Halifax Harbour Task Force

Appendices

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A. Physical Oceanography

APPENDIX A. PHYSICAL OCEANOGRAPHY

1. Physical oceanography of the Harbour

Brian Petrie

Halifax Harbour is an estuary, i. e., a semi-enclosed body of water whose properties and circulation are influenced by freshwater runoff from the land. An idealised picture of the circulation of the Harbour waters is shown in Fig. 1. The near-surface waters tend to flow towards the ocean becoming saltier as they move down the Harbour. The salt is supplied through mixing with waters from the shelf which move into the Harbour from just below the outgoing near-surface flow to the bottom. These shelf waters become less salty as they move into the Harbour because of mixing with the shallower, fresher waters. In addition to the influence of the freshwater, the mean wind acts to reinforce the estuarine circulation pattern of the Harbour waters. Other factors such as tides and winds, which vary over periods of hours to weeks, contribute to the circulation and mixing and, at times, can be so strong that the background estuarine circulation can be overwhelmed.

In this chapter, we shall present a brief, general overview of the physical oceanography of Halifax Harbour relating it when appropriate to the sewage treatment question. The first section will cover the water properties of the Harbour, concentrating on the distributions of salinity. In the second part, the mean circulation derived from current meter observations will be presented. The variable currents due to tides, winds and other forces will be discussed in the third part. The final section will contain an outline of some of the tools that will be used in later chapters to examine the consequences of sewage treatment in the Harbour.

Water Properties

The temperature and salinity distributions in the Harbour are determined by the input of heat from the sun, freshwater from the Sackville River and general runoff, and salt water from the ocean. The heat input is essentially uniform over the Harbour but varies from month to month being largest in June and July and least in December and January when in fact heat flows from the water to the atmosphere. Freshwater input is distributed less uniformly over the Harbour. The major source is the Sackville River which has an annual mean inflow of 5.3 m^3/s and varies from a high of about 9 m^3/s in March and April to a low of 2 m^3/s during the July-September period (Fig. 2). There is additional freshwater inflow from general runoff which amounts to about 2.2 times the discharge of the Sackville River and is distributed throughout the Harbour. Sewage inflow is about 2.1 m^3/s, roughly equal to the summertime flow of the Sackville River.

The freshwater inflow is important to the Harbour in several ways: first, it is one of the forces that contributes to the circulation and therefore to the movement of effluent; secondly, because it is lighter than the salty ocean water, it tends to stay at the surface and to contribute to the density differences between surface and bottom waters; thirdly, it serves as a dye, i. e., by measuring the salinity throughout the Harbour we can follow the progress of the freshwater as it flows toward the shelf.

Salinity Variations

The salinity variations along the axis of the Harbour for mean, high and low freshwater inflow are shown in Fig. 3. For this graph, we averaged 3 to 5 sample stations across the Harbour for 24 cruises conducted over 2 years. Then appropriate individual cruises were averaged to give the 3 diagrams. The difference in the 0-10m salinity along the Harbour for periods of high and low freshwater inflow (Fig. 3b,c) is large. In both cases the minimum salinity does not occur at the site nearest the Sackville River but near the southern end of Bedford Basin just north of the Narrows. Salinity increases towards the mouth of the Harbour by about 3.5 parts per thousand (ppt) during high freshwater inflow and by 0.7 ppt during low discharge. Except for the upper part of Bedford Basin, the salinity distribution fits the idealised picture of estuarine circulation shown in Fig. 1.

Circulation derived from Salinity

We can use the values of salinity (Fig. 3) coupled with the idealised circulation (Fig. 1) to derive currents in the Harbour which represent the average flow in large areas for periods corresponding to months, i. e., not the day to day currents. The areas are centered around the sites where the salinity data were gathered and include Bedford Basin, the Narrows, the downtown Harbour (roughly Dartmouth Cove to Point Pleasant Shoal), the area centered around Sandwich Point (Point Pleasant Shoal to Watley Cove), the outer Harbour and the shelf. This simplified model of currents is depicted in Fig. 4 and the results for high and low freshwater inflow are shown in Fig. 5. For both inflow conditions, they indicate that the strongest horizontal currents occur in the Narrows and the Sandwich Point area with weaker flows in the Basin and outer Harbour. The most vigorous vertical exchanges occur in the Narrows and the downtown Harbour during low discharge periods and in the downtown Harbour and the Sandwich Point area during high discharge. Support for the circulation patterns (Fig. 5) can be obtained if the model currents are in reasonable agreement with observed flows and if the model can reproduce the distribution of other variables (e. g. suspended solids, metals, nutrients) in the Harbour given appropriate inputs. Then the consequences of treatment and location (on a broad scale) can be examined.

Vertical distribution of density and initial sewage dilution

The distribution of water density can markedly affect the level to which a sewage plume can rise after it is introduced into the ocean from a diffuser. Modern diffuser pipes are often designed so that one part of effluent will mix with about 50 parts of the receiving waters. If the water density at the diffuser depth is much greater than that of the surface waters, it is quite possible that the diluted effluent may not reach the surface. Based on the specifications given in the Phase 3 report (The Halifax Inlet Water Quality Study Phase 3), we have calculated the height the effluent plumes would rise given the density measurements made over a 2 year period in the Harbour. (Note that in the Phase 3 Study the waters of the entire Harbour were taken as having a uniform density. In that case, the effluent plume would always reach the surface.) The results (Table 1) indicate that for a number of cases the effluent plume will not reach the surface. Generally, the closer the location to the head of the Harbour, the more frequently the plumes stay subsurface. Moreover, since density differences from surface to deeper waters are greatest in summer, plumes tend to stay below the surface more often during that season. Opting for a shallower depth for the diffuser will allow the plume to reach the surface more frequently (see Herring Cove, Table 1) but will result in less dilution.

In summary, there are several ways that the distribution of water properties is important to the question of sewage treatment in the Harbour - as a force which can cause currents, as a dye which can reveal the way the water flows and as a fundamental property affecting the initial dilution and location of the sewage in the water column.

Mean Circulation in the Harbour

Current meter measurements in the Harbour (Fig. 6) show a circulation pattern very similar to the one derived from the salinity measurements (Fig.5) - surface flow is generally out of the inlet, deeper flow in. In the outer Harbour, the measurements made during the summer of 1989 feature deeper currents flowing up the inlet at rates of 1-3 cm/s while the model gives 0.5-4 cm/s. Near-surface outflows were recorded at up to 2.6 cm/s at Sandwich Point, whereas the model gave 2.8 cm/s for the average 0-10m flow. In the outer Harbour south of Sandwich Point, the two measurements at 6m do not show surface outflow but rather show flow into the Harbour. This may reflect the influence of wind or that these current meters were below the surface layer. In the Narrows (Fig. 6) there is a strong indication of 2 layer flow, i. e., surface outflow and deep water inflow. The measured surface currents range from 1.6-2.4 cm/s while the bottom currents are 0-6 cm/s. The model results give 4-4.8 cm/s for the surface and 5.6-6.2 cm/s for the bottom in reasonable agreement.

Outside the Harbour, the mean currents are stronger with a general tendency to flow along constant depth contours. The pattern is towards the southwest except for the mooring in shallow water off Hartlen Point. This mooring, part of the Harbour study of 1989, perhaps reflects the influence of the wind which predominantly blows from the southwest during the summer. In fact the 2 layer pattern of flow in the Harbour can also result from the wind forcing in this direction and can augment the circulation due to the freshwater input.

In summary, the mean circulation pattern observed in the Harbour from the current meter data is similar to our idealised picture presented earlier in Fig. 1. Near-surface waters, perhaps with the exception of the 6m data from the outer Harbour, tend to move out of the Harbour and deeper waters tend to flow in from the shelf. The magnitude of the observed currents generally are similar to that derived from the salinity data. A bonus from the salinity based model is that it also gives estimates of the vertical exchange of water. It is also highly probable that wind and freshwater act together to produce this circulation pattern. These results can be used to hindcast and forecast, in a broad sense, the fate of effluent in the Harbour.

Current Variability in the Harbour

So far we have presented a picture of the circulation that doesn't change or changes only very slowly in time. This represents what one would see if measurements were averaged over a long period, say several months. In the Harbour, of course, currents can change rapidly, with perhaps the most familiar variation being the tidal flows. Wind also can cause rapid, dramatic changes to the circulation causing, for example, water borne material to cross the Harbour in perhaps an hour.

The current meter data can also give a picture of how flows vary throughout the Harbour. In Fig. 7 the current variance from all current meter data is plotted starting from the Head of Bedford Basin (distance = 0) outwards onto the shelf. The first measurement in the Basin shows very low energy indeed, corresponding to variable currents, with an amplitude of about 3.5 cm/s. In the Narrows, the variable currents, mostly tidal in nature, range from roughly 15-35 cm/s, the highest values in the Harbour. From Sandwich Point to the Harbour mouth, the time varying flows have amplitudes equivalent to 5-15 cm/s. On the shelf, variance rises again to near Narrows levels but due more to non-tidal flows (e. g. wind driven currents).

Measurements of salinity, particularly near the surface, have shown that the near-surface waters can be affected by the wind with fresher waters in the Harbour tending to move downwind. Effluent and near-surface materials are expected to behave in the same way. Deeper measurements of salinity have been found to respond systematically to the wind as well.

Variability of currents is important to the fate of sewage effluent in the Harbour in several ways. It can result in water movements opposed to the long term flow of water with the circulation persisting in opposing directions for hours or even several days. Similarly, it can reinforce the long term current pattern. In addition, currents varying in space and time can contribute significantly to the mixing and dilution of sewage effluent.

Applications

How can we use some of the ideas presented in this overview to address the problem of sewage dispersal? Early in the chapter some of the tools we shall use were discussed. Based on salinity data from the Harbour, we built a simple model of circulation which gave magnitudes of currents in reasonable agreement with the observed flows. We will use this model later to determine if it can reproduce the present conditions in the Harbour for other variables such as suspended solids, metals, nutrients and sedimentation rates. If it can do this then we can try to simulate how the distribution of these variables would change given that the inputs were treated at one or several sewage treatment facilities. It must be emphasized that this model will only give the long term picture for large areas such as the Bedford Basin, the Narrows etc. It cannot forecast the variations that could occur during a storm for example.

Other models are needed to address events that occur over shorter periods. For instance, fecal coliform distributions cannot be dealt with adequately by the model described above since coliform die off at a rate that is too fast - most would die before crossing a compartment of the model. Some simple models that can handle the rapid changes of coliform concentrations will be introduced.

Another question that needs exploring is the very short time period (several minutes) initial dilution that occurs when effluent is ejected from a diffuser and makes its way towards the surface. Given the stratification of the Harbour, we want to estimate an approximate range of initial dilutions and determine if, on average, a sufficient amount of "clean" water flows by the diffuser to enable the maintenance of the initial dilution rate.

Finally, given the amount of mixing in the Harbour due to the variable circulation, we shall address the question of further dispersal.

In summary, there are processes taking place over different time intervals: initial dilution lasting perhaps several minutes, further dispersal and problems such as fecal coliform lasting hours to days and the longer term variations lasting several months.

Figure Captions

Figure 1 An idealised picture of the circulation in Halifax Harbour driven by freshwater flow and mean wind. Freshwater, represented by the Sackville River discharge, flows at and just below the surface from the head of Bedford Basin, through the Narrows and towards the open ocean. As it moves through the Harbour, vertical mixing with saltier, deeper water causes its salinity to increase. The deeper waters move into the Harbour freshening as they flow towards Bedford Basin because of mixing with the shallower water. Occasionally the inflowing shelf waters are dense enough to flush out the water trapped in the deeper parts of Bedford Basin.

Figure 2 Mean monthly flow of freshwater from the Sackville River into Bedford Basin. At the annual average rate of 5.3 m^3/s, it would take 3 years to fill the Basin. The lower broken line represents the current rate, 2.1 m^3/s, of sewage inflow into the Harbour.

Figure 3 The variation of salinity along the Harbour from Bedford Basin to Chebucto Head. The data used to form the averages shown were collected during 24 cruises in the Harbour over a 2 year period. At each location data measurements were taken at from 3 to 5 stations spaced across the Harbour. A) Annual mean salinity along the axis of the Harbour. The mean freshwater flow from the Sackville River for 1970-71 when most of the salinity data were collected was 5.7 m^3/s. B) The mean March-April salinity for the Harbour corresponding to a period of high freshwater flow. The mean flow for the same period was 11.9 m^3/s. C) The mean July-August salinity along the axis of the Harbour corresponding to a period of low freshwater flow. The mean freshwater flow during this period was 2 m^3/s. The letters A-H are the designations of the sampling sites given by Jordan (1972).

Figure 4 Simple model of the Harbour. Salinity data were averaged (S_1 to S_{12}) to produce one value for large areas such as Bedford Basin in 2 depth ranges, 0-10m and 10-20m. Water deeper than 20m is not represented in this model. The model assumes that surface (0-10m) flow is out of the Harbour while the deeper flow (10-20m) is into the Harbour, in keeping with the picture shown in Figure 1 and the salinity data of Figure 2. The Sackville River inflow and general runoff are represented by arrows entering the top of the 0-10m boxes. Mixing between the 0-10m and 10-20m boxes is represented by the up-down arrows at 10m.

Figure 5 Horizontal and vertical velocities derived from a transport model of Halifax Harbour (Fig. 4) and based on the conservation of mass and salt.

Figure 6 a,b-Map of the mean currents in Halifax Harbour and on the adjacent shelf. This figure is a composite of current measurements made over the past 22 years. Records vary in length from several weeks to about 8 months. The number beside each vector indicates the instrument depth.

Figure 7 Variance of currents in the Harbour and on the adjacent shelf from available current meter data. The distance is measured from the Head of Bedford Basin moving offshore. An amplitude scale ($= [2*\text{Variance}]^{1/2}$) is also shown.

Idealized Circulation in Halifax Harbour

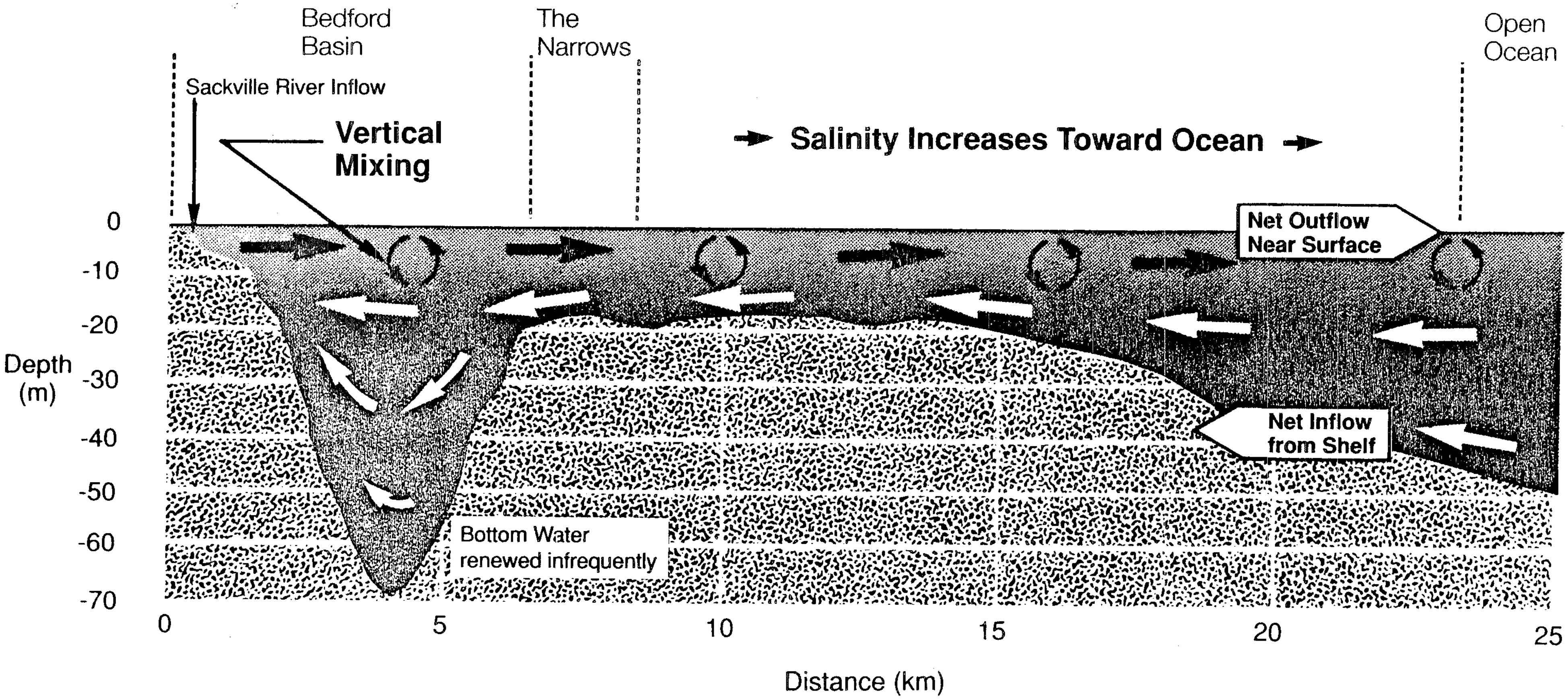


Figure 1

Figure 2

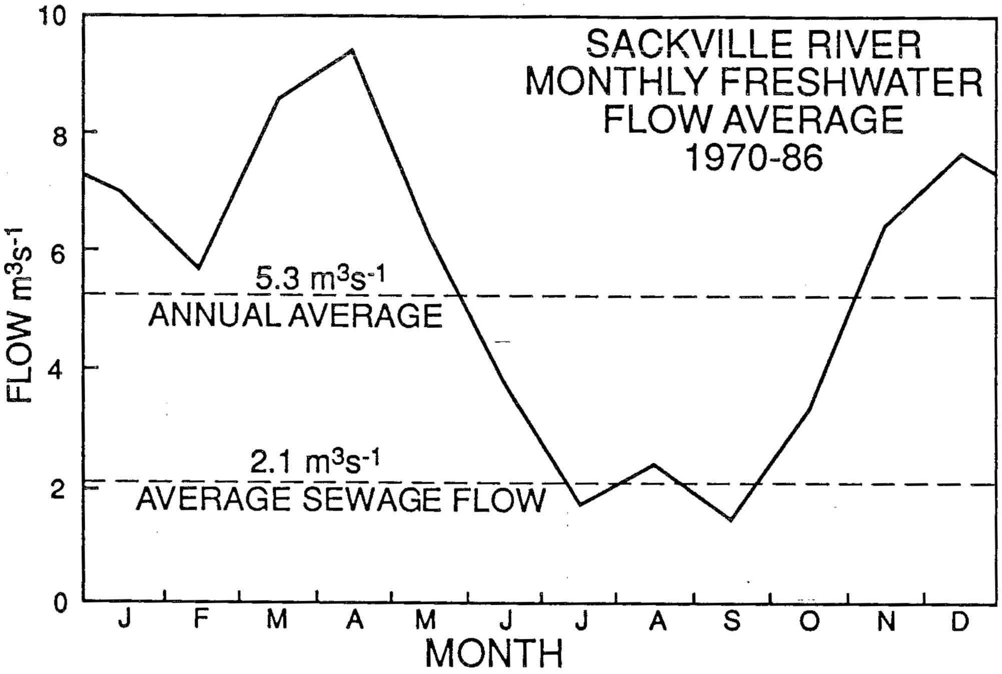

SACKVILLE RIVER
MONTHLY FRESHWATER
FLOW AVERAGE
1970-86
5.3 m³s⁻¹
ANNUAL AVERAGE
2.1 m³s⁻¹
AVERAGE SEWAGE FLOW
FLOW m³s⁻¹
10
8
6
4
2
0
J
F
M
A
M
J
J
A
S
O
N
D
MONTH

Figure 3

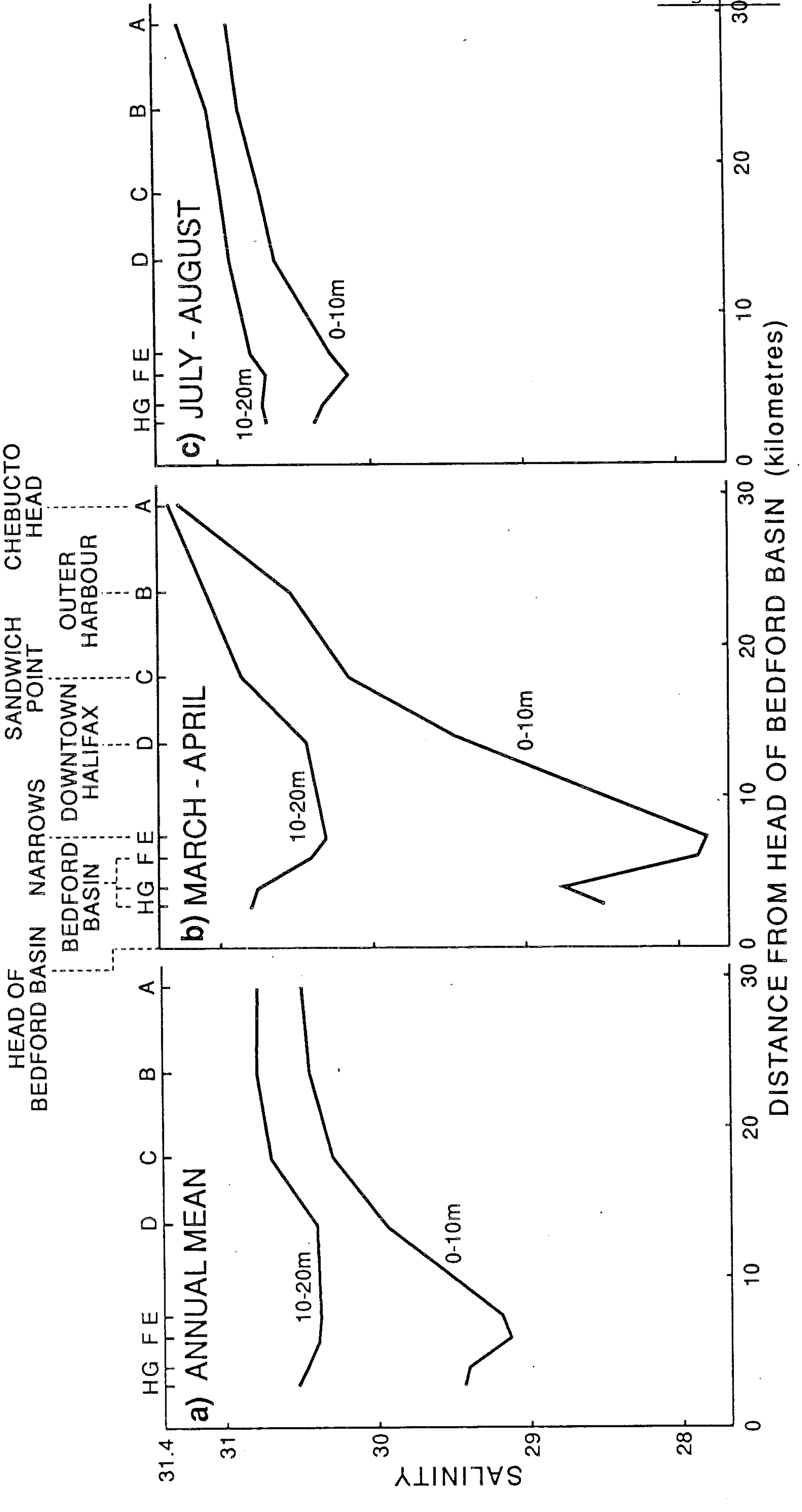
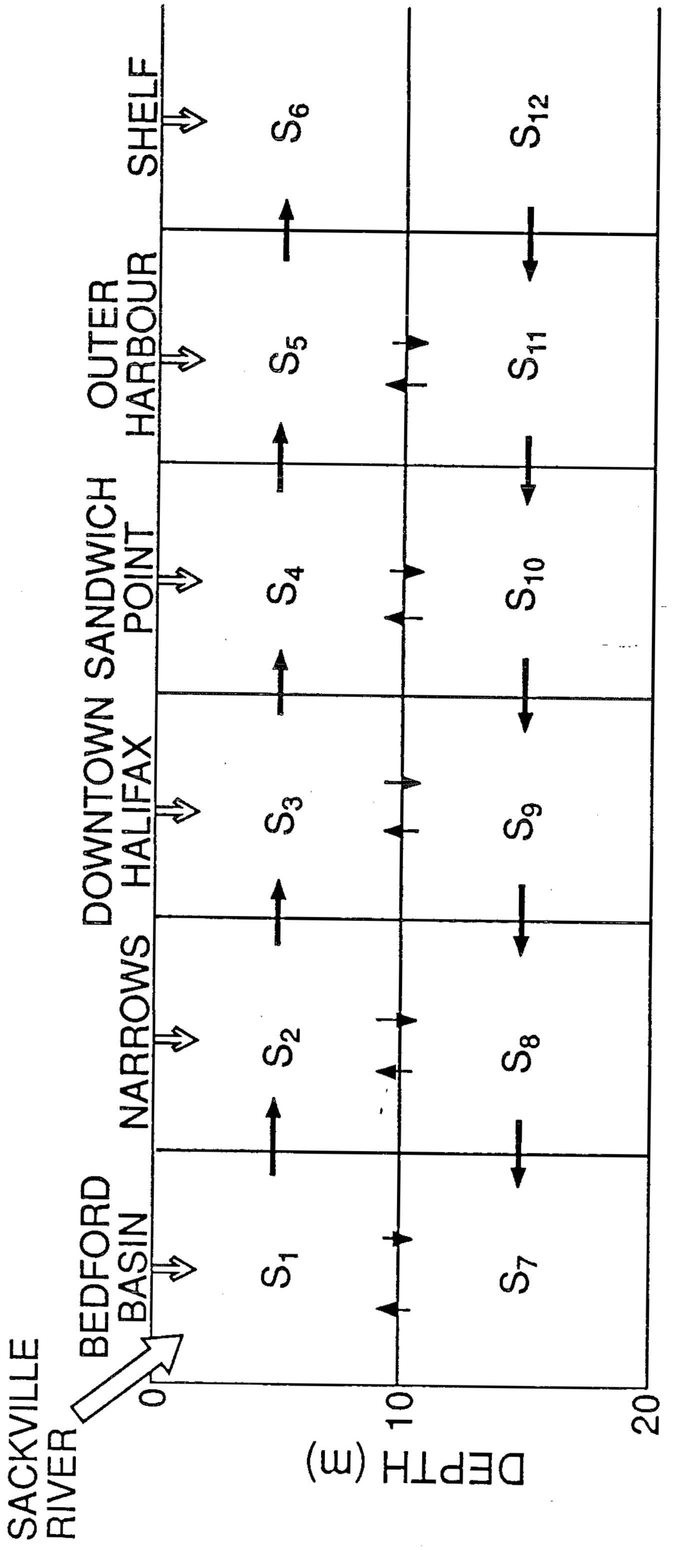

SALINITY
31.4
31
30
29
28
a) ANNUAL MEAN
b) MARCH - APRIL
c) JULY - AUGUST
10-20m
0-10m
HG F E
D
C
B
A
0
10
20
30
HEAD OF BEDFORD BASIN
BEDFORD BASIN
NARROWS
DOWNTOWN HALIFAX
SANDWICH POINT
OUTER HARBOUR
CHEBUCTO HEAD
DISTANCE FROM HEAD OF BEDFORD BASIN (kilometres)

Figure 4


SACKVILLE RIVER
BEDFORD BASIN
NARROWS
DOWNTOWN HALIFAX
SANDWICH POINT
OUTER HARBOUR
SHELF
S_1
S_2
S_3
S_4
S_5
S_6
S_7
S_8
S_9
S_{10}
S_{11}
S_{12}
DEPTH (m)
0
10
20

