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THE OCEANOGRAPHIC PHASE OF THE VANCOUVER SEWAGE PROBLEM

Author

R.L.I. FJARLIE

JOINT COMMITTEE ON OCEANOGRAPHY

The Oceanographic Phase of the Vancouver Sewage Problem

by

R. L. I. FJARLIE

Pacific Oceanographic Group
Nanaimo, B. C.
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Acknowledgements

This research was initiated by request of the Vancouver and Districts Joint Sewerage and Drainage Board who contributed personnel, funds and equipment to the phases of direct concern to the sewage problem.

The National Research Council supported the research with a grant covering salaries and special equipment to further the collection of data for fundamental study of the behaviour of a marine estuary, and the dispersion of fresh water in the sea.

The Institute of Oceanography of the University of British Columbia provided office and laboratory space, and the staff assisted with advice and criticism.

The British Columbia Lands and Forests Department (Air Surveys Branch) conducted 14 photographic surveys of the approaches to the estuary, and assisted in interpretation of the photographs.

The Tidal Branch of the Hydrographic Service of Canada undertook a tidal current survey of English Bay and Vancouver Harbour in co-operation with this research. The present conclusions are confirmed by these data, which are not cited because they will be reported independently by the Tidal Branch.

R.L.I. Fjarlie

AERIAL VIEW LOOKING INTO ENGLISH BAY

Cloud of North Arm water forming off Point Grey

Figure 1
Falling Tide

Cloud of North Arm water fully formed

Figure 2
Low Tide

B.C. Government Photography

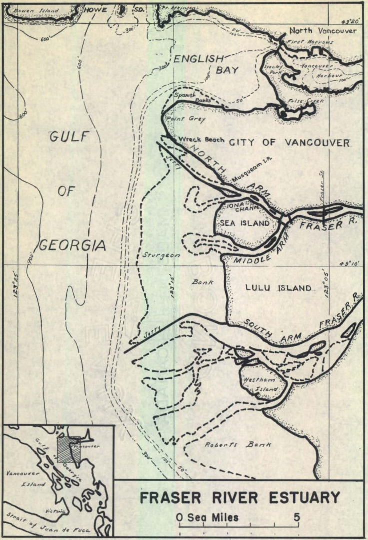

Bowen Island
HOWE SD.
Pt. Atkinson
North Vancouver
49°20'
First Narrows
ENGLISH BAY
Stanley Park
Vancouver Harbour
Spanish Banks
False Creek
Point Grey
GULF OF GEORGIA
Wreck Beach
CITY OF VANCOUVER
NORTH ARM
Jetty
Musqueam I.R.
Fraser St.
IONA CHANN.
SEA ISLAND
FRASER R.
MIDDLE ARM
49°10'
Sturgeon Bank
123°15'
LULU ISLAND
123°05'
123°25'
Jetty
SOUTH ARM
FRASER R.
Westham Island
Roberts Bank
Vancouver Island
Gulf of Georgia
Vancouver
Victoria
Strait of Juan de Fuca
FRASER RIVER ESTUARY
0 Sea Miles 5

Figure 5

PACIFIC OCEANOGRAPHIC GROUP

Report

THE OCEANOGRAPHIC PHASE OF THE VANCOUVER SEWAGE PROBLEM

(File N 7-18 - December 15, 1950)

INTRODUCTION

The immediate possibility of pollution of the beaches around Vancouver by raw sewage has necessitated a comprehensive oceanographic investigation, to find out if there is any natural means of sewage disposal by ocean currents. This investigation was started by the Vancouver and Districts Joint Sewerage and Drainage Board (The Sewerage Board) in November, 1949 with advice from the Pacific Oceanographic Group, and in May, 1950 the Group, with assistance from the National Research Council and the Sewerage Board, assumed the responsibility.

Geography

Vancouver is concentrated on the peninsula between Burrard Inlet and the Fraser River. The north shore of the inlet is also well populated, and Lulu Island and Sea Island to the south, which were at one time rural communities, can now be classed as suburban.

The public bathing beaches extend from Wreck Beach in the North Arm of the Fraser River all around English Bay. There are a few beaches and pools within Vancouver Harbour which are mostly artifical and protected by sea walls.

