquitlam Soil Removal By-law No. 190" (1973).

44. Murrey, M.P.H., and J.J Ganczarczyk, Storage for Stormwater Quality Control Meadowvale Test Site Study, Canada-Ontario Agreement on Great Lakes Water Quality, Research Report No. 63, (1977).

45. Tonnelli, F.A., "Treatment Technology for Urban Runoff", Modern Concepts in Urban Drainage Conference Proceedings No. 5, Canada-Ontario Agreement on Great Lakes Water Quality, p. 252, (1978).

46. Manual of Practice on Urban Drainage, p. 5-73.

47. Juanita Creek Basin Plan, King County, Wash., (1977).

48. Bissonette, P., City of Bellevue, Wash., personal communication.

49. Talbot, D., GVRD, personal communication.

50. Heany, J.P., Stormwater Management Model, Level 1, Preliminary Screening Procedures, Dept. of Environmental Engineering Sciences, Univ. of Florida, Gainesville, Florida, (1976).

51. Benjes, H., et al, Estimating Construction Costs and Operating and Maintenance Requirements for Combined Sewer Overflow and Treatment Facilities, U.S. EPA, Cincinnati, Ohio, unpublished (1975).

52. Penny, N.E., Atmospheric Environment Service, Vancouver International Airport, personal communication.

53. Lager, J.A., W.G., Smith, Metcalf and Eddy, p. 342.

54. Hall, K.J., I. Yesaki, and J. Chan, Trace Metals and Chlorinated Hydrocarbons in the Sediments of a Metropolitan Watershed, Westwater Research Centre, Technical Report No. 10, (May 1976).

55. Stephen, A.G., City of Winnipeg, personal communication.

56. Krahn, P., Site Registry of Stormwater Discharges, Fraser River Estuary Study - Water Quality, Victoria, (1979).

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of the following:

R.T. Cain, Project Engineer, and P. Krahn, Engineering Aide, Dr. M.J.R. Clark, Branch Environmental Chemist and K.W. Hai, Engineering Aide, Ministry of the Environment who gathered information and provided valuable guidance in the preparation of this report.

J. Atwood, Engineering Department, City of Vancouver, who provided information on the City of Vancouver's sewage system.

C.D.D. Howard, Charles Howard and Associates Ltd. who contributed information on stormwater models and storage-treatment costs used in this report and provided valuable comments on the text.

T.J. Tevendale, Technical Advisor, Municipal and Food Industries, Environmental Protection Service, who contributed information and edited this report.

The calculation of pollutant loads in Appendix III and Section 4.3 were conducted by the Westwater Research Centre as part of a water quality management study of the Lower Fraser River which was supported by a grant from Inland Waters Directorate, Environment Canada, to the University of British Columbia.

APPENDIX I

RESULTS OF SOME STORMWATER QUALITY STUDIES CONDUCTED IN NORTH AMERICA

1) Piedmont Region, North Carolina
2) Tulsa, Oklahoma
3) Seattle, Washington
4) Borough of East York
5) Ottawa
6) New York City

APPENDIX I RESULTS OF SOME STORMWATER QUALITY STUDIES CONDUCTED IN NORTH AMERICA

Some results of stormwater quality studies conducted in other cities are shown in Tables 1 and 2. The great range in values reported emphasizes the variability in stormwater quality. Moreover, stormwater monitoring techniques vary considerably with grab, sequential grab, and composite sampling all being employed.

The purpose of this section is not to present a detailed literature review of urban runoff studies, but rather, to indicate the type and scope of programs which have been conducted. Results, conclusions, and recommendations are given to show the progress that has been made to identify and reduce urban runoff problems.

1) Piedmont Region, North Carolina (1)

A rather extensive study of runoff quantity and quality was conducted in Triangle J Piedment Region of North Carolina (1). Streams from various land use drainage catchments were sampled. Results indicated that first flush effects were significant. The results showed that:

1) higher values of COD and NFR concentrations would be expected from land cover types with a greater percentage of impervious surfaces;
2) rural areas tended to have the lowest NFR concentrations;
3) TP concentrations increased with NFR levels (except for the rural area where the TP level was high due to agricultural fertilizer use);
4) peak Pb concentrations increased with increasing impervious area and vehicular traffic. Lead levels also generally correlated with high runoff NFR concentrations.

APPENDIX I

TABLE 1 RESULTS OF STORMWATER MONITORING PROGRAMS REPORTED IN THE LITERATURE

Reference* / Parameter	1	2a		2b		2c	
	avg.	range	avg.	range	avg.	range	avg.
BOD_5 (mg/l)	15	11-62	28	4-37	14	12-100	36
NFR (mg/l)	300	650-11 900	2080	-	-	95-1053	505
TN (mg/l)	4	-	-	-	-	-	-
TP (mg/l)	1	-	-	-	-	-	-
Total Coliforms (MPN/100 ml)	$2x10^4$	-	-	$4x10^3$-$6x10^4$	$2x10^4$	-	-
Fecal Coliforms (MPN/100 ml)	$5x10^3$	-	-	-	-	-	-
TR (mg/l)	-	-	-	-	-	-	-
SM (mg/l)	-	-	-	-	-	-	-
TVR (mg/l)	-	-	-	-	-	-	-
Fecal Streptococci (MPN/100 ml)	-	-	-	-	-	-	-
COD (mg/l)	-	-	-	-	-	-	-
Soluble Phosphorus (mg/l)	-	-	-	-	-	-	-
NO_3 (mg/l N)	-	-	-	-	-	-	-
NH_3-N (mg/l N)	-	-	-	-	-	-	-
TKN (mg/l)	-	-	-	-	-	-	-
pH	-	-	-	-	-	-	-

*See Table 2.

APPENDIX I

TABLE 1 RESULTS OF STORMWATER MONITORING PROGRAMS REPORTED IN THE LITERATURE

Reference* Parameter	2d	2e		2f		2g	
	avg.	range	avg.	range	avg.	range	avg.
BOD_5 (mg/l)	31	-	9.4	-	-	-	12
NFR (mg/l)	-	1013	-	10-1000	81	-	26
TN (mg/l)	-	-	-	-	-	-	-
TP (mg/l)	-	-	-	-	-	-	-
Total Coliforms (MPN/100 ml)	-	$3 \times 10^3 - 2 \times 10^6$	-	-	-	$7 \times 10^3 - 7 \times 10^8$	-
Fecal Coliforms (MPN/100 ml)	3×10^5	-	-	-	-	-	-
TR (mg/l)	-	-	-	-	-	-	-
SM (mg/l)	-	-	-	-	-	-	-
TVR (mg/l)	-	-	-	-	-	-	-
Fecal Streptococci (MPN/100 ml)	-	-	-	-	-	-	-
COD (mg/l)	224	-	-	-	-	-	-
Soluble Phosphorus (mg/l)	-	-	-	-	-	-	-
NO_3 (mg/l N)	-	-	-	-	-	-	-
NH_3 N (mg/l N)	-	-	-	-	-	-	-
TKN (mg/l)	-	-	-	-	-	-	-
pH	-	-	-	-	-	-	-

*See Table 2.

APPENDIX I

TABLE 1 RESULTS OF STORMWATER MONITORING PROGRAMS REPORTED IN THE LITERATURE

Reference* / Parameter	2h	2i		2j		2k
	avg.	range	avg.	range	avg.	range
BOD_5 (mg/l)	7	24-283	106	1-39	11	3-90
NFR (mg/l)	30	3-211	71	84-2052	247	130-11 280
TN (mg/l)	-	-	-	-	-	0.5-6.5
TP (mg/l)	-	-	-	-	-	0.2-4.5
Total Coliforms (MPN/100 ml)	-	-	-	$1x10^3-5x10^6$	$1x10^5$	120-3200
Fecal Coliforms (MPN/100 ml)	-	$2x10^4x1x10^7$	$8x10^5$	-	-	40-1300
TR (mg/l)	-	-	-	-	-	338-14 600
SM (mg/l)	-	-	-	-	-	-
TVR (mg/l)	-	-	-	-	-	-
Fecal Streptococci (MPN/100 ml)	-	-	-	-	-	3-60
COD (mg/l)	-	21-176	58	12-405	85	29-1514
Soluble Phosphorus (mg/l)	-	-	-	-	-	-
NO_3 (mg/l N)	-	-	-	-	-	-
NH_3-N (mg/l N)	-	-	-	-	-	-
TKN (mg/l)	-	-	-	-	-	-
pH	-	-	-	-	-	-

*See Table 2.

APPENDIX I

TABLE 1 RESULTS OF STORMWATER MONITORING PROGRAMS REPORTED IN THE LITERATURE

Reference* Parameter	3	4		5		6	
	range	range	avg.	range	avg.	range	avg.
BOD_5 (mg/l)	1-90	1-250	20	5-111	34	3-167	19
NFR (mg/l)	15-410	1.5-207	33	2.5-635	128	19-1251	322
TN (mg/l)	-	-	-	-	-	3-279	34
TP (mg/l)	-	-	-	-	-	0.1-0.7	0.3
Total Coliforms (MPN/100 ml)	$2800-1.1x10^5$	-	-	-	-	$0.2-9x10^3$	$3x10^3$
Fecal Coliforms (MPN/100 ml)	-	-	-	-	-	0	0
TR (mg/l)	-	55-7320	1345	51-675	258	-	-
SM (mg/l)	-	-	-	-	-	-	-
TVR (mg/l)	-	-	-	-	-	-	-
Fecal Streptococci (MPN/100 ml)	-	-	-	-	-	$0.4x10^2-2.4x10^3$	$4x10^2$
COD (mg/l)	-	3-1000	116	7-277	79	-	-
Soluble Phosphorus (mg/l)	-	-	-	-	-	-	-
NO_3 (mg/l N)	-	-	-	-	-	1.2-3.4	1.8
NH_3-N (mg/l N)	-	-	-	-	-	0.1-0.3	0.2
TKN (mg/l)	-	-	-	-	-	0.03-0.15	0.08
pH	-	-	-	-	-	0.07-0.95	0.47

*See Table 2.

APPENDIX I

TABLE 1 RESULTS OF STORMWATER MONITORING PROGRAMS REPORTED IN THE LITERATURE

Reference* Parameter	7a		7b		7c
	range	mean	range	mean	range
BOD_5 (mg/l)	1-173	17	0.5-23	7	96-234
NFR (mg/l)	5-1200	227	5-2074	313	-
TN (mg/l)	-	-	-	-	-
TP (mg/l)	0.02-7.3	1.1	0.25-3.3	1.7	-
Total Coliforms (MPN/100 ml)	-	-	-	-	9.3×10^5
Fecal Coliforms (MPN/100 ml)	500-76 000	-	$2-5.6 \times 10^4$	-	-
TR (mg/l)	-	-	-	-	310-914
SM (mg/l)	-	-	-	-	-
TVR (mg/l)	-	-	-	-	-
Fecal Streptococci (MPN/100 ml)	-	-	-	-	-
COD (mg/l)	20-610	111	30-159	79	-
Soluble Phosphorus (mg/l)	-	-	-	-	-
NO_3 (mg/l N)	-	-	-	-	-
NH_3-N (mg/l N)	-	-	-	-	-
TKN (mg/l)	-	-	-	-	-
pH	-	-	-	-	-

*See Table 2.

APPENDIX I

TABLE 1 RESULTS OF STORMWATER MONITORING PROGRAMS REPORTED IN THELITERATURE

Reference* Parameter	7d		7e	7f	7g
	max.	mean	max.	avg.	range
BOD_5 (mg/l)	80	17	100	36	18-285
NFR (mg/l)	-	-	2045	14 541	1000-3500
TN (mg/l)	-	-	-	-	-
TP (mg/l)	-	-	-	-	-
Total Coliforms (MPN/100 ml)	-	-	-	-	-
Fecal Coliforms (MPN/100 ml)	$2.0x10^5$	$4.0x10^3$	-	-	-
TR (mg/l)	3000	300	-	-	-
SM (mg/l)	-	-	-	-	-
TVR (mg/l)	580	90	-	-	-
Fecal Streptococci (MPN/100 ml)	-	-	-	-	-
COD (mg/l)	3100	188	-	-	-
Soluble Phosphorus (mg/l)	-	-	-	-	-
NO_3 (mg/l N)	-	-	-	-	-
NH_3-N (mg/l N)	-	-	-	-	-
TKN (mg/l)	-	-	-	-	-
pH	-	-	-	-	-

*See Table 2.

APPENDIX I
TABLE 2 NOTES ON DATA IN TABLE 1

Reference	
1	Values are supposedly representative of data obtained in Canada and United States (2).
2	Values are averages of data from monitoring programs in 11 cities (3): (a) Ann Arbor, Michigan, 1965 (b) Castro Valley, California, 1971-1972 (c) Des Moines, Iowa, 1969 (d) Durham, North Carolina, 1968 (e) Los Angeles, California, 1967-1968 (f) Madison, Wisconsin, 1970-1971 (g) New Orleans, Louisiana, 1967-1969 (h) Roanoke, Virginia, 1969 (i) Sacramento, California, 1968-1969 (j) Tulsa, Oklahoma, 1968-1969 (k) Washington, District of Columbia, 1969
3	Data from study in North York, Toronto, Ontario (4).
4	Environmental Protection Service study of 10 stormdrains (30 samples only) in Kamloops (5).
5	Environmental Protection Service study of 10 stormdrains (20 samples only) in Prince George (6).
6	Results of stormwater monitoring program conducted in Halifax, Nova Scotia (7).
7	Results of stormwater monitoring studies conducted in eight cities (8): (a) Cincinnati, Ohio (b) Coshocton, Ohio (c) Detroit, Michigan (d) Stockholm, Sweden (e) Oxney, England (f) Leningrad, USSR (g) Moscow, USSR

The study concluded that the level of non-point source pollution generally correlated with increasing impervious area except in the central business area where street sweeping was usually practiced and less land disturbing activity occurred.

2) Tulsa, Oklahoma (9)

Relative loadings from stormwater and sewage treatment plants in Tulsa, Oklahoma have been calculated and are shown in Table 3.

APPENDIX I
TABLE 3 ESTIMATED ANNUAL LOAD OF POLLUTANTS ENTERING THE AREA RECEIVING STREAMS, TULSA, OKLAHOMA

Pollutant (mg/l)	Average annual storm sewer discharge pollutant load (kg)	Contribution of storm sewer discharges to total load (%)	1968 Average annual load from treatment plants (kg)
BOD_5	735 000	20	3 200 000
COD	5 085 000	31	11 100 000
NFR	17 706 000	85	3 050 000
Org-N	59 000	31	126 000
Soluble Ortho-PO_4	78 000	4	1 900 000

3) Seattle, Washington (10) (11)

Few cities have conducted more extensive research into stormwater quantity and quality than the City of Seattle. Results of this work is particularly important since the geographical proximity of Seattle to Vancouver makes the two cities subject to similar weather conditions.

A study was conducted by the U.S. Army Corps of Engineers from February to September, 1973 of Seattle stormdrains. Runoff from seven study areas were monitored to gain data to calibrate the RIBCO Urban Runoff Basin Drainage Computer Simulation Model. These seven study areas included the following land use types: single family residential, multiple family residential, commercial and industrial. Runoff from the seven study areas was sampled during six storms and the results are shown in Table 4.

The authors made the following conclusions, among others (10):

1. "The percentages of runoff, ranging from 5% to 64 %, correlated well with the percentage of impervious surface associated with a particular land use."
2. "Five major constituents found in quantity in urban runoff were NFR, BOD_5, COD, oil and grease, and total coliforms."
3. "The washoff pollutant loading factors calculated for the Seattle area are, in general, less than those listed for many other cities in this country. This is particularly true in comparison to street surface contaminants, including residues, oil, nutrients and heavy metals."
4. "Washoff pollutant loading (for BOD_5, TP and NFR) was found to decrease relative with the flow during the course of storm in almost all cases. The first flush effect was observed in about one-third of the cases."

The precipitation encountered during this study was unseasonably light and the authors felt that this may have provided incomplete washoff of accumulated street surface pollutants. They recommended that further sampling be carried out in order to obtain data over a longer period of time (one year) and for storms of greater intensity.

A further study of 3 of the 7 areas monitored by the Corps of Engineers was conducted in 1974 and 1975 by Metro Seattle officials. These three included the Viewridge 1 (VR1) single family residential area, the Southcenter (SC4) commercial area, and the South Seattle (SS3) industrial area. A total of 26 storms were monitored at the Viewridge 1 site, and 27 and 36 storms at the South Seattle and South Center sites repectively. A summary of the results are shown in Table 5. Pollutant loads have been calculated for these storms and the results will appear in a report which is currently being prepared.

APPENDIX I
TABLE 4 SEATTLE URBAN RUNOFF POLLUTANT LOADING SUMMARY (10)

Parameter (mg/l)	Mean Loading, pounds/acre/year*						
	VR1	VR2	SS3	SC4	LH5	HL6	CBD7**
BOD_5	7.1	92	7.1	14	3.6	0.58	110
COD	54	340	39	68	33	12	325
Hexane Ext.	17	144	8.4	13	4.4	2.0	47
Cl	1.8	20	3.0	3.7	2.3	2.1	113
SO_4	3.6	44	14	11	3.0	5.8	32
Org-N	0.8	1.5	1.0	1.5	0.47	0.27	8.0
NH_3-N	0.14	0.14	0.19	0.26	0.071	0.02	6.2
NO_2	0.019	0.32	0.030	0.032	0.009	0.004	0.44
NO_3	0.22	3.1	0.44	0.58	0.22	0.28	3.6
Hydrolyzable PO_4	0.25	1.8	0.16	0.17	0.096	0.071	5.5
Ortho-PO_4	0.048	0.20	0.040	0.052	0.034	0.017	1.2
Cu	0.037	0.23	0.085	0.09	0.026	0.028	1.9
Pb	0.15	0.67	0.14	0.34	0.12	0.028	1.9
Fe	0.75	3.6	0.68	0.55	0.17	0.08	8.0
Cr	0.009	0.04	0.009	0.062	0.005	0.003	1.6
Cd	0.004	0.019	0.004	0.004	0.002	0.002	0.079
Zn	0.05	0.22	0.21	0.21	0.029	0.015	2.9
SM	42.7	240	40	49	21	9.2	511
NFR	107	760	56	87	29	21	964
FR	36	610	53	52	35	22	1410

* February 1973 to September 1973. kg/ha/year = pounds/acre/year x 1.12.
**Due to limited background data from this area, these values are approximate.

Sampling Areas:

1. Single family residential
   - Viewridge (VR1)
   - Lake Hills (LH5)
   - Highlands (HL6)
2. Multiple family residential
   - Viewridge (VR2)
3. Commercial
   - Southcenter (SC4)
   - Central Business District (CBD7)
4. Industrial
   - South Seattle (SS3)

APPENDIX I
TABLE 5 SEATTLE URBAN RUNOFF POLLUTANT CONCENTRATIONS SUMMARY (11)

	Viewridge			South Seattle			Southcenter		
	Mean Conc.	Minimum	Maximum	Mean Conc.	Minimum	Maximum	Mean Conc.	Minimum	Maximum
	mg/l								
TPO_4	.27	.06	2.1	.25	.05	.77	.09	.03	1.5
Ortho-PO_4	.07	.001	.51	.05	.014	.26	.02	.01	1.3
Org-N	1.14	.31	4.3	.76	.24	2.7	.80	.01	3.5
NH_3-N	.08	.002	.75	.12	.012	.50	.03	.008	1.2
NO_2+NO_3	.42	.04	2.2	.33	.0111	2.1	.08	.017	1.7
NFR	51.1	1.01	465	130	7.6	1172	19.5	4.6	291
Turbidity	13.4	.15	27.1	20.3	2.5	83	9.1	5.4	47.2
Conductivity	77.8	1.67	271	42.3	6.6	154	13.6	24.2	235
Cd	.004	.003	.006	.005	.012	.004	.004	.002	.05
Pb	.198	.008	.71	.21	.05	.59	.48	.08	3.5
Zn	.089	.005	.30	.20	.06	.54	.13	.003	1.6

4) Borough of East York (12)

Urban runoff from a drainage area of 22.7 hectares (Barrington) and 25.3 hectares (Broadview) was monitored for a total of 19 storms at Barrington and five storms at Broadview. Both areas are primarily single family residential. Analyses for 26 parameters were made over the study. A major purpose of the research was to compare results with a City of Toronto by-law (2520) which sets limits for chemical constituents of waters entering storm sewers.

Some results of the study are shown in Table 6. BOD_5 values showed a high correlation with season as the maximum values occurred in summer and fall, with definitely lower results in winter and spring. NFR concentrations noted during this study were significantly lower than results found elsewhere in North America. Chloride concentrations were found to correlate with winter road salting procedures. Results of Pb analyses tended to confirm the hypothesis that Pb in urban runoff is associated with NFR and, therefore, tend to settle out when flow velocities decline.

Very few storms exhibited a "first flush" effect in the runoff. Rather, there was a strong correlation between rainfall intensity or runoff flow with concentration for most parameters. Soluble phosphorus was the only parameter which showed a consistent first flush.

Monitoring results tended to support the contention that long periods of dry days allow an accumulation of pollutants in the environment. Rainfall events after extended dry periods tended to produce high pollutant concentrations in the runoff.

The City of Toronto by-law 2520 normally is interpreted to apply to waters entering storm sewers and not to flows from municipal storm sewers themselves. Results of this research indicated that for many parameters, the municipal stormwater quality does not meet the by-law requirements. The authors concluded that if the by-law was intended to protect the environment, then it should apply to municipal storm drainage systems as well as others. The authors recommended that the legislation be based on mass loadings rather than pollutant concentrations since the latter does not sufficiently reflect the true condition of storm drainage. The authors also recommended that:

APPENDIX I

TABLE 6 SUMMARY OF BOROUGH OF EAST YORK SAMPLING RESULTS (12)

Parameter	Maximum Concentration Recorded (mg/l)	Mean Total Flow Volume (m^3)	Mean Total Mass (kg)	Flow Weighted Mean Concentration (mg/l)
Broadview				
BOD_5	100	225	3.8	16
NFR	600	225	33	129
COD	490	225	30	123
TOC	40	188	4.6	26
NH_3-N	0.5	201	0.04	0.2
TKN	7.5	225	0.53	2.3
NO_2	1.9	308	0.019	0.088
NO_3	4.9	156	0.24	1.6
TP	1.5	225	0.095	0.4
Pb	1.1	225	0.12	0.5
Phenolics	0.04	225	0.79	0.0031
Barrington				
BOD_5	320	205	14	70
NFR	630	205	25	131
COD	910	205	47	277
TOC	225	250	16	79
NH_3-N	5.2	183	0.1	0.6
TKN	20	205	0.85	4.4
NO_2	0.9	181	0.018	0.11
NO_3	2.1	117	0.12	0.92
TP	11	205	0.18	0.96
Pb	1.8	205	1.1	0.57
Phenolics	0.145	205	4.3	0.025

1) local municipalities be urged to abandon sumps as part of the catch basin design since they were found to reduce stormwater quality by releasing accumulated pollutants;
2) local municipalities be urged to upgrade cleaning services including street sweeping and catch basin cleaning;
3) consideration be given to the storage and treatment of the initial runoff from a storm;
4) consideration be given to the storage and treatment of all flow in storm sewers below 5% of the design flow;
5) research be conducted to confirm that pollutants concentrate in the snow windrows beside roadways;
6) local municipalities be urged to remove more snow from the streets and place it in locations where it will not cause serious pollution problems when it melts;
7) municipalities who use snow melters to dispose of snow windrows be requested to ensure that melted snow is directed to combined or sanitary sewers and not to storm sewers.

5) Ottawa (13)

A study of Cl and Pb concentrations of snow and runoff in Ottawa was conducted in the winter and spring of 1972. Snow samples were collected from 11 dumping sites and periodically from selected streets and highways throughout the City.

Chloride levels in snow and runoff were found to correlate with salting procedures. The average Cl level in rivers downstream of Ottawa were found to be higher in winter than in summer.

The Pb concentrations in snow were found to be proportional to traffic volume. The highest concentrations were found in snow samples collected near a major highway as shown in Table 7.

Regardless of the concentration of Pb in the particulate fraction, Pb concentrations in the filtrate were found to be low. Moreover, most of the Pb was associated with fine particles where the surface area for adsorption and/or chemical reaction is greater. Snow dump particulates were found to readily adsorb Pb and hold onto it over

APPENDIX I

TABLE 7 DISTRIBUTION OF LEAD IN SNOW AND IN SNOW MELT AS A FUNCTION OF SAMPLING LOCATION - OTTAWA

Location	Number of Samples	Mean Pb Level (mg/l)			Range of Pb Levels for Total Sample (mg/l)
		Filtrate	Particulate	Total Sample	
Snow dumps	149	0.052	555	4.8	0.02 - 50
Major highway	3	0.060	3287	102	86 - 113
Commercial street	41	0.042	822	3.7	0.02 - 11.3
Industrial street	6	0.048	935	4.7	0.06 - 14.3
Residential street	9	0.014	1228	2.0	0.12 - 10.2
Roof samples	7	0.041	-	0.10	0.02 - 0.25
Snow dump runoff	39	0.009	1322	0.11	0.004- 0.51
Storm sewer runoff	50	0.007	1791	0.13	0.002- 1.19
Raw wastewater	5	0.026	479	0.09	0.05 - 0.16
Treated wastewater	13	0.027	448	0.06	0.003- 0.14
River	8	0.006	69*	0.03**	0.004- 0.046

* Value for river bed sediments (22 samples).

** Calculated using lead levels in transported sediment (average 494 ppm) as opposed to river sediments.

a wide pH range. Comparing the total levels in snow dump snow with dump runoff showed that because of adsorption to particulates, most of the Pb is retained at the site after the snow has melted.