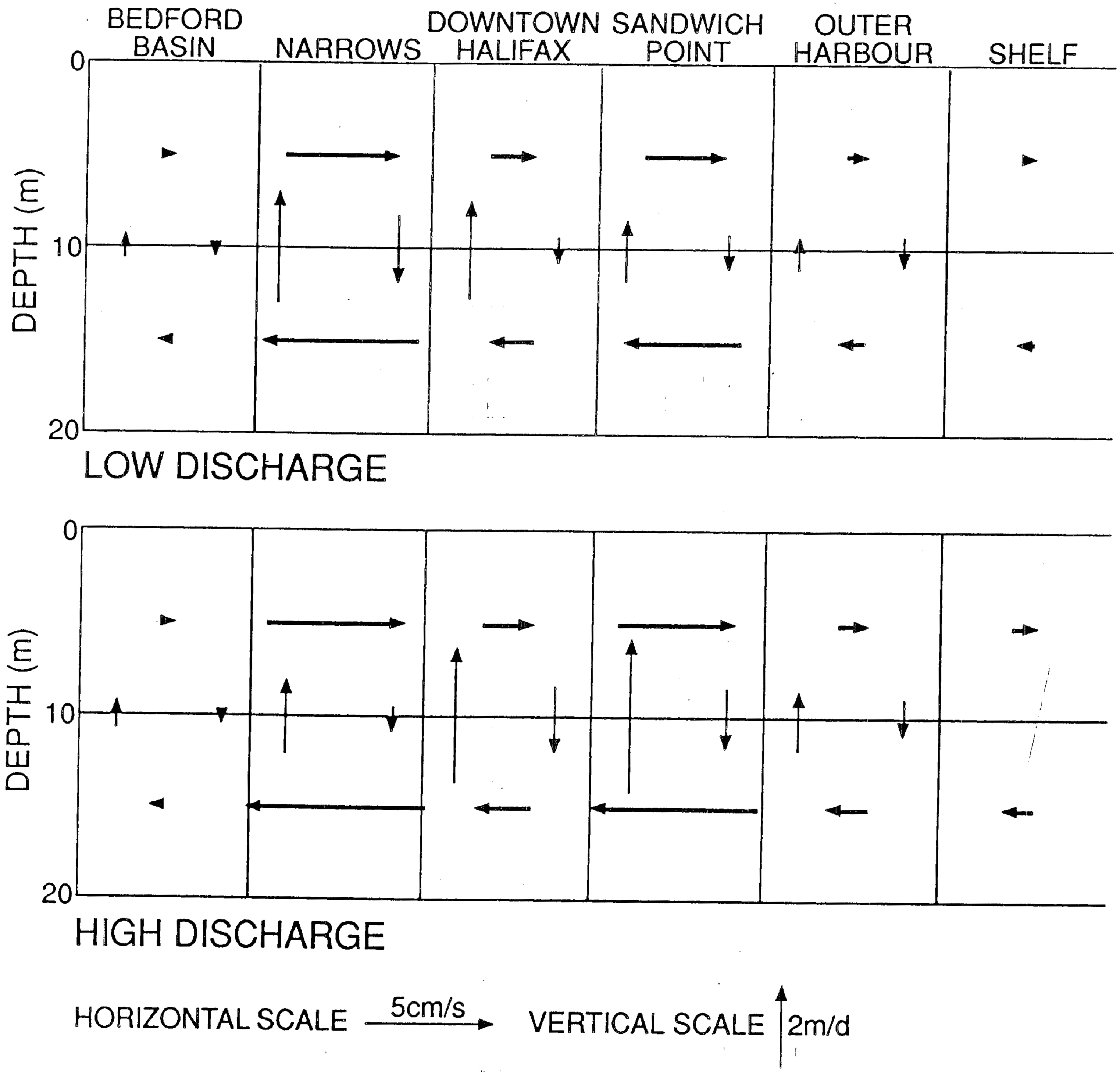

BEDFORD BASIN
NARROWS
DOWNTOWN HALIFAX
SANDWICH POINT
OUTER HARBOUR
SHELF
DEPTH (m)
0
10
20
LOW DISCHARGE
DEPTH (m)
0
10
20
HIGH DISCHARGE
HORIZONTAL SCALE
5cm/s
VERTICAL SCALE
2m/d

Figure 5

Figure 6a

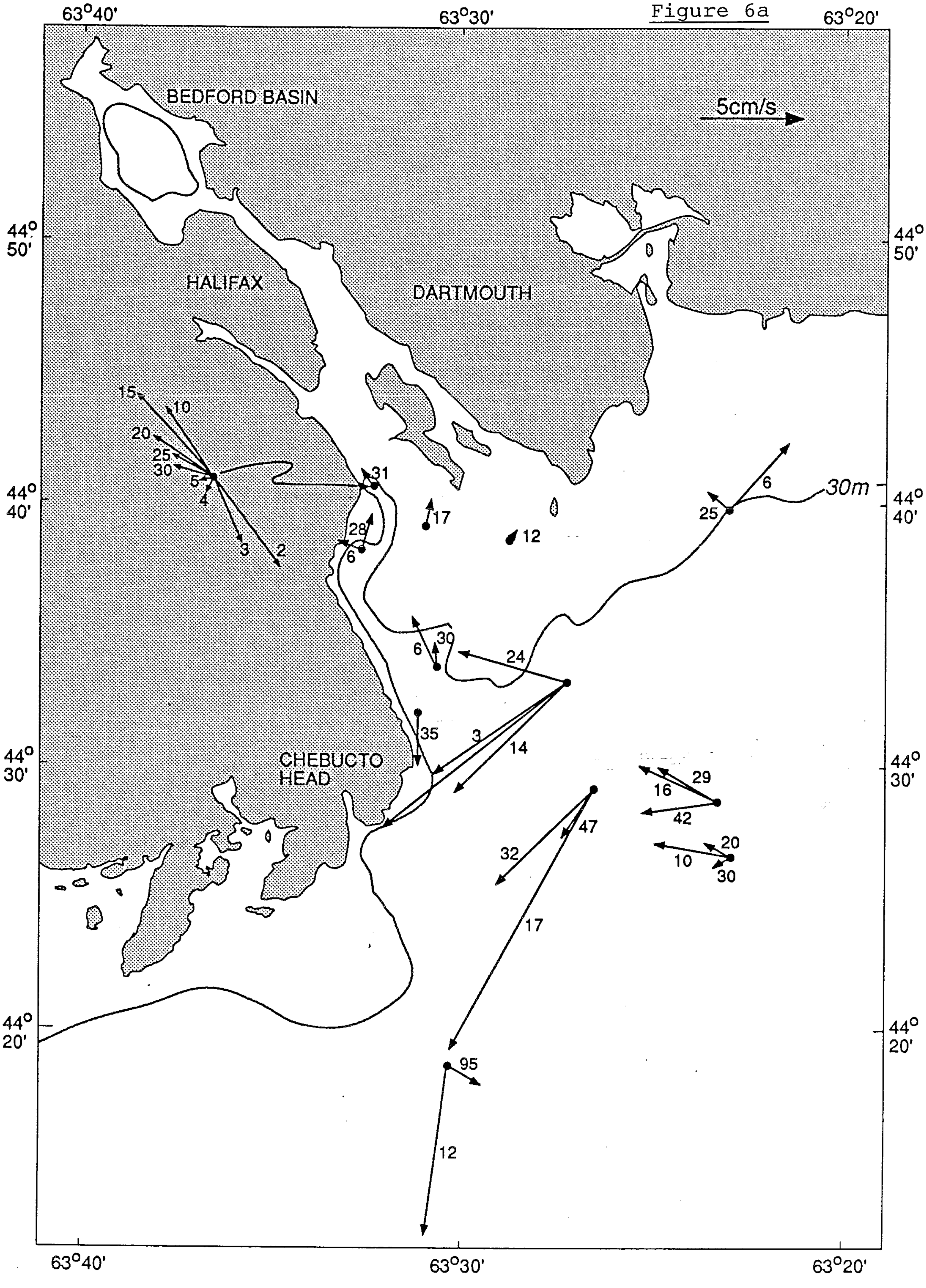
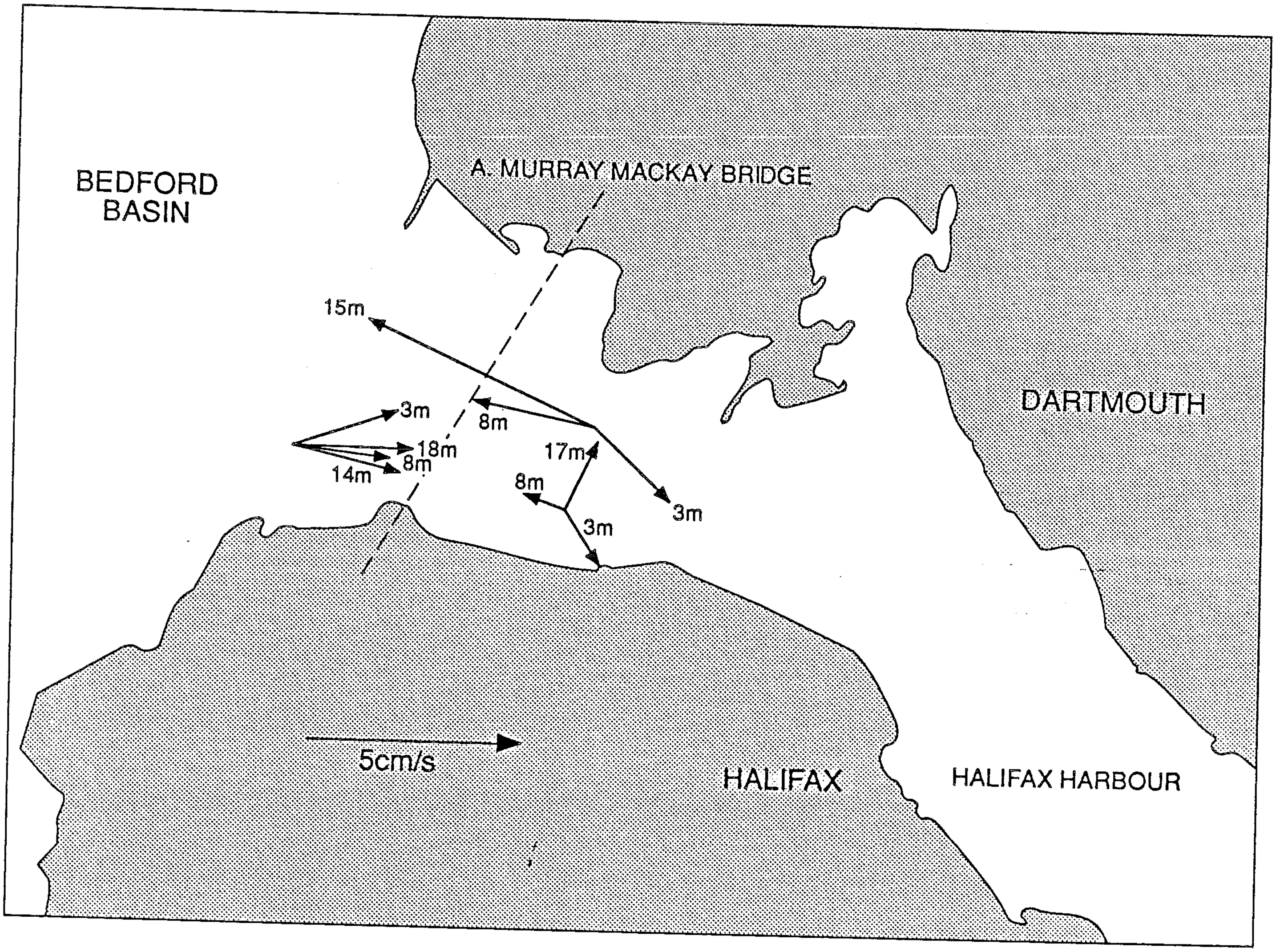

63°40'
63°30'
63°20'
BEDFORD BASIN
5cm/s
44° 50'
HALIFAX
DARTMOUTH
15
10
20
25
30
5
4
3
2
31
28
6
17
12
6
25
30m
44° 40'
6
30
24
35
3
14
CHEBUCTO HEAD
44° 30'
29
16
42
47
32
20
10
30
17
44° 20'
95
12
63°40'
63°30'
63°20'

Figure 6b


BEDFORD BASIN
A. MURRAY MACKAY BRIDGE
15m
3m
8m
18m
8m
14m
17m
8m
3m
3m
DARTMOUTH
5cm/s
HALIFAX
HALIFAX HARBOUR

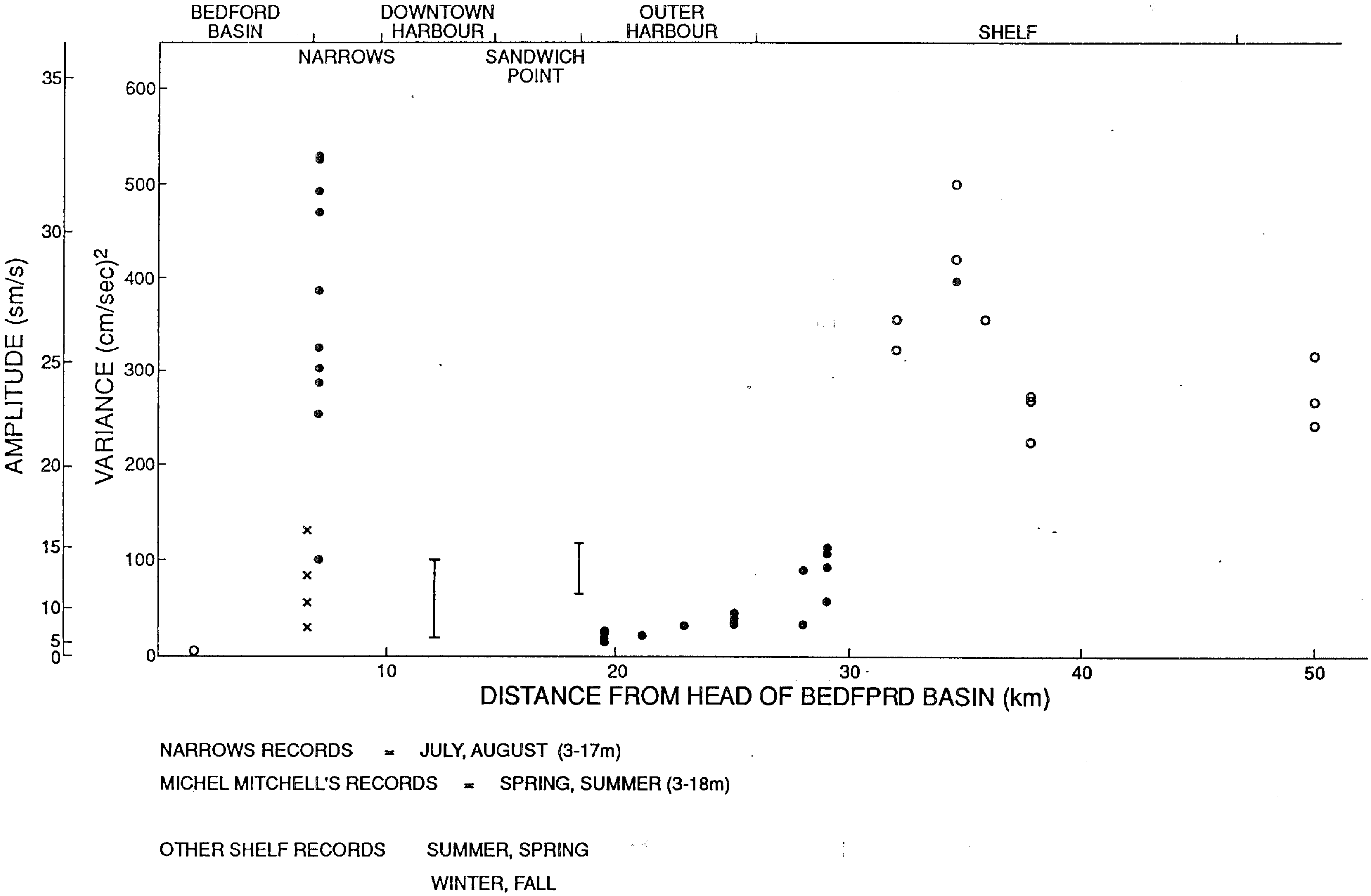

BEDFORD BASIN
NARROWS
DOWNTOWN HARBOUR
SANDWICH POINT
OUTER HARBOUR
SHELF
AMPLITUDE (sm/s)
35
30
25
20
15
10
5
0
VARIANCE (cm/sec)²
600
500
400
300
200
100
0
10
20
30
40
50
DISTANCE FROM HEAD OF BEDFPRD BASIN (km)
NARROWS RECORDS = JULY, AUGUST (3-17m)
MICHEL MITCHELL'S RECORDS = SPRING, SUMMER (3-18m)
OTHER SHELF RECORDS SUMMER, SPRING
WINTER, FALL

Figure 7

Table 1

Location of sewage plume in the water column

Site	Diffuser Depth(m)	Total Number of Density Profiles	Location of Plume Surface	Subsurface
Tufts Cove[1]	9	22	7	15
Duffus St.[1]	12	15	3	12
Peninsula Ctr.[1]	12	25	11	14
Dartmouth Cove[1]	12	23	17	6
Peninsula South[1]	17	24	5	19
Herring Cove[1]	6	24	24	0
Sandwich Point[1]	18	24	12	12
Hartlen Point[2]	20	19	13	6
Chebucto Head[2]	20	10	10	0
Bedford Basin East[3]	20	23	6	17
Bedford Basin West[3]	20	23	3	20

[1] Diffuser characteristics from Phase 3 Report
[2] Diffuser characteristics same as Sandwich Point
[3] Diffuser flux one half of Sandwich Point flux

2. Trace metals, suspended particulate matter and nutrients

Brian Petrie and Philip Yeats

ABSTRACT

Salinity data collected in monthly surveys over a two year period are used to model the horizontal circulation and vertical exchange in Halifax Harbour. The circulation is characterised by near-surface outflow and subsurface inflow at rates of order 1 cm s^{-1}; vertical velocities are found to be up to 2 m d^{-1}. Boundary conditions for 5 metals, suspended solids and nutrients are used with the circulation model to derive the distributions of these variables in the Harbour. The modelled distributions of Cu, suspended solids, nitrate and phosphate agree well with the observations. The derived distribution of Mn, Zn, Pb and Hg are less satisfactory, the differences arising because of the chemical dynamics of the former and the uncertainty of the boundary conditions for the latter three. Nitrogen, mostly in the form of ammonia, from sewage can account for a significant portion of the primary productivity in the Harbour; however, the model overestimates the observed winter concentrations of ammonia by a factor of 3.

INTRODUCTION

For over 200y raw sewage has been dumped into Halifax Harbour (Fig. 1) resulting in the buildup of deposits of organic material and metals in the sediments (Buckley and Hargrave,1989), and dissolved metals in the water (Dalziel et al., 1989). Platt and co-workers (e. g., Platt et al.,1970) have noted on numerous occasions that the nutrient levels in Bedford Basin are elevated relative to those in other nearby inlets. Presently, effluent is flowing into the Harbour at the mean rate of 40 million gallons a day (2.1 m^3s^{-1}).

The purpose of this paper is to make a first attempt, using simple models, to account for the mean distribution of dissolved metals and suspended solids in the Harbour waters. In addition, sedimentation rates are derived and compared to available measurements. The input of nutrients from sewage into the Harbour and its effect on primary productivity are also explored quantitatively. Finally, we examine the effect that sewage treatment would have on the distribution of one of the metals. To accomplish these tasks, a model of the average currents for periods of high and low freshwater inflow was formulated, based on observations of salinity throughout the inlet. Inputs of metals, suspended solids and nutrients from sewage, river inflow, rainfall, the adjacent continental shelf waters and primary productivity were applied to the model where appropriate and the distributions of the different variables derived. It must be emphasized that not all of the potentially important mechanisms are considered explicitly, though in some cases we have been able to estimate their magnitudes. Some processes, such as sedimentation, have been greatly simplified. The input to the Harbour of some variables is still only poorly known despite considerable effort. Nevertheless, the results show that the mean circulation plays a fundamental role in determining the concentration of these variables in the

Harbour. However, for some of them, though the circulation alone apparently does account for the observed data reasonably well, consideration must be given to the chemical dynamics.

In the sections to follow, the circulation model is outlined and compared to existing current measurements and flow patterns derived from other oceanographic analyses. Then, we describe the sources of the metals, nutrients and suspended solids for the Harbour. The next section combines the source functions and the circulation model to determine the distributions of the variables under consideration. A comparison of the results and the observations follows. A sewage treatment scenario proposed for the Harbour and the consequences it would have on the distribution of one of the metals are briefly considered. Finally we assess the utility of this approach when dealing with the pollution of coastal inlets and harbours.

MODEL OF THE MEAN CIRCULATION

Halifax Harbour is an estuary, i. e., a semi-enclosed body of water whose properties and circulation are influenced by freshwater runoff from the land. The main, localized source of freshwater for the Harbour is from the Sackville River (Fig. 2) which has an average inflow of 5.3 $m^3 s^{-1}$, a maximum of about 9 $m^3 s^{-1}$ in the spring and a minimum of about 2 $m^3 s^{-1}$ in the summer. Additional runoff into the Harbour is about twice the River flow and is accounted for in the model as a uniform input into the surface layer. The idealised circulation associated with such an estuary would feature outflow towards the shelf in the upper layer and inflow towards the Head of Bedford Basin in the deeper waters. Mixing would occur between the 2 layers. In such an estuary, the salinity in the upper layer would be expected to increase as the water moved towards the shelf because of the mixing with the deeper, saltier waters. By similar reasoning, the deeper waters would be expected to freshen as they moved from the shelf towards the head of the estuary. The salinity variations along the axis of the Harbour for mean, high and low freshwater inflow are shown in Fig. 3. Three to 5 hydrographic stations across the Harbour have been averaged at 8 locations in order to produce this graph. These data were collected during 24 cruises conducted monthly over a 2y period (Jordan, 1972). The difference in the 0-10m salinity along the axis of the Harbour for periods of high and low inflow is large, amounting to about 3.5 ppt (parts per thousand) and 0.7 ppt respectively. The minimum salinity in both layers is expected to occur at the Head of Bedford Basin where the Sackville River enters the Harbour. However, the observations (Fig. 3) show that the salinity minimum is found towards the southern end of the Basin. We think that this is due in part to the local wind which predominantly (for 70% of the surveys) would move the fresher waters to that area. For the model results reported in this paper, averaged Basin salinities have been used leading to salinity increase towards the shelf in both layers and an estuarine-like behavior. The mean and very low frequency winds over the shelf also contribute to the Harbour circulation by reinforcing the estuarine circulation (Petrie et al., 1987; Ruddick, 1990).

We have combined this simple picture of estuarine circulation, box model techniques (Csanady, 1983), and the conservation of mass and salt to determine the mean currents in the Harbour. A 2 box version of the Harbour is shown in Fig. 4 to illustrate the application of these principles. We have:

Conservation of mass:

upper layer $V_1 + V_2 + V_6 = V_3 + V_5$

lower layer $V_4 + V_5 = V_6$

Conservation of salt:

upper layer $V_1 S_1 + V_2 S_2 + V_6 S_6 = V_3 S_3 + V_5 S_5$

lower layer $V_4 S_4 + V_5 S_5 = V_6 S_6$

$S_3 = S_5$ (both represent the upper layer salinity)

where V_1 is the river inflow, V_2 is the runoff, V_3 is the flow out of the upper layer, V_4 is the flow into the lower layer, V_5 (V_6) is the flow from the upper (lower) layer due to processes such as mixing, entrainment, upwelling or downwelling. The salinities associated with the flows are designated by an S; in fact, they could represent the concentrations of a metal, suspended solid, nutrient or any pollutant. Generally the salinities, river flow and runoff are known, leaving 4 equations and 4 unknowns, V_3, V_4, V_5 and V_6 which thus can be found and which represent the Harbour circulation.

For this paper, the Harbour has been divided into 12 boxes - 6 representing the 0-10m depth range and 6 representing 10-20m. There are 2 boxes each for Bedford Basin, the Narrows, the downtown area, the region adjacent to McNabs Island, the Outer Harbour and the shelf (see Fig. 1). The results for conditions of high and low freshwater inflow are shown in Fig. 5. Strongest horizontal currents occur in the Narrows and in the McNabs Island area. The most vigorous vertical exchanges occur in the Narrows and the downtown harbour area during low runoff periods; for high runoff conditions, the strongest exchanges are found in the downtown and McNabs Island area.

Support for the currents derived from the model can be found in the current data from the Harbour shown in Fig. 6a,b. Surface flow is generally out of the inlet, deeper flow in. In the Outer Harbour, deeper currents flow up the inlet at rates of 1 - 3 cm s^{-1} while the model gives 0.5 - 4 cm s^{-1}. Near-surface outflows were measured at up to 2.6 cm s^{-1} off Sandwich Point, whereas the model gave 2.8 cm s^{-1} for the 0 - 10m flow. In the Outer Harbour, the two measurements at 6m do not show flow out of the Harbour. This may reflect the influence of wind or that these current meters were in the lower layer. In the Narrows (Fig. 6b), 2 layer flow is indicated with outgoing surface currents from 1.6 - 2.4 cm s^{-1} and incoming bottom currents of 0 - 6 cm s^{-1}. The model gave 4 - 4.8 cm s^{-1} for the surface and 5.6 - 6.2 cm s^{-1} for the bottom in reasonable agreement.

In summary, the mean circulation pattern and flow strengths observed in the Harbour from the current meter data are generally similar to our model and the idealised picture of estuarine circulation. An additional piece of information derived from the box model consists of the estimates of vertical exchange between the near- and subsurface layers. The modelled circulation can now be used along with the inputs of metals, nutrients and suspended solids to determine the distributions of these variables throughout the Harbour. Good agreement between the modelled and observed distributions will lend further support to the derived currents.

SOURCES OF METALS, SUSPENDED SOLIDS AND NUTRIENTS

The average values of metals in sewage entering Halifax Harbour were determined by Environment Canada surveys (P. Klaamas, pers. comm., Environment Canada, Dartmouth, N. S.) of 2 outfalls, Herring Cove and Northwest Arm, and the inflow to the Eastern Passage treatment plant (Fig. 1). Collectively these pipes account for approximately 2.6% of the total hydraulic load into the Harbour (ASA, 1986). These outfalls do not service the more industrialized areas and thus may not accurately characterize the sewage load to the Harbour. However, they represent the only data available. Each survey consisted of 48 samples of sewage, one every half hour. The samples were then combined to give one integrated sample which was analysed for the various metal contaminants. The average concentrations of the total metals (dissolved + particulate) are given in Table 1 along with the standard deviations and the number of surveys. The analysis did not distinguish between the dissolved and particulate metals; however, for weak untreated domestic wastewater like the Halifax Harbour effluent, typically dissolved metals would be about 70% of the total (Metcalf and Eddy, 1979). Given the uncertainty of the mean concentrations (Table 1) and the exploratory nature of this modelling, we shall assume that all of the metal is in the dissolved form as a first order approximation. The concentrations (Table 1) appear to be low in comparison to those in other areas which have values ranging from 2-90 times higher than are found in the Halifax Harbour effluent (Morel and Schiff, 1983; Nriagu, 1986).

Table 1
Concentration of Total Metals in Harbour Effluent

Metal	Mean Concentration ($\mu g\ l^{-1}$)	Standard Deviation ($\mu g\ l^{-1}$)	Number of Surveys
Cu	40	30	15
Zn	84	95	15
Hg	0.27	0.24	11
Mn	310	90	15

In addition to the metals shown in Table 1, model runs were carried out for Pb as the input metal. Although the analyses of the effluent included Pb, only one of the measurements showed concentrations above the detection limit of 20 $\mu g\ l^{-1}$.

There are other sources of metals besides the sewage. Shelf waters which move into the Harbour in the lower layer also contain these metals in dissolved form and are a major source. Average trace metal concentrations measured in June, 1985 at three inner shelf stations closest to the mouth of the Harbour were used to estimate the concentrations of the metals in the inflowing shelf water. In this study, the dissolved form is taken as the portion of metal which passes through a 0.4 μm filter. Freshwater runoff into the Harbour is a second major source, however, there are very few data to characterize its metal content. Concentrations of metal for the Sackville River, which accounts for approximately 33% of the freshwater inflow, were estimated by assuming that average values in river waters (Yeats, 1988) adequately describe its input. Another source of freshwater for the Harbour is direct rainfall on the water area itself. This accounts for an additional 26% of the freshwater inflow. Measurements of 8 metals in rainwater have been made for the Halifax region in 1982 (J. Dalziel, Bedford Inst. of Oceanography, Dartmouth, N. S., pers. comm.) and include Cu, Zn, Pb and Mn with mean concentrations of 3.7, 8.3, 4.0 and 3.0 $\mu g\ l^{-1}$ respectively. These values are 10-100 times smaller than the concentrations in the effluent (Table 1). Underwood (1984) found similar values for Cu (2.7 $\mu g\ l^{-1}$), Zn (9.5 $\mu g\ l^{-1}$) and Mn (3.3 $\mu g\ l^{-1}$) - Pb concentrations were not determined. The annual total precipitation of 1.36 m (Cdn. Climate Program, 1982) falling directly onto the Harbour waters is equivalent to a flow of 3.66 $m^3 s^{-1}$, about 1.7 times the effluent flow. However, since the concentrations are considerably lower, the metal input from rainfall is 6.2, 5.8 and 59 times less than the input from sewage for Cu, Zn and Mn respectively. A Hg concentration of 11 ng l^{-1} has been reported for New England rainfall (Fitzgerald, 1976). If this value applies for Halifax Harbour, the input would be 15 times less than the sewage input. We cannot compare the Pb fluxes from rainfall and sewage since we do not have an adequate value for the latter. However, we note that more recent (1988) observations of Pb concentrations in rain for other areas in Nova Scotia show values 4 to 13 times less than the older Halifax area data. This may reflect the reduced use of leaded gasolines. We shall assume that the input of Pb from rainfall is substantially less than that from sewage. Together the Sackville River and direct rainfall account for about 60% of the total freshwater input. Of the remaining 40%, at least 15% (ASA, 1986) is captured by the sewage system and is thus accounted for in Table 1. Given the approximate nature of our calculations, we shall not consider the input of metals from rainfall or the remaining 25% of the freshwater input further.