The western boundary of the Fraser River delta is Sturgeon Bank, an extensive alluvial mud and sand bank. It is intertidal land, drying at low water, and completely covered by a twelve foot tide rise. At its edge the sea bottom drops off very steeply reaching 300 feet depth in about 1/4 mile from the low tide boundary. Its southern limit is bounded by a stone jetty; although this was built to contain the main arm of the river it is covered by water at high tide and can only be identified by the line of piles along its crest, through which the river flows freely. The northern limit of the bank is also bounded by a stone jetty, higher than the southern one, and above water most of the time. It contains the North Arm of the river where about 6% of the total discharge of the Fraser is released.

Burrard Inlet is a deep fjord extending about 23 miles inland from Georgia Strait. The outer part, English Bay, is where most of the beaches are concentrated. The bottom has a gradual slope from the southern shore to about 300 feet depth, and a much steeper slope rises to the northern shore. English Bay is connected to Vancouver Harbour by First Narrows, through which the tide floods and ebbs with a high velocity, approaching six knots. This flow is turbulent, mixing the water thoroughly from top to bottom, and creating a noticeable current along the north shore of the bay.

False Creek is a small inlet in the heart of the industrial section of the city, and a great number of factories, sawmills, and shipyards are located around it. The fresh water drainage into this inlet is very small and most of it comes from sewers.

The whole area is tidal and is dominated by the Fraser River discharge. The declinational tide is characterized by a diurnal inequality, which alternates from spring to neap ranges in a bi-weekly cycle.

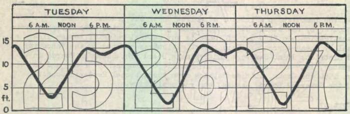


Figure 6 - Spring tides at Point Atkinson July, 1950

During the week of springs (Fig. 6) the tide falls very low on one ebb and rises high on the following flood. There is then a relatively quiescent period when it remains high with only a very minor fall and rise. The cycle repeats with the start of the next strong ebb.

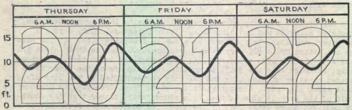


Figure 7 - Neap tides at Point Atkinson July, 1950

In the neap tide week (Fig. 7) there are two similar tides of small amplitude each day.

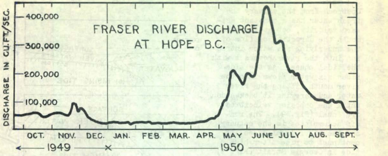


Figure 8 - Fraser River discharge 1949-50

The Fraser River releases fresh water into the system at a variable rate from winter to summer (Fig. 8) the peak summer discharge being almost ten times the average winter discharge. The freshet starts during the first part of May, and the river rises very rapidly to a maximum in mid June, after which it drops gradually to winter levels in October.

The river remains relatively constant for one tide cycle (rise and fall) and imposes a variable seasonal bias on the daily tidal circulation.

Estuary Mechanism

When the Fraser River water reaches Georgia Strait it flows out over the saline sea water forming a distinct "upper layer" which is freshest near the river: it is distinguished by the large amount of suspended silt, and is very shallow. In many places the turbulence caused by a ships propellor is enough to stir up the underlying green sea water so that it can be seen.

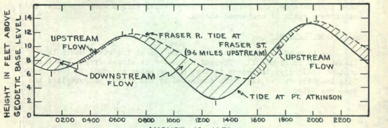


Figure 9 - Relative height of tide water and river at Fraser Street

Upstream from the estuary the fresh water has a constant seaward velocity, but at the river mouth the direction of flow of the underlying sea water intruding into the river reverses with the tidal phase. As the tide rises sea water flows into the river mouth lifting the river water and carrying it backwards until the opposing velocities are equal (Fig. 9). The run-off accumulates in the estuary and the river level rises; it continues to rise after high tide in Georgia Strait (Fig. 9) while the level of the sea is dropping. The upstream velocity vanishes at the start of the ebb, and the upper layer of fresh water moves seaward at an accelerated rate, urged on by the velocity head of the river and the pressure difference between the estuary and the sea. The accumulated run-off is released as a cloud of brackish water which is carried clear of the river mouth by its momentum and the tidal currents (Fig. 10. a,b,c). It is separated from earlier clouds in the system by their net progress during previous tidal cycles. The clouds may remain distinct for several cycles but eventually they mix with the underlying salt water and tend to lose their identity as they merge along the line of flow.