The Ontario Ministry of the Environment recommends that snow dumps must be more than 30 metres from the rivers. Results indicated that compared to the case where snow is dumped directly into watercourses, less than 2% of this Pb would reach the water if dumps were placed away from the streams. Lead is retained on the dumpsite as shown from the results of analyses on soil samples collected at depth (Table 8). Lead levels in the upper levels of the soil were more than ten times the background levels for soil. It was estimated that the total input of Pb from all sources to local watercourses was reduced 30% by moving the snow dump sites.

6) New York City (14)

Samples were obtained in 1972-1973 of the City of New York water supply, municipal treatment plant effluents, urban runoff, electroplating and other industrial effluents to identify the principle sources of heavy metals to New York harbour.

The results of this study are shown in Table 9. Principle sources of pollutants to the areas' 12 major treatment plants and to the harbour as a whole were reported. The electroplating industries were found to contribute the greatest amounts of Cr and Ni to the treatment plants while domestic sewage (residential) was found to contribute the greatest amounts of Cu, Zn, and Cd.

However, in terms of discharges to the receiving waters, the treatment plants discharged the greatest amounts of Cr and Ni, but urban runoff was the largest source of Cu, Zn, and Cd. In fact, the contribution of Cu, Zn, and Cd, from urban runoff represented 37%, 56%, and 35%, respectively, of the total input to the harbour for these metals.

APPENDIX I
TABLE 8 LEAD SOIL PROFILE AT MANN AVENUE DUMP AFTER THE SNOW MELTED - OTTAWA

Depth (cm)	Total Pb Level (mg/l)
0 - 5.1	237
5.1 - 10.2	163
10.2 - 15.2	142
15.2 - 20.3	126
20.3 - 25.4	126
25.4 - 30.5	51
30.5 - 35.6	72
35.6 - 40.6	56
40.6 - 45.7	36
45.7 - 50.8	22
50.8 - 55.9	85
55.9 - 61.0	41
Background sample	21

APPENDIX I
TABLE 9 SUMMARY OF SOURCES OF METALS TO NEW YORK PLANTS AND HARBOUR (14)

Sources	Cu	Cr	Ni	Zn	Cd
	kg/day				
Plant Sources:					
Water supply	230	0	0	120	0
Electroplaters	140	290	320	230	24
Other Industrial	82	61	15	120	4
Runoff	160	61	50	550	9
Residential	540	190	130	750	35
Unknown	0	70	0	0	0
TOTAL*	1160	680	500	1780	72
Harbour Sources:					
Plant effluents	640	350	420	1100	43
Runoff	900	310	300	3100	50
Untreated wastewater	440	260	200	680	27
Sludge	430	270	66	620	23
TOTAL TO HARBOUR* FROM NEW YORK CITY	2400	1200	980	5600	140

*Totals are rounded off.

APPENDIX I REFERENCES

1. Rimer, A.E., J.A. Nissen, and D.E. Reynolds, "Characterization and Impact of Stormwater Runoff from Various Land Cover Types," Journal WPCF, p. 252-264 (February 1978).

2. Manual of Practice on Urban Drainage, The Urban Drainage Subcommittee of the Canada-Ontario Agreement on Great Lakes Water Quality, DOE - Ontario MOE, Draft No. 3, p. 1-11, (March 1977).

3. Lager, J.A, and W.G. Smith, Urban Stormwater Management and Technology: An Assessment, Metcalf and Eddy, EPA-670/2-74-040, p. 80 (December 1974).

4. Stormwater Management Model Study Volume II, Proctor and Redfern, James F. MacLaren, Canada-Ontario Agreement on Great Lakes Water Quality Research Report No. 48, p. 31 (September 1976).

5. Sidhu, S.T., A Preliminary Study on Wastewater Characteristics of Kamloops Stormwater Discharge, Environmental Protection Service, Environment Canada, Manuscript Report EPS 75-3, (October 1975).

6. Sidhu, S.T., A Preliminary Study on Wastewater Characteristics of Prince George Stormwater and Sewage Discharges, Environmental Protection Service, Environment Canada, Manuscript Report EPS 75-2, (June 1975).

7. Waller, D.H., W.A. Coulter, W.M. Carson, and D.G. Bishop, Urban Drainage Model Comparison for a Catchment in Halifax, Nova Scotia, Canada-Ontario Agreetment on Great Lakes Water Quality Research Report No. 43 (August 1976).

8. Water Pollution Aspects of Urban Runoff, American Public Works Association, Federal Water Pollution Control Administration U.S. Department of the Interior, WP-20-15, p. 21 (January 1969).

9. Lager, J.A. and W.G. Smith, p. 87.

10. Environmental Management for the Metropolitan Area Cedar - Green River Basins, Washington, Part II Urban Drainage, Appendix C Stormwater Monitoring Program, U.S. Army Corps of Engineers, (December 1974).

11. Swartz, R.G., Municipality of Metropolitan Seattle, personal communication.

12. Mills, G.W., Water Quality of Urban Stormwater Runoff in the Borough of East York, Canada-Ontario Agreement on Great Lakes Water Quality Research Report No. 66 (1977).

13. Oliver, B.G., J.B. Milne, and N. LaBarre, "Chloride and Lead in Urban Snow", Journal WPCF, 46 (4), pp. 767-771 (April 1974).

14. Klein, L.A., M. Lang, N. Nash, and L.K. Seymour, "Sources of Metals in New York City Wastewater", Journal WPCF, 46 (12), p. 2653-2662 (December 1974).

APPENDIX II

RESULTS OF STORMWATER QUALITY STUDIES CONDUCTED IN THE GVRD

1) 1969-1971 GVSDD Catchbasin Sampling
2) 1972-1973 Westwater Still Creek Study
3) 1973 GVSDD Still Creek Study
4) 1973-1974 Westwater Brunette River - Still Creek Study
5) 1974 Westwater Renfrew Street Storm Sewer Sampling
6) 1976 EPS - GVRD Storm Sewer Sampling
7) 1978 Provincial WIB and PCB Stormwater Sampling Program

1) 1969-1971 GVSDD Catchbasin Sampling

APPENDIX II
TABLE 1

GREATER VANCOUVER SEWERAGE AND DRAINAGE DISTRICT CATCHBASIN SAMPLING SURVEY
SUMMARY 1969, 1970, 1971

Year	No. of Samples	Total Coliforms (MPN per 100 ml)				
		Maximum	Minimum	Average	Geometric Mean	Median
1969	51	G 240 000	L 30	20 423	2598	2300
1970	52	G 110 000	L 30	10 361	1635	930
1971	54	G 240 000	L 30	13 632	1271	930
1969-1971	157	G 240 000	L 30	14 887	1768	1500

G -greater than
L -less than

2) 1972-1973 Westwater Still Creek Study

APPENDIX II

TABLE 2 SUMMARY WESTWATER RESEARCH STILL CREEK STUDY DATA*

January - June, 1973

Station	Parameter	No. of Samples	Maximum	Minimum	Average
Still Creek	pH	24	7.7	7.1	7.3
at Gilmore	Temperature (°C)	24	15.6	4.8	9.3
	Turbidity (J-TU)	23	36.0	2.9	6.5
	Colour (Pt-Co Units)	22	70	20	28
	DO (mg/l)	19	12.6	7.9	9.9
	BOD_5 (mg/l)	24	49	1	10
	COD (mg/l)	24	52	4	16
	NH_3-N (mg/l N)	24	.225	.005	.101
	NO_3 (mg/l N)	24	1.40	.54	1.03
	TKN (mg/l)	23	.860	.220	.415
	Ortho-PO_4 (mg/l P)	24	.032	.008	.021
	TPO_4 (mg/l P)	23	.175	<.100	<.100
	NFR (mg/l)	12	36.8	0**	8.2
	Dissolved Solids (mg/l)	12	700	57	179
	Mn (mg/l)	22	1.620	.013	.261
	Cu (mg/l)	22	.875	.007	.076
	Zn (mg/l)	22	.660	.023	.087

* by Brenda Hockin

** Not significant

APPENDIX II

TABLE 2 SUMMARY WESTWATER RESEARCH STILL CREEK STUDY DATA (Continued)

January - June, 1973

Station	Parameter	No. of Samples	Maximum	Minimum	Average
Still Creek at Douglas	pH	24	7.4	6.7	7.2
	Temperature (°C)	24	19.8	3.7	9.6
	Turbidity (J-TU)	23	33.0	4.3	9.9
	Colour (Pt-Co Units)	22	80	45	65
	DO (mg/l)	19	12.8	4.8	8.6
	BOD_5 (mg/l)	24	12	2	5
	COD (mg/l)	23	56	12	28
	NH_3-N (mg/l)	23	.280	< .005	.120
	NO_3 (mg/l)	24	1.04	.25	.67
	TKN (mg/l)	23	.920	.220	.498
	Ortho-PO_4 (mg/l)	23	.079	.006	.034
	TPO_4 (mg/l)	23	.170	< .100	< .100
	NFR (mg/l)	12	67.5	0*	15.2
	Dissolved Solids (mg/l)	12	169	61	118
	Mn (mg/l)	22	2.84	.044	.510
	Cu (mg/l)	22	.485	.008	.079
	Zn (mg/l)	22	1.060	.037	.184

* Not significant

APPENDIX II

TABLE 2 SUMMARY WESTWATER RESEARCH STILL CREEK STUDY DATA (Continued)

January - June, 1973

Station	Parameter	No. of Samples	Maximum	Minimum	Average
Still Creek	pH	24	7.6	6.7	7.2
at Sperling	Temperature (°C)	24	22.8	3.6	10.8
	Turbidity (J-TU)	23	42.0	4.5	10.3
	Colour (Pt-Co Units)	22	90	50	71
	DO (mg/l)	18	11.2	5.0	8.6
	BOD_5 (mg/l)	24	16	1	5
	COD (mg/l)	24	64	12	29
	NH_3-N (mg/l)	24	.330	.010	.109
	NO_3 (mg/l)	24	1.02	.30	.64
	TKN (mg/l)	23	.900	.260	.521
	Ortho-PO_4 (mg/l)	24	.106	.006	.030
	TPO_4 (mg/l)	23	.175	$<$.100	$<$.100
	NFR (mg/l)	12	58.8	0*	20.9
	Dissolved Solids (mg/l)	12	500	63	150
	Mn (mg/l)	22	2.20	.011	.355
	Cu (mg/l)	22	.275	.008	.054
	Zn (mg/l)	21	.700	.023	.096

* Not significant

APPENDIX II

TABLE 2 SUMMARY WESTWATER RESEARCH STILL CREEK STUDY DATA (Continued)

January - June, 1973

Station	Parameter	No. of Samples	Maximum	Minimum	Average
Still Creek at Gilmore	Temperature (°C)	17	14.4	4.4	7.8
	Dissolved Oxygen (mg/l)	17	12.2	9.0	10.6
	DO (% Sat.)	17	94.7	82.6	88.7
	BOD_5 (mg/l)	7	4.0	1.3	2.4
	TOC (mg/l)	17	10.4	3.0	6.1
	TIC (mg/l)	17	13.0	5.2	10.6
	Colour (Pt-Co Units)	17	30	15	25
	Turbidity (J-TU)	17	8	3	4.8
	Conductance (μmho)	17	218	117	187
	Total Coliforms (MPN/100 mls)	8	54 000	1300	22 163
	Fecal Coliforms (MPN/100 mls)	8	24 000	170	6 671
	Fecal Strep. (MPN/100 mls)	8	16 000	230	5 331
	TKN (mg/l)	17	0.77	0.16	0.51
	NO_2+NO_3 (mg/l)	17	1.20	0.70	0.96
	Ortho-PO_4 (mg/l)	17	0.022	.002	.009
	TPO_4 (mg/l)	17	0.087	0.024	0.050
	Total Hardness (mg/l as $CaCO_3$)	17	81.5	40.2	70.2
	TAlk (mg/l as $CaCO_3$)	17	64.0	28.1	53.1

APPENDIX II

TABLE 2 SUMMARY WESTWATER RESEARCH STILL CREEK STUDY DATA (Continued)

January - June, 1973

Station	Parameter	No. of Samples	Maximum	Minimum	Average
Still Creek	pH	17	7.5	6.8	7.2
at Gilmore	Ca	17	26.0	8.8	20.8
(cont.)	Mg	17	8.9	2.5	4.4
	Na	17	19.8	6.3	11.0
	K	17	2.9	1.3	1.6
	Cl	17	33.5	7.6	16.9
	F	17	0.35	0.05	0.05
	SO_4	17	18.5	10.9	15.3
	SiO_2	17	17.2	8.2	13.6
	Fe	17	1.60	0.63	1.06
	Mn	17	0.28	0.13	0.21
	Cd	17	.008	0.001	.001
	Cu	17	0.030	0.004	.015
	Hg	17	0.0001	0.00005	.00005
	Pb	17	0.120	0.001	0.016
	Zn	17	0.100	0.033	0.008

All parameters except pH are expressed as mg/l.

APPENDIX II

TABLE 2 SUMMARY WESTWATER RESEARCH STILL CREEK STUDY DATA (Continued)

January - June, 1973

Station	Parameter	No. of Samples	Maximum	Minimum	Average
Brunette River	Temperature (°C)	17	13.3	3.3	7.6
at Braid Street	DO (mg/l)	17	11.6	7.1	9.7
	DO (% Sat.)	17	98.3	62.8	81.3
	BOD_5 (mg/l)	7	5	2	3.4
	TOC (mg/l)	17	13.4	5.0	8.3
	TIC (mg/l)	17	9.5	2.7	6.5
	Colour (Pt-Co Units)	17	80	30	46.2
	Turbidity (J-TU)	17	110	3	12.1
	Conductance (µmho)	17	167	90	144
	Total Coliforms (MPN/100 mls)	8	4900	1100	3013
	Fecal Coliforms (MPN/100 mls)	8	1100	<20	363
	Fecal Strep. (MPN/100 mls)	8	2200	110	546
	TKN (mg/l)	16	0.84	0.24	0.51
	NO_2+NO_3 (mg/l)	17	1.30	0.20	0.59
	Ortho-PO_4 (mg/l)	17	11	<3	5.4
	TP (mg/l)	16	85	25	43.6
	Total Hardness (mg/l as $CaCO_3$)	17	57.4	27.2	43.5
	TAlk (mg/l as $CaCO_3$)	17	45.0	20.3	32.9

APPENDIX II

TABLE 2 SUMMARY WESTWATER RESEARCH STILL CREEK STUDY DATA (Continued)

January - June, 1973

Station	Parameter	No. of Samples	Maximum	Minimum	Average
Brunette River	pH	17	7.4	6.8	7.1
at Braid Street	Ca	17	18.9	5.9	13.4
(cont.)	Mg	15	7.2	0.5	2.8
	Na	17	13.3	5.3	9.7
	K	17	2.0	1.3	1.6
	Cl	17	19.7	11.4	15.5
	F	17	0.06	0.05	0.05
	SO_4	17	13.1	8.6	10.8
	SiO_2	17	11.8	7.4	10.2
	Fe	17	1.60	0.60	1.02
	Mn	17	0.23	0.09	.14
	Cd	17	0.005	0.001	0.001
	Cu	17	0.011	0.002	.0048
	Hg	17	0.00005	0.00005	0.00005
	Pb	17	0.031	0.001	0.0116
	Zn	17	0.060	0.002	0.017

All parameters except pH are expressed as mg/l.

3) 1973 Still Creek Study - GVSDD

APPENDIX II

TABLE 3 GVSDD - STILL CREEK STUDY SELECTED SAMPLE STATION LOCATION DESCRIPTIONS

Sampling Series A/C	-	Stations on the mainstream of Still Creek and the Collingwood-Rhodes Street storm sewers.
Station A	-	Still Creek, mid-stream on the Vancouver side of Boundary Road at Cornett Avenue.
Station 1	-	Still Creek, mid-stream on the east side of Rupert Street at 11th Avenue.
Station 2	-	Still Creek, mid-stream between 14th Avenue and Grandview Highway.
Station 4	-	Still Creek, mid-stream in Renfrew Park at the exit from the tunnel section.
Station B	-	Still Creek, mid-stream at 29th and Rupert Street just after entering the open section from the GVSDD 174 cm storm sewer.
Station 5	-	Manhole on Euclid Avenue in the GVSDD 174 cm storm sewer.
Station 11	-	Manhole on Earles Road in the GVSDD 174 cm storm sewer.
Station 12	-	Manhole on Ward Street in the GVSDD 68-inch storm sewer.
Station 13	-	Manhole on the South East corner of Norquary Park in the GVSDD 174 cm storm sewer.
Station C	-	Manhole at Vanness Avenue and Boundary Road in the GVSDD 108 cm storm sewer.

APPENDIX II
TABLE 4 GVSDD - STILL CREEK STUDY - SUMMARY OF BACTERIOLOGICAL TEST RESULTS

Sampling Series: A/C*

Station	Period of Test 1974	Bacterial Group Test	No. of Samples	MPN per 100 mls			
				Maximum	Minimum	Median	G. Mean
A	Jan 9 - Jul 10	Total Coliforms	100	2 400 000+	1500	43 000	
		Fecal Coliforms	100	460 000	90	23 000	19 470
		Fecal Streptococci	77	240 000	90	4 300	
1	Jan 10 - Feb 12	Total Coliforms	23	460 000	2300	23 000	
		Fecal Coliforms	23	93 000	2300	9 300	8 489
		Fecal Streptococci	23	43 000	930	4 300	
2	Jan 10 - Feb 12	Total Coliforms	23	240 000	3900	23 000	
		Fecal Coliforms	23	93 000	1200	9 300	10 110
		Fecal Streptococci	23	93 000	430	9 300	
4	Jan 9 - Feb 12	Total Coliforms	24	460 000	4300	23 000	
		Fecal Coliforms	23	93 000	750	15 000	13 822
		Fecal Streptococci	24	240 000	230	5 900	
B	Jan 9 - Jul 10	Total Coliforms	77	2 400 000+	930	93 000	
		Fecal Coliforms	76	2 400 000+	90	43 000	31 156
		Fecal Streptococci	68	460 000	40	23 000	

APPENDIX II
TABLE 4 GVSDD - STILL CREEK STUDY - SUMMARY OF BACTERIOLOGICAL TEST RESULTS (Continued)

Sampling Series: A/C*

Station	Period of Test 1974	Bacterial Group Test	No. of Samples	MPN per 100 mls			
				Maximum	Minimum	Median	G. Mean
5	Jan 10 - Feb 12	Total Coliforms	23	1 100 000	4300	43 000	
		Fecal Coliforms	23	750 000	3900	23 000	26 265
		Fecal Streptococci	22	93 000	430	8 400	
11	Feb 4 - Jul 11	Total Coliforms	58	2 400 000+	9300	93 000	
		Fecal Coliforms	58	1 100 000	3900	23 000	35 772
		Fecal Streptococci	48	460 000	230	13 500	
12	Feb 1 - Jul 10	Total Coliforms	75	2 400 000+	30	93 000	
		Fecal Coliforms	73	1 100 000	30	23 000	25 199
		Fecal Streptococci	44	1 100 000	30	9 300	
13	Feb 1 - Apr 9	Total Coliforms	45	460 000	2300	43 000	
		Fecal Coliforms	44	120 000	750	15 000	14 194
		Fecal Streptococci	21	240 000	230	7 500	
C	Jan 10 - Jul 10	Total Coliforms	86	1 100 000	750	21 000	
		Fecal Coliforms	86	240 000	230	2 300	3 122
		Fecal Streptococci	76	150 000	70	4 300	

* A/C = Station in the mainstream of Still Creek and the Collingwood-Rhodes Street storm sewer.

APPENDIX II
TABLE 5 GVSDD - STILL CREEK STUDY - COMPARISON OF BACTERIOLOGICAL TEST RESULTS OBTAINED DURING PERIODS OF WET AND DRY WEATHER

Period 1974	Geometric Mean MPN Fecal Coliforms per 100 mls			
	Station A	Station B	Station 11	Station 12
Nominal Wet Weather (1) May 13 to June 4	40 517	32 279	38 070	21 976
Dry Weather (2) June 5 to June 25	3 169	19 288	31 608	3 711
Nominal Wet Weather (3) June 26 to July 10	48 842	134 589	77 864	133 666

(1) Period of 22 days - 5.38" of rain

(2) Period of 21 days - Dry weather

(3) Period of 16 days - 2.76" of rain

APPENDIX II
TABLE 6 GVSDD - STILL CREEK - CHEMICAL ANALYSES SUMMARY

Period of Test:	Station 3 January 30 - October 1				Station A January 11 - October 1				Station B January 11 - October 1				Station C January 11 - October 1			
Parameter	No.	Max.	Min.	Avg.	No.	Max.	Min.	Avg.	No.	Max.	Min.	Avg.	No.	Max.	Min.	Avg.
Temp. (°C)	-	-	-	-	-	-	-	-	-	-	-	-	15	16	8	9.0
DO (mg/l)	11	11.8	7.8	9.6	19	13.3	7.6	11.6	20	12.2	7.0	10.3	19	12.1	8.1	10.9
BOD_5 (mg/l)	10	36.6	2.5	10.0	20	58.0	2.7	8.4	20	46.0	2.7	7.6	20	19.5	1.2	6.8
COD (mg/l)	11	98.4	7.9	30.0	29	188.0	2.0	21.0	22	165.0	5.8	31.1	21	83.7	1.9	17.2
Colour (TCU)	11	54	9.0	18	21	104	12	13	22	108	16	26	21	56	10	17
Turbidity (JTU)	3	30	5.3	14.5	13	14.2	2.15	5.8	13	23	1.0	4.3	13	14.3	2.0	3.5
Conductance (µmho)	12	180	30	135	29	670	45	165	22	200	55	130	29	260	55	160
TKN (mg/l)	11	3.1	0.34	0.89	21	4.6	0.42	0.9	22	3.28	0.11	0.90	19	1.7	0.22	0.42
NO_3 (mg/l)	11	0.91	0.11	0.30	21	0.95	0.03	0.4	22	4.0	0.01	0.5	21	1.02	0.01	0.37
NH_3-N (mg/l)	11	0.58	0.02	0.15	17	0.7	0.00	0.1	18	0.47	0.05	0.25	17	0.48	0.01	0.13
TPO_4 (mg/l)	11	0.37	0.02	0.14	24	0.7	0.05	0.1	22	0.76	0.05	0.12	25	0.17	0.02	0.05
Hardness (mg/l $CaCO_3$)	11	98.0	14.5	60.5	21	84.8	20.7	61.5	22	70.0	21.0	54.5	21	84.0	25.5	63.5
TAlk (mg/l $CaCO_3$)	11	71.5	8.0	40.0	21	75.0	8.0	35.0	22	52.5	10.8	35.3	21	67.0	17.6	46.0
pH	12	7.3	6.7	7.1	29	7.4	6.6	7.0	22	7.6	6.4	7.0	29	7.6	6.5	7.0
TR (mg/l)	11	250	74	124	21	432	43	129	22	2739	69	142	21	219	51	122
NFR (mg/l)	9	53	2	14	29	208	0	6.0	22	2445	1	6.5	26	50	0	3.0
Cl (mg/l)	12	12.3	1.0	7.7	29	167	4.7	11.3	22	18.5	5.5	11.1	29	25.5	6.5	13.0
F (mg/l)	2	0.05	-	-	19	0.05	0.05	0.05	12	0.05	0.05	0.05	20	0.05	0.05	0.05
SO_4 (mg/l)	11	15.9	6.0	12.8	21	22.5	7.6	16.3	22	22.0	7.5	16.1	21	21.7	10.0	16.0
SiO_2 (mg/l)	11	20.0	3.6	11.6	21	15.4	2.0	8.0	22	15.0	3.9	9.8	21	18.0	5.0	11.6
Na (mg/l)	9	7.8	1.2	5.3	21	11.7	2.5	8.1	21	12.9	2.3	8.6	21	19.8	3.9	9.1
Mg (mg/l)	9	4.1	0.91	2.7	21	4.9	1.1	2.7	21	3.8	1.0	2.2	21	5.2	1.1	2.6
K (mg/l)	9	7.7	0.76	1.7	21	7.0	1.4	2.2	21	6.0	1.3	2.4	21	3.4	1.5	2.1
Ca (mg/l)	9	23.7	3.3	15.8	21	30.4	4.7	16.5	21	43.7	6.5	14.9	21	55.0	8.8	17.4
Cd (mg/l)	7	0.01	0.002	-	18	0.021	0.001	-	18	0.02	0.001	-	18	0.02	0.001	0.01
Cu (mg/l)	9	0.05	0.01	-	22	0.13	0.01	-	21	0.09	0.006	0.04	19	0.04	0.04	0.04
Fe (mg/l)	9	2.4	0.4	1.0	20	9.16	0.2	0.9	21	2.3	0.30	0.8	21	1.95	0.28	0.56
Mn (mg/l)	9	0.49	0.04	0.08	21	0.59	0.02	0.2	21	0.25	0.02	0.1	21	0.23	0.02	0.10
Pb (mg/l)	7	0.16	0.13	-	17	0.81	0.003	-	17	0.37	0.02	0.15	17	0.17	0.009	0.13
Zn (mg/l)	7	0.31	0.02	0.05	20	0.47	0.01	0.04	19	0.29	0.01	0.05	18	0.12	0.01	0.03
Cr (mg/l)	7	0.07	0.005	-	17	0.07	0.005	-	17	0.07	0.005	-	17	0.07	0.005	-
Ni (mg/l)	7	0.07	0.001	-	17	0.07	0.002	-	16	0.07	0.001	-	16	0.07	0.001	-
Al (mg/l)	1	1.4	-	-	2	4.4	3.4	3.9	2	2.6	2.2	2.4	2	0.75	-	-
Oil & Grease (mg/l)	-	-	-	-	-	-	-	-	1	143	-	-	-	-	-	-