Values for the input of suspended solids from sewage were taken from CBCL (1987) and amounted to 1.4×10^7 kg y^{-1} or 0.44 kg s^{-1}. Suspended solid production within the Harbour was derived from primary productivity measurements made in Bedford Basin (Fig. 1), the only area of the Harbour where these data are available, by Platt and Irwin (1971). Their observations of total carbon productivity were converted to suspended solids by multiplying by a factor of 1.7 (Pocklington, 1988). Losses of primary productivity due to respiration were also accounted for by multiplying by 0.9 (Steeman Neilson and Hansen, 1959). Productivity is roughly constant at about 50 mg C $m^{-2}d^{-1}$ from April to November after 2 months of low values from mid-December to mid-February and the bloom in March of about 150 mg C $m^{-2}d^{-1}$. The modelling efforts will concentrate on the period of constant input. The measurements made in the Basin were taken as representative for the entire Harbour. As a result, primary productivity accounts for about 2.7 kg s^{-1} of suspended solids over the entire Harbour. The Sackville River accounts for an input of about 0.05 kg s^{-1}. Concentrations of suspended solids in shelf waters were taken from Dalziel et al. (1989) and Bewers et al. (1976).

Nutrient concentrations in the effluent were taken from CBCL (1987). These analyses were for total nitrogen and total phosphorus; they did not determine if these elements were in a form that could be readily utilized for primary productivity. Shelf water nutrient concentrations were from Fournier et al. (1977). We shall consider the impact that nutrients from sewage can have on the total production in the Harbour.

APPLICATIONS

Metals

The circulation for high and low freshwater inflow derived from the box model has been combined with the input of metals from sewage, the Sackville River and from the shelf to predict the distribution of dissolved metals in the water column subject to the assumptions outlined in the last section. In addition, since the concentrations from individual outfalls are not known, we assumed that the input of metal from the sewage was equally divided between the Narrows and the downtown Harbour area, reflecting the distribution of outfall pipes (Fig. 1). Our expectations are only for reasonable not exact agreement between the predicted and observed concentrations. The metal fluxes from the sewage, River and the shelf waters for each run are listed in Table 2, where, again we have taken the limit of the analytical technique as the input concentration for lead in sewage.

Table 2

Input Metal Fluxes (kg s^{-1}) for Model Simulations

	Cu	Hg	Zn	Pb	Mn
Sewage:					
Summer-Winter	8.4×10^{-5}	5.75×10^{-7}	1.76×10^{-4}	4×10^{-5}	6.2×10^{-4}
River:					
Summer	1×10^{-5}	6×10^{-9}	2×10^{-5}	1×10^{-7}	4×10^{-5}
Winter	0.9×10^{-5}	1.8×10^{-8}	1.8×10^{-5}	2.7×10^{-7}	9×10^{-5}
Shelf:					
Summer	9.5×10^{-5}	2×10^{-7}	2.3×10^{-4}	1.7×10^{-5}	2.5×10^{-4}
Winter	2.1×10^{-4}	4.5×10^{-7}	5×10^{-4}	3.7×10^{-5}	5.5×10^{-4}

The input of metals from the river flow is considerably less than that from sewage. On the other hand, it is evident from Table 2 that for 4 of the metals (we do not have an accurate measure of the effluent concentration for Pb), the inputs from shelf waters and sewage are within a factor of 3 of one another. Sewage will dominate in the inner harbour because the shelf input will not penetrate the inlet fully due to vertical mixing and outflow in the upper layer.

The results of the simulations are shown in Fig. 7 and 8. In these diagrams the concentrations in the 0 - 10m and 10 - 20m have been averaged to provide an overall comparison with the observations of Dalziel et al. (1989, 1990) who sampled at 12 depths in their 6 stations in the Harbour, with 5 of these samples taken in Bedford Basin. Their surveys were conducted in January, March, May and June and the overall results are shown in Table 3.

Table 3

Average Concentrations ($\mu g\ l^{-1}$) 0-20m in the Harbour

Metal	Bedford Basin	Narrows	Downtown Hbr	McNabs	Outer Hbr	Shelf
Cu	0.44	0.44	0.47	0.38	-	0.20
Hg (ng l^{-1})	0.61	0.82	1.13	1.23	-	0.53
Zn	4.14	11.5	2.09	1.78	-	0.48
Pb	0.024	0.031	0.044	0.021	-	0.035

The agreement between the simulations and the observations for copper (Fig. 7) is excellent, with only one of the modelled points outside the limits of a standard deviation. This is consistent with our expectation that, of all of the metals considered, copper distributions would be the least affected by chemical reactions within the Harbour waters. It also implies that either most of the copper in the effluent is in the dissolved form or that the available data are from effluent pipes which have lower than average total concentrations.

The observed concentrations for zinc are higher in Bedford Basin and the Narrows than the model predictions (Fig. 7). There is the possibility that zinc may be supplied from the sediments which contain high concentrations of the metal (Buckley and Hargrave, 1989). However, the observations reported by Dalziel et al. (1989, 1990) do not consistently show dissolved zinc gradients near the sediment interface. To first order this does not favour a large flux of metal from the sediment. On the other hand, one of the effluent pipes in the Narrows services the largest industrial park in the region which may lead to an elevated input of metals, though there is no direct evidence that this is indeed the case. An increase to the zinc loading by a factor of 5 in the Narrows brings the predicted concentrations to within the statistical bounds of the observations. In the other 2 areas, the observations and the predictions are within the statistical bounds for the original and the enhanced loads.

The observed concentrations for mercury are less than the model predictions (Fig. 7) for the Basin and the Narrows for high and low inflow conditions. In the downtown Harbour and McNabs areas, the low inflow predictions are slightly elevated, whereas the high inflow values are within the error bars. This suggests that a greater proportion of the mercury may be in the particulate form. A reduction of the mercury input in the Narrows and the downtown Harbour by a factor of 0.4 brings the predictions to within the statistical limits of the observations.

The calculations for lead (Fig. 7) were carried out using the detection limit of the chemical techniques as the input concentration of the effluent. Though the lead concentrations in the Harbour are overestimated by about a factor of 4 - 5 as a consequence, they are at least consistent with the model and the upper bound used for the source. Lead, unlike the other metals, has its lowest concentrations not in the shelf water but in the Basin, the area off McNabs Island and in the Narrows. Consequently, the input from sewage must be reduced to zero to bring the model predictions to within or close to the observed values or dissolved lead must be removed from solution within the Harbour. The metals are largely in the dissolved phase in the effluent. In the Harbour, however, analysis of the filtered metal concentrations indicates that Cd, Cu and Zn remain predominantly (76 - 95%) in the dissolved phase, whereas, 80% of the Pb is found in the particulate phase (Dalziel et al., 1989). This transition from dissolved to particulate Pb would account for at least part of the difference between model and field results, and for the minimum in the dissolved Pb concentrations in the vicinity of McNabs Island - the lowest dissolved Pb concentrations occur where external inputs are low and suspended solid concentrations, and hence scavenging by particles, are greatest.

The predictions for manganese generally agree with the observations (Fig. 8) except for slight overestimates for the Narrows and the McNabs areas under low flow conditions. Given the approximations of the model, the uncertainties of the boundary conditions and the relatively few field observations, these differences are not of great concern. However, unlike the other metals discussed so far, one feature of the manganese data has implications for its dynamics in the Harbour. The vertical distribution of dissolved manganese in Bedford Basin is indicated in Table 4. Samples were collected at 5 or 6 depths at a site in the centre of the Basin (depth = 71m) on 4 occasions.

Table 4

Average Manganese Concentrations in Bedford Basin as a Function of Depth

Depth Range (m)	Concentration ($\mu g\ l^{-1}$)	Standard Error ($\mu g\ l^{-1}$)
0 - 10	2.37	0.51
15 - 25	1.83	0.40
50 - 60	5.88	3.35

There is an indication that the manganese concentrations near the bottom of the Basin are enhanced compared to the surface and mid-depth layer. This is consistent with the reducing conditions found in the bottom sediments (Buckley and Hargrave, 1989) which would convert particulate Mn to the dissolved form. We have estimated the dissolved Mn flux from the bottom waters into the lower box of our model using the vertical exchanges between the deep and middle layer of the 3 layer box model developed for Bedford Basin alone and applied only for the salinity and mass budgets (ASA, 1986). For average conditions the flux amounts to 2.7×10^{-4} kg s^{-1}, approximately 40% of the sewage flux. This flux is enhanced in winter to 7.2×10^{-4} kg s^{-1}, slightly greater than the input from the effluent. Applying the latter flux to the lower layer of the model results in Mn concentrations considerably in excess of the observations (Fig. 9). However, the presence of particulate Mn and oxidizing conditions in the upper layers promotes the conversion of the dissolved Mn to particulate form and subsequent sedimentation. Based on the concentrations of particulate Mn and ambient water temperatures (based on archived data), we have estimated the oxidation constants (which range from 3.2×10^{-7} to 1.5×10^{-6} s^{-1}) for each area of the Harbour and applied these chemical dynamics to our circulation model. The addition of this process reduces the predicted Mn concentrations in the Harbour to roughly half the observed values (Fig. 9). Although the modelled concentrations of Mn using the circulation alone are in closer agreement with the observed values, we think that this is fortuitous and that the inclusion of a bottom source the chemical dynamics, at least for Mn, is a more accurate representation of the processes taking place.

Suspended Solids

The main sources for suspended solids in the Harbour are primary productivity, sewage, freshwater runoff and shelf water. As indicated above, we shall concentrate on the period when the primary productivity was roughly constant which corresponds most closely with low freshwater flow conditions. For suspended solids, there is an additional process to consider, namely, the settling of suspended matter to the bottom.The comparison between model results and the observations is shown in Fig. 10, where the difference between the predictions and the data has been minimized by adjusting a single sinking velocity applied to the suspended solids. As a consequence, the model predicts an average sinking rate of about 2.2 m d^{-1} throughout the Harbour. This gives a sedimentation rate of 820 g $m^{-2}y^{-1}$ which compares favourably to the sediment trap observations at 20m in Bedford Basin of 791 and 638 g $m^{-2}y^{-1}$ for 1973 and 1974 respectively (Hargrave et al., 1976). By comparing water column concentrations and sedimentation rates, Taguchi and Hargrave (1978) find that a sinking velocity of 0.4 - 1.0 m d^{-1} for particulate carbon can account for the bulk of their observations. This is smaller than our estimate but within reasonable agreement. More recent (1987) measurements from the Basin (B. Irwin, Bedford Institute of Oceanography, pers. comm.) indicate that the sedimentation rate may be as high as 1600 g $m^{-2}y^{-1}$. Our estimate falls between the earlier data and this most recent value.

Nutrients

The quantity of total nitrogen and phosphorus from sewage entering the Harbour is estimated from the budgets given by CBCL (1987) as 4.04×10^{-2}kg s^{-1} and 1.81×10^{-2}kg s^{-1} respectively. There was no seasonal variation of these inputs. Morel and Schiff (1983) indicate that about 0.5% of the total nitrogen in typical effluent is in the form of nitrate (input = 2.0×10^{-4}kg s^{-1}), whereas about 85% is in a form, mostly ammonia, that could be readily used by phytoplankton. Similarly, they indicate that about 70% of the total phosphorus is in the form of phosphate (input = 1.3×10^{-2}kg s^{-1}). Generally, nitrate and phosphate measurements are taken during oceanographic surveys, ammonia is less widely sampled. Shelf waters flowing into the Harbour in the bottom layer provide another source of nutrients. Combining the high discharge flow conditions with the March values (Fournier et al., 1977) of nitrate (8 μM) and phosphate (0.8 μM) gives inputs of 0.12 kg s^{-1} and

2.6×10^{-2} kg s^{-1} respectively. Thus, the ocean inputs of nitrate and phosphate are 600 and 2 times greater than the corresponding ones from sewage. In a similar fashion, the appropriate shelf inflows and nutrient concentrations (Fournier et al., 1977) have been combined for May, August and November to get values of 6×10^{-3}, 8×10^{-3} and 4.4×10^{-3} kg s^{-1} for nitrate and 6.9×10^{-3}, 4.6×10^{-3} and 7.8×10^{-3} kg s^{-1} for phosphate. During these months the ocean inputs are from 20 to 40 times greater than those from sewage for nitrate and 2 to 3 times less for phosphate. Therefore, sewage makes a negligible contribution to the nitrate budget but a significant contribution to the phosphate budget in the Harbour.

We ran the model for the following conditions: for nitrate, we used only the ocean source and compared the model results with available observations; for phosphate, we considered the sewage input alone, the shelf flux alone and, finally, the combined inputs again comparing the results to available data. The March inputs from sewage and the shelf water were assigned to the appropriate boxes and were run for the high flow conditions. This should correspond to the time when primary productivity would only have a small effect on nutrient concentrations and would allow the best intercomparison of Harbour observations and model predictions. The results, averaged for the upper 20m are shown in Fig.11 along with a range of values for the same depth interval, mainly from Bedford Basin and collected in January and February. The shelf input alone can account for the nitrate distribution in the inner harbour. The phosphate distribution using only the shelf source underestimates the inner harbour values. The combination of the two sources gives reasonable concentrations that are near the upper bounds of the observations. The small amount of primary productivity occurring in January and February (Platt and Irwin, 1971) could lower the values slightly.

As was the case for manganese, there is evidence in existing data (Krauel, 1969; Taguchi et al., 1975) that nutrient concentrations increase with increasing depth in the Basin. Combining those two data sets for January and February, we find mean values of nitrate of 5.45 and 6.62 μM at 20 and 30m respectively; similarly we calculate averages of 1.00 and 1.20 μM for phosphate. Using these values with the vertical water transports estimated for winter conditions (ASA, 1986), we get inputs of 2.8×10^{-3}kg s^{-1} for nitrate, and 1.1×10^{-3} kg s^{-1} for phosphate. These values, which are about 2% of the shelf input for the former and 8% of the sewage input for the latter, indicate that the vertical sources from the deep basin are relatively unimportant to modelling the upper layers.

The model was run for ammonia, the dominant form of nitrogen in sewage and with an input of 85% of the effluent total nitrogen, and gives concentrations of 4-6 μM in the Basin and Narrows. Primary productivity during this time of year (Platt and Irwin, 1971) is expected to reduce these values by about 0.5 μM. On the other hand, ammonia concentrations tend to increase with depth in the Basin, indicating an input from the sediment. We have estimated that this could be as high as 2.4×10^{-3}kg s^{-1} or about 10% of that from sewage. At this level it would only raise the model values slightly. Platt and Irwin found ammonia concentrations of 1-2 μM, approximately 2-3 times less than the model's estimates. Clearly the model values are too high, perhaps due to the uncertainty of the total sewage input and the forms of nitrogen in the effluent.

Though the model overestimates the concentrations of readily available nitrogen in the Harbour, it is still appropriate to determine if the sewage flux can account for a significant part of the primary productivity. This has not been done previously, though Platt et al. (1970) noted that nutrients from sewage could be a significant source. Assuming that 85% of the nitrogen, being the limiting nutrient, can be converted to organic carbon at the ratio of 5.5 kg carbon per kg nitrogen (Redfield et al., 1963) and that this nutrient input is distributed over the entire inlet, we find that the total production amounts to 0.047 kg carbon m^{-2}y^{-1}. This compares to the measured productivity from Bedford Basin of 0.25 kg carbon m^{-2}y^{-1} for 1969 - 1970 (Platt and Irwin, 1971), 0.20 kg carbon m^{-2}y^{-1} for 1973 - 1974 (Taguchi et al., 1975) and 0.20 kg carbon m^{-2}y^{-1} for 1986 - 1987 (Irwin et al., 1988, 1989a,b). Thus, roughly 20% of the primary production of the Harbour could be accounted for if all of the sewage nutrients were converted to organic carbon. If the nutrient input from sewage were confined to the area of the Harbour north of Sandwich Point, then the production rate per unit area would double to 40% since the outer harbour accounts for one half of the total area of the inlet.

While the nutrients from sewage may contribute significantly to the annual productivity, they may be more important during certain seasons. To sustain the production of 50 mg C m^{-2} d^{-1} (Platt and Irwin, 1971) from April to November requires a nitrogen flux of 1.34x10^{-2} kg s^{-1}. As shown earlier, the ocean fluxes are roughly 1.7 to 3 times less than this. The sewage input of 3.4x10^{-2} kg s^{-1} (85% of total nitrogen) could readily supply the nitrogen demand during this period.

SCENARIO

The CBCL (1987) report presented several scenarios for sewage treatment in the Harbour. A number included the consolidation of the present outfalls in the Narrows and downtown into 1 to 5 treatment plants, but basically not altering the area where the effluent is discharged. Neglecting the real possibility that some metals may be partially removed by the treatment process, these scenarios should produce metal distributions similar to those predicted by the model for the existing situation. Another proposal had all of the sewage effluent being discharged in the area adjacent to McNabs Island. This case is shown along with the model prediction for the current situation in Fig. 12. This figure shows, not surprisingly, that the metal concentrations decrease for the 3 inner areas of the Harbour when all of the sewage flows into the McNabs Island area. It also illustrates the fact that for this type of model in steady state, all of the metal must leave the Harbour in the upper layer of the last box. The flux of metal out of this layer must balance the total input from all sources. Unless the quantity of metal input or the circulation change, then the concentration will be the same regardless of the internal arrangement of sources. This condition influences the concentrations in adjacent boxes as well. Finally, it is useful to note that, if the only source of copper were from the shelf, the concentration in the Harbour would be about 0.2 μM.

CONCLUSIONS

A box model based on salinity data, conservation of mass and salt, and assumptions of estuarine-like flow driven by freshwater inflow and complemented by the wind field has been developed for Halifax Harbour. The model compares favourably with existing observations of the mean currents in the Harbour but cannot be used to predict short term fluctuations of the circulation or the detailed distribution of flow near an outfall. The salinity data were not contemporaneous with surveys made of sewage input or with observations of the concentrations of metals, nutrients and suspended solids. Perhaps the largest potential for error comes from the uncertainty of the source functions. The concentrations of metals in the effluent were made for only 3, accounting for 2.6% of the total flow, of 44 pipes in the inlet; moreover, we suspect that these pipes, which serve largely domestic areas, do not represent the industrial effluent very well. The measurements did not distinguish between the particulate and dissolved form of the metals thus requiring us to make a general assumption based on the available literature. However , we do expect that there will be variations from metal to metal. The sediments in the Harbour could be a source of metals and nutrients. We did consider this input for Mn, Zn, phosphate, nitrate and ammonia and found that the gradients in the deeper waters of Bedford Basin suggested that only for Mn was this source likely significant. A more comprehensive data set and an improved model could alter this conclusion. In addition, the high variance of metal concentrations in the Harbour indicates that large spatial and/or temporal variability probably exists. More data are required to obtain a better estimation of the mean concentrations. Finally, since this is a first attempt to model these variables in the Harbour, many processes were simplified (e. g. particle sinking, oxidation of Mn, and input from the sediment) or neglected (e. g. flocculation). In spite of these shortcomings, the results indicate that:

1)For Halifax Harbour, the circulation plays a major role in determining the distribution of metals, nutrients and suspended solids. The model predicted the distribution of Cu particularly well and was generally within a factor of 2 for Hg, Zn and Mn. Suspended solid concentrations in the Harbour were simulated to within about 20% throughout the Harbour when a sinking term for particles was added to the model. The sinking velocity of 2.2 m d^{-1}, constant regardless of particle size, agreed with other estimates made for suspended material in the Harbour. Nutrients were more of a problem - though the model did a reasonable job of predicting the distributions of nitrate and phosphate, it significantly overestimated the concentrations of nitrogen forms, chiefly ammonia, readily used in primary productivity. Consequently, the amount of primary productivity calculated from the readily available nitrogen may be high. We cannot establish the reason for this but perhaps the most likely candidate is the uncertainty in the effluent flux of nitrogen and the forms that it may take. However, we have been able to indicate that, assuming the input is correct, nutrients from effluent could account for 20 - 40% of the annual productivity in the Harbour if they are distributed over the entire or one half of the inlet's area. This is the first time that the role of nutrients from sewage has been quantified for the Harbour.

2)Despite the model's apparent success in predicting the distribution of Mn from the currents alone, we think that input from the sediment and chemical reactions in the Harbour waters must be considered to fully understand the dynamics of this metal.

3)In an inlet which has a major inflow from the adjacent shelf, the metal and nutrient fluxes from this source may be as or more important than the input from sewage. Our considerations of Pb illustrated this point particularly well where concentrations on the shelf were greater than those in the Harbour.

4)For this inlet, the largest contribution of suspended solids in the water column came from primary productivity, exceeding the amount from sewage by about a factor of 6 over the entire inlet. Of course, in localized areas sewage input can be more important and, in the case of raw effluent, more visual.

5)Clearly, this effort is only a first step towards modelling the distribution of various components in the water column. It is evident that more work is required to properly characterize the inputs, to establish with greater statistical accuracy mean and variable concentrations of metals, nutrients, etc. in the water, and to properly model the physical, chemical, geological and biological processes acting and interacting in the Harbour.

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FIGURE CAPTIONS

Figure 1. The study area with water sampling sites and sewage outfalls indicated.

Figure 2. Monthly average freshwater flow of the Sackville River based on 17y of data.

Figure 3. Along harbour variation of salinity based on the data collected by Jordan (1972). The letters A-H indicate the positions of the lines of oceanographic stations occupied during the surveys (see Fig. 1). The

March-April period corresponds to high freshwater flow, the July-August period to low freshwater flow.

Figure 4. A 2 box model of an inlet to illustrate the mass and salt conservation principles used to derive the circulation.

Figure 5. The circulation in Halifax Harbour derived from the salinity data for periods of high and low freshwater flow.

Figure 6a. Observed currents in the outer Harbour and shelf based on archived current meter records collected over a 22y period. Record lengths vary from about 3 weeks to 8 months. The number beside the arrow indicates the depth (m) at which the data were recorded. The 30m isobath is shown.

Figure 6b. Currents from the Narrows.

Figure 7. Average observed metal concentrations (0-20m) along the axis of the Harbour are indicated by a dot (mean) and vertical bars (standard deviation). The model predictions for high (+) and low (x) freshwater inflows are also shown for Cu, Zn, Hg and Pb. The Harbour areas are BB (Bedford Basin), N (Narrows), DH (downtown Harbour), McN (area opposite McNabs Island), OH (outer Harbour) and S (shelf). Shelf concentrations are from Bewers et al. (1976) and Dalziel et al. (1989).

Figure 8. The same as Fig. 7 but for manganese.

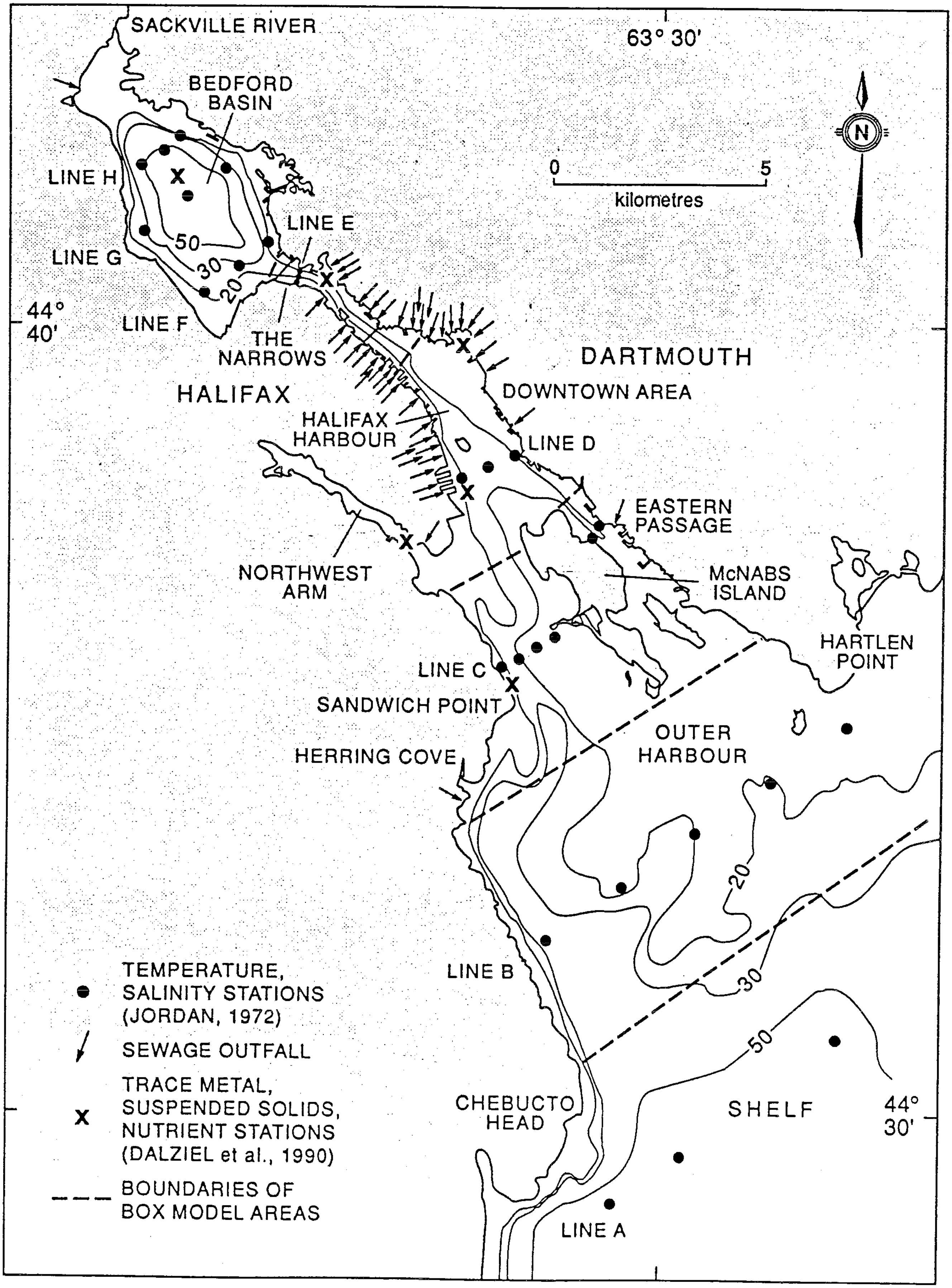
Figure 9. Model runs and observed concentrations (January, designated by an open circle)for manganese. Model runs were made for the circulation alone (+), with an added source of Mn in the deep part of Bedford Basin (dot) and finally by including oxidation of Mn, which converts dissolved Mn to particulate form, in all layers of the model (x).

Figure 10. The observed (dot) and modelled (x) suspended solids concentrations (0-20m) for low flow conditions. Shelf concentrations are from Bewers et al. (1976) and Dalziel et al. (1989).

Figure 11. Observed ranges of the nitrate and phosphate concentrations (0-20m) in the Harbour along with model results for sewage input alone (dot), ocean input alone (open circle) and the combined inputs (x). The observations are from 1) Krauel (1969); 2) Taguchi et al. (1975); 3) Irwin et al. (1988); 4) Irwin et al. (1989b); 5) Dalziel et al. (1990); and, 6) Fournier et al. (1977).

Figure 12. Results of the model runs for Cu with present distribution of sources (dot) and with the sewage sources collected and discharged into the area opposite McNabs Island (x).