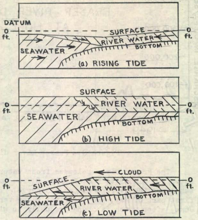


Figure 10

When the river is very high (300,000 c.f.s.) it is always above sea level and it discharges continuously throughout the tide cycle. Under this circumstance, the rate of discharge still varies with the tide, and so forms a chain of connected clouds.

Sea Water Structure

The type of structure imposed on the sea at the river mouth is illustrated in figure 11. The surface water is almost fresh, and the salt content (salinity) increases to that of sea water at about 20 feet depth. This brackish "upper layer" is dominated by the river, and overlies the deep sea water.

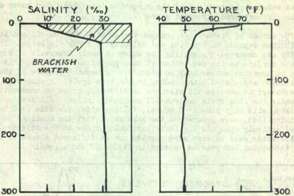


Figure 11 - Salinity and Temperature Structure

The low density of the river water makes it stable on the surface of the sea. The stability is further increased in the summer by surface heating, but temperature is a secondary factor in the determination of the density of this system, and even in the winter when the upper layer is the colder, the low salt content controls its density and ensures that it will float on the sea water.

Properties of Sewage

The discharge of Vancouver sewers is small compared to the Fraser River and has no significant effect on the water mass circulation. It is combined storm water and sanitary sewage, whose principal constituent is fresh water and is always stable in the upper layer. When it is released directly into the upper layer (e.g. on the beach) it will remain in and partake of its movements. When the sewage is released into the deep sea-water zone it will rise to the surface forming an upper zone (Vancouver Harbour) or if an upper zone already exists the sewage will become stable in it (Imperial Street outlet). In every case the eventual distribution of sewage is the same as that of the upper zone moving past the release point.

The Investigation

The presence of fresh water can be detected by the dilution (reduction of salinity) of sea water as illustrated in figure 9. The amount of fresh water present is conveniently defined as the depth of the layer, if the fresh and sea water (salinity 30.2°/..) were separated. The distribution of fresh water is illustrated by contours of its virtual depth interpolated between observations of the structure (Fig. 11) taken under comparable circumstances (Synoptic Survey).

The amount of fresh water present varies with the run-off and its distribution depends on the tide and velocity of river discharge. The salinity was observed by sampling the water at small intervals of depth from the surface to the sea bottom at many positions. Ideally, this should be done instantaneously to provide a "synoptic" picture of the distribution associated with a point in the tide cycle. Practically, it was necessary to observe all stations in different order on consecutive days while the tide cycle and run-off remained similar. All stations associated with high tide (+ 2 hours), falling tide, low tide (+ 2 hours), and rising tide, were grouped on the assumption that the combined pictures were effectively synoptic for their particular stage in the tide cycle. Synoptic water mass surveys were carried out at different stages of the river throughout the year as indexed in figure 12 and appendix I.

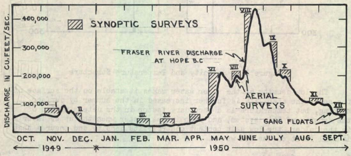


Figure 12 - Schedule of Principal Observations

Interpolation of the depth of fresh water between stations was facilitated by aerial surveys, which showed the distribution of surface muddy water every two hours during the principal fall and rise of a spring and neap tide cycle. Fourteen flights were made, to take 1500 vertical and oblique photographs along the aircraft's track, each photograph having a 60% overlap. The positions of silt laden clouds of river water shown in the pictures (Fig. 1 to 4) from each flight were combined into charts.

Comparison of successive synoptic water mass and aerial survey charts show the changes in distribution of the water masses they represent. These changes mark the path of tidal circulation, and the progress of the water mass in a tidal cycle is a measure of the transport.