4) 1973-1974 Westwater Brunette River
   - Still Creek Study

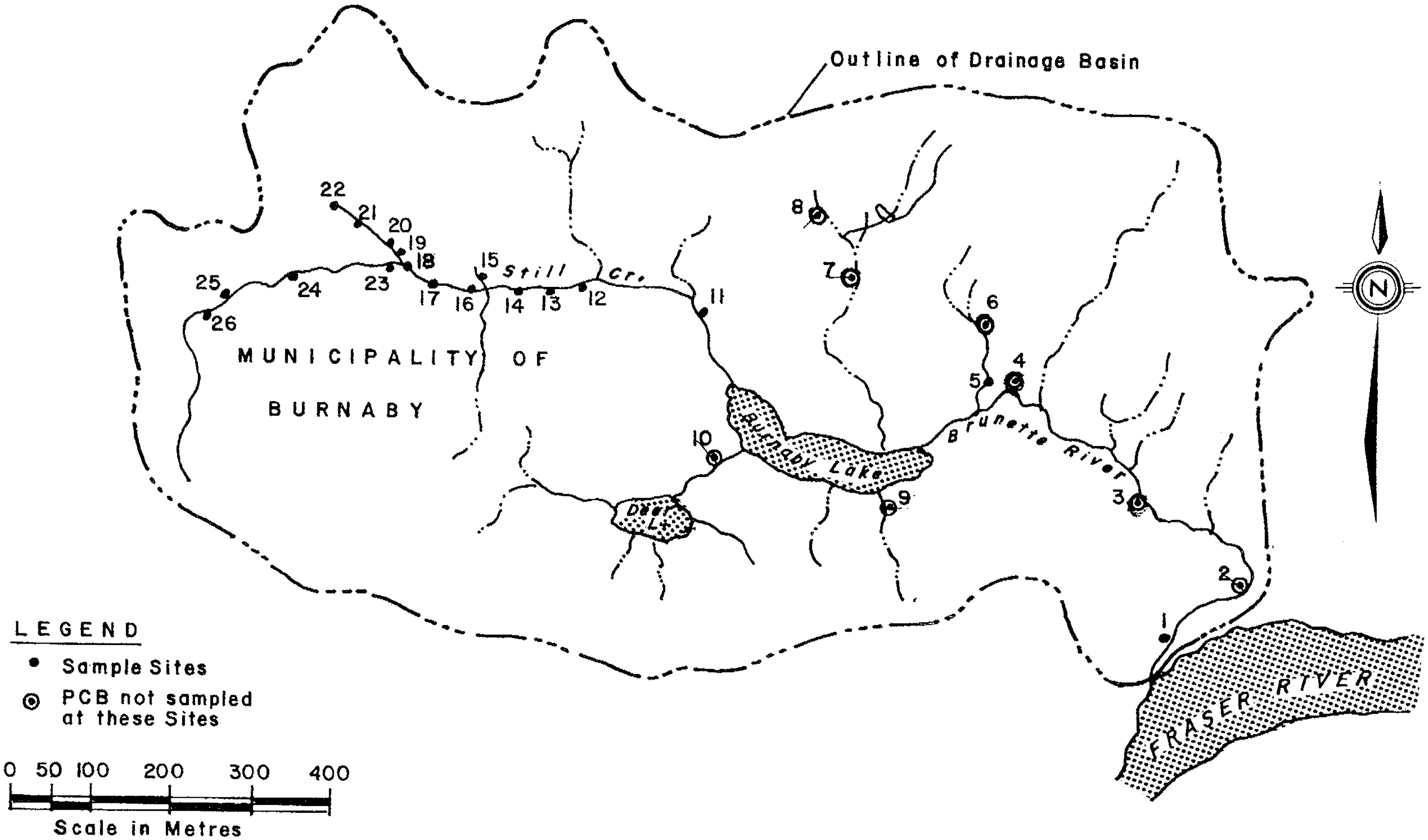
APPENDIX II

TABLE 7 WESTWATER BRUNETTE RIVER - STILL CREEK SEDIMENT SAMPLING LOCATIONS

Station No.	Location	Remarks
1	Brunette River at Spruce Avenue	At mouth of river, wood products industries
5	Small creek north of freeway	Urban dwelling, storm drainage
11	Small creek crosses Government Road east of Brighton	Rechanneling of stream, new industrial construction
12	Upstream of Station 11 at Production Way	Stream discharge from industrial park area
13	Eagle Creek near Piper Ave. and Winston St.	Residential area, near Burnaby Lake
14	Eagle Creek at East Broadway	Below golf course, landfill area
15	Tributary of Eagle Creek	Below oil tank form on Burnaby Mt.
16	Tributary of Eagle Creek near Phillips Avenue	Above golf course in deciduous woods
17	Robert Burnaby Creek	Near exit from Robert Burnaby park
18	Small creek south of Burnaby Lake	Residential area near freeway
19	Deer Creek at Glencairn Drive	North of freeway and south of Burnaby Lake
20	Deer Creek at Canada Way	Residential area
21	Small stream near Gilpin Ave.	Discharge from Forest Lawn Memorial Cemetery
22	Small stream at Bond St. and Sussex Avenue	Residential area - flows to Deer Lake
23	Still Creek at Sperling Ave.	Wooded shores, creek backed up from Burnaby Lake

APPENDIX II
TABLE 7 WESTWATER BRUNETTE RIVER - STILL CREEK SEDIMENT SAMPLING LOCATIONS (Continued)

Station No.	Location	Remarks
24	Small creek, Sperling at Jordan Drive	Residential, creek shore-line is wooded
25	Small creek at Goring Ave.	Industrial - transport and aluminum company
26	Upstream of Station 25 at Lougheed Highway	Residential



APPENDIX II
FIGURE I WESTWATER RESEARCH SEDIMENT SAMPLING SITES IN THE BRUNETTE RIVER DRAINAGE SYSTEM, BURNABY, B.C. (Adapted from Hall et al)

APPENDIX II
TABLE 8 WESTWATER STREET SURFACE CONTAMINANTS SAMPLING STATIONS

Station Number	Location (Burnaby, B.C.)
Residential	
R1	East 14th Ave. (block east of Renfrew St.)
R2	East 16th Ave. (between Renfrew and Rupert Sts.)
R3	Smith Ave. at Spruce Ave.
R4	Whitsell Ave. at Williams Ave.
R5	2400 Duthie St.
R6	Mahon at Eglington
R7	Mayfield and Canada Way
R8	Lee and 10th Ave.
Green Space	
G1	Forest Lawn Cemetery
G2	Robert Burnaby Park
G3	Gaglardi Way at Esterbrook
G4	Phillips and Halifax (near golf course)
Industrial	
I1	Rupert St. (between Grandview and Broadway)
I2	Boundary Rd. and Myrtle Ave.
I3	Gilmore Ave., north of Still Creek
I4	Willingdon Ave. north of "401" interchange
I5	Douglas Rd. at Still Creek
I6	Industrial Park (Lake City)
I7	Spruce Ave. opposite Labatts
I8	Spruce Ave. opposite Capilano Lumber
Commercial	
C1	Canada Way at Boundary Rd.
C2	Willingdon at Lougheed (Brentwood Shopping Center)
C3	Austin at Lougheed (Lougheed Shopping Center)
C4	North Rd. at Lougheed
C5	Sperling at Canada Way
C6	Braid at Columbia St.

APPENDIX II
TABLE 9 RESULTS OF WESTWATER STREAM SEDIMENT SAMPLING

Land Use	Statistical Parameter	Trace Metal Concentrations[a]									
		Cd	Co	Cr	Cu	Fe ($x10^3$)	Hg[b]	Mn	Ni	Pb	Zn
Industrial[c]	Arithmetic Mean	0.7	9.9	122	393	23.8	42	289	29	415	181
	Median	0.5	9.2	122	83	22.3	34	294	19	400	168
	Standard Deviation	0.9	5.7	45.2	599	9.8	29	110	25	336	115
Residential and[d] Green Space	Arithmetic Mean	<.1	7.3	61	14.5	21.4	15	308	8.9	25.6	50
	Median	0	7.6	75	14.6	19.4	13	250	9	24.2	47
	Standard Deviation	<.2	1.7	39.7	2.6	11.9	7	153	2.0	20.1	14

a = values represent total metal in mg/kg dry wt. of sediment

b = mercury values as µg/kg dry wt. of sediment

c = values calculated for 9 stations namely 25, 26, 27, 30, 31, 32, 33, 34, 35

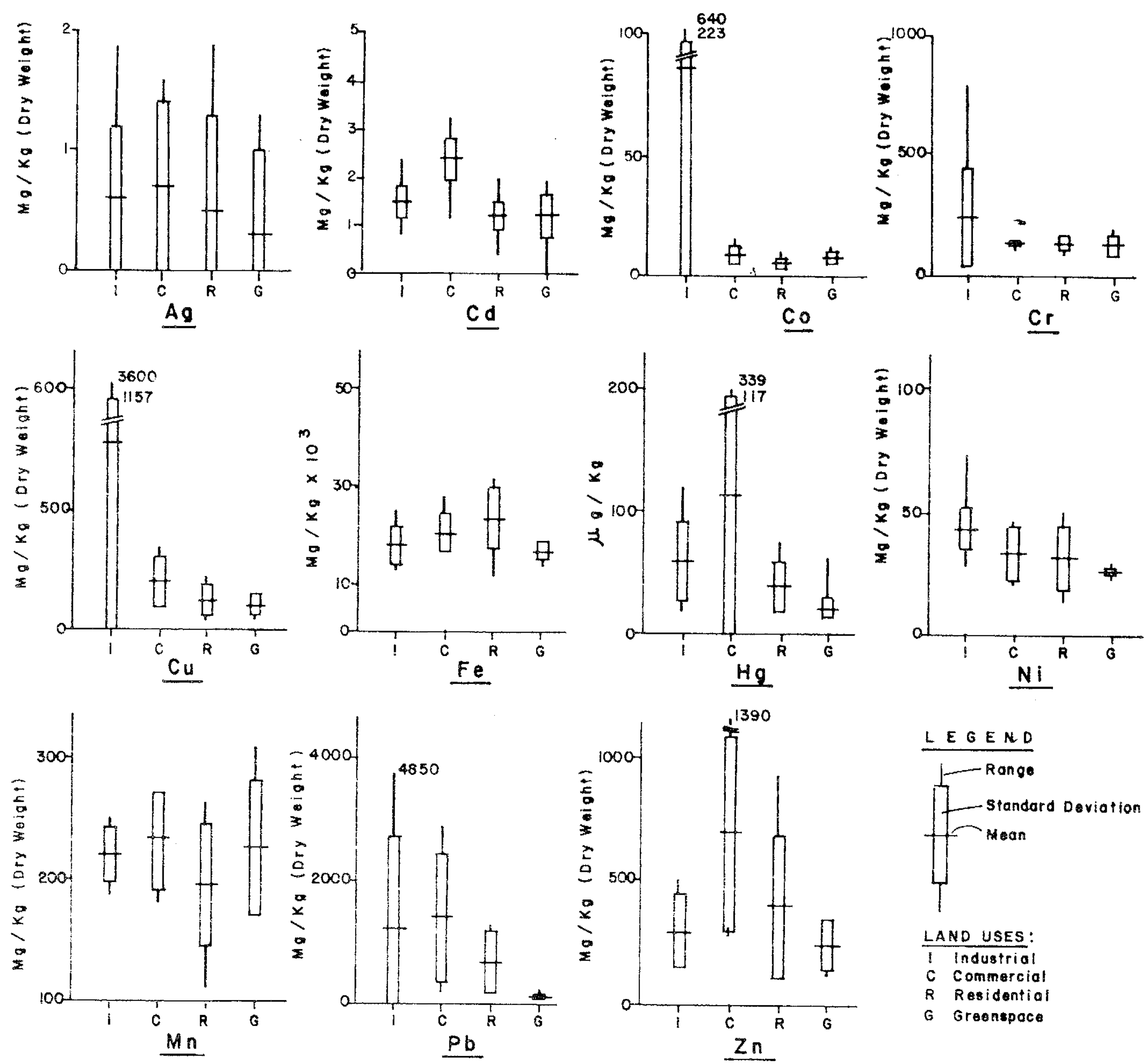
d = values calculated for 9 stations namely 7, 8, 9, 10, 11, 12, 14, 15, 16

APPENDIX II

TABLE 10 CHLORINATED HYDROCARBONS IN SEDIMENTS OF BRUNETTE SYSTEM[a]

				Chlordane			% Fine	
Station No.	p,p'-DDT	p,p'-DDE	p,p'-DDD	α	γ	PCB's	Particulates (<53μ)	CM%
1	(6)	-	-	-	-	-	(57.9)	(2.9)
5	(4)	-	-	-	-	-	(13.9)	(2.3)
11	(13)	(6)	(14)	-	-	(75)	(36.9)	(8.3)
12	-	-	-	-	-	380(64)	32.9(34.4)	14.1(4.9)
13	-	-	-	-	-	400	25.4	3.9
14	-	-	-	-	-	310	44.9	9.7
15	22	-	14	-	-	540	52.2	51.3
16	11(18)	-	33(10)	11	6.5	320(150)	23.6(33.4)	4.9(46.7)
17	90	-	40	23	28	780	37.5	35.9
18	5.4	-	3	-	-	710	24.4	4.7
19	-	-	-	-	-	120	37.3	2.4
20	-	-	-	-	-	37	24.5	6.8
21	(7)	(5)	(15)	-	-	200(230)	28.2(15.3)	7.6(3.2)
22	-	-	-	-	-	120	67.1	6.2
23	135	-	54	43	44	640	12.2	36.0
24	19	-	6.8	2.8	-	49	29.3	5.7
25	(9)	-	-	-	-	55(10)	19.6(6.3)	4.3(1.9)
26	8	-	-	-	-	44	29.7	6.4

a = Chlorinated hydrocarbons as μg/kg dry weight of sediment
() = bracketed values represent samples collected in February



APPENDIX II
FIGURE 2 SUMMARY OF TRACE METALS IN STREET SURFACE CONTAMINANTS

APPENDIX II
TABLE 11 RESULTS OF WESTWATER STREAM SEDIMENT SAMPLING

Land Use & Station No.	Location	p,p'-DDT	p,p'-DDE	p,p'-DDD	Chlordane α	Chlordane γ	PCB's
Industrial							
I1	Rupert St. (between Grandview and Broadway	5	-	2	2	1	57
I2	Boundary Rd. and Myrtle Ave.	5	-	2	1	2	126
I3	Gilmore Ave. North of Still Creek	21	-	8	7	5	140
I4	Willingdon North of 401 Interchange	5	-	4	2	4	208
I5	Douglas Rd. at Still Creek	1	-	-	.3	.5	96
I6	Industrial Park (Lake City)	1	-	1	.5	.6	34
I7	Spruce Ave. opposite Labatts	1	-	1	.8	.5	56
I8	Spruce Ave. opposite Capilano Lumber	3	-	1	.5	.8	48
Commercial							
C1	Canada Way at Boundary Rd.	12	-	4	4	2	57
C2	Willingdon At Lougheed (Brentwood Shopping Center)	24	-	11*	11*	8*	240
C3	Austin at Lougheed (Lougheed Shopping Center)	3	-	4	4	7	184
C4	North Rd. at Lougheed	-	7*	-	.8	.5	71
C5	Sperling at Canada Way	4	-	3	4	5	136
C6	Braid at Columbia	6	-	6	2	4	156

APPENDIX II
TABLE 11 RESULTS OF WESTWATER STREAM SEDIMENT SAMPLING (Continued)

Land Use & Station No.	Location	p,p'-DDT	p,p'-DDE	p,p'-DDD	Chlordane α	Chlordane γ	PCB's
Residential							
R1	East 14th Ave. (blk. E. of Renfrew)	7	-	4	3	5	255*
R2	East 16th Ave. (between Renfrew and Rupert)	10	4	3	2	1	40
R3	Smith Ave. at Spruce Ave.	14	-	3	2	2	67
R4	Whitsell Ave. at Williams Ave.	18	-	5	2	3	127
R5	2400 Duthie Street	20	-	5	2	2	31
R6	Mahon at Eglington	9	-	3	2	2	70
R7	Mayfield and Canada Way	31	-	7	2	2	35
R8	Lee and 10th Ave.	33*	-	7	3	3	102
Green Space							
G1	Forest Lawn Cemetery	22	7*	11*	11*	7	30
G2	Robert Burnaby Park	21	-	4	1	1	87
G3	Gaglardi Way at Esterbrook	1	-	-	.7	.5	32
G4	Phillips & Halifax (near golf course)	6	-	1	2	1	63

a = concentrations are in μg/kg wt.
* = highest values reported.

APPENDIX II
TABLE 12 WESTWATER EXTRACTABLE TRACE METALS IN URBAN RUNOFF

Station	Flow	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Renfrew	Low	<1	<10	650	124	<1	6	17
(upstream #33)	High	<1	14	790	55	<1	123	46
Rupert	Low	1.5	<10	880	146	<1	7	17
(downstream #33)	High	1.9	16	900	61	<1	129	60
Gilmore	Low	<1	<10	920	115	<1	9	23
(#31))	High	<1	24	1000	68	<1	119	60
Willingdon	Low	<1	20	1940	267	19	19	72
(#30)	High	<1	32	1320	106	5.6	157	105
Douglas	Low	<1	13	1570	232	11.6	25	82
(#35)	High	<1	30	1870	136	4.8	143	82
Lougheed	Low	<1	20	3020	655	100	23	115
(#32)	High	<1	36	1120	79	28	98	86

a = extractable metal in μg/l.
b = stations on main branch Still Creek, Lougheed station on north branch of Still Creek (for station location see Figure 3).
c = low flow .056 m^3/s (2 cfs); high flow .79 m^3/s (28 cfs) at Renfrew School with Pechnold tipping bucket rain gauge.

5) 1974 Westwater Renfrew Street Storm Sewer Sampling

APPENDIX II
TABLE 13 RESULTS OF WESTWATER RENFREW STREET STORM SEWER SAMPLING

Station	Sampling Period	Trace Metal Concentration ($\mu g/l$)						Turbidity	Flow (m^3/day)
		Cu	Fe	Mn	Ni	Pb	Zn		
Renfrew Storm Sewer (drainage water)	During Rainfall Event	10	350	40	2	62	166	21.6	1950
	After Rainfall Event	4	622	107	1*	5	106	4.0	490
	Summer Dry Weather	1*	740	136	1*	9	122	-	240*

All concentrations are mean values except for those noted with asterisk (*) which because of presence of indeterminates have been given their median values.

6) 1976 EPS - GVRD Storm Sewer Sampling

APPENDIX II

TABLE 14 LOCATION OF EPS STORMWATER SAMPLING STATIONS

Site Name	Location
Jericho	on beach - ice cream stand
Grandview Highway	at Nookta - south side of Grandview
Boundary - 2nd Avenue	at 2nd Ave. (Burnaby side)
UEL	close to Cecil Green
Rhodes Street	manhole on Ward St.
Collingwood Street	in Slocan Park
Williams Street	open ditch
Schoolhouse Creek	near school
Kyle Street	manhole near tracks
Byrne Road	at Marine Drive
BCIT Pond	BCIT parking lot
Springer Avenue	at Broadway close to Lumberland
Kaymar Raveen	west of Roseberry St.at Marine Drive
Buckingham - Deer Lake	at Deer Lake
New West	23rd Street
Central Area	New Westminster
Surrey Place	close to King George Highway
88th Ave. - Surrey	in ditch along 88th Ave.

APPENDIX II - TABLE 15 RESULTS OF EPS STORMWATER SAMPLING

Sampling Location	Time of Sampling	Date	Weather Condition	LT	CONCENTRATION (mg/l) COD	CN	Total Zn	Diss. Zn	Total Cu	Diss. Cu	Total Cr	Diss. Cr
Jericho Park	9:45	16/3	tr	-	27	0.03	0.12	0.11	0.01	0.02	0.02	0.02
Grandview Hwy.	10:25	16/3	tr	-	65	0.03	0.18	0.14	0.04	0.01	0.02	0.02
Nootka	9:45	19/7	-	NT	25	0.03	0.02	0.01	0.01	0.01	0.02	0.02
Boundary S.	11:15	15/3	-	-	73	0.03	0.02	0.01	0.01	0.01	0.02	0.02
2nd Hwy.	10:10	19/7	-	NT	86	0.03	0.05	0.03	0.01	0.01	0.02	0.02
UEL	11:00	23/3	rain	-	35	0.03	2.7	0.14	0.05	0.01	0.03	0.02
	10.40	26/7	-	NT	20	0.03	0.04	0.03	0.02	0.01	0.02	0.02
Kyle St.	9:05	23/3	rain	-	52	0.03	0.19	0.07	0.03	0.01	0.02	0.02
	9:10	27/7	-	NT	20	0.03	0.02	0.01	0.01	0.02	0.02	0.02
Williams St.	9:15	23/3	rain	-	20	0.03	1.0	0.14	0.01	0.01	0.02	0.02
	9.30	27/7	-	NT	20	0.03	0.02	0.03	0.01	0.01	0.02	0.02
Schoolhouse Cr.	9:25	23/3	rain	-	20	0.03	0.10	0.12	0.01	0.01	0.02	0.02
	9:50	27/7	-	NT	20	0.03	0.01	0.01	0.01	0.01	0.02	0.02
Rhodes St.	10:30	23/3	rain	-	51	0.03	0.13	0.10	0.03	0.01	0.02	0.02
	9.50	27/7	-	NT	20	0.03	0.03	0.02	0.01	0.01	0.04	0.02
Collingwood St.	10:00	23/3	rain	-	59	0.03	0.17	0.10	0.04	0.01	0.02	0.02
	9:15	26/7	-	NT	20	0.03	0.04	0.02	0.02	0.01	0.02	0.02
Byrne Road	10:45	15/3	-	-	20	0.03	0.06	0.02	0.01	0.01	0.02	0.02
	11:15	15/7	-	NT	20	0.03	0.03	0.02	0.01	0.01	0.02	0.02
BCIT Pond	10:40	16/3	tr	-	38	0.03	0.46	0.07	0.01	0.01	0.02	0.02
	12:15	19/7	-	NT	24	0.03	0.02	0.01	0.01	0.01	0.02	0.02
Springer Ave.	11:10	16/3	tr	-	46	0.03	0.08	0.07	0.01	0.01	0.02	0.02
	11:45	19/7	-	NT	20	0.03	0.01	0.01	0.01	0.01	0.02	0.02
Kaymar Raveen	11:00	15/3	-	-	20	0.03	0.02	0.01	0.01	0.01	0.02	0.02
	11:40	15/7	-	NT	20	0.03	0.02	0.01	0.01	0.01	0.02	0.02
Buckingham	10:55	16/3	tr	-	20	0.03	1.3	0.05	0.01	0.01	0.04	0.02
- Deer Lake	10:45	19/7	-	NT	20	0.03	0.01	0.01	0.01	0.01	0.02	0.02
23rd St.	10:30	15/3	-	-	84	0.03	0.12	0.11	0.07	0.05	0.02	0.02
Central Area	10:15	15/3	-	-	20	0.03	0.03	0.02	0.01	0.09	0.02	0.02
King George	9:50	15/3	-	-	20	0.03	0.04	0.01	0.01	0.01	0.02	0.02
& Fraser Hwy.	9:40	15/7	-	NT	22	0.03	0.05	0.02	0.03	0.01	0.02	0.02
88th Ave. &	9:30	15/3	-	-	20	0.03	0.01	0.01	0.01	0.01	0.02	0.02
King George Hwy	9:20	. 15/7	-	NT	20	0.03	0.01	0.01	0.01	0.01	0.03	0.02

NT - non-toxic
tr - trace

APPENDIX II - TABLE 15 RESULTS OF EPS STORMWATER SAMPLING (Continued)