Figure 1



SACKVILLE RIVER
63° 30'
BEDFORD BASIN
LINE H
LINE G
LINE F
LINE E
50
30
20
THE NARROWS
44° 40'
0
5
kilometres
N
DARTMOUTH
HALIFAX
DOWNTOWN AREA
HALIFAX HARBOUR
LINE D
EASTERN PASSAGE
NORTHWEST ARM
McNABS ISLAND
HARTLEN POINT
LINE C
SANDWICH POINT
OUTER HARBOUR
HERRING COVE
20
LINE B
30
50
CHEBUCTO HEAD
SHELF
44° 30'
LINE A
TEMPERATURE, SALINITY STATIONS (JORDAN, 1972)
SEWAGE OUTFALL
TRACE METAL, SUSPENDED SOLIDS, NUTRIENT STATIONS (DALZIEL et al., 1990)
BOUNDARIES OF BOX MODEL AREAS

Figure 2

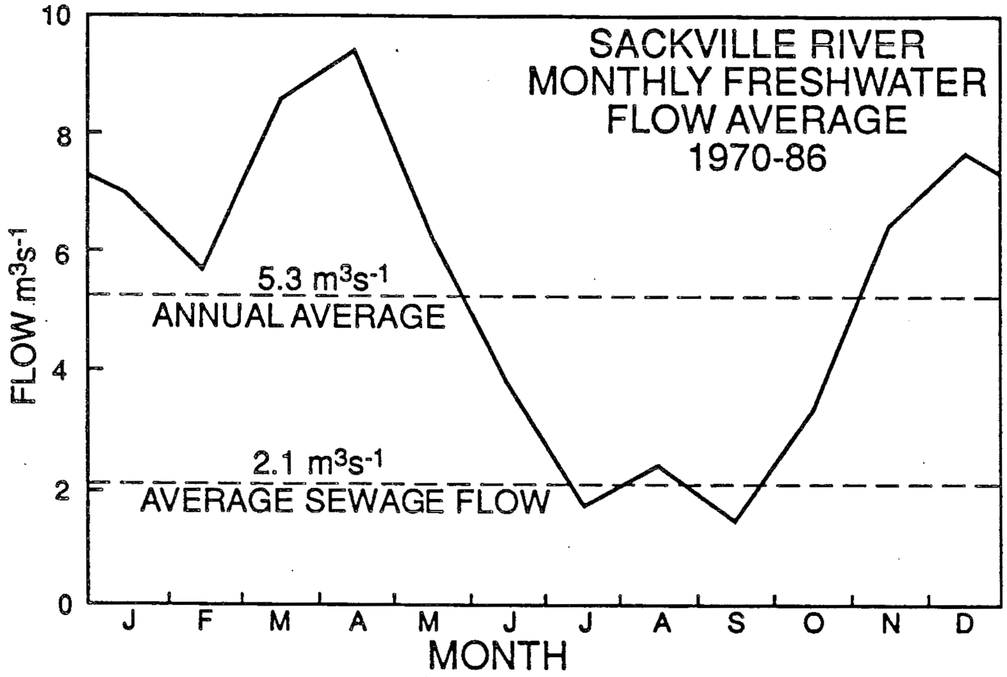

SACKVILLE RIVER
MONTHLY FRESHWATER
FLOW AVERAGE
1970-86
FLOW m3s-1
10
8
6
4
2
0
5.3 m3s-1
ANNUAL AVERAGE
2.1 m3s-1
AVERAGE SEWAGE FLOW
J
F
M
A
M
J
J
A
S
O
N
D
MONTH

Figure 3

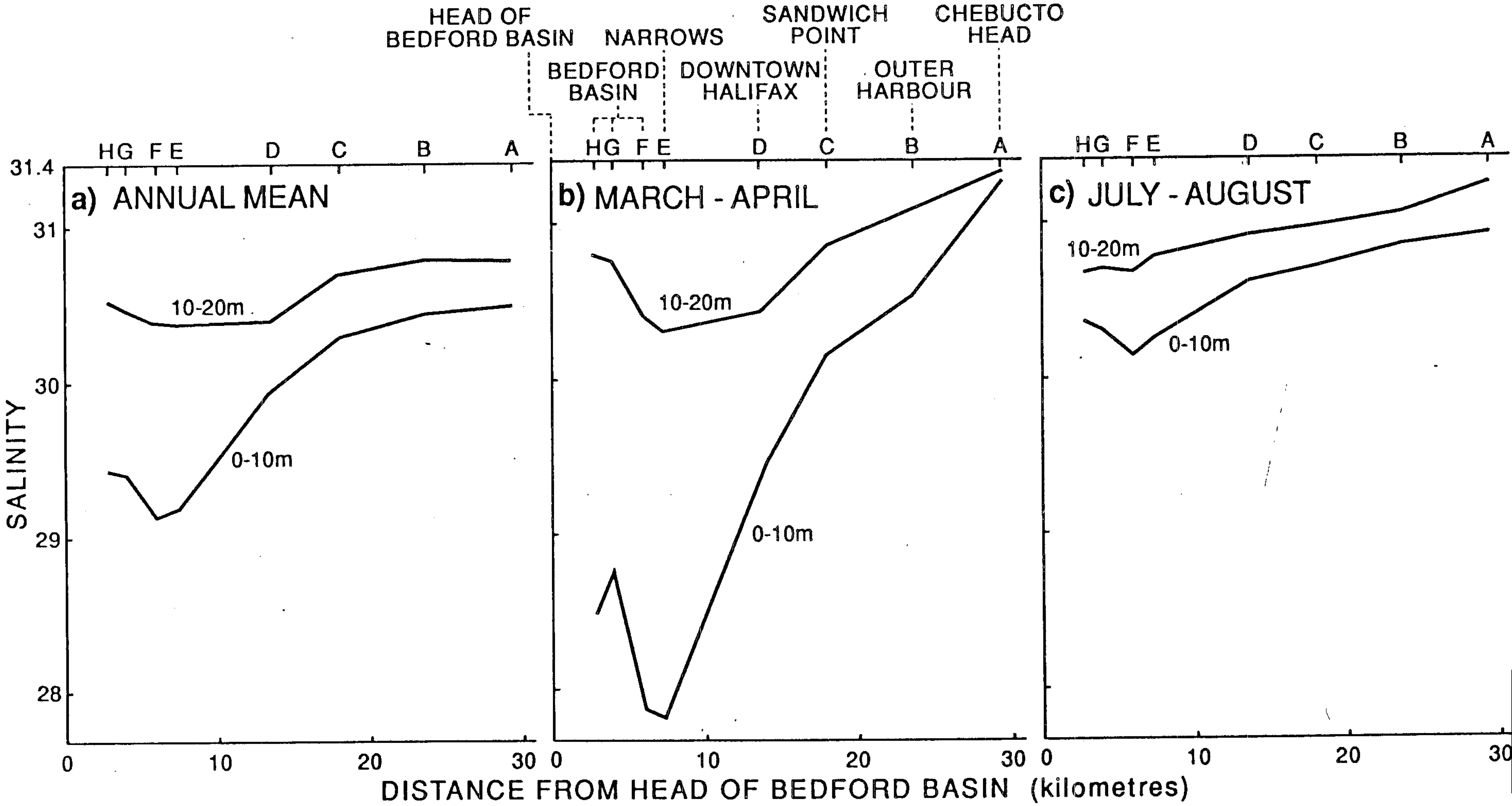
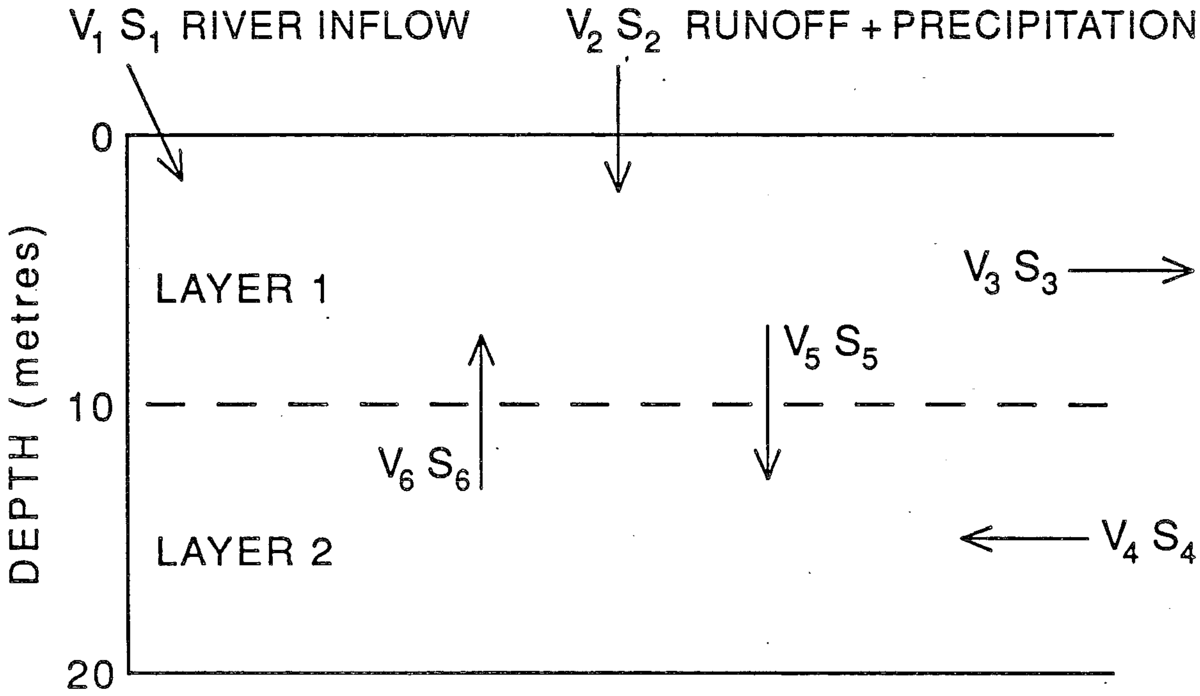

HEAD OF BEDFORD BASIN
BEDFORD BASIN
NARROWS
DOWNTOWN HALIFAX
SANDWICH POINT
OUTER HARBOUR
CHEBUCTO HEAD
HG F E D C B A
a) ANNUAL MEAN
b) MARCH - APRIL
c) JULY - AUGUST
10-20m
0-10m
SALINITY
31.4
31
30
29
28
0
10
20
30
DISTANCE FROM HEAD OF BEDFORD BASIN (kilometres)

Figure 4



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B.Petrie Paragon Jun 90

Figure 5

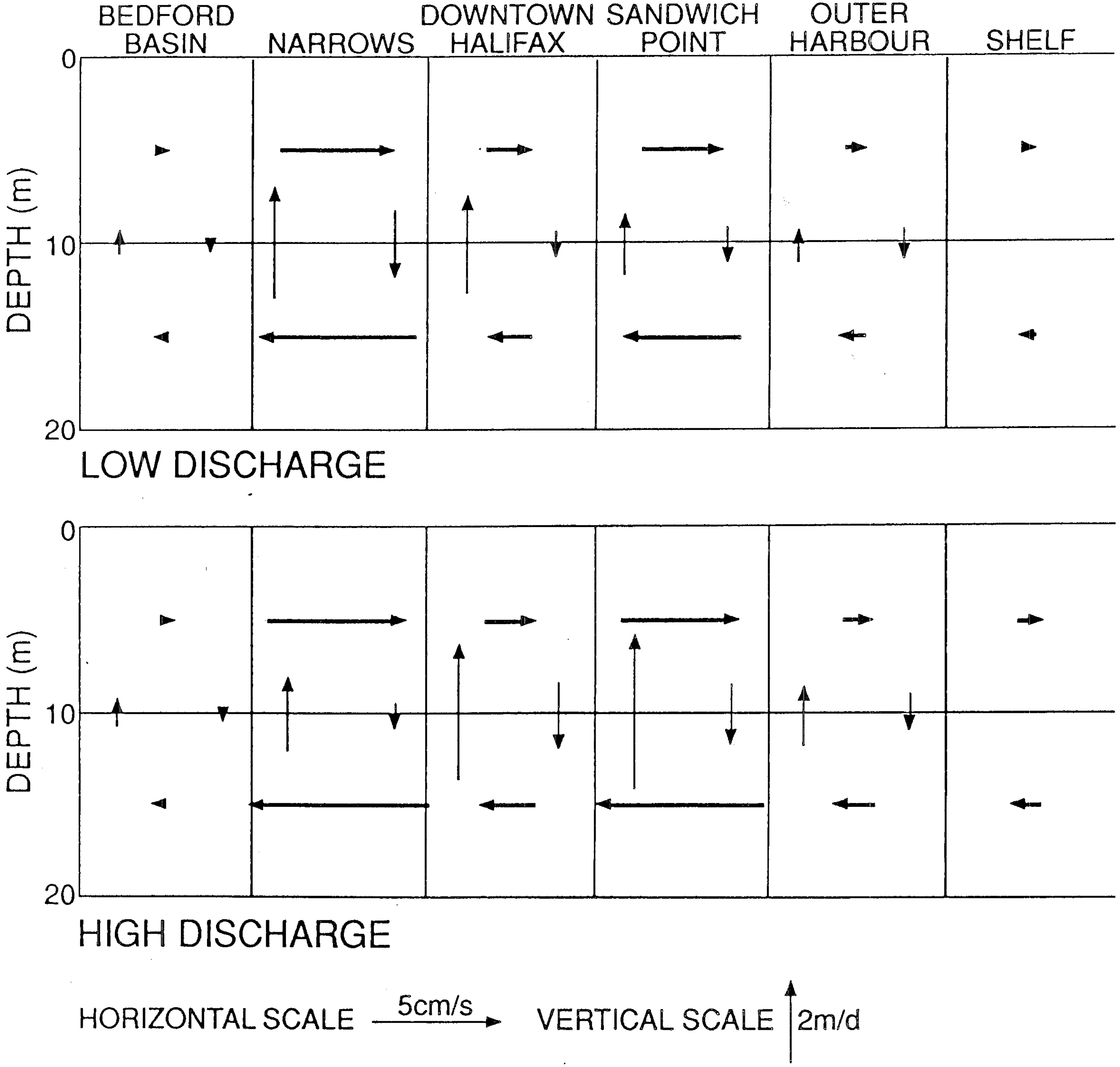
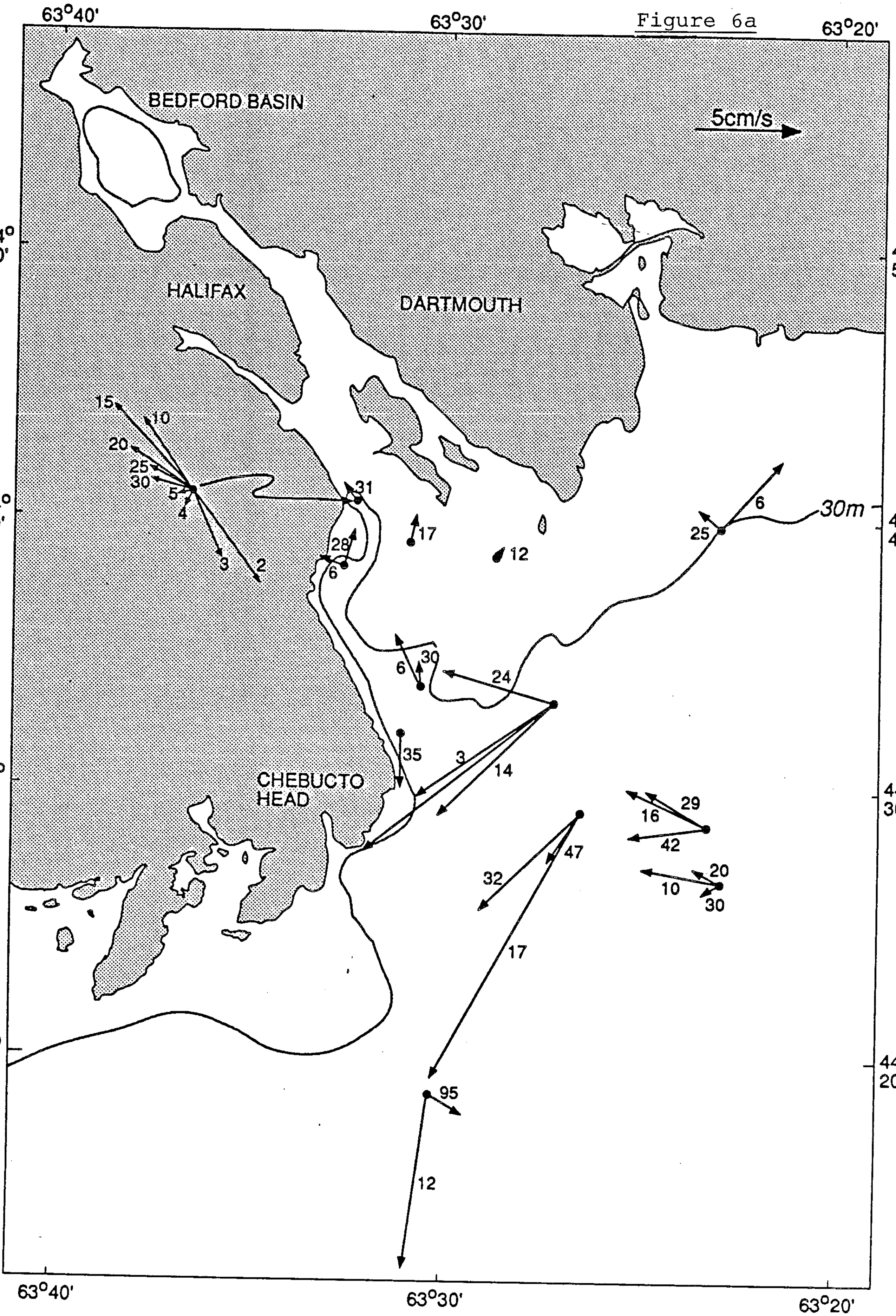

BEDFORD BASIN
NARROWS
DOWNTOWN HALIFAX
SANDWICH POINT
OUTER HARBOUR
SHELF
DEPTH (m)
0
10
20
LOW DISCHARGE
DEPTH (m)
0
10
20
HIGH DISCHARGE
HORIZONTAL SCALE
5cm/s
VERTICAL SCALE
2m/d

Figure 6a



63°40'
63°30'
63°20'
44° 50'
44° 40'
44° 30'
44° 20'
BEDFORD BASIN
HALIFAX
DARTMOUTH
CHEBUCTO HEAD
5cm/s
30m
15
10
20
25
30
5
4
3
2
31
28
6
17
12
6
25
6
30
24
35
3
14
29
16
42
20
10
30
47
32
17
95
12

Figure 6b

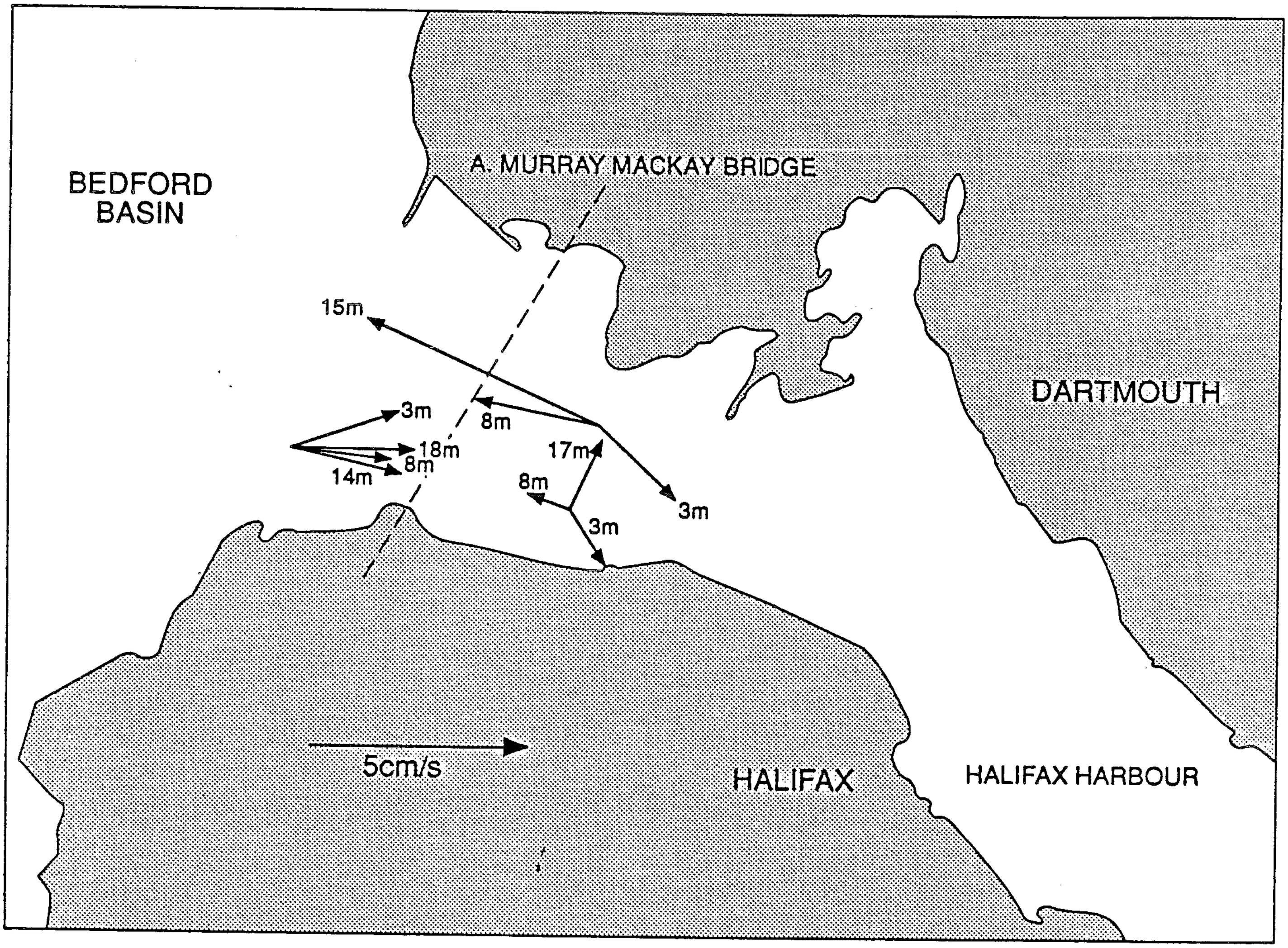

BEDFORD
BASIN
A. MURRAY MACKAY BRIDGE
15m
3m
8m
18m
8m
14m
17m
8m
3m
3m
DARTMOUTH
5cm/s
HALIFAX
HALIFAX HARBOUR

Figure 7

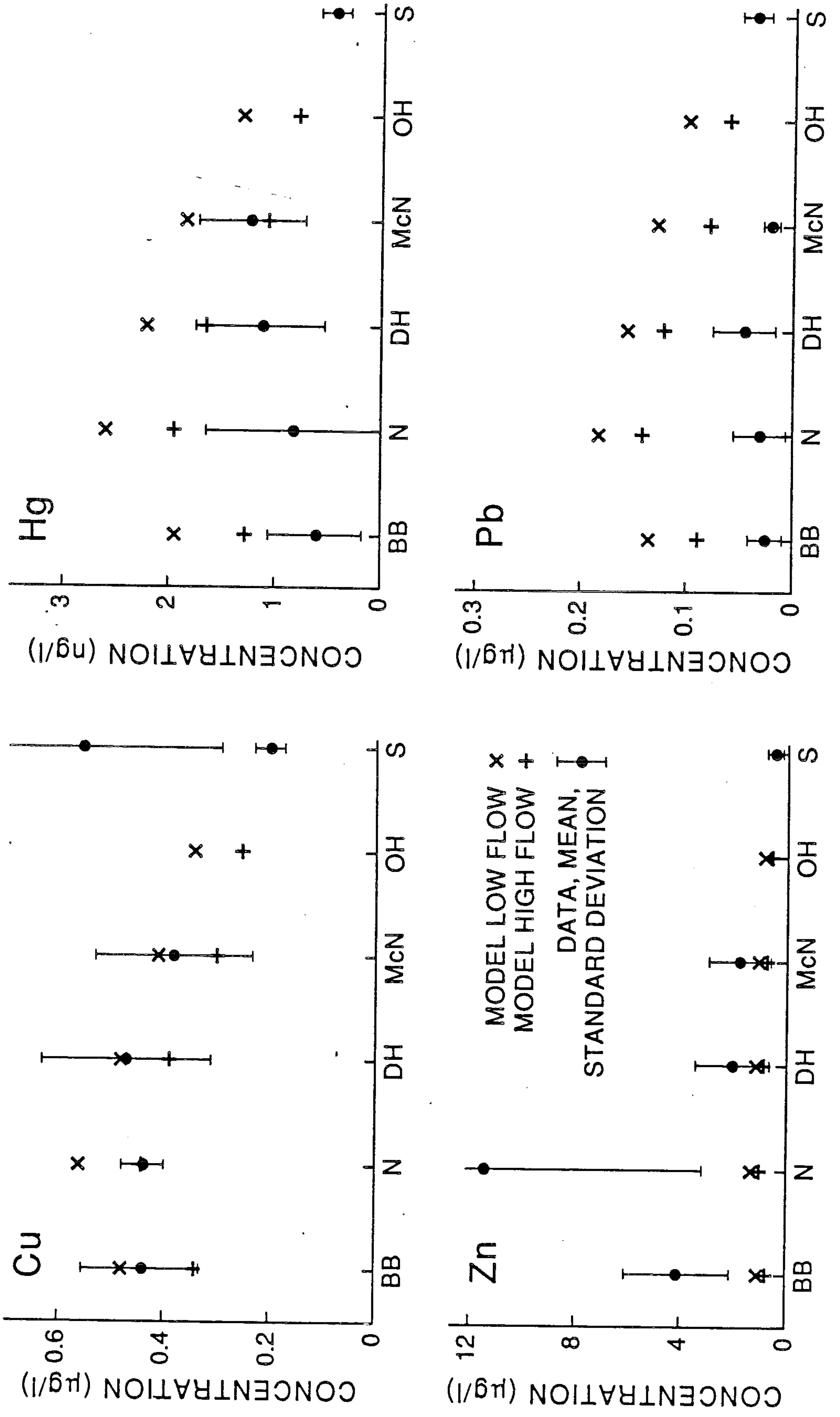
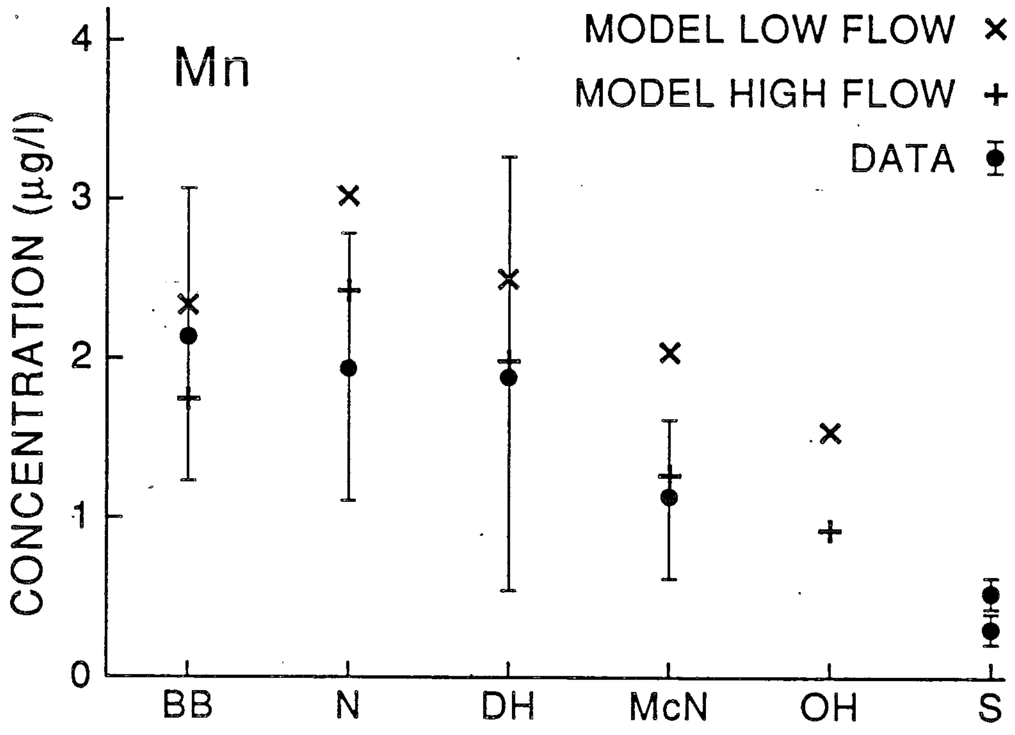
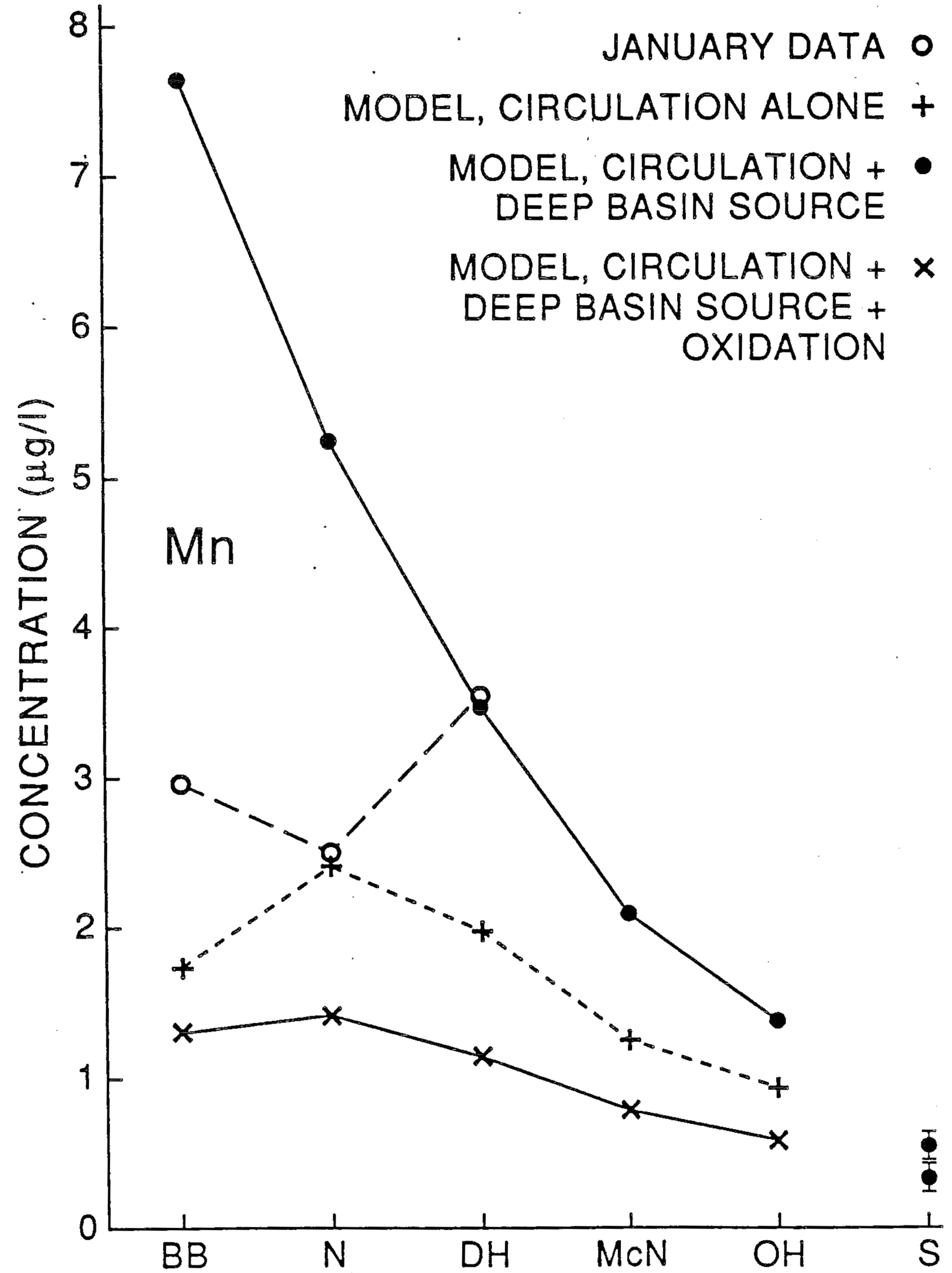