A water mass (cloud) may be transported ahead five miles on the flood tide, and return four miles on the ebb. Under this circumstance direct current measurements would indicate velocities of the order of 3/4 of a knot. However the important conclusion from the standpoint of sewage disposal is that the net transport was only one mile. This and the successive positions of the water mass are more readily discernable from synoptic surveys, than from direct current measurements.

If sufficient velocity measurements are made at various positions in relation to the stages of the tide and river, it should be possible to combine them into continuous flow patterns and deduce the transport. Velocity may be measured with a current meter, or by measuring the rate of drift of a float from an anchored ship. Alternatively one or more floats at different depths may be followed for a period, and their successive positions noted. Earlier researches were limited to this approach, and although an impressive quantity of data were assembled they were not conclusive by themselves. However direct current measurements are necessary to interpret local situations (Imperial Street) and provide velocity scales in confined regions, such as the North Arm, First Narrows, etc. These are not shown in the aerial or water mass surveys.

The contribution of the Sewerage Board in making direct current measurements by charting the progress of free floats has been very complete, as shown in Appendix I, and has assessed the day to day changes in the tidal circulation.

The progress of a cloud structure past points in the area was measured by observing the changes in structure and the current direction and velocity, at frequent intervals of time from an anchored ship. These anchor stations were occupied at intervals in the Fraser River outlets, and upstream in the North and South Arms.

It was found advantageous on several occasions to release a gang of about 100 free floats at a point and observe their progress and dispersion for several days. This allowed statistical study of dispersion and progress of the surface water, particularly in the vicinity of the North Arm and Iona Channel.

MOVEMENTS OF WATER MASSES

The distribution of the fresh water in the area at successive tidal stages is shown in figures 13 to 25 and the movements are deduced from the successive positions of the identifiable clouds.

These pictures were compiled from the synoptic surveys of July 18 to 28 when the discharge of the Fraser River was about 200,000 cubic feet per second, and represent the conditions in mid-summer. They were interpreted with the aid of the aerial survey data, and are consistant with data from previous and subsequent surveys. The contours on the charts represent the depth in feet of the fresh water present in 25 feet of mixed water, if the fresh and sea water (30.2‰) were separated.

The South Arm

Figure 13

During the falling tide a cloud (A) of discharge water forms at the river mouth.

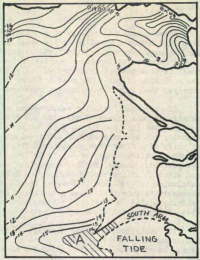


Figure 14

As the tide continues to fall the cloud (A) grows in size, and at low water it is of considerable extent, although still concentrated near the river mouth.

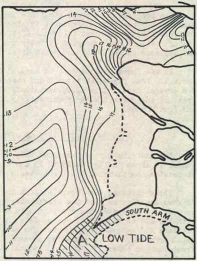


Figure <u>15</u>

The rising tide now moves the cloud A rapidly northward, separating it from the river mouth

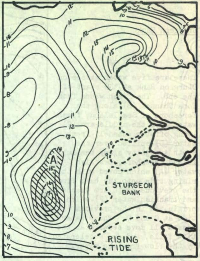
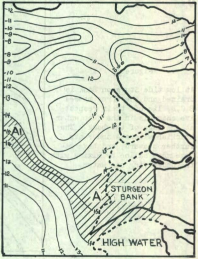


Figure <u>16</u>

At high water the cloud can be distinguished as a band of brackish water lying northwest from the river mouth. Some of it (A) extends over Sturgeon Bank and becomes part of the "bank water" to be discussed later. The remainder (A 1) all mixes with the seawater during the next ebb and leaves the system.

During the tide cycle the river water has mixed with underlying sea water and the salinity of the cloud has increased.



Sturgeon Bank

Figure 17

There are five water masses on Sturgeon Bank at the start of the ebb. The fresh water from Iona Channel (B) along the foreshore of Sea Island, fresh water from the middle arm (C) lying off the channel, fresh water (D) spilled over the South Arm jetty along the Lulu Island foreshore, brackish water (A) which moved with the rising tide onto the bank from the previous South Arm discharge and brackish water (F) which originated in the previous tide at C and D. These water masses all move seaward as the tide falls, and are accelerated by the flow from the river.