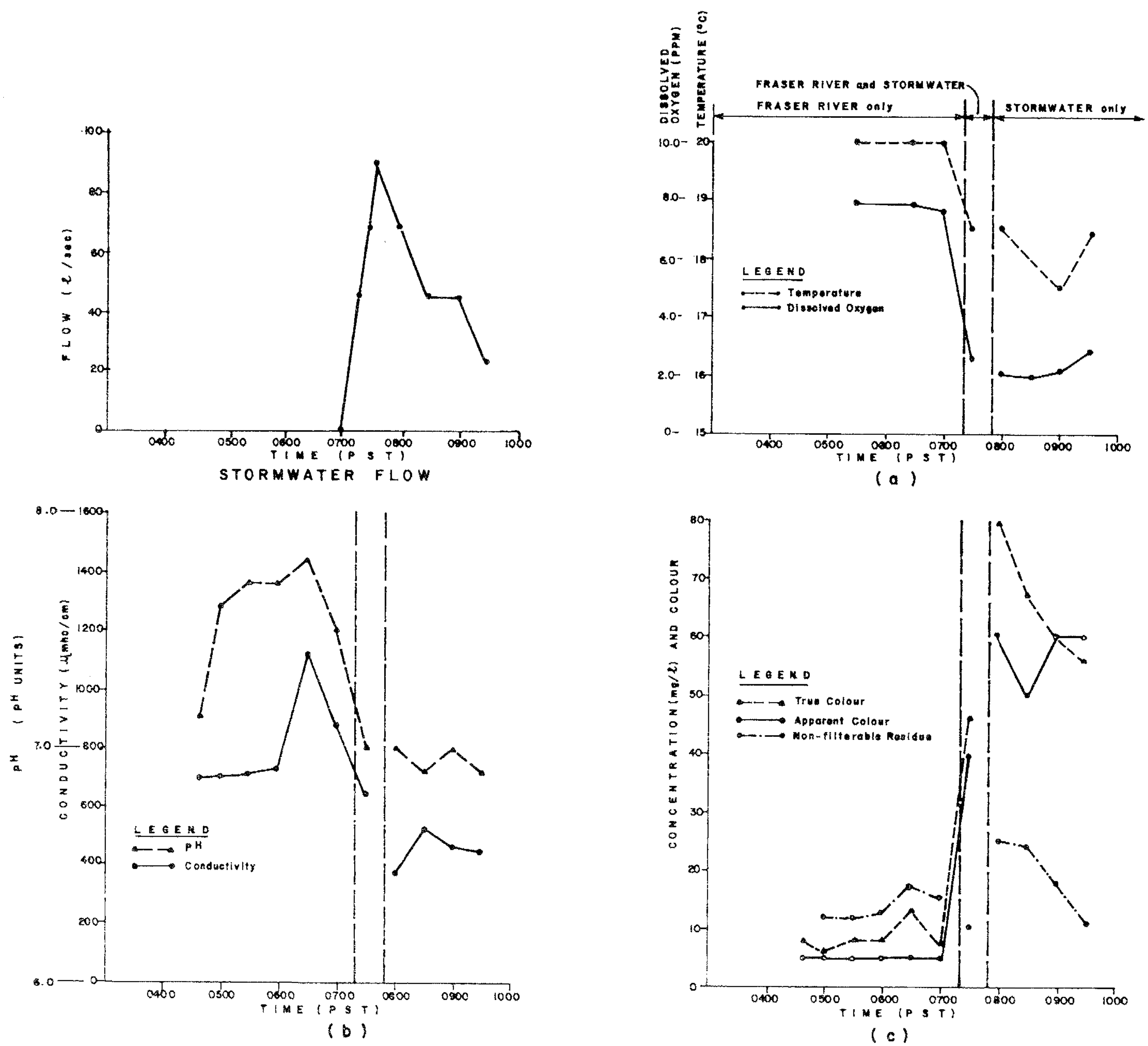
Sampling Location	Time of Sampling	Weather Condition	CONCENTRATION (mg/l) Total Ni	Diss. Ni	Total Cd	Diss. Cd	Total Pb	Diss. Pb	Total Fe	Diss. Fe
Jericho Park	9:45	tr	0.05	0.05	0.01	0.01	0.04	0.02	3.0	1.1
Grandview Hwy.	10:25	tr	0.05	0.05	0.01	0.01	0.19	0.02	5.2	0.40
Nootka		-	0.05	0.05	0.01	0.01	0.03	0.01	1.4	0.35
Boundary S.	11:15	-	0.05	0.05	0.01	0.01	0.02	0.02	5.0	2.4
2nd Hwy.	10:10	-	0.05	0.05	0.01	0.01	0.02	0.02	9.5	2.8
UEL	11:00	rain	0.05	0.05	0.01	0.01	0.08	0.02	4.0	0.05
	10.40	-	0.05	0.05	0.01	0.01	0.02	0.02	0.21	0.06
Kyle St.	9:05	rain	0.05	0.05	0.05	0.01	0.18	0.02	0.11	0.06
	9:10	-	0.05	0.05	0.01	0.01	0.02	0.02	0.55	0.17
Williams St.	9:15	rain	0.05	0.05	0.01	0.01	0.03	0.02	1.0	0.60
	9.30	-	0.05	0.05	0.01	0.01	0.02	0.02	1.2	0.73
Schoolhouse Cr.	9:25	rain	0.05	0.05	0.01	0.01	0.03	0.02	0.80	0.30
	9:50	-	0.05	0.05	0.01	0.01	0.02	0.02	0.44	0.19
Rhodes St.	10:30	rain	0.05	0.05	0.01	0.01	0.20	0.02	2.3	0.13
	9.50	-	0.05	0.05	0.01	0.01	0.02	0.02	0.53	0.08
Collingwood St.	10:00	rain	0.05	0.05	0.01	0.01	0.25	0.02	4.4	0.03
	9:15	-	0.05	0.05	0.01	0.01	0.03	0.02	0.98	0.09
Byrne Road	10:45	-	0.05	0.05	0.01	0.01	0.02	0.02	0.55	0.12
	11:15	-	0.05	0.05	0.01	0.01	0.02	0.02	0.75	0.30
BCIT Pond	10:40	tr	0.05	0.05	0.01	0.01	0.06	0.02	2.8	0.12
	12:15	-	0.05	0.05	0.01	0.01	0.02	0.02	0.48	0.28
Springer Ave.	11:10	tr	0.05	0.05	0.01	0.01	0.04	0.02	1.2	1.0
	11:45	-	0.05	0.05	0.01	0.01	0.02	0.02	0.55	0.31
Kaymar Raveen	11:00	-	0.05	0.05	0.01	0.01	0.02	0.02	0.60	0.03
	11:40	-	0.05	0.05	0.01	0.01	0.02	0.02	0.18	0.05
Buckingham	10:55	tr	0.05	0.05	0.01	0.01	0.02	0.02	0.58	0.12
- Deer Lake	10:45	-	0.05	0.05	0.01	0.01	0.02	0.02	0.16	0.09
23rd St.	10:30	-	0.05	0.05	0.01	0.01	0.20	0.16	1.0	0.15
Central Area	10:15	-	0.05	0.05	0.01	0.01	0.02	0.02	2.0	0.35
King George	9:50	-	0.05	0.05	0.01	0.01	0.03	0.02	1.1	0.03
& Fraser Hwy.	9:40	-	0.05	0.05	0.01	0.01	0.03	0.02	1.1	0.03
88th Ave. &	9:30	-	0.05	0.05	0.01	0.01	0.02	0.02	1.3	0.15
King George Hwy.	9:20	-	0.05	0.05	0.01	0.01	0.02	0.02	0.40	0.07

APPENDIX II - TABLE 15 RESULTS OF EPS STORMWATER SAMPLING (Continued)

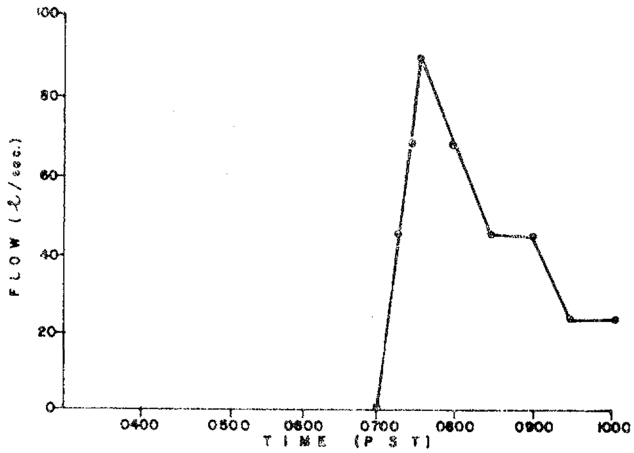
Sampling Location	Time of Sampling	Weather Condition	CONCENTRATION (mg/l) Total Hg	Phenols	Oils & Grease	pH	TR	TVR	NFR	PCB
Jericho Park	9:45	tr	0.0002	0.03	5	6.6	150	36	10	-
Grandview Hwy.	10:25	tr	0.0002	0.04	5	7.1	28	54	42	
Nootka	9:45	-	0.0002	0.02	5	7.3	140	46	5	103
Boundary S.	11:15	-	0.0002	0.07	5	7.0	280	66	10	
2nd Hwy.	10:10	-	0.0002	0.02	5	6.8	280	88	23	166
UEL	11:00	rain	0.0002	0.03	5	7.4	170	37	72	
	10.40	-	0.0002		5	7.2	70	58	5	ND
Kyle St.	9:05	rain	0.0002	0.03	5	7.1	320	57	239	
	9:10	-	0.0002	0.02	5	7.3	120	50	12	638
Williams St.	9:15	rain	0.0002	0.03	5	7.0	88	28	12	
	9.30	-	0.0002	0.02	5	7.1	150	50	6	756
Schoolhouse Cr.	9:25	rain	0.0002	0.03	5	7.3	91	31	26	
	9:50	-	0.0002	0.02	5	7.5	120	74	6	90
Rhodes St.	10:30	rain	0.0002	0.03	5	7.1	120	40	49	
	9.50	-	0.0002		5	7.5	120	72	5	776
Collingwood St.	10:00	rain	0.0002	0.03	5	7.4	160	38	93	
	9:15	-	0.0002		5	7.2	100	44	7	451
Byrne Road	10:45	-	0.0002	0.03	5	7.5	120	12	8	
	11:15	-	0.0002	0.02	5	7.6	110	5	23	55
BCIT Pond	10:40	tr	0.0002	0.03	5	7.3	180	40	34	
	12:15	-	0.0002	0.02	5	8.0	140	46	6	1140
Springer Ave.	11:10	tr	0.0002	0.03	5	7.5	150	48	31	
	11:45	-	0.0002	0.02	5	7.7	94	40	5	330
Kaymar Raveen	11:00	-	0.0002	0.03	5	7.7	110	26	14	
	11:40	-	0.0002	0.02	5	7.8	110	27	5	691
Buckingham	10:55	tr	0.0002	0.03	5	7.9	59	22	10	
- Deer Lake	10:45	-	0.0002	0.04	5	8.1	100	44	5	563
23rd St.	10:30	-	0.0002	0.03	9	7.2	200	56	24	-
Central Area	10:15	-	0.0002	0.03	5	7.1	220	34	6	-
King George	9:50	-	0.0002	0.03	5	7.1	130	30	5	
& Fraser Hwy.	9:40	-	0.0002	0.02	5	7.4	170	22	5	1023
88th Ave. &	9:30	-	0.0002	0.03	5	7.8	120	20	23	
King George Hwy.	9:20	-	0.23	0.02	5	8.4	130	45	7	196

tr - trace of precipitation
PCB - polychlorinated biphenyl (ppt - parts per trillion)
ND - non-detectable

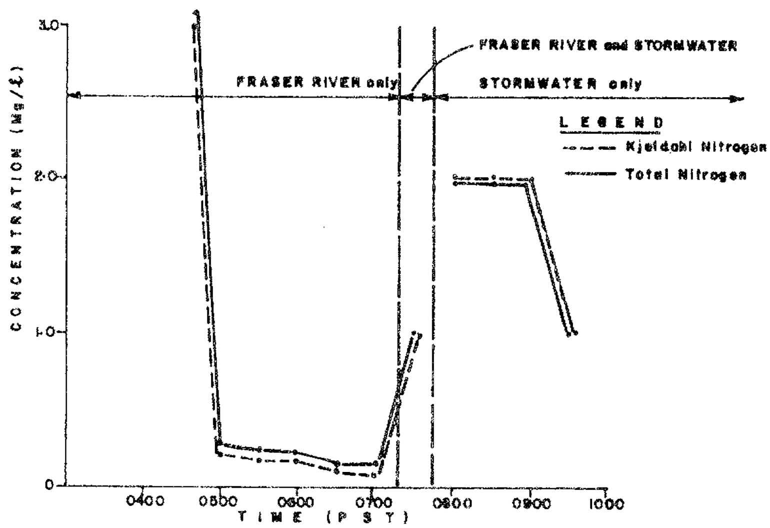
7) 1978 Provincial WIB - PCB Stormwater
Sampling Program



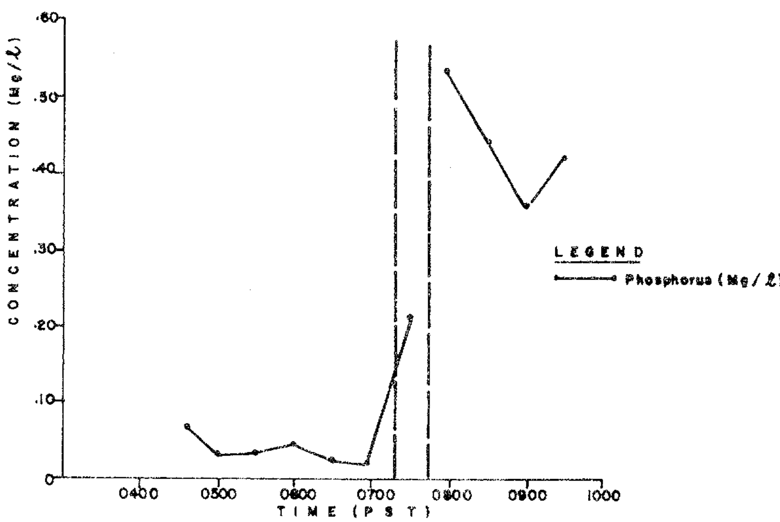
APPENDIX II
FIGURE 3a RESULTS OF WIB-PCB (PROVINCIAL) CARRINGTON STREET TIDAL FLUSH STUDY



STORMWATER FLOW

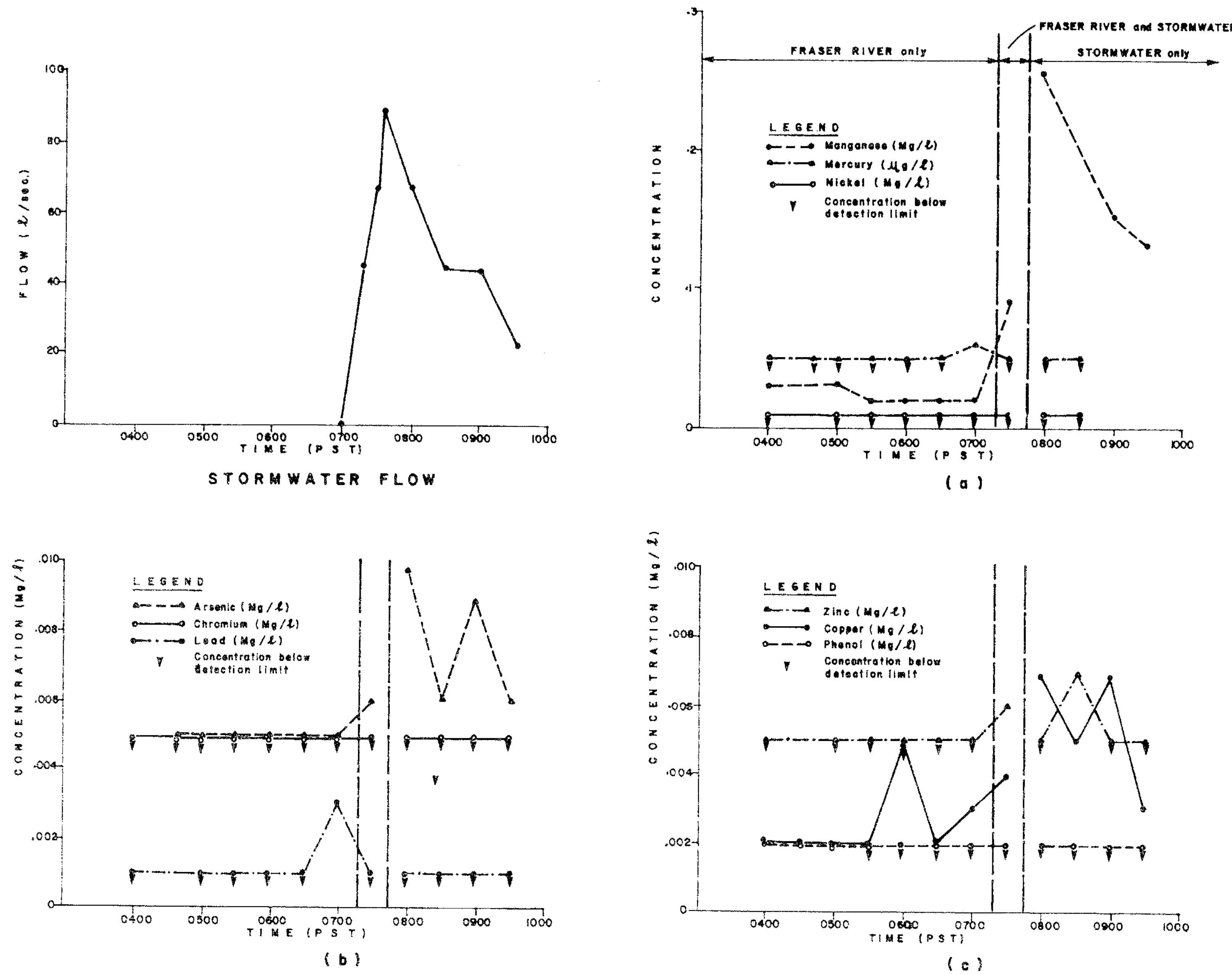


(a)

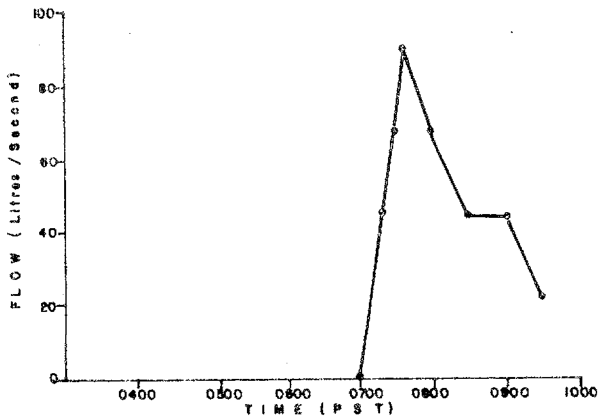


(b)

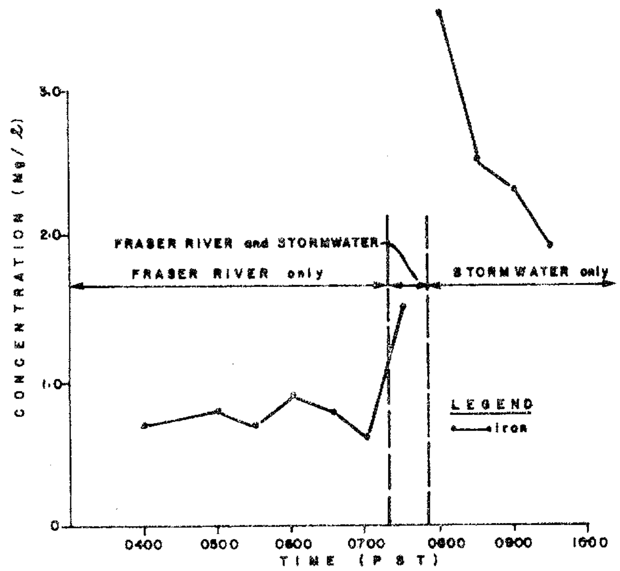
APPENDIX II
FIGURE 3b RESULTS OF WIB - PCB (PROVINCIAL)
CARRINGTON STREET TIDAL FLUSH STUDY



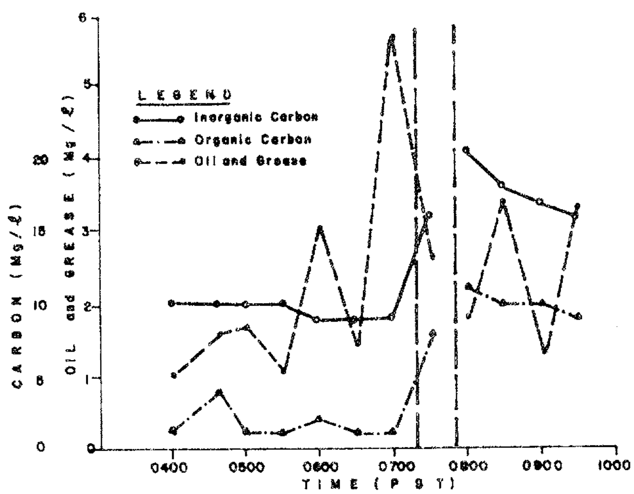
APPENDIX II
FIGURE 3c RESULTS OF WIB-PCB (PROVINCIAL) CARRINGTON STREET TIDAL FLUSH STUDY



STORMWATER FLOW



(a)



(b)

APPENDIX II
FIGURE 3d RESULTS OF WIB - PCB (PROVINCIAL)
CARRINGTON STREET TIDAL FLUSH STUDY

APPENDIX III

STORMWATER POLLUTANT LOADING TO THE FRASER RIVER/ESTUARY

1) Rainfall
2) Land Use
3) Runoff Coefficients
4) Runoff Calculations
5) Pollutant Concentrations
6) Pollutant Loadings

APPENDIX III STORMWATER POLLUTANT LOADING TO THE FRASER RIVER/ESTUARY

Studies of pollutant loadings to the aquatic environment often neglects the contribution from surface runoff. This is probably due to the poor characterization of surface runoff and the sporadic nature of discharge. However, if one is willing to make certain generalizations, it is possible to calculate the pollutant contribution from surface runoff which will be useful for comparison to other pollutant sources. These calculations have been done for the GVRD to determine surface runoff contributions to the Lower Fraser River/Estuary. The first step is to determine the volume of surface runoff that will be generated from the mix of land uses and variation in rainfall distribution that occurs in the GVRD. These volumes in conjunction with concentrations data are used to calculate the different pollutant loadings from the municipality and total load discharged to the Lower Fraser.

1) Rainfall

The annual rainfall for each municipality or city was taken as an average of recorded values from a number of precipitation recording sites. The location of the rain gauges in the GVRD was discussed in Section 2 of this report. The average rainfall for each area used in the runoff computation is presented in Table 1. In general, rainfall is lowest in those municipalities closest to the ocean and furthest from the mountains such as Delta and Richmond. Rainfall gradually increases inland and in municipalities near the mountains, such as Coquitlam and Port Coquitlam, values are twice those in the flat estuary delta.

2) Land Use

The land use pattern is very important in determining the rainfall that will be intercepted and transported to the river as surface runoff.

APPENDIX III

TABLE 1 AVERAGE ANNUAL PRECIPITATION IN GREATER VANCOUVER REGIONAL DISTRICT

City or Municipality	Rainfall (mm)
Burnaby	1531
Coquitlam	2334
Delta	1191
New Westminster	1402
Port Coquitlam	2250
Port Moody	1905
Richmond	1140
Surrey	1516
University Endowment Lands	1190
Vancouver	1281

The proportion of land use in roads and residential, commercial, industrial, agricultural and open space was estimated from each municipality in the GVRD that drains to the Fraser River. Topography maps were used to identify the areas of each municipality which drain to the Fraser River. Estimates were derived from data of acreage of land use by municipality and by inspection of 1970 existing development maps both supplied by GVRD. Table 2 summarized the land use distribution by municipality.

3) Runoff Coefficients

The effect of land use on the proportion of rainfall that becomes surface runoff is determined by a runoff coefficient. A multiplicity of different runoff coefficients are currently employed by various authorities. The range and average values developed for different land uses are summarized in Table 3. However, only the average values have been utilized for runoff computations in this study.

4) Runoff Calculations

By multiplying the rainfall (Table 1) x the land use area (Table 2) x the runoff coefficient (Table 3), the volume of surface runoff from each land use in each municipality that drains to the Fraser can be calculated. These results are summarized in Table 4. A total of 2.53×10^8 m^3/yr of surface runoff is discharged to the Fraser River from the municipalities in the GVRD. Almost half (46.8%) of this runoff comes from roads and residential areas. Even though the agricultural and open space land use areas constitutes half of the total land use it only generates slightly more than one quarter (28.3%) of the surface runoff since percolation into the soil is good and the runoff coefficient low. Stormwater which is collected in the combined sewer system and is transported to the Iona sewage treatment plant has been included in this analysis for simplicity.

5) Pollutant Concentrations

Trace metal concentrations were taken from data collected during studies on the Brunette (1) and Salmon River basins (2). During

APPENDIX III
TABLE 2 LAND USE AREAS IN GVRD DRAINED BY LOWER FRASER RIVER

Area	Roads and Residential	Commercial	Industrial	Agricultural	Open	Total
	ha					
Burnaby	3970	160	550	60	2600	7340
Coquitlam	1980	60	360	80	5370	7860
Delta	990	20	1150	3780	2290	8230
New Westminster	970	60	230	-	260	1520
Port Coquitlam	600	10	80	60	570	1320
Port Moody	60	-	-	-	-	60
Richmond	2700	120	2780	3930	3590	13120
Surrey	2380	130	370	1130		4010
UEL	100	-	-	-	798	890
Vancouver	3890	120	200	-	610	4820
						49170

Roads, Residential and Institutional were combined for the purposes of this study as Roads and Residential. An exception was made for the City of Vancouver in which 44% of the roads are curbed. Here acreages were roads curbed: 466 ha (9.65%), Residential and uncurbed roads: 3425 ha (71.00%).

Industrial, Utility and Railways were combined as Industrial.

Private, Open Space and Vacant were combined as open.

APPENDIX III
TABLE 3 RUNOFF COEFFICIENTS FOR DIFFERENT LAND USES

Land Use	Runoff Coefficient		
	Low	High	Average
Roads and Residential	.3	.6	.45
Commercial	.6	.775	.68
Industrial	.55	.85	.70
Agricultural	.1	.3	.2
Open	.1	.3	.2

APPENDIX III

TABLE 4 SURFACE RUNOFF FROM LAND USE AREAS OF MUNICIPALITIES

Municipality	Roads and Residential	Commercial	Industrial	Agricultural	Open Space	Total
	--------	--------	m^3/year x 10^3	--------	--------	--------
Burnaby	27 200	1600	5800	200	7900	42 700
Coquitlam	20 800	1000	5800	400	25100	53 100
Delta	5 300	200	9600	9000	5400	29 500
New Westminster	6 100	500	2300	-	700	9 600
Port Coquitlam	6 200	200	1200	300	2500	10 400
Port Moody	500	-	-	-	-	500
Richmond	13 900	900	22200	8900	8200	54 100
Surrey	16 200	1400	3900	3400		24 900
Vancouver	22 400	1000	1800	-	1500	26 700
UEL	500	-	-	-	1800	2 300
						253 800

these studies, water quality data were collected from different land use areas under different flow conditions. Concentrations during low base flow, assumed to be groundwater concentrations, were subtracted from high flow values to determine the concentration increment attributable to the predominant land use above the sampling station. Concentration of the other pollution parameters namely BOD_5, TN, TP and coliforms were taken from a literature survey and are hopefully representative of an average value (3), (4), (5), (6), (7), (8). These quality parameters for surface runoff are summarized in Table 5.