Cu
CONCENTRATION (μg/l)
0
0.2
0.4
0.6
Hg
CONCENTRATION (ng/l)
0
1
2
3
Zn
CONCENTRATION (μg/l)
0
4
8
12
Pb
CONCENTRATION (μg/l)
0
0.1
0.2
0.3
BB
N
DH
McN
OH
S
MODEL LOW FLOW ×
MODEL HIGH FLOW +
DATA, MEAN, STANDARD DEVIATION

Figure 8



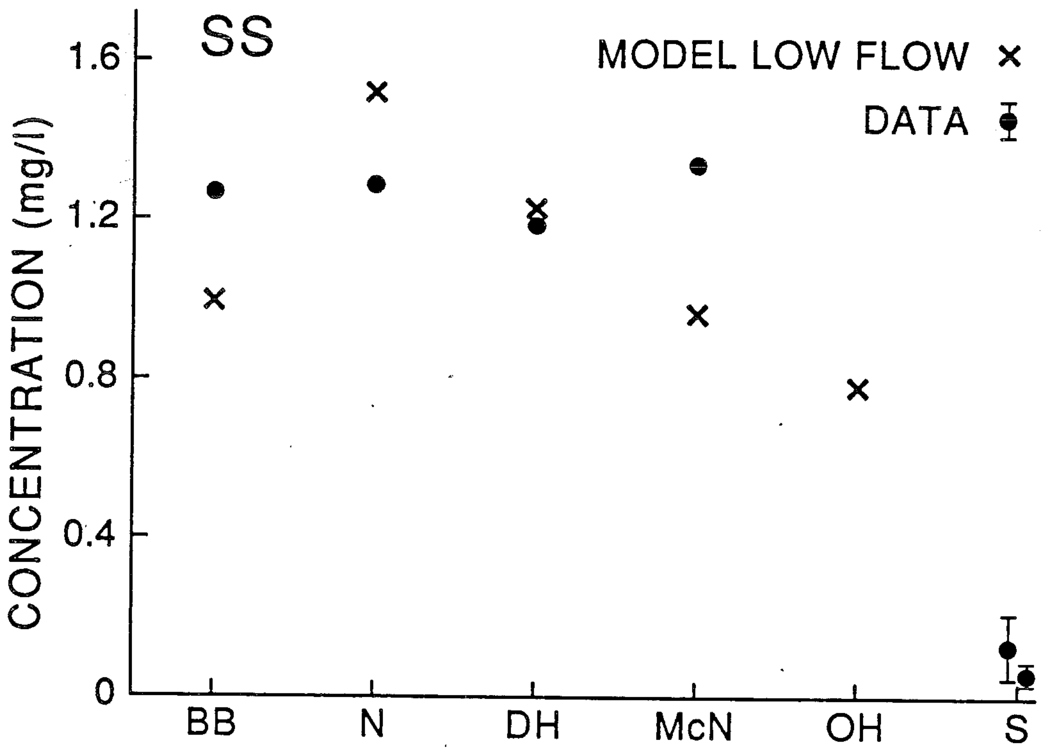
Mn
MODEL LOW FLOW ×
MODEL HIGH FLOW +
DATA
CONCENTRATION (µg/l)
0
1
2
3
4
BB
N
DH
McN
OH
S

Figure 9



JANUARY DATA ○
MODEL, CIRCULATION ALONE +
MODEL, CIRCULATION + DEEP BASIN SOURCE ●
MODEL, CIRCULATION + DEEP BASIN SOURCE + OXIDATION ×
Mn
CONCENTRATION (μg/l)
0
1
2
3
4
5
6
7
8
BB
N
DH
McN
OH
S

Figure 10


SS
MODEL LOW FLOW ×
DATA ●
CONCENTRATION (mg/l)
1.6
1.2
0.8
0.4
0
BB
N
DH
McN
OH
S

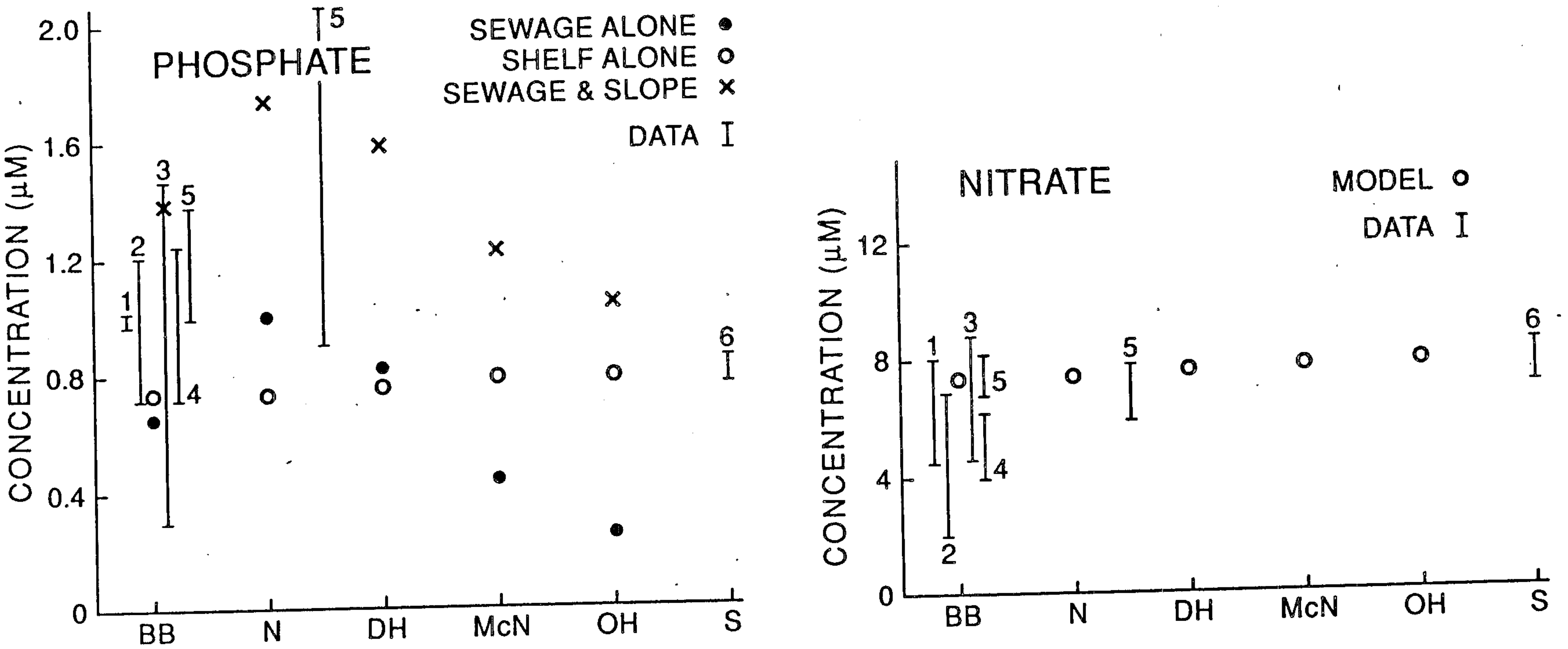


Figure 11

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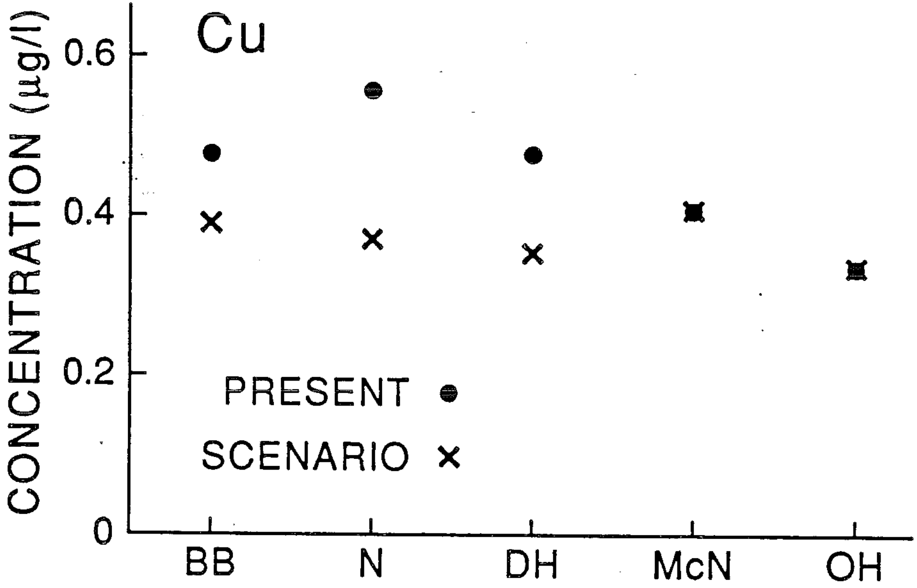
B.Petrie Paragon-R Jun90

Figure 12



Cu
CONCENTRATION (µg/l)
0.6
0.4
0.2
0
PRESENT ●
SCENARIO ×
BB
N
DH
McN
OH

3. Fecal coliform in the Harbour

Brian Petrie

Modelling Fecal Coliform

During the course of this work a number of simple models of fecal coliform concentrations in Halifax Harbour were developed. Some of these are instructive, i.e. they give a sense of importance of various processes, and some are directly applicable to the Harbour. We shall present these models in the order in which they were developed.

Stagnant Box Model

In this model the assumption is made that the fecal coliform in the effluent are mixed into a volume of ocean water of fixed size and that the only mechanism to reduce their concentrations is through die-off. Based on the Phase 3 report (CBCL, 1987) about 3.2 $\times 10^{17}$ fecal coliform are discharged into the Harbour every year. This amounts to a source, S, of 1 $\times 10^{10} s^{-1}$.

The concentration, C, will reach a steady state when the die off rate, R, equals the input. We shall absume that the fecal coliform are mixed into a box, V, of dimensions 1 km × 1 km × 10 m.

We have

$$RC=S/V$$

where R is 1.74 $\times 10^{-5} s^{-1}$, corresponding to an e-folding time of 16 h. Therefore, the concentration C is

$$C=\frac{1\times 10^{10}}{10^{7}\times 1.7\times 10^{-5}}=5.76\times 10^{7}\,\textit{fecal coliform}\ m^{-3}$$

or

$$=5780\ \textit{f.c./100 ml.}$$

For primary treatment with a 95% kill rate of fecal coliform during disinfection the concentration would be

$$C=5780\times 0.05$$

$$=288\ \textit{f.c./100 ml.}$$

In this model, the concentration of fecal coliform depends on the source strength and inversely on the mixing volume and the die-off rate. In earlier studies (ASA, 1986), a die-off rate of 1.16 $\times 10^{-5}$ s^{-1} was used. In the most recent studies, ASA has used a die off rate of 2.3 $\times 10^{-5} s^{-1}$. The former would give a concentration of 431, the latter 216.

Channel Model – Diffusion Only

Consider a channel of width = L and depth = h stretching from ±∞ in the x direction. At x = 0, fecal coliform are added at the rate S s^{-1}. This situation could apply to an area like the Narrows and downtown portion of the Harbour if all the coliform were let out of one diffuser and mixed instantly across the width of the Harbour.

The governing equation is a balance of the horizontal eddy diffusion, K, and the decay rate, R, of fecal coliform. We have:

$$K\frac{\partial^2 C}{\partial x^2} = RC$$

Integrating across the channel and over depth we recover the same equation since variations are only allowed in the x direction.

The boundary condition at x = 0 is

$$2\int_o^h \int_o^L \left(-K\frac{\partial C}{\partial x}\right) dy\, dz = S$$

where the factor of 2 accounts for diffusion is both the positive and negative x directions.

For S = 3.2 × $10^{17}y^{-1}$, R = 1.5 d^{-1} and K = 5, 30 m^2s^{-1} (CBCL, 1987) the solution is

$$C = C_o e^{\mp\sqrt{\frac{R}{K}}x} \text{ for } \pm x.$$

Applying the boundary condition we get

$$C_o = S/2hLK\sqrt{\frac{R}{K}}$$

Evaluating C_0 we have:

$$C_o = 3350\, f.c./100\ ml, \text{ for } K = 5m^2s^{-1}, L = 1600\ m, h = 10m, \text{ untreated sewage}$$

$$= 168\, f.c./100\ ml, \text{ for } K = 5m^2s^{-1}, L = 1600\ m, h = 10m, \text{ primary sewage (95\% kill rate)}$$

$$= 1370\, f.c./100\ ml, \text{ for } K = 30m^2s^{-1}, L = 1600\ m, h = 10m, \text{ untreated sewage}$$

$$= 69\, f.c./100\ ml, \text{ for } K = 30m^2s^{-1}, L = 1600\ m, h = 10m, \text{ primary sewage}$$

The results for $K = 5 m^2 s^{-1}$ are plotted in Fig. 1 and show, as expected, a symmetric distribution of fecal coliform around the source.

Channel Model – Advection Only

Consider a channel similar to that discussed in the last section with a uniform current, U, but without diffusion. The governing equation is a balance between the advection flux and death rate of fecal coliform. We have:

$$U\frac{\partial C}{\partial x} = -RC$$

which leads to a solution

$$C = C_o e^{-\frac{R}{U}x} \; for x > 0$$

$$C = 0 \; for x < 0 \quad .$$

At x = 0, the input must equal the flux away from the source giving

$$C_o = S/hLU$$

for $R = 1.74 \times 10^{-5} s^{-1}$, h = 10 m, L = 1600 m and $U = 0.02$ m s^{-1}

$$C_o = 3130 \; and \; R/U = 8.68 \times 10^{-4} m^{-1}.$$

The results (Fig. 1) show the one-sided distribution of fecal coliform expected when there is a uniform current and no diffusion.

Channel Model – Diffusion and Advection

Consider the same channel discussed in the last section but now include a current, U, and horizontal diffusion, K, in the system. Then the equation which applies to this situation is given by

$$U\frac{dC}{\partial x} - K\frac{\partial^2 C}{\partial x^2} = -RC$$

For positive x the solution has the form

$$C = C_o e^{-ax}$$

Substituting into the equation above, we have

$$a=\frac{U}{2K}\left(-1\pm\sqrt{1+\frac{4RK}{U^2}}\right)\Rightarrow\frac{U}{2K}\left(-1+\sqrt{1+\frac{4RK}{U^2}}\right)$$

where we must take the + root to avoid the solution increasing without bound as $x\to+\infty$.

Following a similar procedure for negative x, we find

$$C=C_o e^{bx}$$

$$b=\frac{U}{2K}\left(1+\sqrt{1+\frac{4RK}{U^2}}\right)$$

The solution will be complete if we can determine the unknown constant C_0. To find C_0 we apply the boundary condition at x=0. Consider what is happening at $x=0^-$ and $x=0^+$. At $x=0^-$, diffusion is carrying fecal coliform away from the source while the current is carrying fecal coliform back to the source. At $x=0^+$, both diffusion and advection are carrying fecal coliform away from the source, whereas at $x=0^-$ diffusion and advection are opposed. We have

$$K\frac{\partial C^-}{\partial x}-UC^-+\left(-K\frac{\partial C^+}{\partial x}\right)+UC^+=S/hL$$

Substituting the 2 solutions as $x\to0$ we find

$$C_o=\frac{S}{KhL(b+a)}$$

$$=\frac{S}{UhL\left\{1+\frac{4RK}{U^2}\right\}^{\frac{1}{2}}}$$

We shall take h=5 m and L=500 m as more realistic conditions for the inner part of the Harbour where a diffuser might be several hundred meters long and produce a mixed ocean effluent layer 5 m thick. For a current of 0.02 m s^{-1}, $R=1.74\times10^{-5}s^{-1}$, $K=5m^2s^{-1}$ and $S=10^{10}$f.c.s^{-1}.

We find C_0 = 14600 (f.c./100 ml) for untreated effluent, where

= 732 (f.c./100 ml) for primary effluent.

$a=7.34\times10^{-4}m^{-1}$ $b=4.73\times10^{-3}\ m^{-1}$.

For $k=30m^2s^{-1}$ and all other parameters the same as above, we find

C_0 = 8030 (f.c./100 ml) for untreated effluent

$= 400$ (f.c./100 ml) for primary effluent, where

a $= 4.97 \times 10^{-4}\ \mathrm{m}^{-1}$ $b = 1.16 \times 10^{-3}\mathrm{m}^{-1}$.

The results of these calculations are shown in Fig. 2. The distribution of fecal coliform is no longer symmetric as it was when there was only diffusion. The current compacts the distribution on the upstream side of the source where the action of the flow and diffusion oppose one another. On the other hand, the distribution is stretched out on the downstream side of the flow where current and diffusion act together. In the case shown, fecal coliform counts remain above 100 f.c./100 ml for nearly 3 km. Lower currents and diffusion sites would lead to higher counts at the source.

Observations of Fecal Coliform in the Harbour

Measurements of fecal coliform concentrations were made at 12 harbour locations (Fig. 3) during 3 surveys in August, 1985. They are reported in the Phase 2 water quality study of Halifax Inlet (Vol. 11, Appendices, ASA 1986). The average concentrations from these surveys are shown in plan view for 1 and 10 m (Fig. 3) and as a function of depth (Fig. 4) where the temporal averages from the observations at each station of each survey are plotted. Within surveys the temporal variations were large, with differences of as much as 6000 counts/100 ml in 2 h. Average values at the same station differed by as much as 1500 counts/100 ml from one survey to another. It is also obvious from Fig. 3 and 4 that spatial variations are large horizontally and vertically. Stations separated by 1 km can have average values differing by nearly 2000 counts/100 ml. At the same site, samples separated by about 10 m can differ by about 6000 counts/100 ml.

We conclude that these measurements of fecal coliform in the Harbour showed large spatial and temporal gradients. There are not enough data to determine if the averages of these observations adequately characterize the coliform levels in the inlet. Therefore, when modelling the fecal coliform levels in the Harbour, we must be careful not to over-interpret the results. Any discrepancy between the model and these observations should be in terms of an overprediction by the model in order to err on the side of safety.

We have incorporated the ideas of the previous section in an attempt to simulate the observed distribution of fecal coliform in the Harbour. Evidence suggest that there is a mean surface outflow in the Harbour. Our simple model consists of 2 segments: the first is a 500 m wide, 3 km long channel corresponding to the Narrows and beginning at approximately Tufts Cove, the site of the northernmost sewage pipe; the second channel, connected to the first at a location corresponding to Dartmouth Cove, is 1500 m wide and extends outwards towards the shelf. Effluent inflow of fecal coliform based on the annual mean load is uniformly distributed along the sides of the first channel and the first 4 km of the second. The coliform are confined to the upper 10 m and are transported seaward by a current. Two values of the current were considered, 0.02 m/s and 0.04 m/s in the Narrows. There is no horizontal diffusion, rather the coliform are mixed instantly across the inlet. Two decay constants, corresponding to e-folding times of 16 and 12 h, were considered. The model results for 3 simulations along with the 1 and 10 m August 1985 observations are shown in Fig. 5. At best, the model results get the right order of the fecal coliform concentrations, with $R^{-1} = 16$ h and $V = 0.02$m/s (in the Narrows) perhaps giving a qualitatively better fit. The higher values north of the Narrows could be due to tidal advection of effluent from the Tufts Cove and Duffus Street outfalls. The rapid decrease of concentrations south of the Harbour indicates a combination of low mean currents and a rapid die-off rate. The 3 model results shown illustrate the dependence of the concentration on the die-off rate, R^{-1}, and the mean current.

Models appropriate to a Single Diffuser

In the previous sections we presented models in which the fecal coliform entered the receiving waters as either a point source or a unformly distributed source. The models consisted of uniform or varying cross section channels in which the coliform were mixed instantly across the channel and spread along the harbour axis either through horizontal diffusion or velocity or both. While these models may resemble the present situation in the Harbour, they do not approximate the case of a single diffuser very well at all. It will be necessary, therefore, to formulate another model in order to develop some idea of what may occur around a single outfall.

Fecal Coliform Counts Associated with a Single Diffuser

Preliminary Calculation

The Phase 3 report of the Halifax Inlet Water Quality Study (CBCL, 1987) gave an annual budget for the fecal coliform in the effluent streams for the major outfall areas of the Harbour. The total for Herring Cove, Halifax South, Halifax Center, Duffus Street, Tufts Cove and Dartmouth Cove was about 32×10^{16} fecal coliform/y or 10^{10} f.c./s. A flow rate of about 2 m^3/s to a diffuser producing a dilution rate of 50 to 1 would give a concentration of 10^4 f.c./100 ml in the initial plume for untreated sewage. A primary (secondary) treatment plant with a 95% (99%) kill rate of fecal coliform would result in counts of 500 (100) f.c./100 ml. Dilution rates of less (more) than 50 to 1 would yield higher (lower) concentrations of fecal coliform If, for example, the standard deviation of the dilution rate is 10, then for 1% of the time the dilution would have a value of 26.7 or less. In that case (a dilution ratio of 26.7), the resulting coliform levels in the initial sewage plume would be 17,600, 880 and 180 f.c./100 ml for untreated, primary and secondary treated effluent respectively. The calculation above also assumes that coliform-free water is always available for mixing with the effluent. This calculation serves as a guide for the more complicated one to follow.

Tidal Ellipse Model of Fecal Coliform Concentrations

A dominant and everpresent feature of the circulation in the inlet is the tidal flows, particularly in the Narrows, downtown Harbour and Sandwich Point area. The approach we shall now take is to put all of the fecal coliform into an ellipse-shaped box defined by the tidal currents and the diffuser width. The latter factor is only critical for colinear or nearly colinear tidal currents. A number of processes can contribute to the concentrations of fecal coliform in this area around the diffuser. We shall consider the random death of fecal coliform, advective losses because of the mean flow, losses due to horizontal diffusion and vertical mixing of coliform.

The balance around a diffuser is illustrated in Fig. 6 and can be written as follows:

$$Concentration = \frac{Source}{Random\ die-off + Mean\ flow + horizontal\ diffusion + Vertical\ mixing}$$

where the source, S, is taken from the Phase 3 report;

the random die-off is given by R*Volume, R=e-folding time;

the mean flow loss is U^*A_1,

where U is the mean current and A_1 is an area;

the horizontal diffusion loss is V^*A_2, where V is a velocity representing the horizontal diffusion and is given by $(KR)^{\frac{1}{2}}$ and is taken to act only in the direction perpendicular to mean flow;

the vertical mixing loss is W^*A_3, where W is a vertical velocity from the upper layer and is derived from the Harbour box model. We have,

$$C=S/(RV_0+UA_1+VA_2+WA_3)$$

The assumptions are made that during horizontal and vertical mixing fecal coliform-free water is available to mix into the spreading plume (ellipse).

Application to Present Harbour Conditions

We consider that the present load of fecal coliform is being spread over the Narrows and downtown area of the Harbour and take the following values for the variables:

$S=10^{10}$ f.c./s; $V_0 = 7000 \times 1000 \times 10$ m^3; U=0.01 m/s;

$A_1 = 1000 \times 10$ m^2; V=0 (coliform are spread over the entire area of this portion of the Inlet which includes the Narrows and downtown region); $W= 4 \times 10^{-6}$ m/s; $A_3=7000 \times 1000$ m^2 $R=1/(16 \times 3600)$ s^{-1}.

We have

$$C= 10^{10}/(1215 + 100 + 28)$$
$$=7.4 \times 10^6 f.c./m^3 \, or \, 740 \, f.c./100 \, ml.$$

This value is 3 times larger than the observed average count for the upper 10 m of the Harbour of 244 f.c./100 ml from three surveys in 1985 (ASA, 1986). Given that we are using flow rates derived from 1969-1971 hydrographic surveys, an R from ASA (1986) based on the 1985 Harbour fecal coliform surveys, it is not surprising that the results disagree. However, it is encouraging that the disagreement is on the conservative side, i.e., our estimate exceeds the observations.

Application to Single Diffusers in Various Sites

We have considered 200 m long diffusers handling all of the sewage flow in each area of the inlet. The appropriate values of the various parameters are given in Table 1. We have assumed a value of 5 m^2/s for the horizontal eddy diffusivity which is taken to act only perpendicular to the mean flow. The diffusers are assumed to be perpendicular to the mean flow and the major tidal axis. The diffuser length is added to the minor tidal axis in calculating volumes and areas. The volume, V_0, is taken as (major axis)(minor axis + diffuser length)(5 m) – the effluent is assumed to settle out in a layer 5 m thick. The results indicate that for primary treatment the fecal coliform concentrations inside the tidal ellipse range from about 225-300/100 ml from the Narrows to the Shelf. These differences are certainly within the uncertainty of the model. Moreover, the concentrations would be expected to decay to about 0.37 of the values shown in about 1 km (assumes a current of 0.02m/s and random death constant of 16 h). Much higher counts, about 1400, are predicted for Bedford Basin.

It is of interest to compare these results with those obtained in the 1989-1990 ASA modelling studies. Generally, those efforts, which are considerably more sophisticated than this one, found much lower counts. There are two factors that can account for some of the difference – their R corresponded to 12 h and their layer depth was about 10 m. Applying these values to the downtown Harbour area, for example, we get 2600 for untreated, 130 for primary and 30 for secondary or roughly half our values. In addition, their study included greater variability in the horizontal currents probably leading to greater dispersion.

As a final illustration and summary of this section, we show (Fig. 7) how fecal coliform concentration can vary as a function of diffuser length, current, die-off rate and horizontal diffusion. For the four cases shown, the parameters are as was given in Table 1, area DH, except for the one variable which is changed. Increasing diffuser length, current and horizontal diffusivity and decreasing the time scale of coliform die-off all act to decrease fecal coliform concentrations.

Table 1

	AREA					
	BB	N	DH	SP	OH	S
Tidal Current (m/s) major	0.02	0.25	0.08	0.10	0.08*	0.032
Minor	0	0	0.008	0.01	0.008	0.015
Mean flow (m/s)	0.002	0.03	0.02	0.02	0.03	0.05
Diffusive flows (m/s)	0.01	0	0.01	0.01	0.01	0.01
Vertical flow (10^{-6}m/s)	0.04	3.5	5.8	8	7	0
Tidal Excursion (m)						
Major	285	3560	1140	1420	1140	455
Minor	–	– +	114	142	114	214
RV_0	5	124	31	42	31	16
UA_1	2	60	31	34	47	104
VA_2	14	–	114	142	114	46
WA_3	–	5	2	4	3	–
Coliform counts/ 100 ml						
Untreated	29000	5300	5600	4500	5100	6000
Primary (95° kill)	1440	265	270	225	255	300
Secondary (99°kill)	290	50	55	45	50	60

*Includes diurnal tides; + effective width taken as 400 since coliform would diffuse to shore in less than an e-folding time.

BB = Bedford Basin; N = Narrows; DH = downtown Harbour; SP = Sandwich Point; OH = outer Harbour; S = Shelf

Figure Captions

Figure 1. Concentration of fecal coliform in a channel 1600 m wide and 10 m deep where only diffusion (5 m^2s^{-1}) and die-off are allowed (solid line) or only a current (0.02 m s^{-1}) and die-off (broken line).

Figure 2. Concentration of fecal coliform in a channel 500 m wide and 5 m deep with a current of 0.02 m s^{-1} in the positive x direction and horizontal diffusion of 5 and 30 m^2 s^{-1}.

Figure 3. Average fecal coliform concentrations (counts/100 ml) at (a) 1 m and (b) 10 m from 3 surveys in August, 1985.