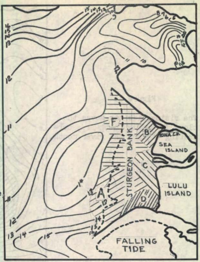
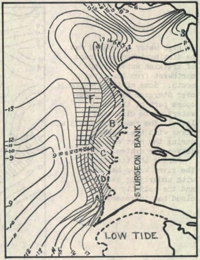


Figure 18

At low tide Sturgeon Bank is drained and the three masses B,C,D, lie off their respective channels in the deep water at the edge of the bank. The brackish waters A and F are further seaward, and have become more saline by mixing with the underlying sea water.



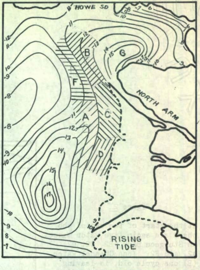


Figure 19

With the rising tide all of the seawater masses move rapidly northward mixing with the underlying sea water enroute, and extend toward Howe Sound, seaward of North Arm water (G).

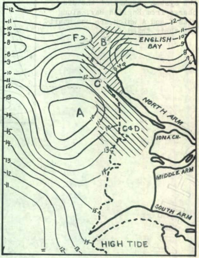


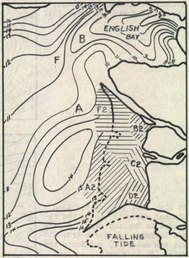
Figure 20

At high tide part of the Iona Channel water (B) is in the entrance to English Bay, and part has intruded the North Arm. Middle Arm water (C) and South Arm water (D) have retreated onto Sturgeon Bank, and seaward of them the brackish water (A) from the South Arm is two cycles old and has almost lost its identity.

The brackish water (F) which originated at C and D two tide cycles previously, is now west of English Bay and is also well mixed with sea water.

Figure 21

At the start of the second ebb there are again five water masses on Sturgeon Bank, B2, C2, D2, A2, and F2. Iona Channel water (B) one cycle old, is leaving the system seaward of the discharge from English Bay, along with F and A which are now starting their third cycle.



The North Arm

Figure 22

On the ebb tide fresh water (G) emerges from the North Arm. It is the forerunner of the cloud which has accumulated upstream during the previous flood.

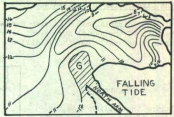


Figure 23

At low tide the North Arm cloud (G) is fully developed, it extends almost as far as Howe Sound and is spreading shoreward around Point Grey into English Bay.

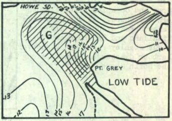


Figure 24

As the tide rises the first part of the discharge (G 1) is separated from the latter part (main cloud) by the intrusion of the stream from along the North Shore of English Bay. The main part of the discharge (G) has moved into English Bay.

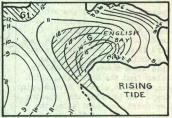
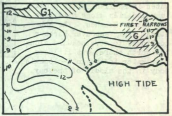


Figure 25

At high tide the North Arm cloud (G) has almost disappeared into Vancouver Harbour. The part remaining in First Narrows will leave the system on the next ebb tide. This, together with the part which reached Howe Sound (G 1) is the only water to be expelled from the system in one cycle.



The Circulation of English Bay

The circulation of English Bay can best be shown by reference to the results of the aerial survey and direct current measurements, because the area is so small that the details are not visible in the water mass surveys.

Figure 26

During the falling tide the cloud of water from the North Arm moves eastward around Point Grey and occupies all the southern foreshore. At the same time False Creek discharges along Kitsilano and Second Beach towards Stanley Park, and Vancouver Harbour discharges seaward along the North Shore.

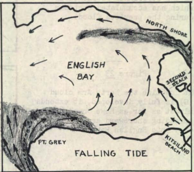


Figure 27

Towards the last of the ebb the south shore flow slackens, becomes "weak and variable", and tends to reverse, so that a seaward flow may be observed along the southern shore of the bay. This water moves underneath the water from the North Arm, which continues to advance around Point Grey. At low tide the opposing (westward) movement along the southern shore of the bay ceases.