Biochemical oxygen demand is considerably higher in residential, commercial and industrial areas than in agricultural or open space areas probably as a result of the more extensive paved areas which prevent the sorptive capacity of the soil from being utilized and also transports the runoff faster before the readily oxidizable organics can be degraded. Most forms of TN are very soluble and therefore higher concentrations are expected than for TP which can be readily adsorbed and/or precipitated. It was very difficult to select an average value for the pathogen indicators since the range of values can often vary by at least three orders of magnitude. There is also the problem in determining whether or not there is contamination from sanitary sewer cross connections and septic tanks since the literature does not usually provide an adequate description of the study area. Most trace metal concentrations are higher in runoff from the more densely developed areas. High Pb concentrations are largely attributable to the combustion products from leaded gasoline. Zinc can originate from corrosion of vehicles, paints and atmospheric industrial discharges. Iron concentrations were slightly higher in agricultural and open space areas as a direct result of the iron content of soil material which is transported during high flow periods.

6) <u>Pollutant Loadings</u>

With the information generated on the volume and quality of surface runoff from each land use in each municipality, calculations can

APPENDIX III
TABLE 5 CONCENTRATIONS OF QUALITY PARAMETERS IN SURFACE RUNOFF

Land Use	BOD_5	TN	TP	Total Coliforms*	Fecal Coliforms*	Trace Metals**					
						Cu	Fe	Mn	Ni	Pb	Zn
	------------mg/l------------										
Roads and Residential	29	2.0	0.6	100 000	11 000	10	255	23	2	61	8
Commercial and Industrial	29	2.0	0.6	100 000	11 000	49	259	48	5	60	68
Agricultural	3	2.0	0.1	30 000	3 000	3	375	8	1	3	3
Open Space	3	1.0	0.1	65 000	600	3	375	8	1	3	3

* values in no./100 ml.
** values in μg/l.

be made to determine the load of pollutant transport. The results of these calculations are presented in Tables 6 through 16. The data in these tables is presented in units per day which is convenient for comparison to direct discharge sources.

APPENDIX III
TABLE 6 BIOCHEMICAL OXYGEN DEMAND IN SURFACE RUNOFF

Area	Roads and Residential	Commercial	Industrial	Agricultural	Open Space	Total
	----------	----------	kg BOD_5/day	----------	----------	----------
Burnaby	2170	130	460	1	60	2820
Coquitlam	1650	80	460	3	200	2390
Delta	420	10	760	70	45	1300
New Westminster	480	40	180	-	6	710
Port Coquitlam	490	20	100	2	20	630
Port Moody	40	-	-	-	-	40
Richmond	1100	70	1760	70	70	3070
Surrey	1290	110	300	30		1730
Vancouver	1780	80	140	-	10	2010
University Endowment Lands	40	-	-	-	20	60
						14760

APPENDIX III
TABLE 7 TOTAL NITROGEN IN SURFACE RUNOFF

Area	Roads and Residential	Commercial	Industrial	Agricultural	Open Space	Total
	kg TN/day					
Burnaby	150	9	32	1	22	210
Coquitlam	110	6	32	2	69	220
Delta	29	10	53	49	15	150
New Westminster	33	3	12	-	2	50
Port Coquitlam	33	1	7	2	7	50
Port Moody	3	-	-	-	-	3
Richmond	76	5	120	49	22	280
Surrey	89	8	21	14		130
Vancouver	120	6	10	-	4	140
University Endowment Lands	3	-	-	-	5	8
						1240

APPENDIX III
TABLE 8 TOTAL PHOSPHORUS IN SURFACE RUNOFF

Area	Roads and Residential	Commercial	Industrial	Agricultural	Open Space	Total
	----------	----------	---------- kg TP/day	----------	----------	----------
Burnaby	45	3	10	0.04	2	60
Coquitlam	34	2	10	0.09	7	53
Delta	87	0.3	16	2	1	106
New Westminster	10	1	4	-	2	17
Port Coquitlam	10	0.4	2	0.09	1	13
Port Moody	1	-	-	-	-	1
Richmond	23	1	36	2	2	64
Surrey	27	2	6	1		36
Vancouver	37	1	3	-	0.4	41
University Endowment Lands	1	-	-	-	1	1
						392

APPENDIX III

TABLE 9 TOTAL COLIFORMS IN SURFACE RUNOFF

Area	Roads and Residential	Commercial	Industrial	Agricultural	Open Space	Total
	number/day x 10^{12}					
Burnaby	75	4	16	0.1	14	109
Coquitlam	57	3	16	0.3	45	121
Delta	15	0.5	26	7	10	58
New Westminster	17	1	6	-	1	25
Port Coquitlam	17	0.6	3	0.2	5	26
Port Moody	1	-	-	-	-	1
Richmond	38	3	61	7	15	124
Surrey	44	4	11	5		64
Vancouver	61	3	5	-	3	72
University Endowment Lands	1	-	-	-	3	4
						604

APPENDIX III
TABLE 10 FECAL COLIFORMS IN SURFACE RUNOFF

Area	Roads and Residential	Commercial	Industrial	Agricultural	Open Space	Total
	number/day x 10^{11}					
Burnaby	82	5	18	0.1	1	106
Coquitlam	63	3	18	0.3	4	88
Delta	16	0.6	29	7	0.9	54
New Westminster	18	2	7	-	0.1	27
Port Coquitlam	18	0.7	4	0.2	0.4	23
Port Moody	2	-	-	-	-	2
Richmond	42	3	67	7	1	120
Surrey	49	4	12	2		67
Vancouver	68	3	5	-	0.2	76
University Endowment Lands	2	-	-	-	0.3	2
						565

APPENDIX III
TABLE 11 COPPER IN SURFACE RUNOFF

Area	Roads and Residential	Commercial	Industrial	Agricultural	Open Space	Total
	kg/day					
Burnaby	0.74	0.22	0.78	0.001	0.06	1.80
Coquitlam	0.57	0.14	0.78	0.003	0.21	1.70
Delta	0.14	0.03	1.29	0.09	0.07	1.62
New Westminster	0.17	0.07	0.30	-	0.006	0.55
Port Coquitlam	0.17	0.03	0.17	0.002	0.02	0.39
Port Moody	0.01	-	-	-	-	0.01
Richmond	0.38	0.12	2.97	0.07	0.07	3.61
Surrey	0.44	0.19	0.52	0.03		1.18
Vancouver	0.61	0.14	0.24	-	0.01	1.00
University Endowment Lands	0.01	-	-	-	0.03	0.04
						11.90

APPENDIX III
TABLE 12 IRON IN SURFACE RUNOFF

Area	Roads and Residential	Commercial	Industrial	Agricultural	Open Space	Total
	kg/day					
Burnaby	19	1	4	0.2	8	32
Coquitlam	15	0.7	4	0.4	26	46
Delta	4	0.1	7	9	6	26
New Westminster	4	0.4	2	-	1	7
Port Coquitlam	4	0.2	0.9	0.3	3	8
Port Moody	0.3	-	-	-	-	0.3
Richmond	10	0.6	16	9	8	43
Surrey	11	1	3		4	19
Vancouver	16	0.8	1	-	2	19
University Endowment Lands	0.4	-	-	-	2	2
						202

APPENDIX III
TABLE 13 MANGANESE IN SURFACE RUNOFF

Area	Roads and Residential	Commercial	Industrial	Agricultural	Open Space	Total
	kg/day					
Burnaby	1.7	0.22	0.76	0.004	0.17	2.9
Coquitlam	1.3	0.14	0.76	0.008	0.54	2.7
Delta	0.3	0.02	1.3	0.20	0.12	1.9
New Westminster	0.4	0.07	0.29	-	0.02	0.8
Port Coquitlam	0.4	0.03	0.16	0.006	0.06	0.7
Port Moody	0.03	-	-	-	-	0.03
Richmond	0.88	0.12	2.9	0.20	0.18	4.3
Surrey	1.0	0.18	0.51	0.75		2.4
Vancouver	1.4	0.14	0.24	-	0.03	1.8
University Endowment Lands	0.03	-	-	-	0.04	0.07
						17.6

APPENDIX III
TABLE 14 NICKEL IN SURFACE RUNOFF

Area	Roads and Residential	Commercial	Industrial	Agricultural	Open Space	Total
	kg/day					
Burnaby	0.15	0.02	0.08	0.0005	0.02	0.27
Coquitlam	0.11	0.01	0.08	0.001	0.07	0.27
Delta	0.03	0.002	0.13	0.02	0.01	0.19
New Westminster	0.03	0.007	0.03	-	0.002	0.07
Port Coquitlam	0.03	0.003	0.02	0.0008	0.007	0.06
Port Moody	0.003	-	-	-	-	0.003
Richmond	0.08	0.01	0.30	0.02	0.02	0.43
Surrey	0.09	0.02	0.05	0.009		0.17
Vancouver	0.12	0.01	0.02	-	0.004	0.15
University Endowment Lands	0.003	-	-	-	0.005	0.008
						1.62

APPENDIX III
TABLE 15 LEAD IN SURFACE RUNOFF

Area	Roads and Residential	Commercial	Industrial	Agricultural	Open Space	Total
	kg/day					
Burnaby	4.6	0.3	1.0	0.001	0.06	5.9
Coquitlam	3.5	0.2	1.0	0.003	0.2	4.9
Delta	0.9	0.03	1.6	0.07	0.04	2.6
New Westminster	1.0	0.09	0.4	-	0.06	1.5
Port Coquitlam	1.0	0.04	0.2	0.002	0.2	1.4
Port Moody	0.82	-	-	-	-	0.08
Richmond	2.3	0.15	3.6	0.07	0.07	6.2
Surrey	2.7	0.23	0.6	0.03		3.6
Vancouver	3.7	0.17	0.3	-	0.01	4.2
University Endowment Lands	0.09	-	-	-	0.02	0.1
						30.5

APPENDIX III
TABLE 16 ZINC IN SURFACE RUNOFF

Area	Roads and Residential	Commercial	Industrial	Agricultural	Open Space	Total
	-----------	-----------	-----------	kg/day	-----------	-----------
Burnaby	0.6	0.3	1.1	0.001	0.6	2.1
Coquitlam	0.5	0.2	1.1	0.003	0.2	1.9
Delta	0.1	0.03	1.8	0.07	0.05	2.0
New Westminster	0.1	0.1	0.4	-	0.006	0.6
Port Coquitlam	0.1	0.04	0.2	0.002	0.21	0.6
Port Moody	0.01	-	-	-	-	0.01
Richmond	0.3	0.2	4.1	0.07	0.07	4.7
Surrey	0.4	0.3	0.7	0.03		1.4
Vancouver	0.5	0.2	0.3	-	0.01	1.0
University Endowment Lands	0.01	-	-	-	0.02	0.03
						14.3

APPENDIX III REFERENCES

1. Hall, K.J., I. Yesaki, and J. Chan, Trace Metals and Chlorinated Hydrocarbons in the Sediments of a Metropolitan Area, Westwater Research Centre, Technical Report No. 10, Vancouver, 74 pp. (1976).

2. Wiens and Beale, unpublished data.

3. Vernon, S.A., Still Creek Water Quality Report, GVSDD, Vancouver, 108 pp. (1974).

4. Kluesner, J.W. and G.F. Lee, "Nutrient Loading from a Separate Storm Sewer in Madison, Wisconsin", JWPCF, 46 (5), 920-936, (1974).

5. McElroy III, F.T.R., and J.M. Bell, Stormwater Runoff Quality for Urban and Semi-Urban Rural Watersheds. PB-231-48-NTIS, U.S. Dept of Commerce, Springfield, Va., 74 pp. (1974).

6. Waller, D.H., Pollution Attributable to Surface Runoff and Overflows from Combined Sewerage Systems. Atlantic Industrial Research Institute, Halifax, N.S., 168 pp. (1971).

7. Weibel, S.R. et al, "Characterization, Treatment and Disposal of Urban Stormwater in Advanced in Water Pollution Research", Proc. 3rd International Conference on Water Pollution Research, WPCF, 1, 329 p. , Wash. D.C., (1967).

8. Whipple, W., J.V. Hunter, and S.L. Yu, "Unrecorded Pollution from Urban Runoff", JWPCF, 46, 873-885 (1974).

APPENDIX IV

STORMWATER TREATMENT COSTS AND METHOD OF CALCULATION

1) Stormwater Pollutant Removal Costs for the GVRD
2) Method of Cost Calculation

APPENDIX IV STORMWATER TREATMENT COSTS AND METHOD OF CALCULATION

The mathematical model developed by C.D. Howard and Associates attempts to relate probability density functions for rainfall parameters, watershed characteristics, and various storage/treatment works alternatives to arrive at least cost stormwater management techniques. The analysis in Section 5.2 of this report presented costs for various levels of percent pollutant control in the GVRD. The purpose of this Appendix is to present the input data used in the calculation, some of the results, and to describe the method used. The method is described in a paper by P.E. Flatt and C.D. Howard, which is included in this Appendix.

1) Stormwater Pollutant Removal Costs for the GVRD

The model used for the calculation of least cost storage-treatment works for stormwater pollutant removal requires rather extensive input data preparation. The rainfall probability density functions are determined by a computer analysis of the hourly rainfall data available from rain gauges in the region of study. In the GVRD, the precipitation records for stations in UBC, Vancouver, and North Vancouver, and Langley have been analyzed previously by Charles Howard and Associates Ltd. (CHA). Precipitation functions for the Annacis, Lulu, and Iona Island sewerage areas were selected based upon area weighted average annual precipitation in each sewerage area (1668.8, 1137.9, and 1264.9 mm, respectively) and the average annual precipitation at each of the four stations analyzed by CHA (Table 1). The UBC station had an average annual precipitation of 1155.7 mm, close to the average for the Lulu and Iona sewerage area, and, therefore, the precipitation data for UBC was used to approximate that experienced in those sewerage areas. The average annual precipitation for the Annacis sewerage area does not correspond to any of CHA's four stations. For this area, data was synthesized by taking the average between the UBC and North Vancouver data.

APPENDIX IV
TABLE 1 PARAMETERS IN THE PRECIPITATION PROBABILITY DENSITY FUNCTIONS FOR STATIONS IN THE GVRD

Station	Langley	North Vancouver	Vancouver	UBC	Synthesized (Annacis)
Avg. Annual Precipitation (mm)	470	2123	998	1138	1643
Parameters					
Lambda	0.275	0.222	0.287	0.284	0.253
Beta	716.53	640.6	874.15	848.1	744.25
Zeta	135.5	87.9	178.75	168.05	127.98
Psi	0.03942	0.0456	0.0374	0.0403	0.0430
Tau	1	1	1	1	1
Theta	101.75	298.54	285.14	305.92	302.2
No. @ 0.25 mm.	72.93	85.03	81.14	88.08	86.55

where:
Lambda - is the reciprocal of the average duration of rainfall in hours.
Beta - is the reciprocal of the average rainfall intensity, in mm per hour.
Zeta - is the reciprocal of the average rainfall depth, in mm.
Psi - is the reciprocal of the average time between rainfall events, in hours.
Tau - is the minimum time separating rainfall events (inter-event time), in hours.
Theta - is the number of storm events per year.
No. @ 0.25 mm - is the number of storms with 0.25 mm of storm volume or less.

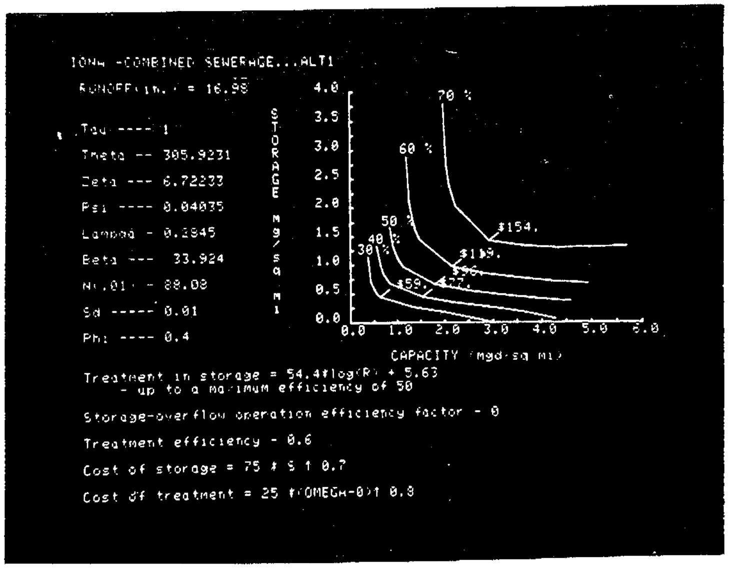
Runoff coefficients were obtained for each sewerage area by area weighting the coefficients for each municipality as determined in the calculation of stormwater pollutant loadings (Section 4.3). This technique yielded runoff coefficients of 0.34, 0.36, and 0.40 for the Annacis, Lulu, and Iona sewerage areas respectively.

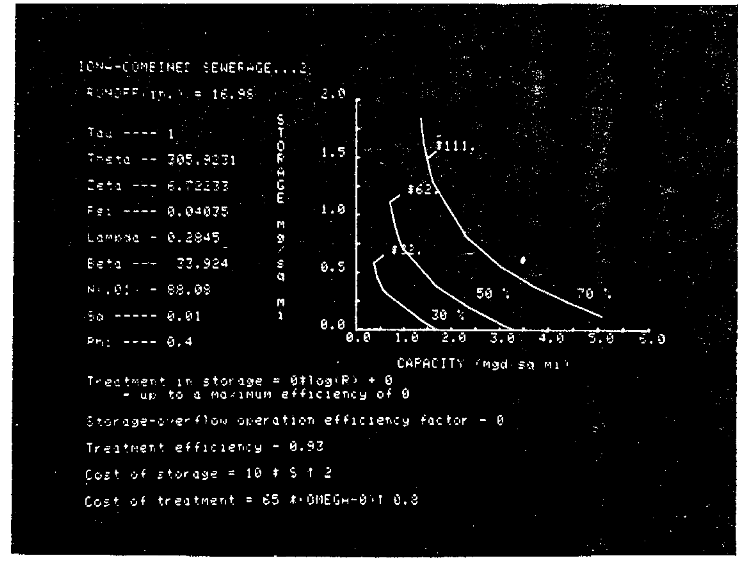
Other input parameters used were as described in Section 5.2.

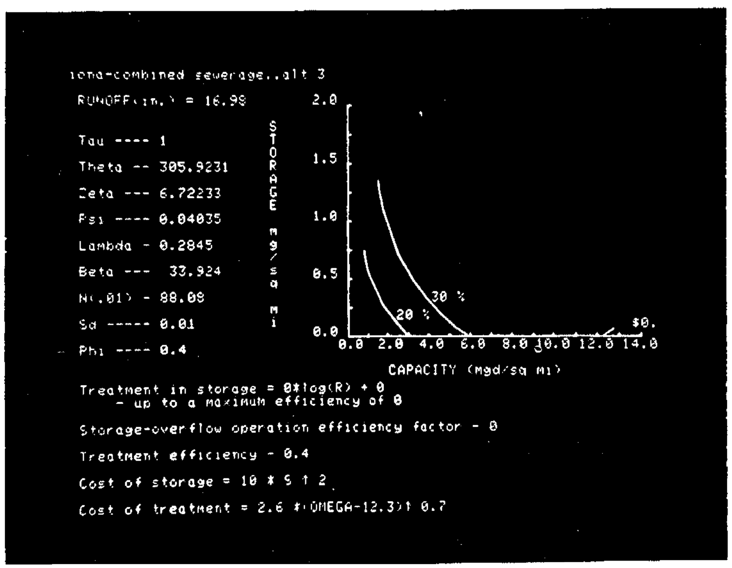
The results of the computer analysis appear as isoquants for each alternative. These results are shown in Figures 1, 2, and 3. Least cost alternatives are marked by a "tick" mark with the approximate cost shown. Isoquants for alternative 1 for each sewerage area are of a different shape than those for the other three alternatives since this alternative is the only one which allows for treatment in the storage facility. Other isoquants show the typical shape.

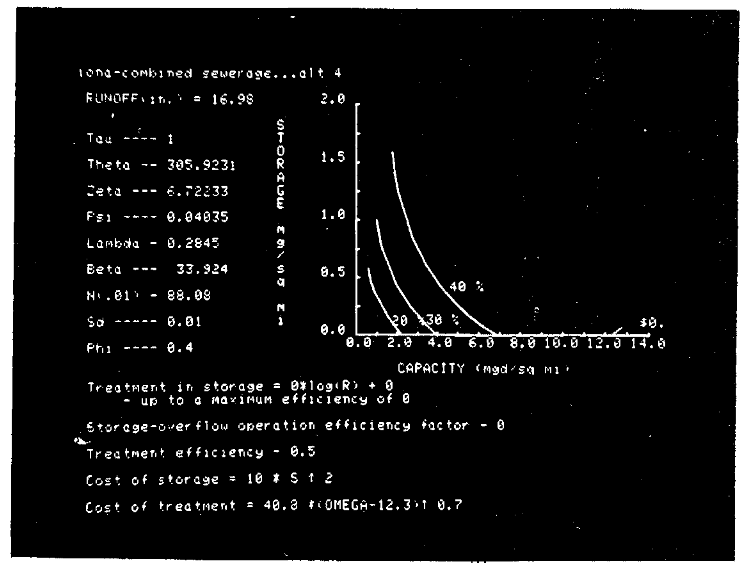
2) Method of Cost Calculation

The method used for the calculation of stormwater pollutant removal costs is outlined in the following paper by P.E. Flatt and C.D. Howard (reprinted with permission).