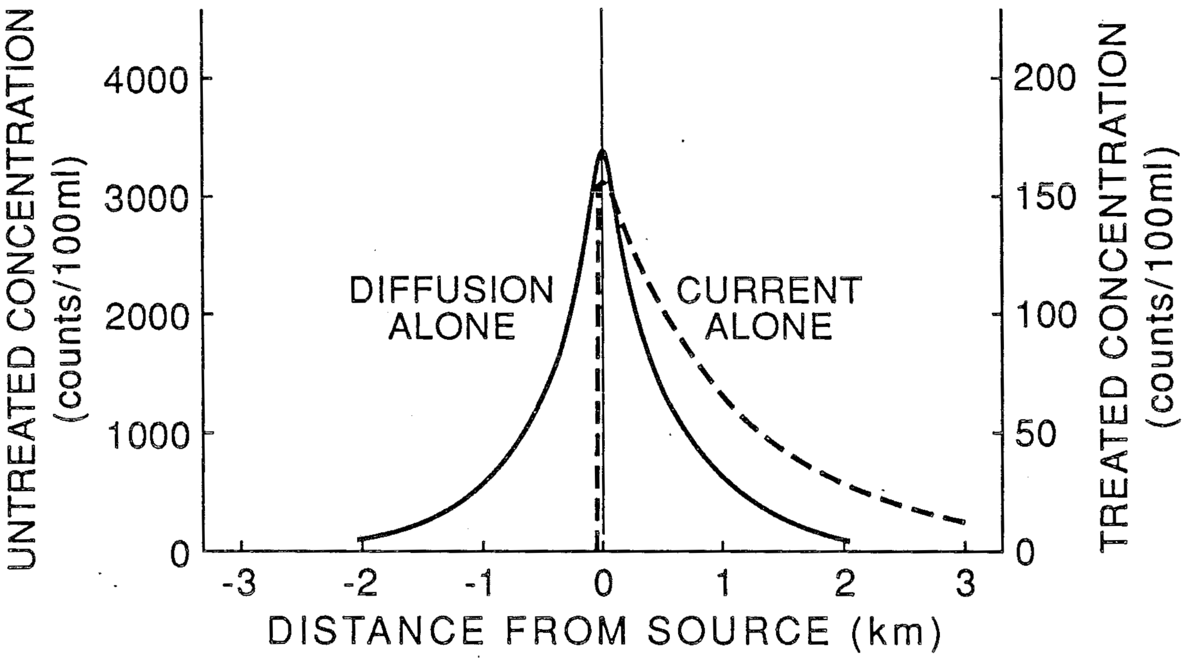
Figure 4. Depth variation of fecal coliform concentrations (counts/100 ml) from 3 surveys in the Harbour during August, 1985.

Figure 5. Observations of fecal coliform concentrations in the Harbour at 1 m (●) and 10 m (×) from the August 1985 surveys. Three model results are shown in which the current and die-off rate corresponded to 0.02 m s^{-1} and 16 h, 0.02 m s^{-1} and 12 h, and 0.04 m s^{-1} and 12 h.

Figure 6. Schematic of processes which take place around a diffuser and lead to dilution of fecal coliform concentrations.

Figure 7. Variation of fecal coliform concentrations for primary treatment in an area where the major tidal axis is 1140 m, the minor 114 m, the mean current 0.02 m s^{-1}, the diffusive velocity 0.01 m s^{-1}, the vertical velocity 5.8×10^{-6} m s^{-1}, the die-off rate 1.736×10^{-5} s^{-1}, the eddy diffusivity 5 m^2 s^{-1} and the diffuser length 200 m. Individual variables are varied to give the concentrations as a function of a diffuser length, (b) mean current, (c) die-off rate, and (d) eddy diffusivity.

Figure 1



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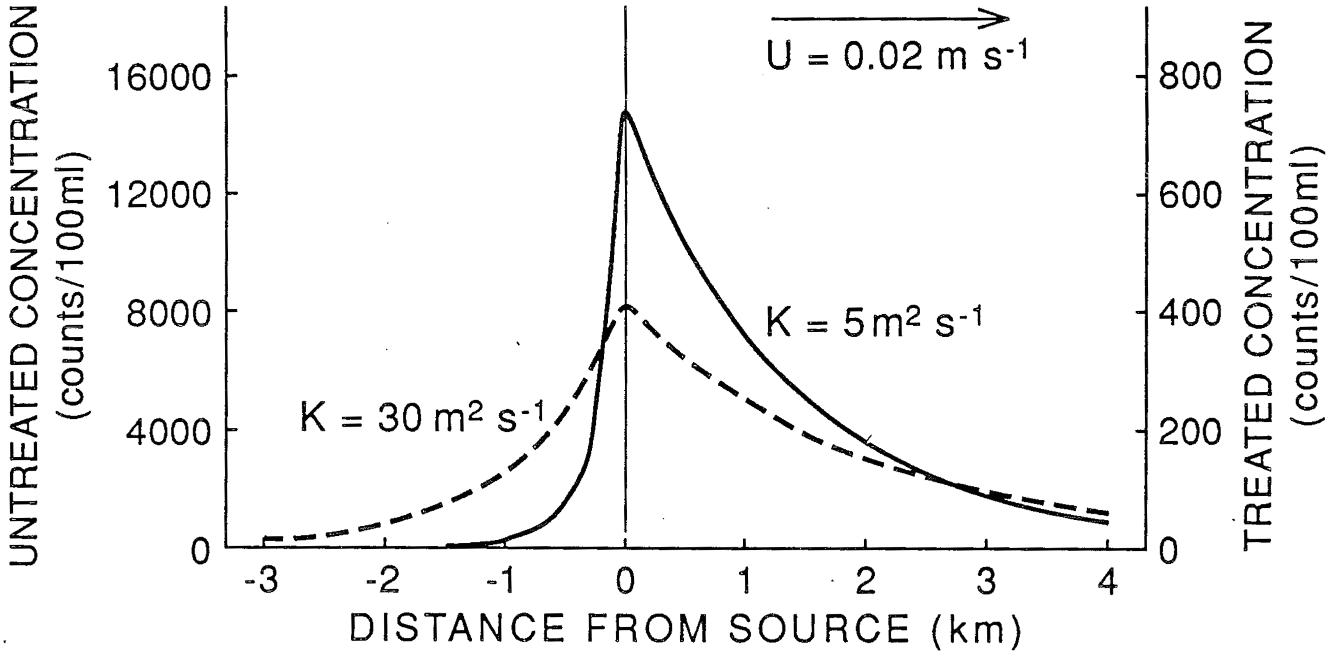
Petrie Paragon Jun 90

Figure 2



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EK 3

Figure 3

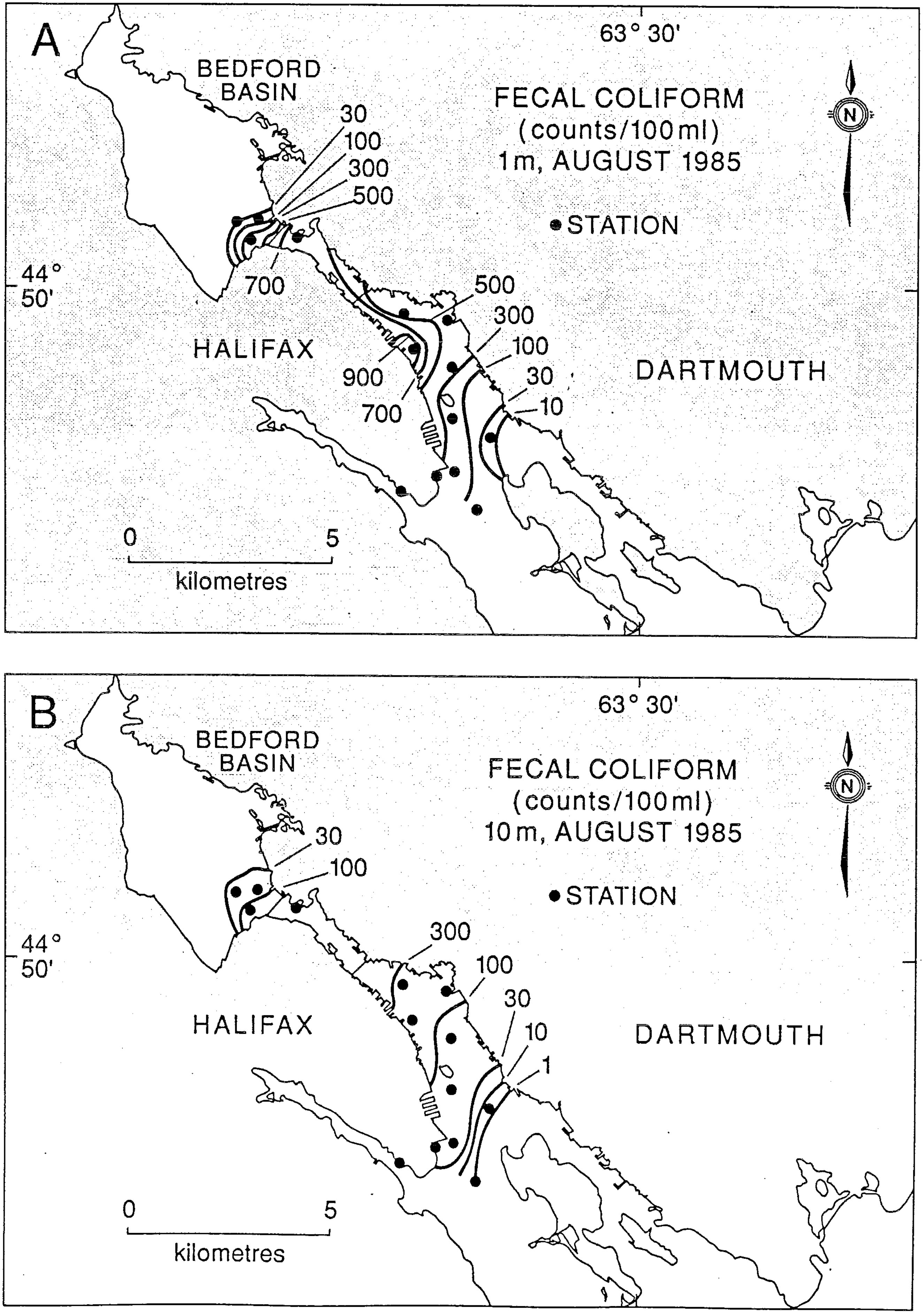

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Figure 4

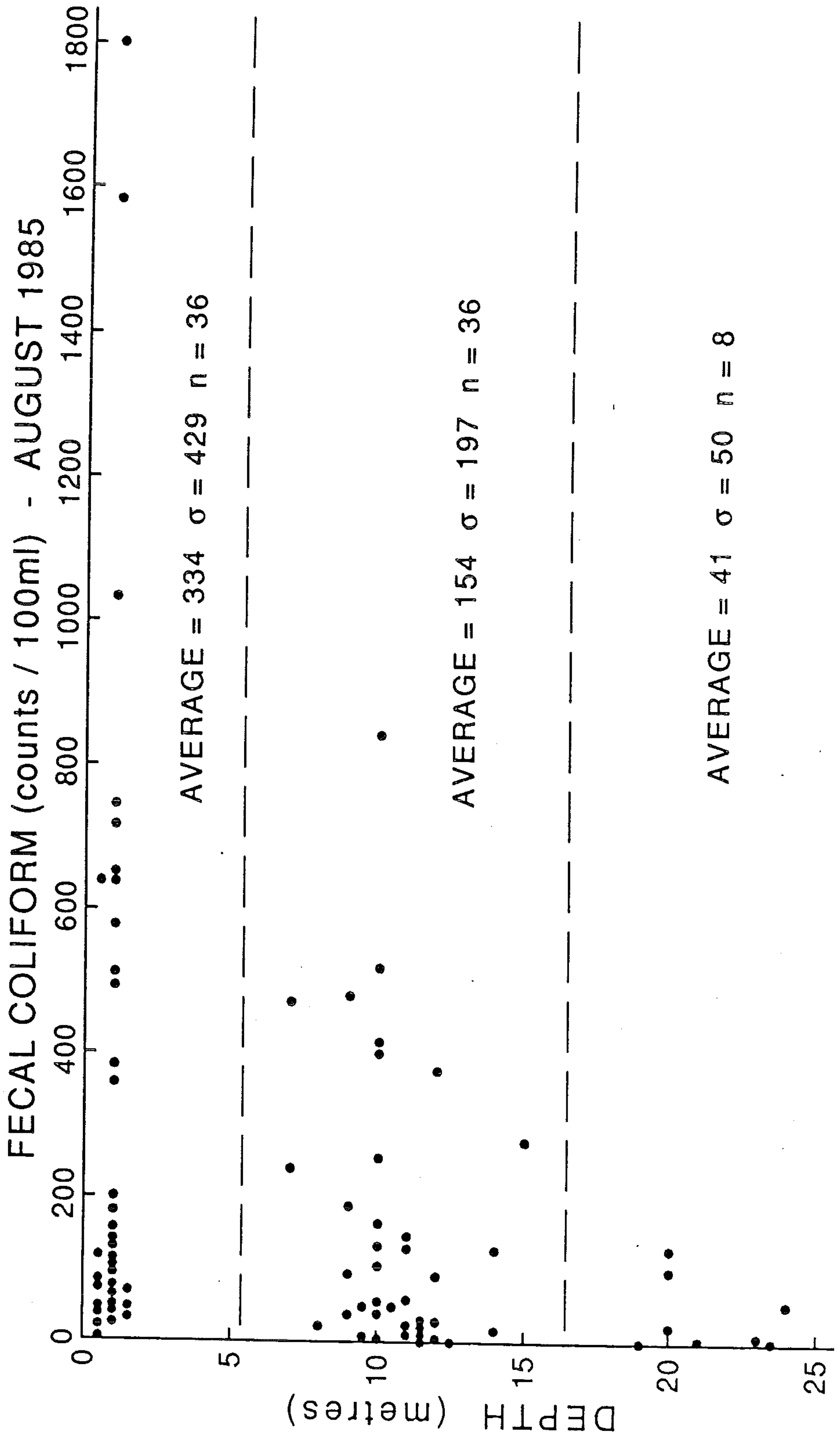
FECAL COLIFORM (counts / 100ml) - AUGUST 1985
0
200
400
600
800
1000
1200
1400
1600
1800
DEPTH (metres)
0
5
10
15
20
25
AVERAGE = 334 σ = 429 n = 36
AVERAGE = 154 σ = 197 n = 36
AVERAGE = 41 σ = 50 n = 8

Figure 5

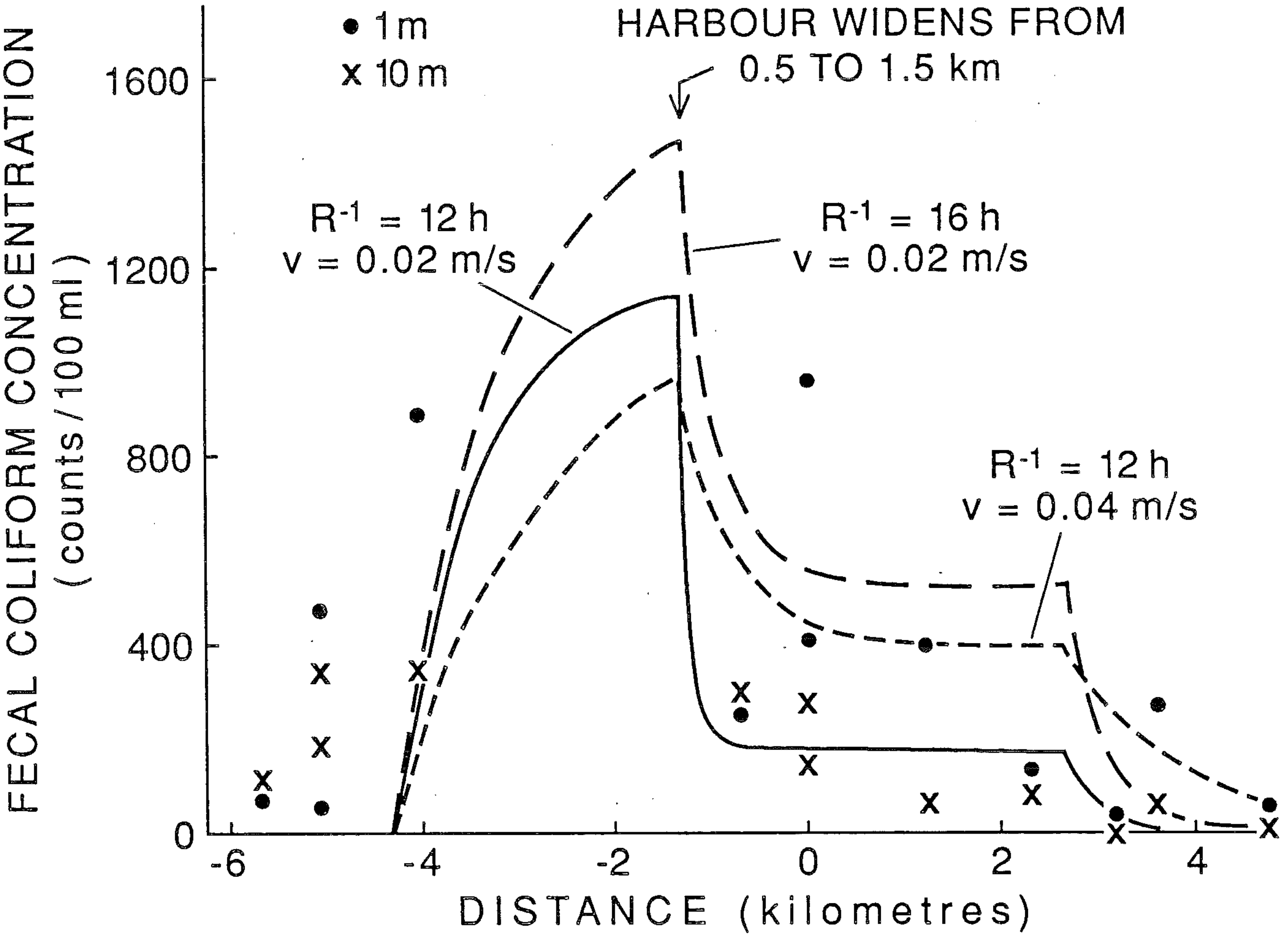

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Figure 6

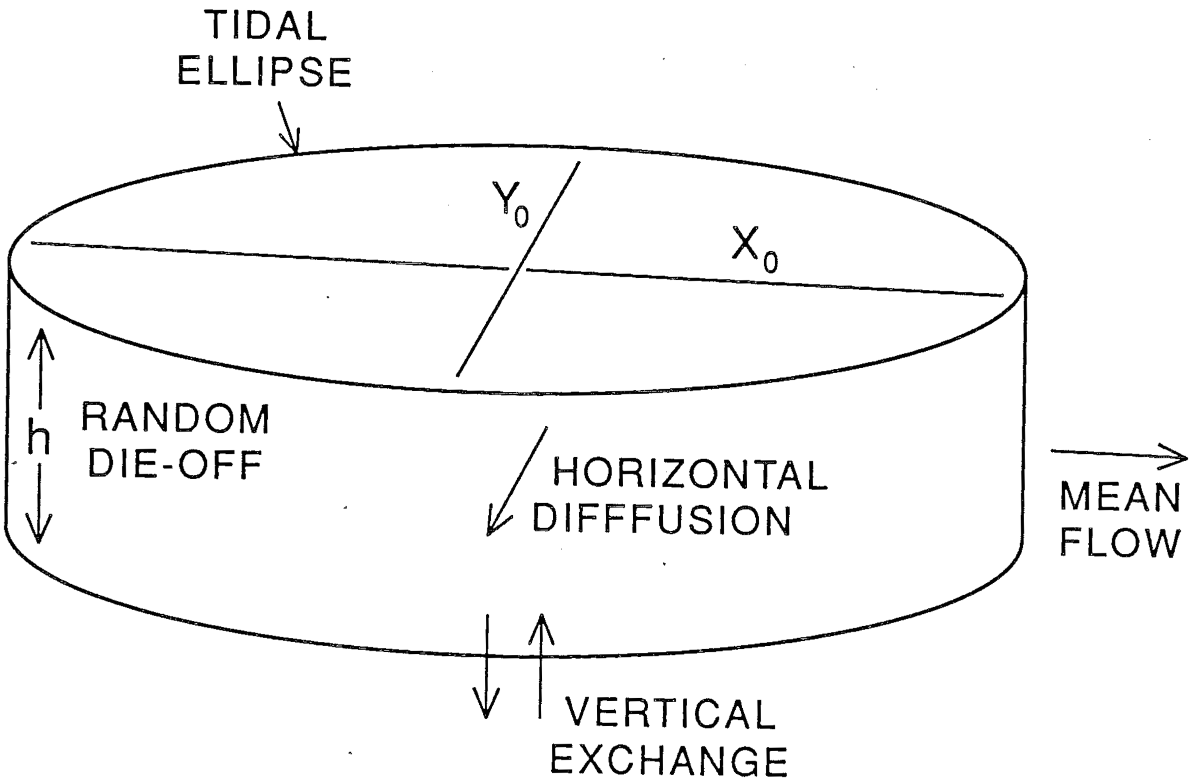

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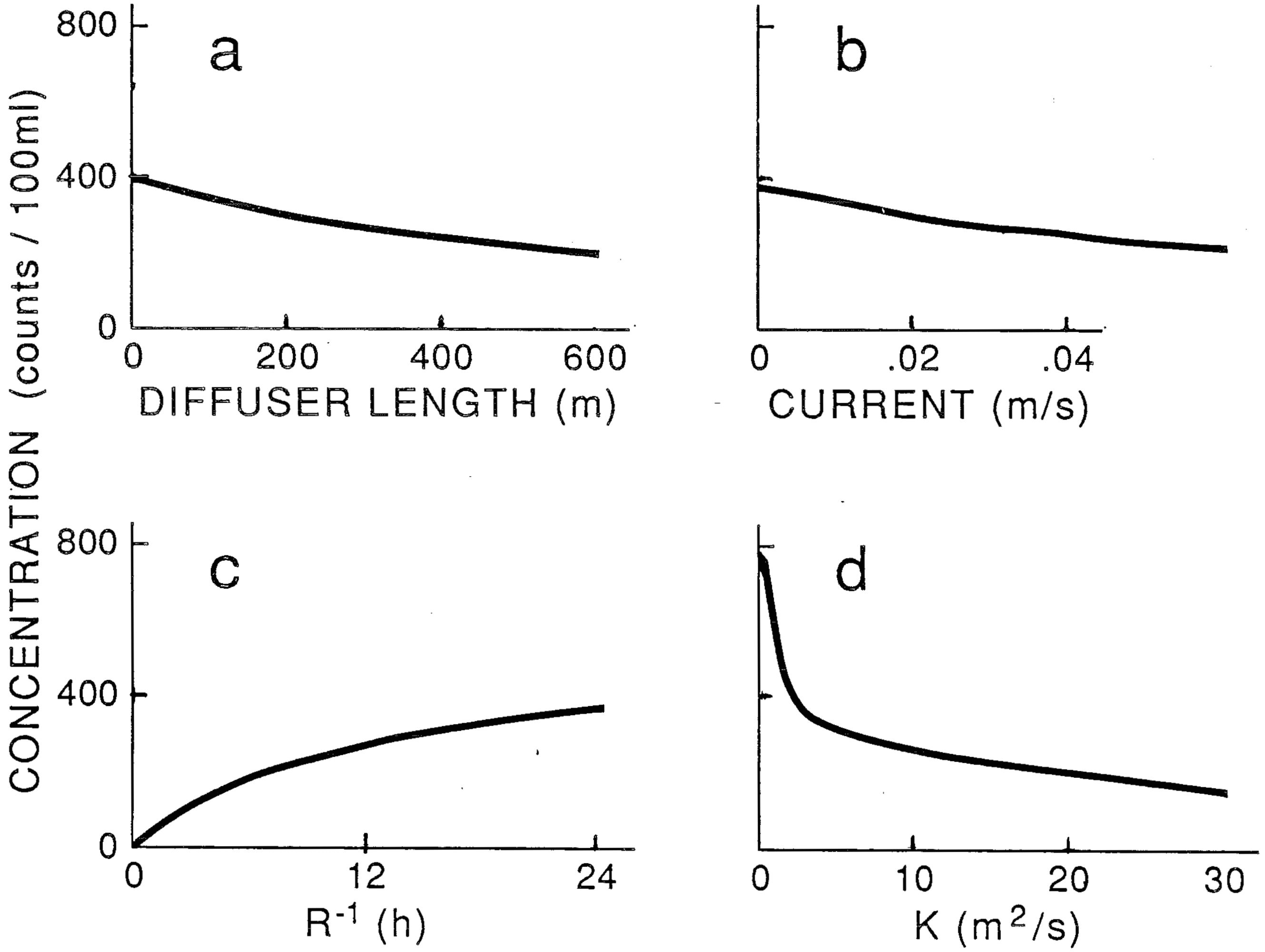
Figure 7



CONCENTRATION (counts / 100ml)
800
400
0
a
0
200
400
600
DIFFUSER LENGTH (m)
b
0
.02
.04
CURRENT (m/s)
800
400
0
c
0
12
24
R^{-1} (h)
d
0
10
20
30
K (m^2/s)

Distance Required to Reduce Fecal Coliform Concentration to 200/100ml

The CBCL Phase 3 report gives a fecal coliform input to the Harbour of 10^{10}/s. Combining this with a sewage flow of 2 m^3/s gives a count of $5x10^5$/100ml discharged into the Harbour without dilution or disinfection.

Assumption 1- the diffuser achieves an initial dilution of 50:1; the currents in the area of the diffuser can supply sufficient water free of fecal coliform to maintain this rate. This is an important assumption since, in an area of relatively strong tidal flows, water that has previously been mixed with effluent can be carried back over the diffuser. In effect what we are assuming is that the deeper water above the diffuser, not the shallower water with diluted effluent, is mixed with the effluent and, as it rises towards the surface, displaces the shallower water.

$$\text{Count} = 5x10^5/50 = 10^4/100\text{ml}$$

Assumption 2- the disinfection process achieves a 95% fecal coliform kill.

$$\text{Count} = 10^4x0.05 = 500/100\text{ml}$$

We expect then that above the diffuser there will be a continuous stream of dilute sewage with fecal coliform counts of 500/100ml. Consider that this stream is carried away by currents without any further mixing. The only mechanism causing a decrease of coliform is the natural die-off. In this case the concentration, C, is given by

$$C = C_0 e^{-Rt}$$

where C_0 is 500/100ml; R is the natural die-off rate and t is time.

Given R = 1/16h (CBCL, 1987) or 1/12h (ASA, 1990), then C is reduced to 200/100ml in 14.7 or 11h respectively. In the Harbour the farthest excursion taken by a water parcel in 1/2 a tidal cycle (taken as 6.21h) would be, for example:

1600m for the Inner Harbour, assuming a tidal current of 0.08 m/s and a mean flow of 0.02 m/s;

1900m for the Middle Harbour, assuming a tidal current of 0.10 m/s and a mean flow of 0.02 m/s.

After 6.21h the fecal coliform counts would be reduced by a factor of 0.68 (R=1/16h) or 0.60 (R=1/12h). The tidal current would then reverse and on the return flow the count would be below 200/100ml for either die-off rate and subject to the assumptions above.

A second way of looking at this problem can be based on the statistics of the current data from the 1989 Harbour current meter field program. We have derived the visitation frequency of finding a conservative tracer (note that fecal coliform are not conservative) at initial dilution concentration at various distances from the diffuser. For the 2m data from the mooring off Sandwich Point, the 1% curve is skewed in the direction of the mean flow, i. e. out of the Harbour, and reaches nearly 2km. In the upstream direction, the curve extends to about 1km, whereas, in the lateral directions the curve reaches about 400m. The time scale associated with the curves is 4h (roughly the time it would take mixing processes to penetrate to the center of the diluted effluent stream) so for fecal coliform we would estimate that the concentrations would be reduced to 390 /100ml (R=1/16h) or 360 /100ml (R=1/12h). We expect that in the Inner Harbour, these distances would be reduced slightly because of a generally larger cross sectional area.

From the above calculations we would choose approximately 2 km as the distance that a diffuser should be located from an area where it is desirable to keep concentrations below 200/100ml.

It is very important to appreciate how dependent these calculations are on the initial assumptions. For example, if during disinfection a kill rate of 98% could be achieved, then given a 50:1 dilution rate and a continuous supply of clean water, the fecal coliform count in the plume would be 200 /100ml and primary body contact would be possible. This works both ways if, for example, we consider the case of a kill rate of less than 95% or a breakdown of the disinfection process. Moreover, it may not be possible to attain and maintain an initial dilution rate of 50:1. On the other hand, these calculations have neglected additional mixing that will occur in the Harbour. Clearly, these calculations are subject to many assumptions and are meant to be a guide to decisions that must be made.

It is also worthwhile to note that the calculations carried out in the ASA study (1990) give areas of counts exceeding 200 /100ml that are less than the ones that we have presented here. Moreover, in another appendix a Task Force member presents calculations that also indicate smaller areas for counts exceeding 200 /100ml than the ones given above.

4. Metals in the water column and sediment

Brian Petrie

DISSOLVED METALS

Present Values in Harbour (Yeats et al.)