The volume of False Creek water in English Bay is a maximum and lies along Kitsilano and Second Beaches. The ebb stream from Vancouver Harbour continues to move seaward along the North shore, but it loses some water to the anti-clockwise eddy in the middle of the bay.

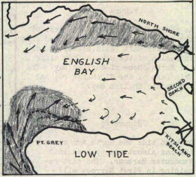
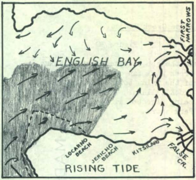
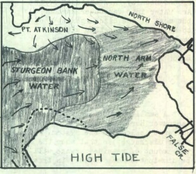


Figure 28



During the rising tide conditions change very rapidly. The North Arm cloud moves towards First Narrows spreading over Spanish Banks and Locarno Beach. It moves the water which was along Jericho and Kitsilano beaches in front of it, and part of this goes into False Creek, following the old False Creek water that was in the corner of the bay. The False Creek water which had moved northward on the ebb, now enters Vancouver Harbour in front of the North Arm cloud, and behind the last of the ebb discharge from First Narrows. The main stream of Vancouver Harbour water along the northern side of the bay continues to flow westward; it contributes water to the eddy in the middle of the bay that is returned to the harbour embodied in North Arm water. This eddy persists until the last of the tidal rise.

Figure 29



At high tide North Arm water lies along the south and east sides of English Bay enclosing residual water from the beaches near False Creek. Water from Vancouver Harbour lies along the North Shore towards Point Atkinson, and water discharged from Sturgeon Bank during the previous ebb is in the entrance of the bay

This discussion of the movements during the tide cycle indicates that the only water lost to Georgia Strait was in the vicinity of Point Atkinson. Essentially there has been a slight anti-clockwise progress around the bay, equivalent to the contribution of fresh water from the North Arm and Vancouver Harbour. Consequently any sewage must progress slowly around the bay and through Vancouver Harbour from its point of discharge, before it is dissipated into the sea.

MOVEMENT OF SEWAGE

False Creek Sewage

Figure 30

On the ebb tide, sewage from False Creek will fan out from the mouth of the inlet toward Second Beach and Kitsilano. The main stream being directed along the Stanley Park shore.

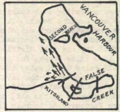
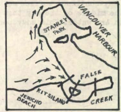


Figure 31

When the tide turns to flood, the outer end of the stream moves around Stanley Park ahead of North Arm water into Vancouver Harbour, but most of the discharge returns to False Creek together with a small amount of dilution water from the Kitsilano and Jericho Beach foreshore.



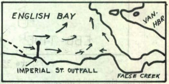
A small amount (10% to 20%) of False Creek water is released to Vancouver Harbour on each tide cycle, and eventually reaches Point Atkinson where it is lost to the system. This exchange varies with the Fraser River discharge, so that when the river is low in late summer and winter the amount of retained sewage will be greatest; conversely, the sewage will be dissipated most rapidly in freshet time.

Imperial Street Sewage

The Imperial Street outfall is located between Jericho and Locarno beaches and extends 3000 feet out under the sea into English Bay. The predominant direction of currents here is eastward on the flood and first part of the ebb. It is only on the last of the ebb that they turn westward, and even then can be classed as weak and variable.

Figure 32

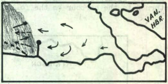
Sewage embodied in this water at the first of the ebb will move eastward with an ever lessening velocity.



FIRST OF EBB

Figure 33

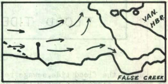
At the last of the ebb the stream turns seaward and runs under the advancing cloud from the North Arm.



LAST OF EBB

Figure 34

When the flood starts, the flow is again directed eastward and the water moves toward False Creek and Vancouver Harbour ahead of North Arm water.



RISING TIDE

Most of the Imperial Street sewage will be retained in the corner of English Bay for more than one tide cycle, and part will be included in the water entering False Creek. All of it eventually goes into Vancouver Harbour, and ultimately it will leave the system in the First Narrows stream past Point Atkinson.