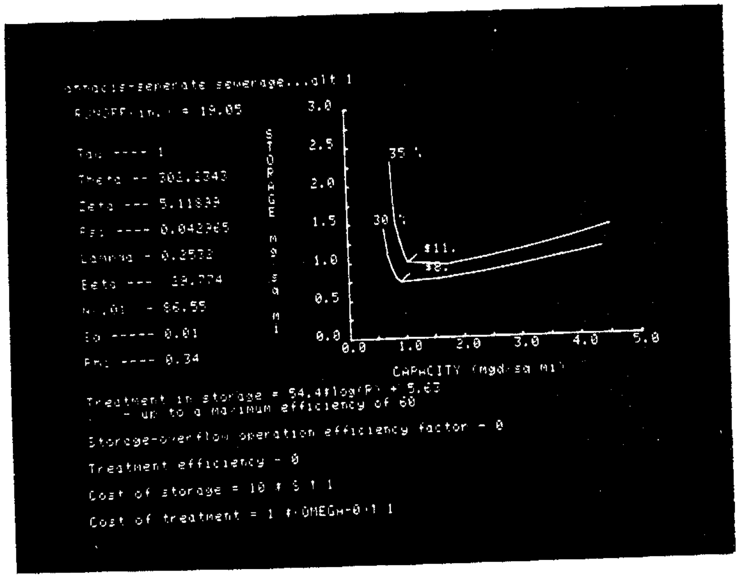


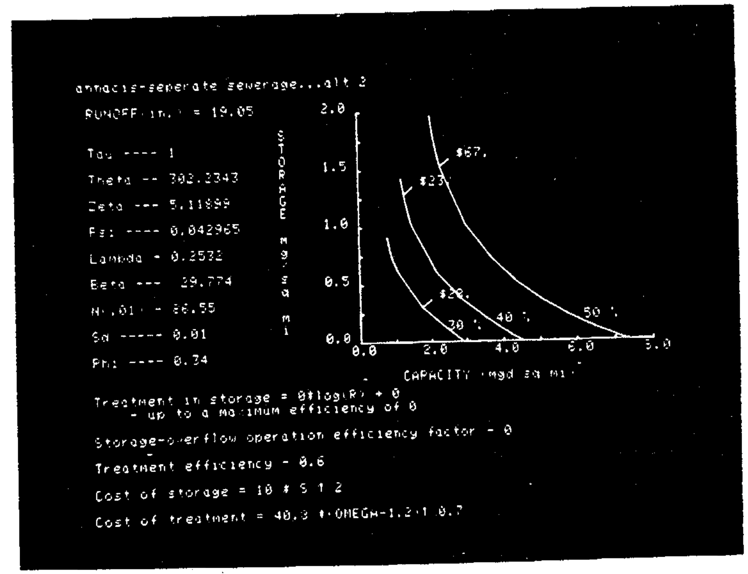


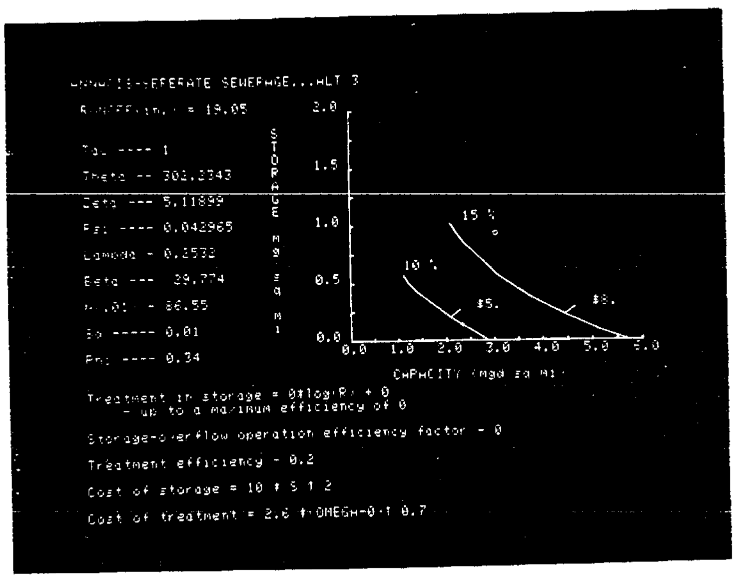


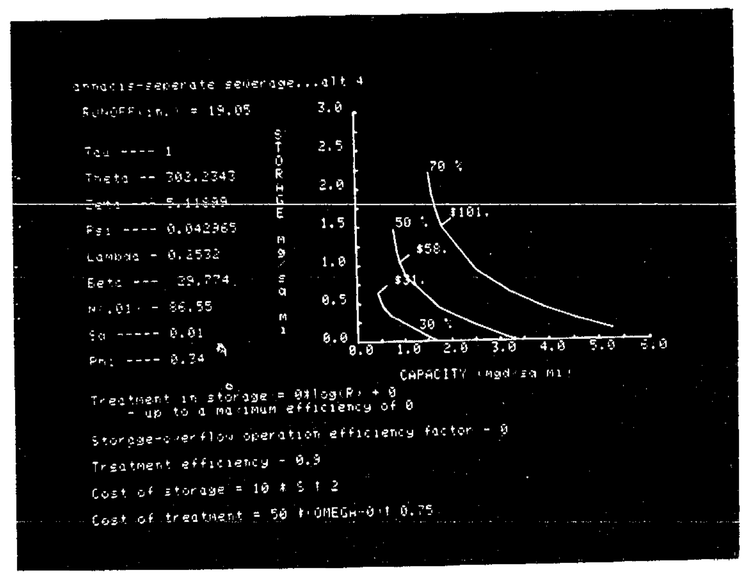


APPENDIX IV
FIGURE 3 IONA SEWERAGE AREA ISOQUANTS

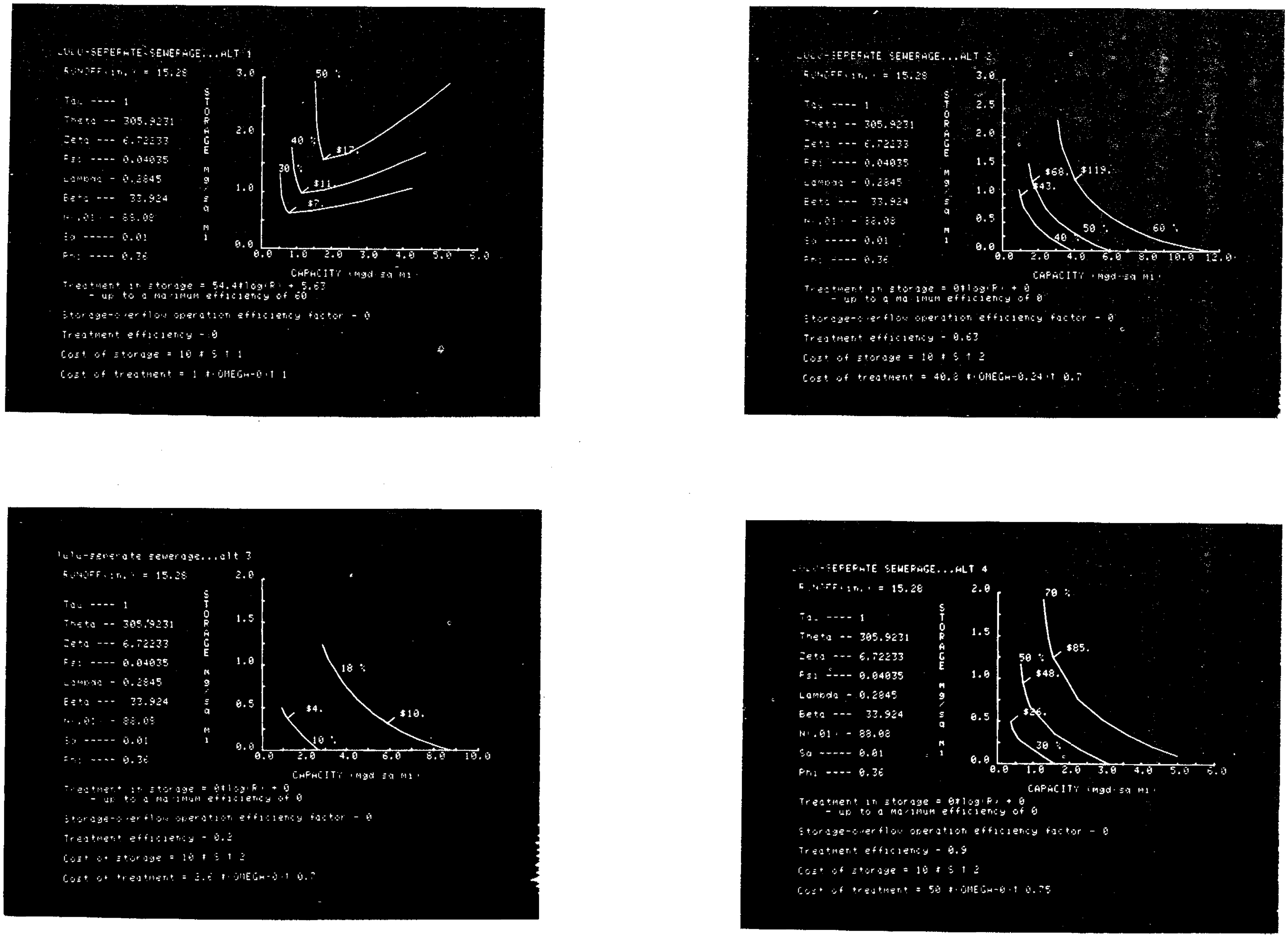








APPENDIX IV
FIGURE I ANNACIS SEWERAGE AREA ISOQUANTS



APPENDIX IV

FIGURE 2 LULU SEWERAGE AREA ISOQUANTS

International Symposium on Urban Storm Water Management
(University of Kentucky, Lexington, Kentucky – July 24-27, 1978)

PRELIMINARY SCREENING PROCEDURE FOR ECONOMIC STORAGE-TREATMENT TRADE-OFFS IN STORM WATER CONTROL

by

Paul E. Flatt* and C.D.D. Howard**

Abstract. A probabilistic mathematical model of the urban rainfall-runoff process was used to determine least-cost storage-treatment combinations for various levels of control over both runoff and pollution. Runoff control results were verified by comparison to simulation results from STORM. Pollution control by detention in storage was included in the analysis. The methodology is inexpensive to use, being well suited to desk-top procedures and has been applied in practice.

Introduction

The cost effective design of stormwater pollution control facilities must consider: the probabilistic aspects of the climate; the effect of the watershed and sewer network in transforming rainfall and snowmelt to runoff; and the effect of constructed control facilities on pollution loadings to receiving water bodies. Conditions in the receiving water itself may be very important but these are not considered here. Detailed computer simulation models such as STORM and SWMM provide comparative descriptions of alternative designs. The procedures described in this paper can be used to identify directly the least-cost design of storage and treatment facilities to meet receiving water quality loading criteria. The methodology is based on a number of simplifying assumptions and as such is intended to compliment detailed simulation procedures. However, the methodology, by itself, provides a powerful planning tool, permitting economic trade-off among types of storage and treatment facilities as well as between the size of the facilities themselves. The purpose of this paper is to present briefly: 1) the probabilistic mathematical model which is the basis of the preliminary screening procedure; 2) a verification of the procedure; and 3) a demonstration of the methodology. The procedure is presented in sufficient detail to permit its implementation on a programmable calculator or mini-computer.

To date the procedure has been used to determine least-cost storage treatment combinations for a range of pollution control levels in an area wide basin and for preliminary sizing of large scale urban runoff control facilities.

The Mathematical Model

The ability of a given storage-treatment combination to process subsequent runnoff events is affected by:

i) the volume of water expected from the next runoff event, v;

ii) the time available to draw down the reservoir (the inter-event time), b;

iii) the duration of the runoff event, t, (determines the volume of water which the treatment plant can process during the event);

iv) the average runoff intensity, i, (determines the portion of the storm event which can be processed by the treatment plant during an event);

v) the current contents of the reservoir; and

vi) the average annual number of runoff events.

Probability Density Functions

The probability density functions (pdf's) for rainfall storm event volume, inter-event time, duration, and intensity can be approximated by exponential equations of the following form:

for inter-event times, b,

$$f_B\ (b) = \psi e^{-\psi b}, 0<b<\infty \qquad (1)$$

* Senior Engineer, Charles Howard & Associates Ltd., Winnipeg, Canada.
**Consulting Engineer, Winnipeg, Canada.

for storm volumes, v,

$$f_V(v) = \zeta e^{-\zeta v} \quad , \; 0<v<\infty \qquad (2)$$

for storm durations, t,

$$f_T(t) = \lambda e^{-\lambda t} \quad , \; 0<t<\infty \qquad (3)$$

for storm intensities, i,

$$f_I(i) = \beta e^{-\beta i}, \; 0<i<\infty \qquad (4)$$

as shown in Figure 1.

Statistics of Runoff

The values of ζ, ψ, λ and β define the pdf's of rainfall events. To use the stormwater overflow theory,developed by Howard, it is necessary to normalize the rainfall distributions and to estimate the parameters defining the statistics of runoff events.[1] If actual runoff data are not available, empirical methods have been developed to estimate the rainfall-runoff transform (Chow, Heaney).[2,3] In the present work, the methodology used by the U.S. Army Corps of Engineers stormwater simulation computer program, STORM, was used.[4] There, the water loss from rainfall is approximated using two parameters, depression storage, s_d, and a runoff coefficient, Φ. The depression storage represents an initial water loss from a storm resulting from factors such as initial infiltration, interception and storage in depressions. The runoff coefficient represents a continuous water loss for the duration of a storm resulting from factors such as infiltration, percolation and evaporation. The effect of these water loss parameters is to reduce the number and volume of runoff events, making them fewer and smaller than the precipitation events.

The average annual number of runoff events, n_r, is computed using the probability density function of storm volumes and, θ, the average annual number of rainfall events, as follows:

$$n_r = \theta e^{-\zeta s_d} \qquad (5)$$

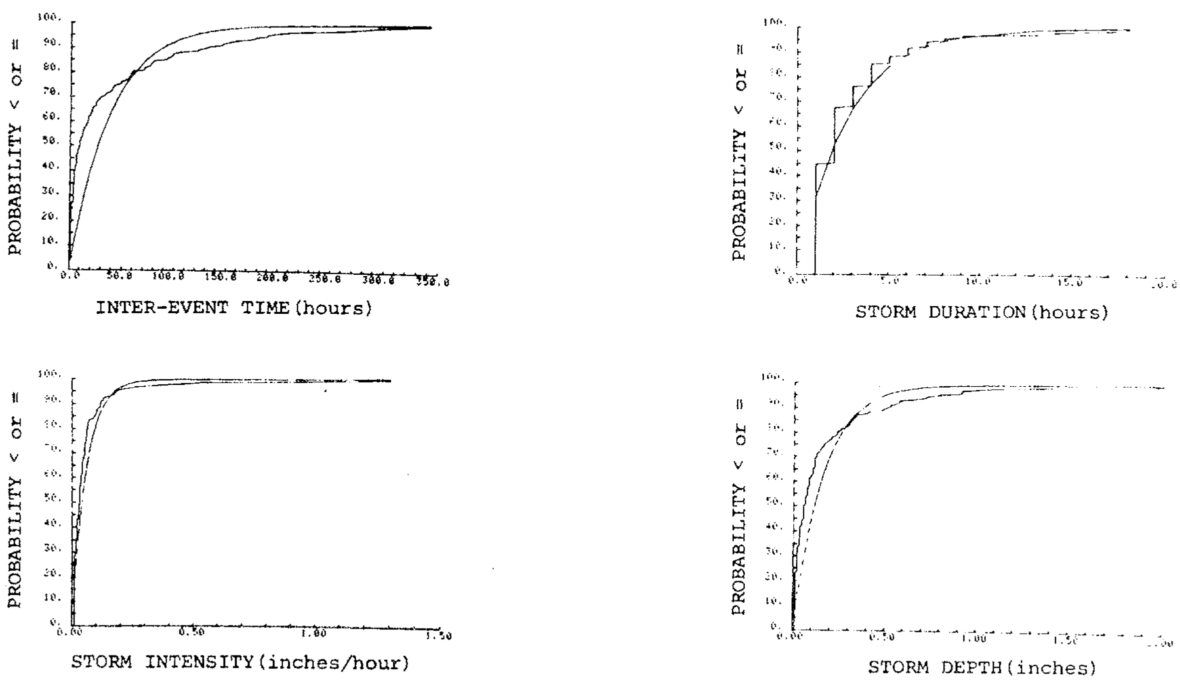
The volume of annual precipitation remaining, P', after all storms have been reduced by the depression storage is given by:

$$P' = P - \{(\theta - n_r)\, \bar{v}_1 + n_r s_d\} \qquad (6)$$

where, $\bar{v}_1$, the expected value of storm volumes less than or equal to the depression storage volume is given by:

$$\bar{v}_1 = \frac{1}{\zeta}\{1-e^{-\zeta s_d}(1+\zeta s_d)\} \; , \qquad (7)$$

$$0 \le v \le s_d$$



DATA: MINNEAPOLIS 1971

τ - 1 hour
θ - 163 events
$n_{0.01}$ - 38 events
ζ - 6.3227 inches^{-1}
λ - 0.3747 hours^{-1}
β - 17.5521 hours/inches
ψ - 0.0266 hours^{-1}

NOTE: Smooth curves developed from the theoretical equations; rough curves directly from an analysis of the data.

Figure 1. Comparison of Theoretical Cummulative Frequency Distributions with Acutal Data - Minneapolis 1971

The average annual volume of runoff events, R, is then computed using the runoff coefficient, Φ :

$$R = \Phi P' \quad (8)$$

The parameter describing the probability density function of storm runoff volumes, ζ', is given by:

$$\zeta' = \frac{n_r}{R} \quad (9)$$

The parameter describing the probability density function of storm runoff duration, λ', is assumed to be equal to the parameter describing the pdf rainfall durations, λ. The parameter describing the probability density function of storm runoff inter-event times, ψ', is defined by λ', and the average annual number of hours in the rainfall year, H, such that:

$$\psi' = \frac{\lambda' \ (n_r - 1)}{H\lambda' - n_r} \quad (10)$$

where the average annual number of hours in the rainfall year, H, is given by:

$$H = \frac{\theta}{\bar{\lambda}} + \frac{\theta - 1}{\psi} \quad (11)$$

Where intensity and duration are independent an estimate of β', the parameter defining the probability density function of runoff intensity, is obtained from:

$$\beta' = \frac{\zeta'}{\lambda'} \quad (12)$$

Statistics of Storage and Overflow

Runoff events with average intensities less than or equal to the treatment plant capacity, Ω, can be processed without utilizing storage. The expected value of the treatment rate during storms is given by:

$$\bar{i}_\Omega = \bar{i}_1 + \Omega e^{-\beta'\Omega} \quad (13)$$

where $\bar{i}_1$ is the expected value of runoff intensity for intensities less than the treatment capacity, Ω, and is given by:

$$\bar{i}_1 = \frac{1}{\beta'} \{1 - e^{-\beta'\Omega}(1 + \beta'\Omega)\}, \quad (14)$$

$$0 \leq i \leq \Omega$$

The expected volume of runoff not treated during the runoff event, ζ'' is given by:

$$\zeta'' = \frac{\lambda'\zeta'}{\lambda' - \bar{i}_\Omega \zeta'} \quad (15)$$

and the average annual number of events utilizing storage, n_s, is given by:

$$n_s = n_r \ e^{-\beta'\Omega} \quad (16)$$

The parameter describing the probability density function of inter-event times for storage-utilizing events is given by:

$$\psi'' = \frac{\lambda' (n_s - 1)}{H\lambda' - n_s} \quad (17)$$

assuming that the expected value of storage utilizing event duration is equal to the expected value of runoff event duration.

Basis of the Model

The available storage space in a reservoir which is assumed full at the end of the last runoff event depends on the rate, Ω, at which the storage can be drawn down and the elapsed time since the last event, b. For a maximum reservoir capacity, s, the amount of spill, p, will be either:

$$p_1 = v - \Omega b \ , \ b < s/\Omega \quad (18)$$

or

$$p_2 + v - s \ , \ b \geq s/\Omega \quad (19)$$

The probability of an overflow is the sum of the probabilities of either of these two mutually exclusive conditions occurring. Using the pdf's of storage utilizing events, the following equation for the probability of a non-zero overflow, $F_p(0'')$, as explained in Appendix II is:

$$F_p(0'') = \frac{\psi'' e^{-\psi''\tau} + \zeta''\Omega EXP(-\psi''(\frac{s}{\Omega} - \tau) + \zeta'' s)}{\psi'' + \zeta''\Omega} \quad (20)$$

This function does not exhibit maxima or minima when differentiated. However, using the corresponding approximate function given by Howard an effective maximum utilizable live storage for a given treatment capacity is given by:[1]

$$s = \frac{2}{\zeta''} \{\ln(\zeta''\Omega + \psi'') - \ln(\psi'')\} \quad (21)$$

and the minimum useful treatment for a storage capacity is given by:

$$\Omega = \frac{\psi''}{\zeta''} \ (e^{\zeta'' s/2} - 1) \quad (22)$$

The expected average annual number of overflow events, n_o, is given by:

$$n_o = n_s \ F_p \ (0'') \quad (23)$$

The expected annual volume of overflows, P_u, is given by:

$$P_u = \frac{n_s \ F_p \ (0'')}{\zeta''} \quad (24)$$

Finally, the percent runoff control, C_R, is given by:

$$C_R = 100 \ (1 - \frac{P_u}{R}) \quad (25)$$

Pollutant Control

The assumed interconnection of storage and treatment facilities is shown in Figure 2. When runoff occurs water is routed either directly through the treatment facility or through storage to first utilize the treatment efficiency, n_s, of the storage facility. At the same time the treatment facility may operate at or below its

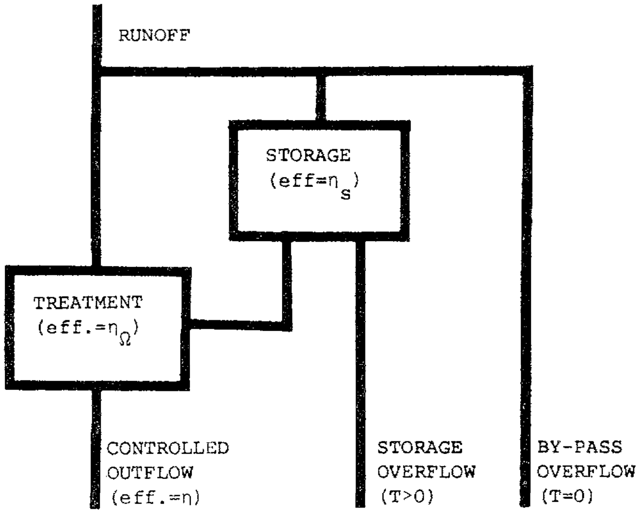


Figure 2. Inter-connection of Storage and Treatment Facilities

capacity, Ω, treating the water from storage at an efficiency of η_Ω. The overall efficiency, η, of this system under normal operating conditions is given by:

$$\eta = \eta_s + \eta_\Omega - \eta_s \eta_\Omega \qquad (26)$$

When the treatment facility is operating at capacity, Ω, and the storage is full to its capacity, s, overflows can occur. If overflow occurs from storage it is assumed to have been treated at an efficiency, $T\eta_s$, in which T is an operational factor varying between 0 and 1. This factor reflects the possibility that storage overflows may have received some treatment by detention in storage. Such controlled overflows may be used to develop storage space for any anticipated first flush. In the present work, T was assumed to be 0.0; that is, overflows were assumed to occur through a by-pass and not from storage. This low value will slightly underestimate the potential value of such facilities but might realistically represent some practical operating condition.

The percent pollutant control, C_p, is given by:

$$C_p = \frac{100(R-P_u)\eta + P_u\eta_s T}{R} \qquad (27)$$

In this equation, no allowance has been made for potential loss of efficiency during overflow conditions, nor for potential gain of efficiency from more continuous operation of the treatment facility through use of storage. The efficiency of treatment facilities was assumed to be constant and independent of design capacity or operation.

Verification

Simulated results from STORM for Minneapolis using 1971 data, were available in the form of computer results summarized in Table 1. The hourly rainfall data, used in the STORM analysis, were analyzed to obtain the statistics of the climate. The levels of runoff control obtained using the mathematical methodology are compared with those from STORM and a simple simulation, Table 1. The differences between the mathematical methodology and the STORM results can be attributed to two factors: 1) deviations of the assumed probability density functions from the actual data; and 2) differences in methodology. The differences between the mathematical methodology and the simple simulation can be attributed only to the fit of the pdf's to the actual data. As shown in Table 1, for treatment capacities in the practical range up to .010 in/hr, the comparison is close for all three procedures. For higher treatment capacities the difference between STORM and the mathematical methodology increases to a maximum of 13%. In the same range, the maximum difference between the simple simulation and mathematical methodology is 6%. These results indicate that differences between the mathematical methodology and STORM are caused by both difference in methodology and the fit of the pdf's to the actual data. Although Table 1 deals only with percent runoff control at zero storage, it is representative of the worst fit to the STORM results by the mathematical methodology - the maximum difference for storage greater than zero is about 10%. These results provide confidence that the methodology is a practical tool for stormwater management analysis.

Treatment Provided by Detention Stormwater Ponds

Reliable data describing the treatment received by stormwater runoff in detention ponds are not currently available while references on sedimentation processes in storage reservoirs do not deal directly with stormwater ponds.[4,5] They do suggest however, using a function of the form:

$$\eta_s = a*\log(RT)+b \qquad (28)$$

where RT is the average detention time, estimated to be $s/2\Omega$, and a and b are empirical constants which were estimated using actual data from stormwater ponds in Winnipeg, Canada.

Table 1. Comparison of Procedures PERCENT RUNOFF CONTROL at zero storage.

Treatment (in/hr)	STORM	Mathematical Procedure	Simple Simulation
.001	6	5	5
.004	21	17	17
.010	39	37	38
.050	77	90	84
.150	93	100	95

Figure 3 presents the resulting isoquants of suspended solids control for a one square mile area in Minneapolis determined by the mathematical analysis. (The Figure was prepared using a graphics desktop mini-computer with less than 8k bytes of core.)

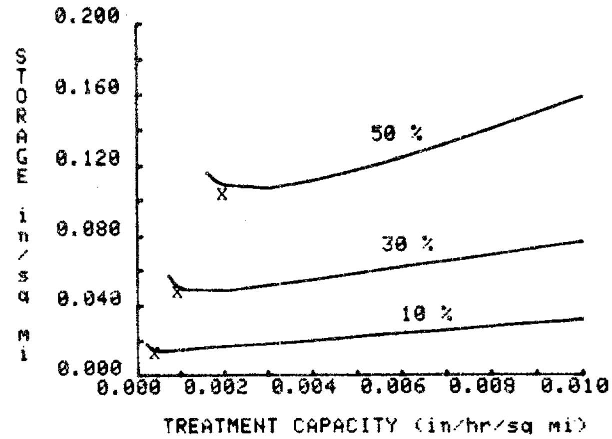
The effect of using the above empirical storage efficiency function is to cause a trade-off between runoff control and treatment efficiency. As shown in Figure 3, the required live storage decreases with increases in outlet capacity to a minimum, and then live storage again increases with increasing outlet capacity. This peculiar crescent shape is unique to this particular storage-treatment combination and reflects the operation of only the live storage. Briefly, as a live storage decreases and outlet capacity increases, the average removal efficiency decreases. From left to right, in Figure 4, initially a small increase in outlet capacity permits a large decrease in live storage for the same runoff control. Therefore, even with the reduction in sedimentation efficiency, the isoquant for the stormwater pond still slopes down to the right. However, as the slope of the runoff control isoquant flattens, the decreasing sedimentation efficiency requires additional live storage with increasing outlet capacity to provide sufficient runoff control to maintain the same overall level of pollution control. In this example the sensitivity of the economic optimum storage-treatment combination to changes in cost data for a given level of control will be very low, located near the minimum live storage point. Figures 3 through 5 were prepared using a graphics desk-top mini-computer with less than 8k bytes of core. To develop the isoquants in these Figures the procedure presented above was programmed using a numerical Newton-Raphson procedure to calculate a number of points for each isoquant. Using non-linear cost functions, the optimum storage-treatment combination for each isoquant was identified by direct calculation using the points on the isoquant.

Regardless of the types of storage and treatment facilities involved in the analysis, using current cost data, the economic optimum falls on or near the portion of the isoquant with highest curvature (marked with an "x" in Figure 3). This result was found even in combined sewered areas where the cost of storage was estimated at $75,000 per mgd. These results demonstrate the large value of storage in cost effective design of stormwater control systems.

Conclusions

The following conclusions may be made:

1) The mathematical procedure provides a very good approximation to the results obtained by STORM for the range of practical treatment and storage capacities.



Note: Efficiency of treatment in storage, $\eta_s = 54.4*\log(RT) + 5.63$, $\eta_s < 100\%$

Figure 3. Isoquants of Suspended Solids Control - Stormwater Ponds - Minneapolis

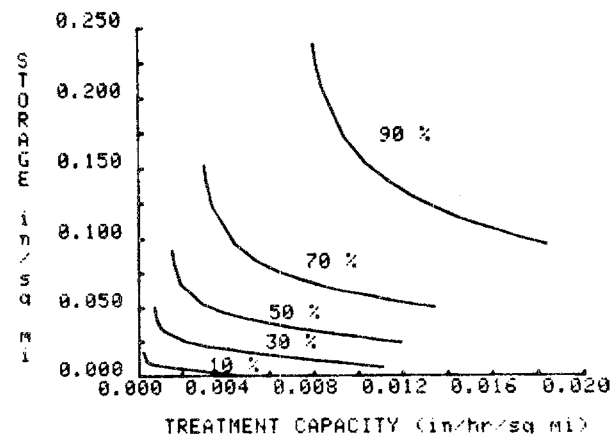


Figure 4. Isoquants of Runoff Control Minneapolis

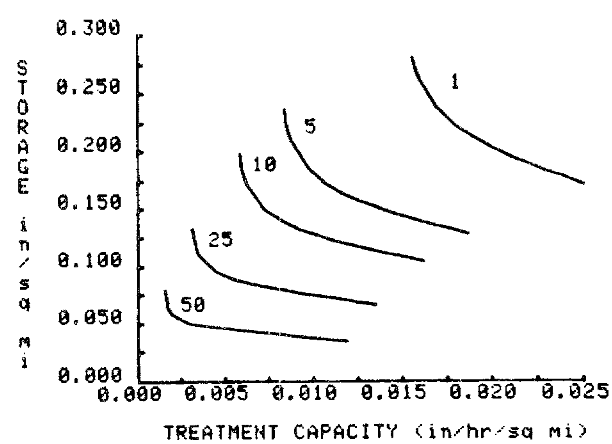


Figure 5. Isoquants of Average Annual Number of Overflows - Minneapolis

2) The mathematical procedure is economical and simple to use and can be implemented on programmable calculators or mini-computers.