The ratio of concentration for the 4d guidelines/maximum mean concentration for the Harbour ranges from 6 - 260 (see Fig. 1);

The ratio of concentration for the 4d guidelines/maximum single measured concentration for the Harbour ranges from 4 - 176.

At present the data indicate no problems with dissolved metals.

Future Values in the Harbour

Consider one plant releasing effluent into the Harbour and achieving a dilution of 50 to 1, assume that the total metal concentrations measured at inflow pipes are all in the dissolved form, assume that these measurements which were made at Herring Cove, Eastern Passage and Northwest Arm pipes are representative of all Harbour effluent streams. Then the ratio of the 4d guideline /maximum effluent concentration ranges from 0.5 - 14. Specifically, Pb is 0.5, Cu is 1.2 and Hg is 1.3.

For the future these calculations indicate that there are potential problems for at least these 3 metals in the vicinity of the diffuser. To better resolve this problem the following are needed:

a)knowledge of the partition between dissolved and particulate forms of metals in the effluent;

b)measurements at more inflow pipes to characterize the incoming metal concentrations;

c)measurements for longer times at the inflow pipes to determine the longevity of the higher concentrations;

d)more sampling in the Harbour to determine if the higher concentrations are seen. At present the inflows are perhaps better sampled than the Harbour waters.

However, these calculations have little bearing on the level of treatment - the dissolved fraction of metals passes through the treatment process largely unaffected.

Diffuser design to achieve a dilution of greater than 50 to 1 and source control of metal input would help to reduce the metal concentrations in the receiving waters.

PARTICULATE METALS

The first step is to determine if the sewage inflow can account for the total amount of metal in the Harbour; further, is the concentration of the metal in the sewage the same as in the sediments. The answers to these questions will indicate the importance of sewage to the condition of the sediment.

Assumptions: **ALL** the inflowing metal measured at the 3 sites mentioned earlier is in the particulate form; these measurements are representative of all inflows into the Harbour; inflow is 2000 l/s.

METAL	TOTAL METAL IN SEDIMENT BUCKLEY (KG)	INCOMING METAL CONC. (MG/L)	YEARS TO ACCOUNT FOR TOTAL
Hg	5000	0.00027	290
Pb	580,000	0.02*	460
Cd	1600	0.01*	2.5
Cr	60000	0.028[1]	34
Zn	500000	0.084	94
Cu	200000	0.04	79
Ni	17000	0.014	19

*Concentrations for Pb and Cd are the threshold values for the analytical technique used to measure the concentrations. Thus, the number of years represents a lower bound.

[1] Eight of 17 Cr measurements were below the threshold value of the analytical technique used to measure the metal concentration. Thus, the number of years estimated to accumulate the metal will be underestimated.

Sewage inflow can reasonably account for the total amount of Ni, Cu and Zn in the sediments; it can probably account for the amount of Cr as well; it can account for a significant part of the Hg in the sediment as well; it cannot account for much of the lead content of the sediment; until better measurements are available, an evaluation for Cd cannot be made.

The second related question is: does the metal concentration in the sewage match the concentration in the sediment? Two additional assumptions are made, namely, that all of the metal is attached to the suspended solids, i. e., the small particles and that these particles mix with the primary productivity of the Basin, Narrows and Downtown area of the Harbour to produce the concentrations found in the sediment. Sewage puts 1.32×10^7 kg/y of suspended solids into the Harbour while primary productivity contributes 2.81×10^7 kg/y in the areas specified above.

METAL	AMOUNT/YEAR (KG)	SEWAGE CONC. (PPM)	SEWAGE + PRIMARY PRODUCTIVITY (PPM)	SEDIMENT CONC.[1] (PPM)
Hg	17	1.3	0.4	0.97
Cu	2500	190	61	91
Zn	5300	400	130	230
Pb*	1260	96	31	161

[1] BUCKLEY AND HARGRAVE

*Pb conc. taken as threshold of 0.02 mg/l
suspended solids inflow at 1.32×10^7 kg/y, MC and EP excluded

On the basis of the above table, a good match is attained for these metals.

Don Gordon's memo of Feb. 23 has assessed the health of the sediments. Based on the lower value of guidelines (mostly from Puget Sound) that he recorded, we get the following ratios for the guideline/(mean conc. of metal in sediment; maximum concentration of metal in sediment):

Zn	1.13; 0.36	Pb	1.9; 0.68
Cu	3.4; 0.34	Hg	0.77 0.07

In summary, the sediments are not in good shape;
sewage input can account for a significant amount of the total amount in the sediment for a number of metals;
the concentration of metals in the sewage is close to that measured in the sediment.

Assessment of treatment levels on sediments

Assumptions; same as above for the incoming metal, calculations are based on the amount coming in per year, primary treatment removes 50% SS and 20% metals (based on mid value from newsletter 3); advanced primary removes 80% SS and 42.5% metals; secondary removes 90% SS and 42.5% metals; tertiary removes 95% SS and 87.5% metals.

TOTAL METAL (KG)

METAL	PRESENT	PRIMARY	ADVANCED	SECONDARY	TERTIARY
Hg	17	13.6	9.8	9.8	2.1
Cr	1770	1416	1018	1018	221
Zn	5300	4240	3048	3048	663
Cu	2500	2000	1438	1438	313
Ni	880	704	506	506	110
Pb*	1260	1008	725	725	158

CONCENTRATION OF METAL IN SEWAGE (SEWAGE + PRIMARY PRODUCTIVITY)(PPM)

METAL	PRESENT	PRIMARY	ADVANCED	SECONDARY	TERTIARY	AET
Hg	1.3 (.41)	2.1 (.39)	3.7 (.32)	7.4 (.33)	3.2 (.07)	0.75
Zn	400 (128)	640 (122)	1154 (99)	2309 (104)	1004 (23)	260
Cu	190 (61)	303 (58)	545 (47)	1089 (49)	474 (11)	310
Pb*	96 (31)	153 (29)	274 (24)	549 (25)	239 (5.5)	300

*Pb at threshold level of 0.02 mg.1

Based on the above and cost, advanced primary is clearly better than secondary;

FECAL COLIFORM

Fecal coliform predication is one of the most uncertain calculations because of its dependence on mixing rates and the die off rate, both poorly known parameters and both very difficult to determine to a good degree of accuracy. Nevertheless, we expect from a primary plant about 500/100ml and from a secondary plant about 100/100ml; we expect that these are conservative estimates. At EP we have seen a disinfection kill rate of 99.95%, considerably higher than the 95% rate used for primary in the above calculations.

With the uncertainty of the calculations and the possibility of greater than 95% kill rate with a primary plant, it may be difficult to argue for a degree of treatment beyond primary on the basis of fecal coliform alone.

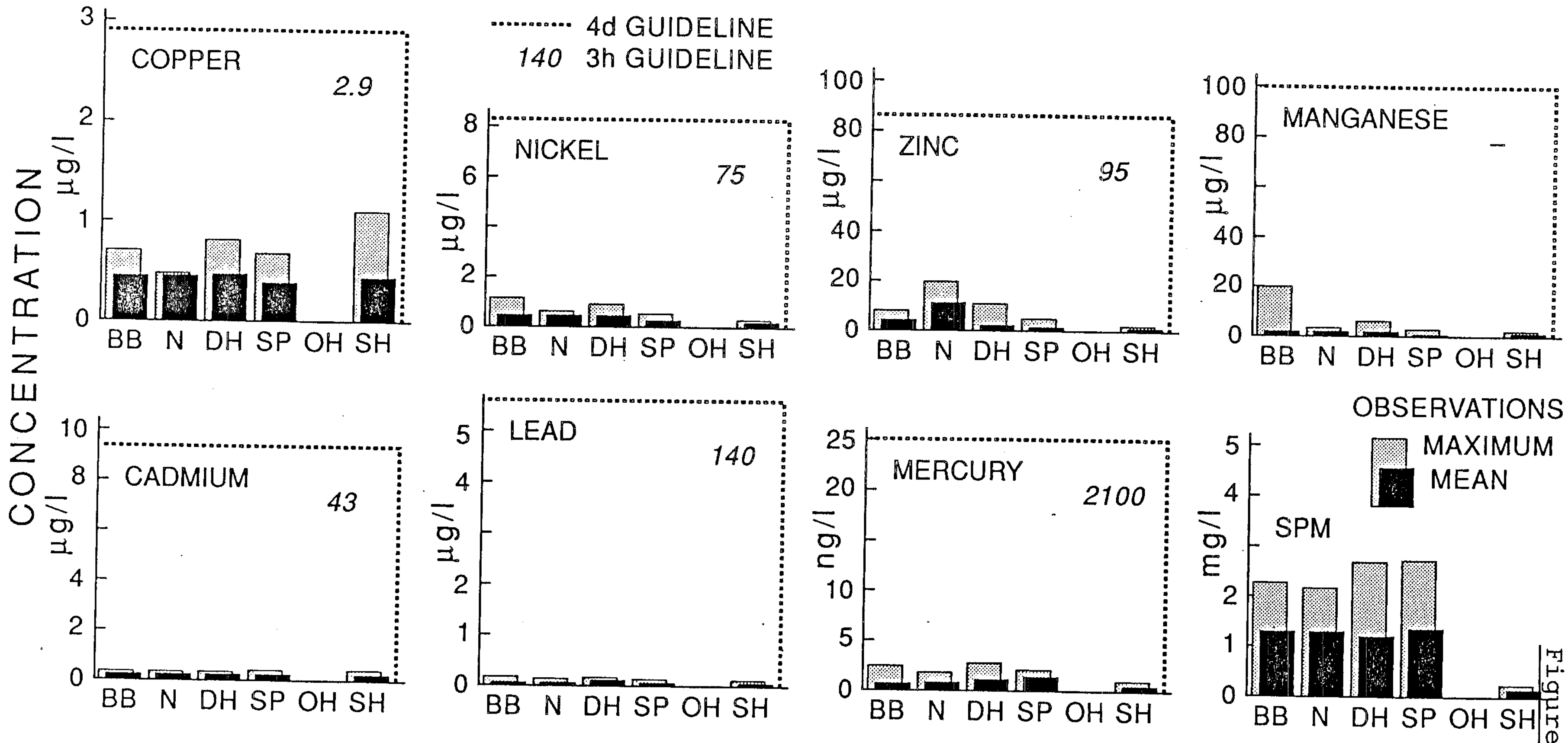


Figure 1

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B.Petrie Paragon-R Jun90

EK 6

5. Sewage treatment scenarios

Brian Petrie

A subgroup of the Task Force selected 15 scenarios involving single regional and multiple sewage treatment plants in the inlet. The percentages of total loading for copper and suspended solids are given in Table 1. Copper was chosen as the test metal because its concentrations in the Harbour are closest to available guidelines for the protection of the marine environment and because it is the metal least likely to be affected by chemical interactions in the receiving waters; i.e., currents are likely to play the greatest role in determining copper's distribution.

The results are presented in a series of tables which also take into account the potential of removal of metal because of the treatment process. The removal rate varies significantly for individual metals, treatment levels and even for plants with nominally the same treatment process. For copper, therefore, we have considered no removal, 20, 40, 60 and 80% removal. For suspended solids, we have assumed 55% removal for primary, 80% for advanced primary and 95% for secondary treatment. The sources of copper include the Sackville River, shelf waters and sewage. Suspended solids are derived from the River, shelf waters, sewage and primary productivity. The strength of these sources is discussed in another appendix.

The subgroup increased the rate of effluent flow from the present 2.14 to 2.89 m^3/s and the total load of copper from the present 1×10^{-4}kg/s to 1.45×10^{-4}kg/s. Each table shows in the first column the conditions obtained by the model if the copper in the sewage was allowed to flow into the Harbour as it does now. This is followed by the results of the particular scenario with no removal, 20%, etc. Box A corresponds to Bedford Basin, B to the Narrows and so on out the Harbour. In each region there are 2 boxes, one represents 0-10m and the second, 10-20 m.

For suspended solids, the model incorporated a particle sinking velocity of 2.5×10^{-5}m/s determined by optimizing the fit of the modelled to the observed present day concentrations. It is worthwhile to note that the amount of suspended solids from sewage, primary productivity and the Sackville River is 0.45, 2.7 and 0.05 kg/s respectively.

Table 1

Distribution of sewage load of copper.

Scenarios	Percent of Total Loading					
	A	B	C	D	E	F
1. Large reginal plant discharging to A plus MC and EP	92%	-	8%	-	-	-
2. Ditto to B	18	74	8	-	-	-
3. Ditto to C	18	-	82	-	-	-
4. Ditto to D	18	-	8	74	-	-
5. Ditto to E	18	-	8	-	74	-
6. Ditto to F	18	-	8	-	-	74
7. 6-8 plants CBCL's 4-6 plants plus MC and EP	18	33	44	5	-	-
8. 5 plants CBCL's 3 plants plus MC and EP	18	44	33	5	-	-
9. 4 plants CBCL's 2 plants plus MC and EP	18	44	7	31	-	-
10. Flow from Tufts and Duffus directed into Bedford Basin	51	-	44	5	-	-
11. All Halifax/Dartmouth sewage to one plant north of McNab's	18	-	77	5	-	-
12. Dartmouth and EP sewage to Hartlen Point, Halifax to Sandwich Point	18	-	8	48	-	26
13. All sewage inc. MC and EP to one reginal plant discharging to D	-	-	-	100	-	-
14. Ditto to E	-	-	-	-	100	-
15. Ditto to F	-	-	-	-	-	100

Table 1, Continued
Distribution of sewage load of suspended solids (kg/s)

Scenarios	AREA					
	A	B	C	D	E	F
1. Large reginal plant discharging to A plus MC and EP	0.45	-	0.01	-	-	-
2. Ditto to B	0.01	0.43	0.01	-	-	-
3. Ditto to C	0.01	-	0.45	-	-	-
4. Ditto to D	0.01	-	0.01	0.43	-	-
5. Ditto to E	0.01	-	0.01	-	0.43	-
6. Ditto to F	0.01	-	0.01	-	-	0.43
7. 6-8 plants CBCL's 4-6 plants plus MC and EP	0.01	0.19	0.23	0.03	-	-
8. 5 plants CBCL's 3 plants plus MC and EP	0.01	0.26	0.16	0.03	-	-
9. 4 plants CBCL's 2 plants plus MC and EP	0.01	0.26	0.01	0.18	-	-
10. Flow from Tufts and Duffus directed into Bedford Basin	0.20	-	0.23	0.03	-	-
11. All Halifax/Dartmouth sewage to one plant north of McNab's	0.01	-	0.42	0.03	-	-
12. Dartmouth and EP sewage to Hartlen Point, Halifax to Sandwich Point	0.01	-	-	0.28	-	0.16
13. All sewage inc. MC and EP to one reginal plant discharging to D	-	-	-	0.46	-	-
14. Ditto to E	-	-	-	-	0.46	-
15. Ditto to F	-	-	-	-	-	0.46

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

	Present Conditions	No Reduction	20%	40%	60%	80%
Bedford 1	0.65	1.70	1.42	1.14	0.86	0.58
2	0.60	.81	0.70	0.58	0.47	0.35
Narrows 1	0.98	1.34	1.12	0.91	0.70	0.49
2	0.59	0.66	0.58	0.49	0.40	0.32
Downtown 1	0.83	0.82	0.71	0.59	0.47	0.35
2	0.50	0.50	0.44	0.39	0.33	0.27
Sandwich Point 1	0.68	0.68	0.59	0.50	0.41	0.32
2	0.43	0.43	0.39	0.34	0.30	0.26
Outer Harbour 1	0.52	0.52	0.46	0.40	0.34	0.28
2	0.36	0.36	0.33	0.30	0.27	0.24
Scenario 1						

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

	Present Conditions	No Reduction	20%	40%	60%	80%
Bedford 1	0.65	0.91	0.79	0.67	0.54	0.42
2	0.60	0.70	0.61	0.52	0.42	0.33
Narrows 1	0.98	1.34	1.13	0.91	0.70	0.49
2	0.59	0.66	0.58	0.49	0.40	0.32
Downtown 1	0.83	0.83	0.71	0.59	0.47	0.35
2	0.50	0.50	0.44	0.39	0.33	0.27
Sandwich Point 1	0.68	0.68	0.59	0.50	0.41	0.32
2	0.43	0.43	0.39	0.34	0.30	0.26
Outer Harbour 1	0.52	0.52	0.46	0.40	0.34	0.28
2	0.36	0.36	0.33	0.30	0.27	0.24
Scenario 2						

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

	Present Conditions	No Reduction	20%	40%	60%	80%
Bedford 1	0.65	0.79	0.69	0.59	0.49	0.40
2	0.60	0.58	0.51	0.44	0.37	0.31
Narrows 1	0.98	0.70	0.62	0.53	0.44	0.36
2	0.59	0.54	0.48	0.42	0.35	0.29
Downtown 1	0.83	0.83	0.71	0.59	0.47	0.35
2	0.50	0.50	0.44	0.39	0.33	0.27
Sandwich Point 1	0.68	0.68	0.59	0.50	0.41	0.32
2	0.43	0.43	0.39	0.34	0.30	0.26
Outer Harbour 1	0.52	0.52	0.46	0.40	0.34	0.28
2	0.36	0.36	0.33	0.30	0.27	0.24
Scenario 3						

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

	Present Conditions	No Reduction	20%	40%	60%	80%
Bedford 1	0.65	0.75	0.66	0.57	0.48	0.39
2	0.60	0.53	0.47	0.41	0.35	0.30
Narrows 1	0.98	0.66	0.58	0.50	0.43	0.35
2	0.59	0.49	0.44	0.39	0.33	0.28
Downtown 1	0.83	0.55	0.49	0.42	0.36	0.30
2	0.50	0.45	0.41	0.36	0.31	0.26
Sandwich Point 1	0.68	0.68	0.59	0.50	0.41	0.32
2	0.43	0.43	0.39	0.34	0.30	0.26
Outer Harbour 1	0.52	0.52	0.46	0.40	0.34	0.28
2	0.36	0.36	0.33	0.30	0.27	0.24
Scenario 4						

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

		Present Conditions	No Reduction	20%	40%	60%	80%
Bedford	1	0.65	0.69	0.61	0.54	0.46	0.38
	2	0.60	0.48	0.43	0.38	0.33	0.29
Narrows	1	0.98	0.60	0.54	0.47	0.41	0.34
	2	0.59	0.44	0.40	0.36	0.31	0.27
Downtown	1	0.83	0.50	0.45	0.39	0.34	0.29
	2	0.50	0.40	0.36	0.33	0.29	0.25
Sandwich Point	1	0.68	0.45	0.41	0.36	0.32	0.27
	2	0.43	0.38	0.35	0.31	0.28	0.24
Outer Harbour	1	0.52	0.52	0.46	0.40	0.34	0.28
	2	0.36	0.36	0.33	0.30	0.27	0.24
Scenario	5						

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

		Present Conditions	No Reduction	20%	40%	60%	80%
Bedford	1	0.65	0.59	0.53	0.47	0.41	0.36
	2	0.60	0.37	0.34	0.32	0.29	0.29
Narrows	1	0.98	0.50	0.45	0.41	0.36	0.32
	2	0.59	0.33	0.31	0.29	0.27	0.25
Downtown	1	0.83	0.39	0.36	0.33	0.30	0.27
	2	0.50	0.29	0.28	0.26	0.25	0.23
Sandwich Point	1	0.68	0.35	0.32	0.30	0.27	0.25
	2	0.43	0.27	0.26	0.25	0.24	0.23
Outer Harbour	1	0.52	0.30	0.28	0.27	0.25	0.23
	2	0.36	0.25	0.24	0.23	0.22	0.22
Scenario	6						

Comment – the 74% of the copper dispersed onto shelf is assumed not to reenter the Harbour.

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

		Present Conditions	No Reduction	20%	40%	60%	80%
Bedford	1	0.65	0.84	0.73	0.62	0.52	0.41
	2	0.60	0.63	0.55	0.47	0.39	0.32
Narrows	1	0.98	0.98	0.84	0.70	0.56	0.41
	2	0.59	0.59	0.52	0.45	0.37	0.30
Downtown	1	0.83	0.81	0.69	0.58	0.46	0.35
	2	0.50	0.50	0.44	0.38	0.33	0.27
Sandwich Point	1	0.68	0.68	0.59	0.50	0.41	0.32
	2	0.43	0.43	0.39	0.34	0.30	0.36
Outer Harbour	1	0.52	0.52	0.46	0.40	0.34	0.28
	2	0.36	0.36	0.33	0.30	0.27	0.24
Scenario	7						

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

		Present Conditions	No Reduction	20%	40%	60%	80%
Bedford	1	0.65	0.86	0.75	0.64	0.52	0.41
	2	0.60	0.65	0.56	0.48	0.40	0.32
Narrows	1	0.98	1.08	0.92	0.76	0.59	0.43
	2	0.59	0.61	0.53	0.46	0.38	0.30
Downtown	1	0.83	0.81	0.69	0.58	0.46	0.35
	2	0.50	0.50	0.44	0.38	0.33	0.27
Sandwich Point	1	0.68	0.68	0.59	0.50	0.41	0.32
	2	0.43	0.43	0.39	0.34	0.30	0.26
Outer Harbour	1	0.52	0.52	0.46	0.40	0.34	0.28
	2	0.36	0.36	0.33	0.30	0.27	0.24
Scenario	8						

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

		Present Conditions	No Reduction	20%	40%	60%	80%
Bedford	1	0.65	0.85	0.74	0.63	0.52	0.41
	2	0.60	0.63	0.55	0.47	0.39	0.32
Narrows	1	0.98	1.06	0.90	0.75	0.59	0.43
	2	0.59	0.59	0.52	0.45	0.37	0.30
Downtown	1	0.83	0.71	0.62	0.52	0.43	0.33
	2	0.50	0.48	0.43	0.37	0.32	0.27
Sandwich Point	1	0.68	0.68	0.59	0.50	0.41	0.32
	2	0.43	0.43	0.39	0.34	0.30	0.26
Outer Harbour	1	0.52	0.52	0.46	0.40	0.34	0.28
	2	0.36	0.36	0.33	0.30	0.27	0.24
Scenario	9						

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

		Present Conditions	No Reduction	20%	40%	60%	80%
Bedford	1	0.65	1.19	1.01	0.83	0.66	0.48
	2	0.60	0.68	0.59	0.50	0.41	0.33
Narrows	1	0.98	0.98	0.84	0.70	0.56	0.41
	2	0.59	0.59	0.52	0.45	0.37	0.30
Downtown	1	0.83	0.81	0.69	0.58	0.46	0.35
	2	0.50	0.50	0.44	0.38	0.33	0.27
Sandwich Point	1	0.68	0.68	0.59	0.50	0.41	0.32
	2	0.43	0.43	0.39	0.34	0.30	0.26
Outer Harbour	1	0.52	0.52	0.45	0.40	0.34	0.28
	2	0.36	0.36	0.33	0.30	0.27	0.24
Scenario	10						

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

		Present Conditions	No Reduction	20%	40%	60%	80%
Bedford	1	0.65	0.79	0.69	0.59	0.49	0.40
	2	0.60	0.57	0.51	0.44	0.37	0.30
Narrows	1	0.98	0.70	0.61	0.53	0.44	0.36
	2	0.59	0.54	0.47	0.41	0.35	0.29
Downtown	1	0.83	0.81	0.69	0.58	0.46	0.35
	2	0.50	0.50	0.44	0.38	0.33	0.27
Sandwich Point	1	0.68	0.68	0.59	0.50	0.41	0.32
	2	0.43	0.43	0.39	0.34	0.30	0.26
Outer Harbour	1	0.52	0.52	0.46	0.40	0.34	0.28
	2	0.36	0.36	0.33	0.30	0.27	0.24
Scenario	11						

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

		Present Conditions	No Reduction	20%	40%	60%	80%
Bedford	1	0.65	.69	0.61	0.53	0.45	0.38
	2	0.60	.47	0.43	0.38	0.33	0.28
Narrows	1	0.98	0.60	0.54	0.47	0.40	0.34
	2	0.59	0.44	0.39	0.35	0.31	0.27
Downtown	1	0.83	0.49	0.44	0.39	0.34	0.29
	2	0.50	0.40	0.36	0.32	0.29	0.25
Sandwich Point	1	0.68	0.56	0.49	0.43	0.36	0.29
	2	0.43	0.38	0.34	0.31	0.28	0.25
Outer Harbour	1	0.52	0.44	0.40	0.35	0.31	0.26
	2	0.36	0.32	0.30	0.27	0.25	0.23
Scenario	12						

Comment: the 26% of copper dispersed onto the shelf is assumed not to reenter the Harbour.

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

	Present Conditions	No Reduction	20%	40%	60%	80%
Bedford 1	0.65	0.51	0.47	0.42	0.38	0.34
2	0.60	0.45	0.41	0.37	0.32	0.28
Narrows 1	0.98	0.49	0.44	0.40	0.36	0.31
2	0.59	0.45	0.40	0.36	0.32	0.27
Downtown 1	0.83	0.45	0.41	0.37	0.32	0.28
2	0.50	0.44	0.39	0.35	0.30	0.26
Sandwich Point 1	0.68	0.68	0.59	0.50	0.41	0.32
2	0.43	0.43	0.39	0.34	0.30	0.26
Outer Harbour 1	0.52	0.52	0.46	0.40	0.34	0.28
2	0.36	0.36	0.33	0.30	0.27	0.24
Scenario 13						

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

	Present Conditions	No Reduction	20%	40%	60%	80%
Bedford 1	0.65	0.44	0.41	0.38	0.35	0.33
2	0.60	0.38	0.35	0.33	0.30	0.27
Narrows 1	0.98	0.42	0.39	0.35	0.33	0.30
2	0.59	0.37	0.34	0.32	0.29	0.26
Downtown 1	0.83	0.38	0.35	0.32	0.29	0.27
2	0.50	0.36	0.33	0.31	0.28	0.25
Sandwich Point 1	0.68	0.37	0.34	0.32	0.29	0.26
2	0.43	0.36	0.33	0.30	0.27	0.24
Outer Harbour 1	0.52	0.52	0.46	0.40	0.34	0.28
2	0.36	0.36	0.33	0.30	0.27	0.24
Scenario 14						

Copper concentration (µg/ℓ)
Dry weather flow - Model Results

	Present Conditions	No Reduction	20%	40%	60%	80%
Bedford 1	0.65	0.30				
2	0.60	0.24				
Narrows 1	0.98	0.27				
2	0.59	0.23				
Downtown 1	0.83	0.24				
2	0.50	0.22				
Sandwich Point 1	0.68	0.23				
2	0.43	0.21				
Outer Harbour 1	0.52	0.22				
2	0.36	0.21				
Scenario 15						

Comment: All sewage is dispersed onto shelf and does not reenter the Harbour. The only sources are the Sackville River and the deep water from the shelf. The percentage reductions do not apply in this case.

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

	Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford 1	0.97	1.25	1.08	1.01
2	1.04	1.17	1.03	0.97
Narrows 1	1.70	1.05	0.96	0.92
2	1.31	0.89	0.85	0.84
Downtown 1	1.39	0.89	0.87	0.86
2	1.11	0.81	0.80	0.79
Sandwich Point 1	1.07	0.84	0.83	0.83
2	0.86	0.74	0.74	0.73
Outer Harbour 1	0.86	0.82	0.81	0.81
2	0.70	0.66	0.66	0.66

Sinking velocity = 2.5×10^{-5}m/s

Scenario 1

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

		Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford	1	0.97	0.96	0.95	0.94
	2	1.04	1.00	0.95	0.93
Narrows	1	1.70	1.67	1.23	1.06
	2	1.31	1.16	0.97	0.90
Downtown	1	1.39	1.05	0.94	0.89
	2	1.11	0.90	0.84	0.81
Sandwich Point	1	1.07	0.90	0.86	0.84
	2	0.86	0.78	0.75	0.74
Outer Harbour	1	0.86	0.83	0.82	0.82
	2	0.70	0.67	0.67	0.66

Sinking velocity = 2.5 × 10^{-5}m/s

Scenario 2

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

		Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford	1	0.97	0.95	0.94	0.94
	2	1.04	0.95	0.93	0.92
Narrows	1	1.70	0.92	0.90	0.89
	2	1.31	0.95	0.88	0.85
Downtown	1	1.39	1.15	0.98	0.91
	2	1.11	0.96	0.86	0.82
Sandwich Point	1	1.07	0.95	0.88	0.85
	2	0.86	0.80	0.76	0.75
Outer Harbour	1	0.86	0.84	0.82	0.82
	2	0.70	0.68	0.67	0.66

Sinking velocity = 2.5 × 10^{-5}m/s

Scenario 3

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

		Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford	1	0.97	0.94	0.94	0.94
	2	1.04	0.93	0.92	0.92
Narrows	1	1.70	0.90	0.89	0.89
	2	1.31	0.87	0.84	0.83
Downtown	1	1.39	0.88	0.86	0.85
	2	1.11	0.86	0.82	0.80
Sandwich Point	1	1.07	1.04	0.92	0.87
	2	0.86	0.85	0.78	0.76
Outer Harbour	1	0.86	0.86	0.83	0.82
	2	0.70	0.69	0.68	0.67

Sinking velocity = 2.5×10^{-5}m/s

Scenario 4

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

		Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford	1	0.97	0.94	0.94	0.94
	2	1.04	0.92	0.92	0.92
Narrows	1	1.70	0.89	0.89	0.88
	2	1.31	0.84	0.83	0.82
Downtown	1	1.39	0.86	0.85	0.85
	2	1.11	0.81	0.80	0.79
Sandwich Point	1	1.07	0.84	0.83	0.83
	2	0.86	0.78	0.75	0.74
Outer Harbour	1	0.86	0.90	0.85	0.83
	2	0.70	0.73	0.69	0.67

Sinking velocity = 2.5×10^{-5}m/s

Scenario 5

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

		Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford	1	0.97	0.94		
	2	1.04	0.92		
Narrows	1	1.70	0.88		
	2	1.31	0.82		
Downtown	1	1.39	0.85		
	2	1.11	0.79		
Sandwich Point	1	1.07	0.82		
	2	0.86	0.73		
Outer Harbour	1	0.86	0.81		
	2	0.70	0.66		

Sinking velocity = 2.5 × 10^{-5}m/s

Scenario 6

Comment: sewage other than from Mill Cove and Eastern Passage is assumed to be dispersed onto the shelf and not to re-enter the Harbour. In this case, the treatment level of the sewage dispersed onto shelf does not matter. Mill Cove and Eastern Passage treatment levels are taken to be as they are today.