Vancouver Harbour Sewage

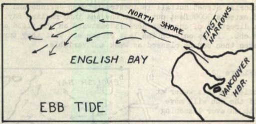


Figure 35

During the ebb tide, sewage discharged from First Narrows sweeps along the North Shore beach. The first part (10%) of the discharge reaches Point Atkinson and leaves the system. Some remains along the North Shore; the remainder is dissipated into the eddy in the middle of English Bay, and returned to the harbour on the following flood tide.

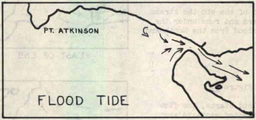


Figure 36

During the flood tide, sewage released near First Narrows will enter the harbour, along with water from English Bay. Towards the last of flood North Shore water retreats towards Vancouver Harbour.

Because of the turbulence in First Narrows, any sewage passing through will be completely mixed with the sea water and aquire maximum dilution at this point.

North Arm Sewage

The sewage discharge into the North Arm at the Musqueam Indian Reserve (Fig. 1) must be considered during the flood and ebb tide because there is a difference in the elapsed time from its discharge until it reaches the end of the river channel.

Sewage released during the ebb tide will move directly down stream with the river water at a velocity dependent upon the height of the tide and volume of run-off. The worst possible circumstance observed to date (from the sewage standpoint) was a strong ebb in freshet time; North Arm water travelled from the Indian Reserve to Wreck Beach in one hour. The best circumstance which can be considered occurs on a strong ebb at low river flow. Then the time required for the same journey is about 2 1/4 hours.

After the effluent leaves the river mouth it will travel around Point Grey to Spanish Banks, some to be displaced immediately into Vancouver Harbour (G Fig. 24, 25) and some to move past Jericho and Kitsilano beaches and be included in the exchange water entering False Creek, (Fig. 28, 29).

Release on the flood tide, when the main stream is moving up river, will increase the elapsed time before the sewage will come in contact with the beaches. Water from the Indian Reserve has been traced as far upstream as the junction of the North and Middle Arms, and if sewage is discharged into the river at the start of the upstream flow it will be continuous to that vicinity. When the tide turns to ebb this sewage will be augumented by that released during the ebb, and behaves the same as the ebb tide discharge.

Sewage released continuously into the North Arm will be discharged intermittently at the river mouth. Under the best circumstance, e.g. low river flow and the strong ebb of a spring tide, each discharge will have sewage of two ages. One never more than 2 1/4 hours old and the other between 2 1/4 and 8 hours old.

Iona Channel

Sewage released into Iona Channel at the start of the ebb will form part of the northern foreshore water (B) along Sea Island (Fig. 17). It is doubtful if any of this discharge will contribute to Jericho, False Creek or Vancouver Harbour water, but it is certain to be included in the water near Point Grey and Western Spanish Banks at high tide, when it will be approximately 12 hours old.

Discharge into Iona Channel at the start of the flood will be analogous to discharge into the North Arm. The sewage will move up the channel and the North Arm. At the start of the ebb there will be a continuous line of polluted water beginning to move down stream. That part in Iona Channel will return past the discharge point, and that in the North Arm may divide, contributing water to both outlets.

If Iona Channel were closed, its discharge would continue out the North Arm, and the flushing action along the south side of this jetty would be slightly, but probably not noticeably reduced. Sewage discharged seaward of the dam would move very much as the northern foreshore water (B) does now (Fig. 17 to 21), north past the approaches to English Bay without entering it. It is possible that sewage sludge would accumulate on the bank in fine weather, but it would certainly be dissipated in rough weather.

The Middle Arm

If sewage effluent were released into the Middle Arm of the Fraser on the ebb tide it would follow the path of southern foreshore water (C) to seaward of English Bay (Fig. 17 to 21).

If it were released on the flooding tide some might travel up the Middle Arm and be discharged out of the North Arm on the subsequent ebb, but only a negligable amount would take this path and the time lag between discharge at the Middle Arm and arrival at Wreck Beach, would be approximately 10 hours.

Effect on the Circulation of Changes in the Variables

The Tide

The above is a description of the circulation of a spring tide where there is a strong ebb and a strong flood. During small tides the main difference in the circulation would be in the distance of transport per cycle. The movement in English Bay would not be as rapid as illustrated and sewage discharged there would accumulate. While this is a worse condition in the bathing area, such accumulation would not reach the bathing area, from a discharge on Sturgeon Bank, because it is doubtful if Sturgeon Bank water ever intrudes English Bay on the low velocities and transports associated with small tides.