3) The mathematical procedure has been successfully implemented using the water loss procedure of STORM; other applications of the procedure can use any rainfall-runoff transformation deemed appropriate.

4) The mathematical procedure facilitates identification of the least-cost storage-treatment combination for a given level of control.

5) The results of the stormwater control analysis illustrate the large economic value of storage in stormwater control systems.

6) The differences between the results from the mathematical procedure and STORM are caused by differences in methodology and imperfect fitting of the theoretical probability density functions to the actual data. Since the one year of actual data provide only a sample of the real distributions, the mathematical results may well be more realistic than those given by STORM.

7) The main difference in methodology between the mathematical procedure and STORM is that the mathematical procedure uses defined rainfall events while STORM directly uses the hourly rainfall data without first transforming them into events.

Acknowledgements

Initial development of the mathematical model was supported by the United States-Canada-Ontario Agreement on Great Lakes Water Quality. Further application of the theory was funded by the Central Mortgage and Housing Corporation, Canada.

Suggestions by Drs. James Heaney and Wayne Huber of the University of Florida were instrumental in leading to the development of the theory by Howard. Subsequent specific technical contributions by Dr. Uri Shamir and Douglas I. Smith of Charles Howard and Associates Ltd. have led to continuing development and improvement of the model.

References

1. Howard, Charles D.D., (1976), Theory of Storage and Treatment-Plant Overflows, Journal of the Environmental Engineering Division, ASCE, Vol. 102, No. EE4.

2. Chow, V.T. (Editor), (1964) Handbook of Applied Hydrology, McGraw-Hill Book Company, New York.

3. Heaney, James P. et al., (1976), Storm Water Management Model, Level I, Preliminary Screening Procedures, Dept. of Environmental Engineering Sciences, University of Florida, Gainesville, Florida.

Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges, Volume II, (1977), Dept. of Environmental Engineering Sciences, University of Florida, Gainesville, Florida.

4. American Society of Civil Engineers (1973), Civil Engineering Classics, Outstanding Papers of Thomas R. Camp, ASCE, New York, N.Y.

5. U.S. Army Corps of Engineers, (1976), Users Manual, Storage, Treatment, Overflow Runoff Model "STORM", The Hydrologic Engineering Center, Davis, California.

6. Vanoni, Vito A., Editor, (1975), Sedimentation Engineering, ASCE Manuals and Reports on Engineering Practice, New York, N.Y.

Appendix I

List of Variables

β Parameter of the distribution of rainfall event intensities (hr/in) (beta)

β' Parameter of the distribution of runoff event intensities (hr/in) (beta, prime)

ζ Parameter of the distribution of rainfall event volumes (in^{-1}) (zeta)

ζ' Parameter of the distribution of runoff event volumes (in^{-1}) (zeta, prime)

ζ'' Parameter of the distribution of storage-utilizing events (in^{-1}) (zeta, double prime)

θ The average annual number of rainfall events (theta)

λ Parameter of the distribution of rainfall durations (hr^{-1}) (lambda)

λ' Parameter of the distribution of runoff event durations (hr^{-1}) (lambda, prime)

ψ Parameter of the distribution of rainfall inter-event times, time between events (hr^{-1}) (psi)

ψ' Parameter of the distribution of runoff inter-event times (hr^{-1}) (psi, prime)

ψ'' Parameter of the distribution of storage utilizing inter-event times (hr^{-1}) (psi, double prime)

τ Minimum inter-event time used to define individual storms (hr) (tau)

θ Runoff coefficient representing temporarily and spatially averaged losses during a storm event (phi)

η The overall treatment efficiency of constructed storage and treatment facilities (eta)

η_s The efficiency (of treatment) of the constructed storage facility (eta,s)

η_Ω The efficiency of the constructed treatment facility (eta, omega)

Ω The constructed capacity of a treatment or outflow facility (omega)

b Inter-event time (hr)

H The average annual rainfall period (hr)

i Intensity of rainfall/runoff events (in/hr)

I Percent imperviousness of a watershed

$\bar{I}$ Expected value of runoff event intensities less than Ω (in/hr)

n The average annual number of overflows from storage

n_r The average annual number of runoff events

$n_{0.01}$ The average number of storm events with a depth of exactly 0.01 inches

n_s The average annual number of runoff events requiring storage

n_o The average annual number of overflow events

P Average annual precipitation (in)

R Average annual runoff (in)

S Constructed storage facility volume (in)

S_d Water loss parameter, depression storage, representing initial storm losses

t Duration of rainfall excess (hr)

t' The average difference between rainfall event duration and runoff event duration (hr)

T Storage operation efficiency factor

v Volume of rainfall (in)

v_1 Average volume of rainfall events less the rainfall volume loss parameter, s_d (in)

Appendix II

Discussion of Equation which gives Probability of a Non-Zero Overflow *

The function given by equation is different from that given by Howard because 1) it accounts for the discreet nature of the real data and includes a normalization of the continuous function used in development of the theory and, 2) it corrects a minor error in the original paper, Equation (12) of Howard reads:[1]

$$x = -\Omega b; \quad 0 \le b \le \infty \qquad (12)$$

and should be:

$$x = -\Omega b; \quad 0 \le b \le s/\Omega \qquad (12a)$$

This mistake results in an incorrect upper limit of integration which adds an additional term to the exponent of equation (23). The corrected equation is:

$$F_p(p_0) = \left(\psi \frac{1-e^{-\left[\left(\frac{\psi}{\Omega}+\zeta\right)s\right]}}{\psi+\zeta\Omega} + e^{-\left[\left(\frac{\psi}{\Omega}+\zeta\right)s\right]}\right) e^{-\zeta p_0} \qquad (23a)$$

which can be reduced to:

$$F_p(p_0) = \left[\frac{\psi + \zeta\Omega e^{-\left(\frac{\psi}{\Omega}+\zeta\right)s}}{\psi+\zeta\Omega}\right] e^{-\zeta p_0} \qquad (23b)$$

Douglas I. Smith of Charles Howard and Associates Ltd. noted the error in the development of the original equation (23) by Howard.

* Equation numbers refer to Howard[1]

Appendix III

BASIC Computer Program

This program calculates percent runoff and pollutant control for given storage and treatment.

```
100 REM*FROM "THEORY OF STORAGE AND TREATMENT-PLANT OVERFLOWS
105 REM*BY C.D.D. HOWARD, ASCE, VOL 102, NO. EE4, AUG. 1976
110 REM*MODIFIED AND IMPLIMENTED BY PAUL E. FLATT, (WITH HELP
115 REM*FROM DOUGLAS I. SMITH) CHARLES HOWARD AND ASSOCIATES LTD
```

```
120 REM*WINNIPEG, CANADA    TEL. (204) 474-1368
125 REM*********************************************************
130 PAGE
135 INIT
140 E=EXP(1)
145 PRINT "JJJ  STORAGE-TREATMENT ANALYSIS"
150 PRINT "JJ   ENTER NAME OF STATION - G ";
155 INPUT N$
160 PRINT "J ***** INPUT ALL CLIMATIC VALUES IN INCHES,HOURS"
165 PRINT "J ENTER TAU - G ";
170 INPUT W
175 PRINT "J ENTER THETA - G ";
180 INPUT T
185 PRINT "J ENTER ZETA  - G ";
190 INPUT Z
195 PRINT "J ENTER NO. OF VALUES AT 0.01 IN. IMPULSE - G";
200 REM THIS VALUE NEED NOT BE ENTERED IF DEPRESSION STORAGE
205 REM IS NOT EQUAL TO 0.01.  ENTER A NEGATIVE VALUE IN THIS CASE.
210 INPUT N3
215 PRINT "J ENTER PSI   - G ";
220 INPUT P0
225 PRINT "J ENTER LAMBDA- G ";
230 INPUT L0
235 PRINT "J ENTER BETA  - G ";
240 INPUT B0
245 PRINT "J ENTER DEPRESSION STORAGE(Sd) - G ";
250 INPUT D1
255 PRINT "J ENTER RUNOFF COEFFICIENT(PHI) - G ";
260 INPUT H1
265 PAGE
270 GOSUB 630
275 PRINT "J ENTER PARAMETERS FOR TREATMENT IN STORAGE FACILITY"
280 PRINT "    TREATMENT=A*LGT(RT)+B G";
285 INPUT E3,E4
290 PRINT "J ENTER MAXIMUM EFFICIENCY(FRACTION) G";
295 INPUT E7
300 PRINT "J ENTER EFFICIENCY OF TREATMENT FACILITY(FRACTION) G";
305 INPUT E1
310 PRINT "J ENTER EFFICIENCY OF STORAGE OPERATIONS ON OVERFLOWS  "
315 PRINT " ENTER AS A FRACTION - G";
320 INPUT E6
325 PRINT "J IN WHICH UNITS DO YOU WISH TO ENTER TREATMENT/STORAGE"
330 PRINT "  (INCHES,HOURS=1  - MG,DAYS=2) G";
335 INPUT C
340 C1=1
345 IF C=1 THEN 360
350 C=14.42981366
355 C1=C*24
360 PRINT "J ENTER RATE OF TREATMENT(NEGATIVE VALUE TO STOP)- G ";
365 INPUT O
370 IF O<0 THEN 620
375 O=O/C1
380 GOSUB 725
385 S=2/Z2*(LOG(Z2*O+P2)-LOG(P2))
390 PRINT "APPROX. MAXIMUM STORAGE FOR THIS TREATMENT IS ";S*C
395 PRINT "STORAGES LARGER THAN THIS WILL NOT INCREASE CONTROL"
400 PRINT " (BY MUCH)"
405 PRINT "J ENTER STORAGE CAPACITY - G ";
410 INPUT S
415 S=S/C
420 R9=S/(O*2)
425 E5=0
430 IF R9=0 THEN 460
435 E5=(E3*LGT(R9)+E4)/100
440 IF E5>0 THEN 450
445 E5=0
450 IF E5<E7 THEN 460
455 E5=E7
460 E2=1-(1-E1)*(1-E5)
465 REM END OF COMPUTATION OF EFFICIENCY
470 REM CALC OF F"P(0)
475 W1=P2*(S/O-W)
480 IF W1>0 THEN 490
485 W1=0
490 B1=P2*E^(P2*W)/(O*Z2+P2)*(1-E^-W1)
```

```
495 B2=E^-(U1+Z2*S)
500 F0=B1+B2
505 U6=N2*(F0/Z2)
510 U7=(U6*E5*E6+(R-U6)*E2)/R
515 PAGE
520 PRINT N$
525 PRINT "J TAU ";W
530 PRINT "J THETA ";T;"  Nr  ";N1;"  Ns ";N2;"  No ";N2*F0
535 PRINT "J ZETA ";Z;"   ZETA' ";Z1;" ZETA'' ";Z2
540 PRINT "J PSI ";P0;"  PSI' ";P;"  PSI'' ";P2
545 PRINT "J BETA ";B0;"  BETA' ";B
550 PRINT "J LAMBDA ";L0;"  LAMBDA' ";L
555 PRINT "J Sd  ";D1;"  PHI ";H1
560 PRINT "J STORAGE ";S*C
565 PRINT "J TREATMENT ";O*C1
570 PRINT "J RATIO STORAGE/TREATMENT ";S/O
575 PRINT "J PERCENT RUNOFF CONTROL ";(1-U6/R)*100
580 PRINT "JJ TREATMENT FACILITY EFFICIENCY ";E1
585 PRINT " STORAGE FACILITY TREATMENT EFFICIENCY ";E5
590 PRINT " CAPACITY-INFLOW RATIO ";R9
595 PRINT " OVERALL EFFICIENCY OF COMBINATION ";E2
600 PRINT "JJ PERCENT POLLUTANT CONTROL ";U7*100;
605 INPUT L$
610 PAGE
615 GO TO 360
620 STOP
625 END
630 P1=T/Z
635 IF N3<0 THEN 645
640 GO TO 675
645 V1=1/Z*(1-E^(-Z*D1)*(1+Z*D1))
650 N1=T*E^(-Z*D1)
655 R=P1-((T-N1)*V1+N1*D1)
660 R=R*H1
665 Z1=N1/R
670 GO TO 695
675 N1=T-N3
680 Z1=N1/(P1-T*0.01)
685 Z1=Z1/H1
690 R=N1/Z1
695 H=(T-1)/P0+T/L0
700 L=L0/(1-L0*1)
705 B=Z1/L
710 P=L*(N1-1)/(H*L-N1)
715 REM END OF COMPUTATION OF RUNOFF PARAMETERS
720 RETURN
725 U4=E^-(B*O)
730 U5=1/B*(1-U4*(1+B*O))
735 U5=U5+O*U4
740 Z2=1/Z1-U5/L
745 Z2=1/Z2
750 N2=N1*E^(-B*O)
755 P2=L*(N2-1)/(H*L-N2)
760 REM END OF COMPUTATION OF STORAGE,UTILIZING EVENT PARAMETERS
765 RETURN
```

APPENDIX V

CONTROL OF COMBINED SEWER OVERFLOWS

APPENDIX V CONTROL OF COMBINED SEWER OVERFLOWS

The pollutant loading from combined sewer overflows may be reduced by decreasing the volume of overflow or by increasing its quality. Methods to decrease the volume of overflow are primarily aimed at reducing the number of incidents, the duration, and the peak flows. This is usually accomplished by reducing or attenuating the stormwater component of combined sewage or by increasing the ability of the collection system to handle wet weather flows by modifications. Some of the stormwater management techniques discussed in Section 5 of this report are examples of methods designed to reduce or attenuate stormwater.

Modifications of sewer systems designed to reduce combined sewer overflows include partial or complete sewer separation, increased sewer capacity, utilization of existing system storage, additional storage facilities, removal of roof drains and downspouts, and express sewers. A study of the sewage system in the City of St. Thomas, Ontario, showed that the elimination of combined sewer overflows by sewer separation was the most cost-effective alternative to reduce wet weather pollution loadings from the City (1). In many cities, however, sewer separation has been shown to be more costly than other techniques for combined sewer overflow pollution abatement as shown in Table 1. In particular, storage is a cost-effective method of reducing combined sewer overflows, and both off-line and in-line storage facilities are applicable to combined sewer systems. In-line systems have been used in Seattle, Minneapolis - St. Paul, and Detroit. Generally they involve using gates or dams to prevent the release of wastewater to receiving waters by increasing system storage. Off-line storage facilities have been constructed at Chippewa Falls, Michigan; Akron, Ohio; New York City; Milwaukee, Wisconsin; Boston, Massachusetts; Chicago, Illinois; Washington D.C.; Sandusky, Ohio; Halifax, Nova Scotia; Welland, Ontario; and the Borough of East York (Toronto, Ontario).

A 45 500 m^3 (10 IMG) off-line combined sewage storage basin was built for the City of Welland, Ontario, in 1972 at a cost of $400 000 (3). The basin provides for retention of wet weather flows in excess of

APPENDIX V
TABLE 1 SEWER SEPARATION VERSUS CONCEPTUAL ALTERNATIVES (2)

Location	Capital Costs[a], $		Cost Ratio[b]	Alternative
	Separation	Alternative		
Boston, Mass.	997 280 000	779 692 000	1.3	Deep tunnel storage
Bucyrus, Ohio	15 957 000	9 220 000	1.7	Lagoon system
Chicago, Ill.	6 772 255 000	1 322 378 000	5.1	Storage tunnels and quarries
Cleveland, Ohio	372 405 000	111 842 000	3.3	Offshore stabilization ponds
Detroit, Mich.	2 859 185 000	2 859 000	1000.0[c]	Sewer monitoring and remote control of existing combined sewer storage system.
Seattle, Wash.	15 486 000	8 185 000	1.9[d]	Computer controlled in-sewer storage system
Washington D.C.	677 778 000	353 333 000	1.9	Tunnels and mined storage

[a] Adjusted to ENR = 2000.

[b] Ratio of separation cost to alternative cost.

[c] Alternative costs are for first phases only and do not include future total system.

[d] Separation costs are only for southwest and east central Seattle, while alternative costs are for the total combined sewer area.

the interceptor capacity, so that the combined sewage may be returned to a secondary treatment plant. The basin serves a 137 ha (95% residential, 5% industrial) area. A total volume of $1.6 \times 10^5 m^3$ or about 12% of the estimated combined sewage flow was captured during 1976 which would have otherwise been discharged untreated.

In many cases, storage facilities are designed to act as sedimentation basins as shown in Table 2. As such, they function as treatment works. Sedimentation facilities are highly sensitive to changes in hydraulic loading. Typically, large sized facilities with long detention times are required to provide significant combined sewage pollutant removal.

A 61 m long x 12.2 m wide x 4.6 m deep retention tank was constructed to store and treat the combined sewage overflows which would have occurred from a 6800 m^2 (168 acre) area in Halifax, Nova Scotia (3). Combined sewage is aerated, coarse screened, chlorinated, and allowed to settle in the tank before being discharged to the North West Arm of Halifax harbour. When flow rates in the interceptor drop, the retention tank is emptied back via the inlet channel and grit tank. The performance of the facility was evaluated from June to November 1970, and it was found that about 2/3 of the potential overflows were not discharged. About 30% to 70% of the NFR were removed during a 0.5 to three hours detention time.

Overflow regulators have been designed that incorporate quantity and quality control. One of these is the Swirl Regulator-Concentrator as shown in Figure 1. These regulators are primary-type systems designed for NFR removal from combined sewage. The swirl concentrator regulates flow by a central weir spill-way while treating the wastewater by a swirl action, which causes solids/liquid separation (5). The supernatant from the device may be stored, diverted for further treatment directly, or discharged. The concentrated settleable matter collected in the concentrator are transferred via a "foul sewer" (Figure 1) to the sanitary sewer. Tests of a swirl concentrator in Syracuse, New York, indicate that the device is capable of functioning efficiently over a wide range of combined sewer overflow rates (10:1). Effective NFR

APPENDIX V
TABLE 2 SUMMARY DATA ON SEDIMENTATION BASINS COMBINED WITH STORAGE FACILITIES

Location of Facility	Size (mil gal.)	Type of Storage Facility	Removal Efficiency (%)		Type of Residue Removal Equipment[a]
			NFR	BOD	
A. In operation					
Cottage farm detention and chlorinated facility, Cambridge, Mass.	1.3	Covered concrete tanks	45	Erratic	Manual washdown
Chippewa, Falls, Wis.	2.8	Asphalt paved storage basin	18-70	22-74	Solids removal by street cleaners
Columbus, Ohio					
Whittier Street	4.0	Open concrete tanks	15-45	15-35	Mechanical wash-down
Alum Creek	0.9	Covered concrete tanks	NA[b]	NA	Mechanical wash-down
Humboldt Ave., Milwaukee, Wis.	4.0	Covered concrete tanks	NA	NA	Resuspension of solids by mixers
Spring Creek Jamaica Bay, New York, N.Y.	10.0	Covered concrete tanks	NA	NA	Travelling bridge hydraulic mixers

APPENDIX V
TABLE 2 SUMMARY DATA ON SEDIMENTATION BASINS COMBINED WITH STORAGE FACILITIES (Continued)

Location of Facility	Size (mil gal.)	Type of Storage Facility	Removal Efficiency (%)		Type of Residue Removal Equipment
			NFR	BOD	
B. In planning or construction phase					
Mount Clemens, Mich.	5.8	Concrete tanks	--	--	Resuspension of solids and mechanical washdown by eductors
Lancaster, Pa.	1.2	Concrete silo	--	--	Air agitation and pumping
Weiss Street, Saginaw, Mich.	3.6	Concrete tanks	--	--	Mechanical and annual washdown

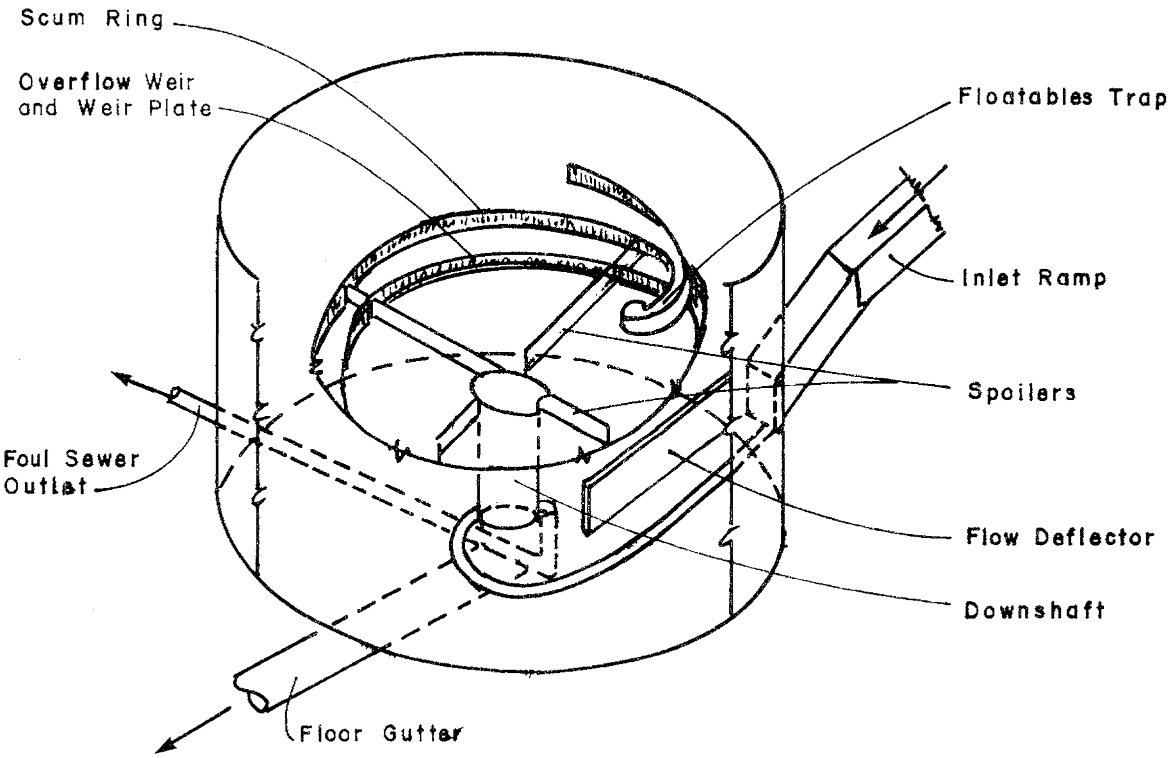
[a] All facilities store solids during storm event and clean sedimentation basin when flows to the interceptor can handle the solid water and solids.
[b] NA = not available

Note: mil gal. x 3785.0 = cu. m

separation was achieved at a fraction of the detention time required for conventional sedimentation (seconds to minutes versus hours by conventional systems) (5). At least 50% BOD_5 and NFR removal was achieved by this facility. Some other swirl concentrators installed in North America are described in Table 3.

Other physical removal systems such as dissolved air flotation, high rate filtration, and various types of screening have been used for combined sewer overflow treatment. Dissolved air flotation involves the use of fine air bubbles to float suspended matter. The residues are then removed from the liquid surface by skimming. Dissolved air flotation also aids in the removal of oil and grease (6). A complete prototype dissolved air flotation plant was constructed to treat combined sewer overflows in San Francisco. The plant is fully automated and includes bar screens, chemical feed equipment, pressurizing pumps, saturation tanks, two 325 l/sec dissolved air flotation tanks, and chlorination. Alum was found to be most effective to convert the influent residues to forms amenable to dissolved air flotation. On the average, the facility was found to remove 46% of the BOD_5, 48% of the SM, 99.91% of the fecal coliforms, 18% of the TN, and 81% of the ortho-PO_4 (8). A summary of the same systems in the United States is shown in Table 4.

Virtually every type of screen has been tested for combined sewer overflow treatment including: microstrainers, drum screens, rotary fine screens, and hydraulic sieves (Table 5). Generally, the micro-stainer is designed as a major treatment device that removes most of the NFR in combined sewer overflows. The other types of screens are designed to serve as pretreatment units which remove the coarser material found in the wastewater. Microstrainers and drum screens consist of a low speed, continuously back-washed drum rotating about a horizontal axis and operating under gravity conditions. The filter is usually a tight-woven wire mesh fabric. Microstrainers have screen openings from 15 to 65 microns, while drum screens have from 100 to 600 microns openings. A rotary fine screen is similar to a microstrainer and drum screen except the drum rotates at high speeds about a vertical axis. Typically a rotary screen has 74 to 230 micron openings. The hydraulic sieve



APPENDIX V

FIGURE I SWIRL CONCENTRATOR-REGULATOR

APPENDIX V
TABLE 3 SUMMARY OF SWIRL/HELICAL SOLIDS CONCENTRATOR-FLOW REGULATOR FACILITIES (7)

Project Location	Type of Facility	Unit Size Diameter (ft)[a]	Process Application	Period of Service
Denver, Colorado	Swirl	6	Sanitary and simulated wet weather swirl regulator concentrate-pilot scale grit removal	1975 - currently out of service
Lancaster, Pensylvania	Swirl - Unit 1	24	Residue concentration and flow regulation-prototype.	Under construction
	Swirl - Unit 2	8	Degritter for foul flow from Unit 1 - prototype.	
Lasalle, Quebec, Canada	Swirl	3	Residue concentration and flow regulation - hydraulic model studies with synthetic combined sewage.	------

APPENDIX V
TABLE 3 SUMMARY OF SWIRL/HELICAL SOLIDS CONCENTRATOR-FLOW REGULATOR FACILITIES (7) (Continued)

Project Location	Type of Facility	Unit Size Diameter (ft)	Process Application	Period of Service
Lasalle, Quebec, Canada	Helical bend	--	Residue concentration and flow regulation - hydraulic model studies with synthetic combined sewage	------
Nantwich, England	Helical bend	--	Residue concentration and flow regulation - prototype.	1971 to present
Rochester, New York	Swirl - Unit 1	3	Degritter - pilot.	1975 to 1976
	Swirl - Unit 2	6	Primary treatment - pilot.	
Syracuse, New York	Swirl	12	Residue concentration and flow regulation - prototype.	1974 to present
Toronto, Ontario, Canada	Swirl	12	Primary treatment of combined sewer overflows and municipal wastewater - pilot.	1975 to early 1977

a Outer chamber diameter.
ft x 0.3048 = m.