The River

The preceding detailed descriptions of the flow system is associated with typical late July discharge of the Fraser River (200,000 c.f.s. at Hope, B.C.). At higher river level, in freshet time, the seaward flow in the North Arm does not reverse during the flood tide; the discharge velocity is high and the main stream is directed towards Bowen Island, rather than around Point Grey. The great velocity and volume of this stream effectively prevents the intrusion of water from the tide flats into English Bay, and the large amount of fresh water released increases the displacement per tide cycle in all parts of the system. However, the amount of North Arm water entering the bay during the freshet is greater than that at lower river flow because of the increased lateral dispersion from the high velocity stream.

When the river is low in September the opposite effect is observed. The North Arm discharge is affected by the tide to a greater extent than is shown here (G Fig. 24); its water moves directly into English Bay on the flood, and does not provide any barrier against the intrusion of Sturgeon Bank water. Also sewage will tend to move more slowly off the bank because the momentum of the fresh water clouds from the river is small.

In English Bay low river discharge has the effect of reducing the displacement per tide cycle, so that there would be more tendency for sewage to accumulate.

Postscript

The large mass of data listed in the appendix suggests the problems presented in completing the analysis, which will require some time. The description of the circulation given here was founded on the work to date and is adequate for the purpose.

R.L.I. Fjarlie
Assistant Oceanographer

APPENDIX I

Synoptic Surveys

Date	Survey Number	Number of Serial Observations	Number of Samples	Direct Current Measurements
1949				
Nov.	I	52	407	None
Dec.	II	52	832	None
1950				
Feb.	III	52	832	None
Mar.	IV	52	806	None
April	V	52	816	None
May 1-15	VI	41	848	None
May 29 - June 1	VII	87	1458	24
June 13-17	VIII	39	418	195
July 4-8	IX	102	724	408
July 18-28	X	199	1837	None
Aug. 28 - Sept. 3	XI	115	1308	106
Sept. 28 - Oct. 6	XII	115	1191	100

Aerial Photographic Surveys 1950

June 1 Spring tides, seven surveys.
June 10 Neap tides, seven surveys.

Direct Current Measurements by the Sewerage Board

(On each day listed the progress of floots at 0, 5, 10, 20, 30, 40, and 50 feet depth was charted).

1927 Observations in English Bay

August 30, 31
September 1, 2, 6, 7, 9, 12, 15, 16, 19, 22, 26, 27, 28, 29
October 3, 4, 7, 10, 11, 14, 20, 24, 25, 26

1929 Observations in English Bay and North Arm Fraser River

July 9, 20
October 3

1941 Observations in English Bay and North Arm Fraser River

August 13, 14, 15, 18, 20, 21, 24, 28, 30
September 4, 17, 18, 19, 20

1945 Observations in English Bay and Vancouver Harbour

June 7, 8, 11, 12, 14, 18, 19, 20
July 3, 4, 5, 6, 9, 10, 11, 12, 17, 18, 19, 24, 25, 26, 27, 30, 31
August 1, 2, 30
September 4, 5, 6

1949 Observations in English Bay and Vancouver Harbour

June 29, 30, 27
July 4, 5, 6, 7, 14, 18, 20, 27
August 3, 4, 12, 16, 17, 19, 22, 30, 31
September 1, 2, 6, 8
November 17, 18
December 7, 9, 15, 10, 16

1950 Observations in Fraser River Estuary, English Bay and Vancouver Harbour

March 3, 27, 28, 29, 30
April 3, 4, 20, 21
May 1, 2, 3, 8, 9, 12, 16, 17, 18, 19, 29, 31
June 2, 5, 7, 8, 13, 15, 16, 17, 19, 20, 23, 26, 27, 29, 30
July 3, 4, 5, 7, 10, 12, 14, 18, 21, 24, 25, 26, 28
August 4, 7, 9, 11, 14, 16, 18, 21, 23, 28
September 1, 8