APPENDIX V
TABLE 4

SUMMARY OF TYPICAL DISSOLVED AIR FLOTATION INSTALLATIONS (7)

Project Location	No. of Tanks	Pressurization Mode	Design Flow (MGD)	Process Description	Period of Service
Milwaukee, Wisconsin Hawley Road	1	Effluent recycle and split flow	5.0	Pilot main treatment dissolved air flotation system with pretreatment screening and chemical addition	1969 to 1974
Racine, Wisconsin Site I	3	Split flow	14.1	Full scale main treatment utilizing screening for pretreatment	1973 to present
Site II	8	Split flow	44.4	Full scale main treatment utilizing screening for pretreatment	1973 to present
San Francisco, California Baker Street	2	Either split flow or effluent recycle	24.0	Full scale main treatment with chemical addition; facility has both float and bottom scrapers, with no pretreatment	1970 to present

MGD x 43.808 = L/s

APPENDIX V
TABLE 5 DESCRIPTION OF TYPICAL SCREENING INSTALLATIONS (7)

Project Location	Type of Screening Equipment	No. of Screening Units	Screen aperture (microns)	Screening Application	Period in Service
Belleville, Ontario	Rotary screen Static screen Static screen Rotostrainer	1 1 1 1	105 305 762 500	Pilot plant operating to test effectiveness of screening combined sewer overflows	1974 to 1975
Cleveland, Ohio	Drum screen	1	420	Pilot pretreatment to dual media filtration	1970 to 1971
Euclid, Ohio	Microstrainer	4	30	Dual use: dry weather effluent polishing 98% of time plus main treatment of combined sewer overflow	Under construction
Flint, Mich.	Microstrainer	6	20	Effluent polishing	Under construction
Ft. Wayne, Indiana	Static screen Drum screen Rotary screen	12 1 8	1525 147 105	Parallel screening facility to test effectiveness of various screens, main treatment and pretreatment	1975 to present
Milwaukee, Wisconsin Hawley Road Test 1	Drum screen	1	297	Pretreatment to dissolved air flotation	1969 to 1972

APPENDIX V
TABLE 5 DESCRIPTION OF TYPICAL SCREENING INSTALLATIONS (7) (Continued)

Project Location	Type of Screening Equipment	No. of Screening Units	Screen aperture (microns)	Screening Application	Period in Service
Test 2	Drum screens Microstrainer	2 1	841 149 63	Sequential screening main treatment, screens operated in series	1971
Test 3	Microstrainer	1	20	Main treatment of combined sewer overflow and dissolved air flotation effluent polishing	1973
Test 4	Drum screen	1	297	Pretreatment to dissolved air flotation with chemical addition	1974
Mt. Clemens, Michigan	Microstrainer	1	20 & 60	Polish pond effluent	1972 to 1975
New York City, New York	Rotostrainer Disc strainer	1 1	297 250 & 420	Pretreatment to high rate filtration	1975 to 1976 1976 to present
Norwalk, Connecticut	Microstrainer	6	35 or 70	Dual use: dry weather effluent polishing and main treatment of combined sewer overflow	Under construction
Oil City, Pennsylvania	Microstrainer	2	35	Dual use: effluent polishing and main treatment	1976 to present

APPENDIX V
TABLE 5 DESCRIPTION OF TYPICAL SCREENING INSTALLATIONS (7) (Continued)

Project Location	Type of Screening Equipment	No. of Screening Units	Screen aperture (microns)	Screening Application	Period in Service
Philadelphia, Pennsylvania	Microstrainer	1	23 & 35	Main treatment with dis-infection	1969 to 1974
Racine, Wisconsin					
Site I	Drum screen	2	297	Pretreatment to dissolved air flotation	1973 to present
Site II	Drum screen	4	297		
Site IIA	Drum screen	1	297	Main treatment	
Rochester, New York	Microstrainer	1	70	Pilot main treatment	1975 to 1976
Syracuse, New York	Rotary screen	1	105	Pilot main treatment	1974 to present
	Microstrainer	2	20 & 71		

consists of a fixed flat screen inclined at 25 to 35 degrees from the vertical with a header box that directs the flow down the screen. The wires making up the screen are placed in the horizontal direction with a spacing of 290 to 1600 microns. The characteristics of the various types of screens for combined sewer overflow treatment are shown in Table 6 (9).

Filtration has been shown to be more effective at treating stormwater runoff than sanitary sewage because of the reduced tendency to clogging by runoff residue. Examples for filtration facilities are shown in Table 7. Removal efficiencies for the Cleveland, Ohio plant were 65% NFR, 40% BOD_5, and 60% COD. With the addition of polyelectrolyte, the NFR removal increased to 94%, BOD_5 to 65%, and COD to 65%. Filtration units have been shown to provide good pollutant removal but costs are high (10).

Biological treatment of both industrial and sanitary wastewaters has been used extensively as a cost effective method to produce high quality effluents. The major problem in the application of this type of treatment to combined sewer overflows, is that the biomass must be kept alive during dry weather and must not be upset by erratic loading conditions. The systems constructed to date have overcome this problem, at least to a degree, by constructing wet and dry weather facilities side by side such that the biomass may be transferred, or by using treatment processes that can treat a highly variable flow and strength wastewater (trickling filters and rotating biological contactors), or by extended storage of combined sewer overflows with low biomass concentrations (lagoons). Storage is required to control the flow of combined sewer overflows into the treatment system for all cases except lagoons.

Contact stabilization has been used for the treatment of combined sewer overflows in Kenosha, Wisconsin (11). Waste activated sludge is utilized from a dry weather activated sludge plant. The design capacity of the plant is 88 l/sec (20 mgd). During 1972, the facility achieved 83% and 92% removal of BOD_5 and NFR from combined sewer overflows.

APPENDIX V
TABLE 6 CHARACTERISTICS OF VARIOUS TYPES OF SCREENS (7)

	Microstrainer	Drum Screen	Rotary Fine Screen	Hydraulic Sieve [a]
Principal use	Main treatment	Pretreatment to other devices and main treatment	Pretreatment to other devices and main treatment	Pretreatment to other devices
Approx. removal efficiency, (%)				
BOD	50	15	15	--
NFR	70	40	35	--
Land requir. (sq ft/mgd)	15 - 20	15 - 20	24 - 62	20
Cost ($/mgd)[b]	12 000	4800	8000	5600
Can be used as dry weather flow polishing device	Yes	No	No	No
Automatic operation	Possible with controls	Possible with controls	Possible with controls	No controls needed
Able to treat highly varying flows	Yes	Yes	Some limitation	Yes
Removes only particulate matter	Yes	Yes	Yes	Yes
Requires special shutdown and startup regimes	Yes	Some	Some	No
Screen life with continuous use	7 - 10 yr	10 yr	1000 hr	20 yr
Uses special solvents in backwash water	No	No	Yes	No
High residue conc. vol. (% of total flow)	0.5 - 1.0	0.5 - 1.0	10 - 20	0.5

a Information on hydraulic sieves is limited. Formal study on treatment of combined sewer overflows is just beginning.
b Based on a 25-mgd plant capacity.

Note: sq ft/mgd x 2.2 = sq m/cu m/sec
$/mgd x 0.38 = $/cu m/sec

NDIX V
E 7

DESCRIPTION OF COMBINED SEWER OVERFLOW HIGH RATE FILTRATION PILOT PLANT DEMONSTRATION FACILITIES (7)

oject cation	Process Description	No. of Filter Columns	Diameter of Columns (in.)	Pretreatment Facilities	Filter Media	Period of Operation
eland,	Pilot deep bed, dual media high rate filtration, with chemical addition. Facilities included pretreatment, storage and filtration	3 1	6 12	420 micron drum screen	5 ft of No. 3 anthracite over 3 ft of No. 612 sand	1970 to 1971
York City, York, on Creek	Pilot deep bed, dual media high rate filtration, with polyelectrolyte addition. Facilities include pretreatment, storage, and filtration. Dry weather and combined sewer flow is pumped from grit chamber of Newton Creek plant.	1 2	30 6	420 micron rotostrainer later replaced with a 420 micron disc strainer	5 ft of No. 3 anthracite over 2 ft of No. 612 sand	1975 to present
ester, York	Pilot deep bed, dual media high rate filtration with chemical addition	3	6	Screening	5 ft of No. 1-1/2 or No. 2 anthracite over 3 ft of No. 1220 sand	1975 to 1976

tems operated at flux rates ranging from 8 to 30 gal/ft^2 min.
h rate deep bed filtration has recently, (October-November 1976), been piloted directly on stormwater runoff in the nehaha Creek Watershed near Wayzata, Minnesota, under USEPA demonstration grant S-802535. Pretreatment storage was vided to lengthen filtration runs. Publication of result is expected shortly.

x 2.54 = cm
0.305 = m
ft^2 min. x 0.679 = L/m^{2}s

A demonstration project in Providence, New Jersey, tested the effectiveness of a trickling filter to treat both dry weather flow and combined sewer overflows from a heavily infiltrated sewer (12). The plant is designed for a dry weather flow of 26.3 l/sec (0.6 mgd) and maximum wet weather flow of 263 l/sec (10 mgd). Two trickling filters are utilized with one measuring 11 meters in diameter by 4.4 m high packed with a plastic medium, and the other 19.8 m in diameter by 1.8 m which is packed with stone. Under normal operation, the two filters operate in series with the plastic medium filter first. At flows above 123 l/sec (2.8 mgd) the plants automatically switch to parallel operation. Removal efficiencies have been reported to be 85% to 95% for BOD_5 and NFR during dry weather flow and 65% to 90% during wet weather flow. Both filters recover rapidly after returning to dry weather conditions.

Lagoons for combined sewer overflow treatment often have multiple uses. They can be used as dry weather treatment plant effluent polishers or inflow equilization basins. Examples of lagoons used for the treatment of combined sewage are shown in Table 8. Pollutant removal efficiencies reported for these facilities are variable , but generally good with BOD_5 and NFR removal usually above 50%.

By far, most of the disinfection of combined sewer overflows has been accomplished using some form of chlorine, although ozone has been tested as an alternative (Table 9).

A demonstration project of the use of chlorination for combined sewer overflows in Philadelphia, Pennsylvania (13), showed that chlorine contact times of only two minutes, under relatively high turbulence conditions and with chlorine dosages as low as 5 mg/l, could effect a reduction of total coliforms from 1 000 000/100 ml in the combined sewer overflow to 5 to 10/100 ml. Fecal coliform concentrations were reduced from 100 000/100 ml to 5 to 10/100 ml. Tests using ozone indicated that an ozone concentration of 3.8 mg/l was required to match the performance of 5 mg/l of chlorine.

APPENDIX V
TABLE 8 COMPARISON OF DIFFERENT TYPES OF LAGOONS TREATING COMBINED SEWAGE FOR VARIOUS CITIES (7)

Location	Type of Lagoon	Size (acres)	Volume (mil. gal.)	Detention Time (days)	Design Flow Rate (mgd) [a]
Springfield, Ill.	Equalization-oxidation pond	10	22.4	0.3	67
Shelbyville, Ill.					
Southeast site	Storage-oxidation pond	1	1.9	5.0	0.3
Southwest site	Storage basin	3.9	4.0	2.8	1.4[b]
	Facultative pond	10.8	13.0	9.0	1.4[b]
	Facultative pond	2.1	2.1	1.5	1.4
Mt. Clemens, Mich.	Storage-aerated lagoon	1.5	5.6	5.6	64.6[c]
	Oxidation pond	2.8	8.2	8.2	1.0
	Aerated lagoon	2.3	7.0	7.0	1.0
East Chicago, Ind.	Aerated facultative lagoon	30	185	1.0	185

a Designed outflow rate; inflow can be much greater.
b Storm flow rate; the ponds also treat 0.3 mgd of trickling filter effluent.
c Design storm flow rate; outflow is 1.0 mgd.

Note: acre x 0.405 = ha
mil gal x 3785.0 = cu m
mgd x 3785.0 = cu m/day

APPENDIX V
TABLE 9 SUMMARY OF DEMONSTRATION STORMWATER DISINFECTION PROJECTS (7)

Project Location	Disinfectant Agent	Source	Description of Disinfection System	Period of Operation
Boston, Massachusetts Cottage Farm Detention and Chlorination Station	Sodium hypochlorite (NaOCl)	Purchased/ stored	Automatic disinfection system injects up to 3000 gal of 10 to 15% NaOCl into the influent channel to the detention basins for the design storm.	1971 to present
Cleveland, Ohio	Sodium hypochlorite (NaOCl)	Purchased/ stored	Disinfection of two bathing batches enclosed by fabric barriers and disinfection of polluted streams and overflow points influent to Lake Erie.	1968 to 1970
Fitchburg, Massachusetts	Sodium hypochlorite (NaOCl)	Purchased/ stored	High rate application of disinfection via thin film in a Dynactor. System incorporates chemically assisted high rate settling.	1974 to present
New Orleans, Louisiana	Sodium hypochlorite (NaOCl)	Central generation	NaOCl is generated at a central manufacturing facility with a capacity of 1000 gal/hr. The 12% NaOCl is transported and stored at 4 pumping stations on 3 overflow channels to disinfect pumped stormwater.	1972 to present

APPENDIX V
TABLE 9 SUMMARY OF DEMONSTRATION STORMWATER DISINFECTION PROJECTS (7) (Continued)

Project Location	Disinfectant Agent	Source	Description of Disinfection System	Period of Operation
New York City, New York Spring Creek	Sodium hypochlorite (NaOCl)	Purchased/ stored	Automatic disinfection system injects up to 60 000 lb/d of 5% NaOCl into the inlet sewer of the storage/ detention facilities	1972 to present
Philadelphia, Pennsylvania	Sodium hypochlorite (NaOCl)	Purchased	Comparison of two disinfectants on screened and unscreened combined sewer overflow. Short contact times are achieved by high velocity gradients in a plug flow contact chamber regime.	1969 to 1973
	Ozone (O_3)	On-site generation		
Rochester, New York	Chlorine (Cl_2)	Purchased	Sequential addition of Cl and ClO with flash mixing at each point of application. Disinfection is final treatment step following sedimentation, storage, dual media filtration, and carbon column pilot facilities.	1975 to 1976
	Chlorine dioxide (ClO_2)	On-site generation		
Syracuse, New York	Chlorine gas (Cl_2)	Purchased	Evaluation of individual and sequential addition of Cl and ClO following treatment of combined sewer overflows by screening and swirl concentration.	1974 to present
	Chlorine dioxide (ClO_2)	On-site generation		

gal x 3.785 = L
lb/d x 0.454 = kg

APPENDIX V REFERENCES

1. "Stormwater Management Technology Systems Demonstration in the City of St. Thomas", James F. MacLaren Ltd., (May 1978).
2. Lager, J.A., and W.G. Smith, Urban Stormwater Management and Technology - An Assessment, Metcalf and Eddy Inc., Environmental Protection Agency, EPA-670/2-74-040, pp. 151, (December 1974).
3. Tonelli, F.A., Treatment Technology of Urban Runoff, in Modern Concepts in Urban Drainage - Conference Proceedings No. 5, Canada-Ontario Agreement on Great Lakes Water Quality, (March 1977).
4. Lager, J.A., and W.G. Smith, p. 216.
5. Field, R., "Development of and Application of the Swirl and Helical Bend Devices for Combined Sewer Overflow Abatement and Runoff Control", paper presented at USEPA Technology Transfer Seminar Series on Combined Sewer Overflow Assessment and Control Procedures, (1978).
6. Lager, J.A., and W.G. Smith, p. 221.
7. Lager, J.A., "CSO Treatment - Potential and an Information Source for Small to Medium Sized Communities", paper presented at USEPA Technology Transfer Series on Combined Sewer Overflow Assessment and Control Procedures, (1978).
8. Lager, J.A., and W.G. Smith, p. 230.
9. Ibid., p. 233-253.
10. Ibid., p. 256.
11. Ibid., p. 263.
12. Ibid., p. 270.
13. Ibid., p. 346.

APPENDIX VI

PROPOSED STORMWATER MONITORING PROGRAMS

1) Stormwater Pollutant Loads
2) City of Vancouver's First Flush Separators
3) Sensitive Pollutant Concentrations
4) Impact of Stormwater on the Fraser River/Estuary

APPENDIX VI PROPOSED STORMWATER MONITORING PROGRAMS

Very little stormwater monitoring has been conducted in the GVRD - not enough to be certain that estimates of pollutant loadings to the receiving water are realistic. Since stormwater quality and quantity vary considerably, the monitoring programs must be carefully designed to address specific questions.

There are four major subjects which should be addressed by stormwater monitoring programs conducted in the GVRD. These are:

1) recalculation of stormwater pollutant loadings to the Fraser River/Estuary based upon monitoring data and a more comprehensive analysis;
2) assessment of the performance of the City of Vancouver's first flush separators;
3) direct identification of the more important pollutants to be found in stormwater as noted in receiving water quality assessments and objectives;
4) investigation of the impact of stormwater discharges on the water quality of the Fraser River/Estuary;

1) Stormwater Pollutant Loads

a) Wet Weather Stormwater Pollutant Loads

A stormwater monitoring program should be conducted in the GVRD to obtain pollutant accumulation and washoff rates which can be used to calculate representative stormwater pollutant loads. It is necessary to confirm that the accumulation and washoff rates calculated for other cities in North America apply to the GVRD. A monitoring program is recommended to obtain these parameters for each of the land use groups, and to generate other data required to verify and calibrate a model. Runoff quantity parameters used as input data to a model, such as runoff coefficients and hydrograph characteristics, will also be identified by the monitoring program. The program must be designed to provide the necessary data for stormwater models and will provide valuable insights into the relationship between stormwater quantity and quality, precipitation patterns, and land use in GVRD. This information has not been gained by programs conducted in the GVRD up to now.

Regardless of the technique employed to calculate stormwater pollutant loadings, reliable monitoring data must be available. Single grab samples are not sufficient to determine average pollutant concentrations, accumulation or washoff rates. As such, the work done to date in the GVRD is not suitable for this project. Sequential grab or composite samples are required to characterize stormwater parameters. Analyses of sequential grab samples provide data which may be used to determine the time variation in stormwater quality. Determination of this variation is particularly important if continuous simulation models such as STORM or SWMM are employed, since these models require calibration and verification. Moreover, sequential grab results provide a better understanding of the stormwater system by identifying the presence or absence of a first flush or flow-related pollutant discharge. This is vital information in assessing the effectiveness of stormwater management of the overflow control devices in the GVRD.

It is expected that there is a seasonal variation in stormwater pollutant loading in response to the changing number of antecedent dry days, runoff volumes, and rainfall intensities.

In many respects, the monitoring of runoff from single land uses such as residential, commercial, industrial, agricultural, or open spaces is preferable over mixed land use areas since accumulation and washoff rates may be determined separately. However, there are likely few catchments in the GVRD of suitable size with easily accessible sampling points. Where possible, single land uses should be used. An exception to this would be streams which drain a large area of the GVRD. Monitoring of these would provide pollutant loadings for a large section of the region without the need for modelling. If economic constraints require that only three land use groups may be monitored, then residential, commercial, and industrial sites should be chosen. Residential areas occupy the largest land area while research indicates that commercial and industrial areas could contribute the greatest quantity of pollutants per unit area.

In other studies conducted of stormwater in North America determinations have been done for many chemical and bacteriological parameters. Parameters for the proposed program should normally be related to receiving water concerns. A possible list includes COD, BOD_5, TR, NFR, TP, specific conductance, TN, NH_3, NO_3, pH, DO, fecal coliforms, fecal streptococci, and total and dissolved metals (Cu, Pb, Zn, Cd, Hg, Ni). Analytical parameters may be added or deleted based upon preliminary results of the program which may show that some of these are correlated.

In addition to water quality determinations, water flow and precipitation must be recorded. GVSDD or Environment Canada rain gauges may be used if one is located close to the sampling areas. Flow measurements should be made over the entire runoff event. Runoff coefficients and pollutant washoff rates as a function of precipitation volume or intensity may be determined from this information.

It is proposed that an attempt be made to obtain samples and measure flows for every precipitation event that occurs in a nine month period from July 1 to March 30 at each of the selected land use catchments. This program should be patterned after studies conducted in Seattle.

A study of stormwater pollutant loadings in Seattle was conducted from October 1974 to December 1975 and included collection of rainfall data, runoff quantity and quality. Three sites were monitored - these represented residential, commercial, and industrial land uses. The data was gathered in an attempt to define the factors (rainfall volume and intensity, land use, antecedent conditions, etc.) and relationships that affect pollutant loadings, and to establish a statistically valid data base deemed necessary for stormwater model calibration. Samples were collected by automatic samplers set to collect samplers every 15 minutes (two 7.5 minute samples composited). Samplers and flow measurement equipment were triggered by a pressure switch which operated when the flow in the storm drain reached a specified level. About 150 storms were sampled during the study period, however, only 88 of these produced useful data (59%) due to equipment failures and inadequate precipitation, among other problems. Some results from this program were presented in Appendix I (Page 72 to 75).

Detailed raw and processed data from this Seattle study is available. If the proposed nine-month GVRD study yields similar results to the Seattle work, then the methods used there may be applied here. The GVRD monitoring program may have to be extended if a correlation is not determined or if inadequate volume storms are sampled. It is important to obtain a wide range of rainfall intensities, antecedent conditions, and precipitation volumes as possible since washoff and accumulation rates must reflect an average condition. The nine-month period from July to March should encompass such a range.

Data from the monitoring program should be processed continously and an evaluation made at the end of each three-month period to determine the range of precipitation events encountered. If a representative range of events has been sampled and additional resources are available then it is recommended that other catchments in the selected land use designations be monitored.

It is difficult to estimate the costs and manpower requirements for the proposed stormwater monitoring program in the GVRD. An attempt is made here using local costs of sampling and flow measurement equipment, and manpower requirements for the Seattle study (Table 1).

A suggested sampling set-up is discussed in an ancillary report in this series (reference 11, main text).

b) Dry Weather Stormwater Pollutant Loads

Dry weather stormwater pollutant loads could be significant. It is suggested that 24-hour composite samples and flow measurments be obtained once per month during dry weather intervals for 10 catchments over a six-month period. The samples should be analyzed for the same parameters noted in the wet weather stormwater monitoring program.

c) Combined Sewer Overflows

The frequency, duration, and flow of combined sewer overflows from the GVRD should be obtained over a three-year period. The quality of these overflows may be approximated from data obtained from the sewage treatment plants with appropriate dilution factors. Moreover,

APPENDIX VI

TABLE 1 ESTIMATED CAPITAL COSTS AND MANPOWER REQUIREMENTS FOR STORMWATER MONITORING PROGRAM

Capital Costs

a) 3 flowmeters (gas bubblers or equivalent)	$7500
b) 3 flumes or weirs	1800
c) 3 automatic samplers	8400
d) 3 security housings	600
	$18300

Manpower Requirements (1) (manhours/month)

a) field equipment maintenance	71
b) actual field sampling	68
standby time	33
c) laboratory analyses	214
d) data processing and compiling	204
TOTAL	590 hr/month or 79 days/month or 3.5 employees

(1) Farris, G.D., *et al*, "Urban Drainage Stormwater Monitoring Program", Municipality of Metropolitan Seattle, Seattle, Wash., March 1979.

results of the City of Vancouver's study of combined sewers will provide some quality data. The implementation of any further studies of combined sewer overflows should be delayed until the Vancouver report is reveiwed.

2) City of Vancouver's First Flush Separators

No monitoring has been done to assess the performance of these separators. A monitoring program should be conducted to:

a) determine the actual quantity of stormwater which is diverted to the sanitary system by the separator.
b) determine the quality of stormwater which is diverted.
c) determine the total pollutant load diverted relative to the total stormwater load for the event.
d) recommend modifications to the separator design as required to increase its efficiency.

3) Sensitive Pollutant Concentrations

A review of the literature reveals that complex chlorinated hydrocarbons, heavy metals, and other toxic persistant compounds have been found in stormwater elsewhere in North America. Should either available data or information obtained in furture studies of the Fraser River/Estuary water quality, sediments, or aquatic organisms indicate that there is a contaminant of special concern, it is recommended that samples of stormwater in the GVRD be obtained and analyzed for that pollutant.

Stormwater samples were collected by the WIB during autumn 1978 and analyzed for pesticides. There was little evidence of pesticide contamination of stormwater, however, samples should be collected during the high-use periods of spring and early summer. If organic chemical scans are conducted of other effluents, then one should be performed on composite stormwater samples. These may include samples from each of the land use groups selected for study in the wet weather stormwater monitoring study.

4) Impact of Stormwater on the Fraser River

Monitoring at the Carrington Street storm drain conducted by the provincial WIB and PCB in August 1978, demonstrated that the stormwater discharges was of poorer water quality than the Fraser River. It is doubtful if the stormwater discharged from one storm drain would have a significant effect over the entire cross-section of the Fraser River. However, it is possible that the water quality of the river could be degraded for some distance out from shore and for some distance downstream on that side. This may be called an "edge effect". The existence, extent, and quality of this edge effect, particularly in small tributary streams and sloughs, is not known but should be investigated. Data gathered on this subject would aid in determining the impact of stormwater discharges on fish habitats in the Fraser River and the design of stormwater outfalls which minimize adverse impact.