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

		Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford	1	0.97	0.95	0.95	0.94
	2	1.04	0.97	0.94	0.93
Narrows	1	1.70	1.25	1.05	0.97
	2	1.31	1.04	0.92	0.87
Downtown	1	1.39	1.09	0.95	0.90
	2	1.11	0.93	0.85	0.82
Sandwich Point	1	1.07	0.93	0.87	0.85
	2	0.86	0.79	0.76	0.75
Outer Harbour	1	0.86	0.83	0.82	0.82
	2	0.70	0.68	0.67	0.66

Sinking velocity = 2.5 × 10^{-5}m/s

Scenario 7

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

	Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford 1	0.97	0.95	0.95	0.94
2	1.04	0.98	0.94	0.93
Narrows 1	1.70	1.36	1.10	0.99
2	1.31	1.07	0.93	0.87
Downtown 1	1.39	1.07	0.95	0.90
2	1.11	0.92	0.85	0.82
Sandwich Point 1	1.07	0.92	0.87	0.85
2	0.86	0.79	0.76	0.74
Outer Harbour1	0.86	0.83	0.82	0.82
2	0.70	0.68	0.67	0.66

Sinking velocity = 2.5×10^{-5}m/s

Scenario 8

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

	Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford 1	0.97	0.95	0.95	0.94
2	1.04	0.97	0.94	0.93
Narrows 1	1.70	1.35	1.09	0.99
2	1.31	1.04	0.92	0.87
Downtown 1	1.39	0.98	0.90	0.88
2	1.11	0.89	0.83	0.81
Sandwich Point 1	1.07	0.96	0.88	0.85
2	0.86	0.80	0.76	0.75
Outer Harbour1	0.86	0.84	0.82	0.82
2	0.70	0.68	0.67	0.66

Sinking velocity = 2.5×10^{-5}m/s

Scenario 9

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

		Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford	1	0.97	1.08	1.00	0.97
	2	1.04	1.05	0.97	0.94
Narrows	1	1.70	0.98	0.92	0.90
	2	1.31	0.92	0.86	0.84
Downtown	1	1.39	1.02	0.92	0.88
	2	1.11	0.89	0.83	0.81
Sandwich Point	1	1.07	0.91	0.86	0.84
	2	0.86	0.78	0.75	0.74
Outer Harbour	1	0.86	0.83	0.82	0.82
	2	0.70	0.67	0.67	0.66

Sinking velocity = 2.5×10^{-5}m/s

Scenario 10

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

		Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford	1	0.97	0.95	0.94	0.94
	2	1.04	0.95	0.93	0.92
Narrows	1	1.70	0.92	0.90	0.89
	2	1.31	0.94	0.87	0.85
Downtown	1	1.39	1.13	0.97	0.91
	2	1.11	0.96	0.86	0.82
Sandwich Point	1	1.07	0.95	0.88	0.85
	2	0.86	0.80	0.76	0.75
Outer Harbour	1	0.86	0.84	0.82	0.82
	2	0.70	0.68	0.67	0.66

Sinking velocity = 2.5×10^{-5}m/s

Scenario 11

Suspended solids(mg/ℓ).
Dry weather flow - Model Results

		Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford	1	0.97	0.94	0.94	0.94
	2	1.04	0.92	0.92	0.92
Narrows	1	1.70	0.89	0.89	0.89
	2	1.31	0.85	0.83	0.83
Downtown	1	1.39	0.87	0.86	0.85
	2	1.11	0.83	0.81	0.80
Sandwich Point	1	1.07	0.96	0.88	0.85
	2	0.86	0.81	0.76	0.75
Outer Harbour	1	0.86	0.84	0.82	0.82
	2	0.70	0.68	0.67	0.66

Sinking velocity = 2.5×10^{-5}m/s

Scenario 12
Comment: In this scenario, 34% of the total sewage input into the Harbour is dispersed onto the shelf and is assumed not to reenter the inlet.

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

		Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford	1	0.97	0.92	0.92	0.92
	2	1.04	0.91	0.90	0.90
Narrows	1	1.70	0.89	0.88	0.87
	2	1.31	0.86	0.83	0.82
Downtown	1	1.39	0.86	0.84	0.83
	2	1.11	0.85	0.81	0.79
Sandwich Point	1	1.07	1.04	0.92	0.87
	2	0.86	0.85	0.78	0.75
Outer Harbour	1	0.86	0.86	0.83	0.82
	2	0.70	0.70	0.67	0.67

Sinking velocity = 2.5×10^{-5}m/s

Scenario 13

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

	Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford 1	0.97	0.92	0.92	0.92
2	1.04	0.90	0.90	0.90
Narrows 1	1.70	0.88	0.87	0.87
2	1.31	0.83	0.82	0.81
Downtown 1	1.39	0.84	0.83	0.83
2	1.11	0.80	0.79	0.78
Sandwich Point 1	1.07	0.83	0.82	0.82
2	0.86	0.77	0.75	0.74
Outer Harbour 1	0.86	0.90	0.85	0.83
2	0.70	0.73	0.69	0.67

Sinking velocity = 2.5 × 10^{-5}m/s

Scenario 14

Suspended solids(mg/ℓ)
Dry weather flow - Model Results

	Present Conditions	Primary (55% reduction)	Adv. Primary (80% reduction)	Secondary (90% reduction)
Bedford 1	0.97	0.92		
2	1.04	0.90		
Narrows 1	1.70	0.87		
2	1.31	0.81		
Downtown 1	1.39	0.83		
2	1.11	0.77		
Sandwich Point 1	1.07	0.81		
2	0.86	0.73		
Outer Harbour 1	0.86	0.81		
2	0.70	0.66		

Sinking velocity = 2.5 × 10^{-5}m/s

Scenario 15

Comment: All sewage is dispersed onto shelf and is assumed not to reenter the Harbour. The sources of suspended solids are the Sackville River and primary productivity. The treatment level is irrelevant in this scenario.

APPENDIX B. GEOLOGY AND SEDIMENTS

Gordon B.J. Fader

THE ROLE OF GEOLOGY AND SEDIMENTS IN THE HALIFAX HARBOUR CLEANUP

Fundamental to the present and future uses of the Harbour, and the design of an appropriate sewage treatment facility which will discharge materials into the inlet, is an understanding of the geological environment and the earth materials present within the system and how they affect and will be affected by such a facility. This need arises for two reasons. Firstly, from a sedimentation and sediment transport perspective, it is important to understand the present distribution of sediments, contaminants and their transport pathways, as they will be affected by any changes to the present discharge system, and secondly, from an engineering perspective, as structures such as pipes, diffusers, tunnels and other engineering facilities will be built on and within these materials.

The sediments and bedrock on the seafloor of the Halifax Inlet are the historical recording medium for events which have occurred in the Harbour spanning millions of years. This history first began with continental drift, whereby a large section of the African continent was attached to North America before the last phase of continental drift when the early Atlantic Ocean was formed. This large continental fragment consisted of deep water sediments now known as the Halifax Slate and Goldenville Quartzite which underlie most of the Harbour and Metro area. During a subsequent phase, Devonian granites were intruded or injected into the slates and quartzites. These granites presently form the western flank of the Harbour from the entrance to the Northwest Arm, to Chebucto Head. The most recent events which finally shaped Halifax Harbour and which have a more direct bearing on the proposed sewage treatment, were the development of rivers (early ancestors of the Sackville River) and the intermittent advance and retreat of glaciers during the ice ages which, through erosion by ice and meltwater, produced the shape of the inlet as we know it today. The glaciers directly deposited sediments known as till over the Harbour and adjacent landscape. In early post-glacial time relative sea level was much lower than present, and Bedford Basin and parts of the Harbour were lakes. During the last 10,000 years, sea level returned to its nonglacial position as the ice sheets melted. This flooding advanced up Halifax Harbour from the adjacent inner Scotian Shelf, altering all the previous freshwater lakes and ponds into marine embayments. The final major flooding episode occurred when Bedford Basin, which was a lake until this time, was flooded by the rising sea, as the 20 m sill in The Narrows area of the Harbour was breached. The Harbour as we now know it was finally formed but now acted as a trap for sediments eroding off the land and from the local rivers. Organic rich muds were deposited over most of the inlet.

Today the seafloor of the Harbour still reflects a large part of this ancient history, as the sediments formed by these early processes remain either buried beneath younger sediments, or lie presently exposed at the seabed. Some sediments have experienced little modification since they were deposited. With the founding of Halifax in 1749, major changes took place on the surrounding land and shoreline areas which affected the seabed of the Harbour. These were the cutting of large tracts of forest, the cultivation of crops, the infilling of shoreline areas, the discharge of waste water and the channeling of runoff into the Inlet. As the urbanization of the surrounding area of the Harbour continued at a rapid pace, so did the deposition of sediments into the Harbour. In addition to the natural glacial soils and bedrock that were eroded from the adjacent land, sewage and associated domestic and industrial wastes were mixed with these materials and deposited through discharge outfalls at many locations. As the uses of the Harbour continued to expand, as a result of increased industrial and military development, the sediments on the Harbour floor were further modified by direct disturbance. Dredges scoured and deepened many areas, docking facilities were built, sand and gravel was mined, dredge spoils were dumped, ships anchors were dragged, old ships and debris were scuttled, and bridge footings were constructed. All of these types of activities have influenced the seabed and sediments in different ways.

Concurrent with these anthropogenic uses of the Harbour is its use by shellfish, finfish and benthic invertebrates as a marine habitat. Changes in the rates and patterns of sedimentation and constituents of sewage and industrial wastes have affected this habitat. The biological community in the Harbour presently reflects these new conditions established by the uses of the Harbour and is in a constant state of flux in response to these inputs.

From this background, it can be clearly seen that the materials on the floor of the Harbour contain a history of uses of the Inlet (both natural and anthropogenic) but in particular, record the most recent history of Harbour use as a repository for wastes. Sediments therefore, can be used to reveal these uses and their history, but can additionally be used as a predictive tool to understand future changes to inputs into the system through the construction of sewage treatment facilities and the industrial control of contaminants.

One of the major issues which has arisen involving the sediments is a concern for trace metals which have been identified to occur within certain areas of the Harbour. Are they stable within the sediments or are they released through natural or other processes? Further still is the concern for the future release of these metals under various sewage treatment/outfall scenarios which will alter the amount, location and type of materials discharged into the Harbour. Will the contaminants be introduced to the food chain? These are questions that have been proposed and which illustrate the importance of the sediments to a final solution for design of a sewage facility for Halifax Harbour.

With the treatment of sewage, that presently discharges untreated into the Harbour, the amount of suspended solids and their associated contaminants will be greatly reduced. In addition, the existing large number of outfalls will be consolidated to one or a few large outfalls at different locations than at present. This will change the areas where these sediments are presently accumulating.

Deposition of these sediments is coupled closely with the oceanographic currents which exchange water between the Scotian Shelf and the Harbour and transport sediments in the process. Early models on how this system functioned were simplistic and suggested that the Harbour was flushed regularly and sediments were removed by this process. The oceanographic data most recently collected, together with a knowledge of sediment and contaminant distributions on the seafloor, indicate that conditions are much more complex and that a large part of the discharged material remains at the seabed in the Harbour.

A secondary role that geology plays in the cleanup project is related to the construction phase of a sewage facility. Aspects such as tunneling and the production of large quantities of waste rock, some of which produces acid runoff when exposed to weathering processes, must be considered. The siting of discharge pipes and diffusers on the seabed is also affected by the sediments and their engineering properties. In turn, the sediments on the seabed will be affected by the discharge from these pipes and diffusers. It is important that these types of relationships be understood so as to maximize the efficiency and operation of the facilities.

This report will attempt to summarize the geological conditions in the Harbour and discuss their relationship to the design and siting of sewage facilities.

THE GEOLOGICAL/GEOPHYSICAL DATA BASE

Two techniques are normally employed to understand the distribution of sediments at and below the seabed. Firstly, remote sensing studies are conducted by towing various sensors behind a vessel. The sensors used are seismic reflection profilers and sidescan sonars. Seismic reflection systems use sound frequencies to penetrate the sediments and resolve the layering or structure within. The data produced, presents a cross-section (FIGURE 1) of the seabed and subsurface and shows differing character for each of the layers that allows the construction of maps of sediment thickness. Sidescan sonars use a fan-shaped, high frequency sound source that sweeps across the seabed and presents a plan-view image that resembles an aerial photograph on land (FIGURE 2). These are very powerful images as they reveal sediment distributions and topography, ie. the presence of hills and valleys and features including wrecks, anchor marks and debris. The images from the sidescan data are formed from an integration of all of the processes that have affected the seabed. For example, when collecting samples from the seabed, the sidescan sonar data can indicate whether the material sampled is the natural sediment deposited from runoff off the adjacent land or whether it is a pile of material deposited by a dredge which may have been removed from another area of the habour in a dock maintenance program. A wide variety of seismic and sidescan sensors are available and the choice of a particular system is dependant on the nature of the geology of the area and the desired amount of resolution.

Secondly, samples of the seabed and subsurface are collected to "ground truth" the images obtained with the remote sensing equipment. For the immediate seabed, grab sampling devices are used to obtain a portion of sediment at the water column/seabed interface. The samples collected are often disturbed by the sampling procedure, but can preserve detailed structure when carefully handled. To obtain samples from beneath the sediment/water interface, a variety of coring devices are employed. These are long tubes which when dropped to the seafloor, penetrate the sediments and retrieve intact samples. Simple corers can obtain samples up to 10m below the seabed. These pieces of equipment work well in muddy sediments but when hard materials such as bedrock, till or gravel are encountered, drilling must be used to obtain samples. Seismic reflection profiles provide the preliminary data necessary to determine which of the sampling devices to use.

Most of the earlier studies of the geology of Halifax Harbour were non-regional in nature, and addressed specific aspects in small local areas. Many were conducted as University Thesis and a considerable knowledge base has developed as a result. In 1986 and 1988 a regional set of sediment samples were collected within the Harbour. These 224 samples provided a comprehensive sample data base and were analysed for organic carbon, nitrogen, redox potential and oxygen uptake. These samples were further studied for geochemistry and sedimentological information and were reported on in1989.

In 1988 a geological/geophysical study was initiated as part of a new program to map the geology of nearshore areas of eastern Canada. This was expanded in1989 with a comprehensive regional survey of high resolution seismic reflection, sidescan sonar and precise navigation. During this survey, cores were collected at critical locations within the Harbour where the seismic reflection data indicated that complete sections existed. The last of the regional cruises was completed in May of 1990, (Fader and Miller, in prep.). Data gaps were filled, additional samples were collected and a Remotely Operated Vehicle (ROV) with bottom cameras was deployed to investigate 12 targets at the seabed.

DISTRIBUTION OF SEDIMENTS AT THE SEABED

The distribution of sediments at the seabed is mainly derived from analysis of seabed samples, sidescan sonar imagery, seismic reflection profiles, echograms and bathymetry. In this discussion we are concerned with the distribution of sediments at the immediate seafloor and not in the subsurface. These sediments can vary in thickness from a few centimetres to over 20 m. The classification of sediment texture is based on the Wentworth Scale and the sediments are classified as gravel, sand, silt and clay. The fine-grained sediments of silt and clay adsorb minor trace elements and contain more organic matter than coarser sand and gravel. The organically rich sediments also contain higher concentrations of most metals. The first regional map of sediment distribution, based only on samples, was released in 1989, (Buckley). It presented the distribution of mud (silt and clay) in the Harbour. This interpretation did not have the advantage of sidescan or seismic reflection data to measure the thickness of the mud or to interpolate between samples and only the upper 2 cm of sample was analysed. The sidescan data that have been since collected indicate that the mud covers less area of the seabed. However, the broad regional distribution mapped from the sample data alone is essentially correct.

BEDFORD BASIN AND BEDFORD BAY

Much of the floor of Bedford Basin is covered with sediment consisting of more than 60% mud (see map of sediment distribution). Sediments with more than 80% mud occur in the deepest areas of Bedford Basin and Bedford Bay. Areas of coarse sediment (sand and gravel) occur in the shallow areas along the shores of the Basin to a depth of 10 m, and in deeper areas of the southeastern Basin. In the nearshore area many large boulders occur and bedrock occasionally outcrops. Two conspicuous boulder ridges ring Bedford Basin at a depth of 23 m. They were probably developed when the Basin was a lake and freezing of this lake concentrated the boulders as push ridges. At the sill between Bedford Bay and Bedford Basin bedrock outcrops. It is covered in places with boulders. Scattered across the floor of Bedford Basin are many patches and mounds of coarse debris which are interpreted as dredge spoils dumped by barges. Samples of some of these were collected during the sampling operation and the material consisted of angular rock fragments.

THE NARROWS

In The Narrows area, particularly between the A. M. MacKay Bridge and Piers 9 (A-C), the sediments are much coarser and consist mostly of gravel with broken and whole shells (FIGURE 3). Boulders are common and bedrock outcrops. Pebbles and cobbles are subrounded and form the dominant grain-size at the seabed. The footings of the first two bridges constructed in 1884 and 1891 remain on the harbour floor, approximately 500 m south of the A. M. MacKay Bridge. These consist of wooden cribwork filled with boulders and old rusted rail track is scattered across the seabed. At the south end of Pier 9, off the Duffus St. sewage outfall, a zone of fine grained sediment covers the harder gravelly seabed in a depression extending across the Harbour. Some of this sediment may be sourced from the Duffus St. outfall. Tufts Cove consists of soft, fine-grained sediment which continues out into the main channel of The Narrows where it terminates.

THE INNER HARBOUR

Adjacent to the Halifax Dartmouth Industries Drydock (Nova Dock) the main body of Harbour mud begins and continues to the south throughout the Inner Harbour to the Maugher Beach area on McNabs Island. As the inner Harbour widens south of The Narrows, to the south of the Macdonald Bridge, large mud patches with more than 80% mud, occur. The most northern deposit, up to 7 m (see isopach map of Holocene Mud) in thickness occurs north of Georges Island and trends toward Dartmouth Cove. The largest body of sediment is found south east of Georges Island and continues up Eastern Passage. It is over 9 m in thickness and is charged with methane gas. Similar muddy sediments occur in the Northwest Arm. Mud continues south of the Northwest Arm to the Sandwich Point area. It is gas-charged and is over 8 m in thickness. On the eastern side of the Harbour in this area, north of Major Beach, another area of gas-charged mud is also over 8 m in thickness. However, these two outer areas of mud deposition are separated by a bedrock ridge extending to the south from the Point Pleasant area. In the inner Harbour, areas of coarse sandy and gravelly sediments occur on Ives Knoll north of McNabs Island continuing across the Harbour to the southend container pier, in many small isolated occurrences throughout the Harbour some of which may represent ridges of till or small drumlins similar to Georges Island and in a major zone extending to the southeast from the Point Pleasant area of Halifax. This shoal area covers Pleasant Shoal and Middle Ground and consists of gravel with outcropping bedrock. The shoal appears to separate the area between south Halifax Peninsula and the Maugher Beach area of McNabs Island into separate sedimentary basins in the west and the east. Geochemical fingerprints of metals in the sediments from both areas suggest that material does not cross the shoal and is deposited locally in each of the basins.

THE NORTHWEST ARM

The Northwest Arm consists of two separate depositional areas of thick gas-charged mud on either side of an area of coarse sediment adjacent to Fleming Park (see map of sediment distribution). The area of very coarse and hard sediments extends from both shores across the Arm. This is a seward extension beneath the Arm, of the till hill on which the Dingle Tower is constructed. A lack of fine-grained sediments in this area is similar to the distribution of sediments in The Narrows of the Harbour and likely results from strong currents which are generated in the narrowest part of the channel preventing the deposition of fine-grained silts and clays.

EASTERN PASSAGE

The sediments of Eastern Passage consist of thick gas-charged muds similar to those found in the Northwest Arm. Coarse sediment only occurs in the shallow nearshore areas. The mud of Eastern Passage connects with the main body of mud in the Inner Harbour. Evidence for the buildup of sediment adjacent to the effulent outfall in Eastern Passage could not be found on the acoustic information.

OUTER HARBOUR

In the outer Harbour, which begins at Maugher Beach and continues to Chebucto Head/Hartlen Point, the character of the seabed changes dramatically and resembles more the inner continental shelf rather than the inner Harbour. The sediments are well sorted silts, sands and gravels of the Sable Island Sand and Gravel Formation (King, 1970, and King and Fader, 1986) and fine-grained cohesive muddy sediments are absent. The first bedforms found at the seabed, going out of the Harbour, are subdued megaripples in sand. These occur in a deep 30 m channel adjacent to Sandwich Point and continue seaward. Megaripples are straight-crested, flow transverse bedforms with a ripple-like profile. They are formed by currents with a near bed flow of between 40-60 cm per second. The megaripples adjacent to Sandwich Point have broken crests which can be used as transport indicators and these suggest sediment transport up the Harbour from south to north. They were probably formed during one strong current event which occurred during the past several years. The crests are not well-defined indicating a relict aspect.

A major zone of megaripples occurs south of Litchfield Shoal and continues out the harbour to Chebucto Head. North of Litchfield Shoal there is an absence of bedforms and the silty-sandy seabed is slightly rippled with wave formed ripples. This suggests that Litchfield Shoal acts as a topographical barrier to strong inflowing bottom currents protecting the sediments directly off Herring Cove from the higher energy flow. This is supported by the oceanographic current measurements and observations from the local fishing community. A small sewage bank has been deposited at the seabed adjacent to the raw sewage outfall in Watleys Cove.

The outer Harbour area is morphologically dominated by the deep channel which hugs the western side of the outer Harbour. This channel extends to over 40 m in depth along the western edge of the outer Harbour and is interpreted as the glacially modified channel of the ancestral Sackville River, the course of which was controlled in the outer Harbour by the resistant granite bluffs which extend from Sandwich Point to Chebucto Head. The channel continues for over 30 km further seward beyond Chebucto Head, cutting across the inner Scotian Shelf. This channel is floored by thin sands overlying glacial and estuarine muds. To the south of McNabs Island, and dominating the eastern area of the outer Harbour, the seabed is composed mainly of outcropping bedrock, gravel with boulders and smaller isolated patches of sand. Many bedrock shoals occur in the outer harbour. Most consist of exposed bedrock of granite, quartzite or Halifax Slate, surrounded by a zone of gravel with boulders, and further seaward, sand. Many of these shoals such as Mars Rock, Litchfield Shoal, and Portuguese Shoal come to within a few metres of the seasurface. These shoals deflect the currents in the outer Harbour and the energy from large waves impinges on the seabed mobilizing sediments including fine-grained gravel and forming features termed gravel ripples.

SEABED CHARACTER AND FEATURES INTERPRETED FROM SIDESCAN SONOGRAMS

Sidescan sonar is a powerful technique for imaging the seabed and can reveal details of sediment distributions and topography with a great degree of clarity. Data collected in 1988 (Miller and Fader) and 1990 (Miller et al.) in a regional grid pattern throughout the Harbour, present a set of images which can be interpreted for an understanding of the natural and anthropogenic processes that have affected the seabed. In addition to differentiating sediment type (soft muddy seabeds from hard coarse-grained materials), the sidescan data have identified a large variety of other features such as, dredge spoils, dredge marks, borrow pits, pockmarks, wrecks, cables, sewage and cooling water plumes, anchor marks, propeller wash scours, boulders, bedforms, bedrock, and unidentified debris. These features indicate a dominant anthropogenic influence on the seabed of the

Harbour since the founding of Halifax in contrast to the adjacent inner continental shelf where the dominant processes are natural.

ANCHOR SCOUR MARKS

The presence of anchor scour marks are a dominant characteristic of the seabed which occurs over broad areas and can be used as an important bench mark in attempts to understand the history of sedimentation and Harbour use. The seabed in these areas consists of criss-crossing, linear-curvilinear trenches up to 2 m in depth, with adjacent flanking berms (FIGURE 4). This pattern dominates the floor of Bedford Basin and the areas of the seabed north of McNabs Island. It is significant for two reasons. Firstly, from a sampling and coring perspective, it is important to know the relationship between the anchor marks and the collected samples. The sediments have been disturbed in the anchor marks and do not necessarily represent or preserve natural depositional relationships. The base of the anchor marks may expose sediments several thousand years old. If the history of the most recent past is desired, then cores must be collected in non-scoured areas. In addition, because the anchor marks are depressions they may preferentially trap sediments and present an exaggerated sedimentation rate or contaminant concentration. The anchor marked areas of seabed can also be used to define the distribution of recent sediments and sewage banks and assist in understanding sediment transport. The sidescan data indicate that many of the anchor marked areas are likely relict. Those in Bedford Basin are interpreted to have developed during the second world war when large convoys of ships assembled and anchored over broad areas of the Basin, prior to sailing across the north Atlantic to Europe. Those in Halifax Harbour, particularly in the present main navigational channel, are probably much older and in some areas may represent the total population of anchor marks formed since the founding of Halifax. In places, this surface is covered with recent sediment and the old anchor marks can be seen dipping beneath the recent sediment on the flanks of the deposit as they are buried. In Bedford Basin this relationship occurs in the northern part, near the sill of Bedford Bay. The sediment which covers the anchor marked surface in this area is likely material from the Sackville River which has been transported out of Bedford Bay and into Bedford Basin. The anchor marked surface also indicates that since its formation, the amount of material deposited has not been sufficient to completely bury the surface and infill the depressions. Thus, the sedimentation rate throughout much of the Harbour has been less than 2m since the founding of Halifax. This has been exceeded in several areas of the Harbour particularly near a few of the sewage outfalls and suggests that the material emanating from these discharges is largely deposited in the near field. The distribution of these "sewage banks", as they are called, can be easily mapped overlying the anchor scoured areas. These maps then can be further used as sediment transport indicators, as the patterns of sedimentation reveal the directions in which much of the material preferentially moved as it settled to the seabed. Adjacent to downtown Halifax, discharges from sewer outfalls at Historic Properties indicate transport up the inlet toward Bedford Basin. Of particular concern to the Harbour cleanup is the future possible restriction of anchorages to areas of non-contaminated sediments so as to prevent their continual remobilization.

DREDGE SPOILS

Dredge spoils are common over the Harbour bottom and their greatest density occurs in Bedford Basin. They have many different sonar patterns which indicates that the materials vary greatly in composition from sandy-muddy sediments to bouldery materials and in some cases may consist of debris consisting of wire, cables, logs and other materials. Their distribution can give rise to unusual geochemistry anomalies, as the materials are transported before dumping from many areas of the Harbour. Of particular concern to the Harbour cleanup project, is the control of future dredge disposal in the Harbour so as to minimize the resuspension of contaminated sediments.

SEABED MINING PITS

In some areas of the Harbour large depressions occur on the seabed up to 15 m in diameter. These are interpreted as "borrow pits" which were excavated during seabed mining for construction aggregate. These are common north of McNabs Island and are several m in depth. Areas of the outer Harbour contain clean, coarse-grained gravels and sands that offer a potential for further seabed mining for aggregate. The presence of these resources should be evaluated and considered in relation to the design of sewage outfalls which may preclude their usage.

PROPELLAR WASH

A large number of linear scours occur on the adjacent seabed of many of the docks and wharfs along the waterfront. These scours or erosional features, appear to be formed by two dominant processes, propeller wash and anchoring while docking. Adjacent to the container pier in Bedford Basin and the seawall in southend Halifax, the seabed has a scalloped appearance suggesting that the energy from large ship propellers is impinging on the seabed and causing considerable erosion. Many of the outer ends of the docks along the Halifax Harbour waterfront experience undermining, whereby gravel-sized sediment is eroded by propeller wash. In addition, many of the docks also show a large population of anchor marks radiating seaward and terminating a few 100 m's offshore. These are likely made by anchors which are deployed as a speed and direction control measure by ships during docking. Taken together, it appears that a large amount of erosion, scour and resuspension of sediments results from shipping in the Harbour. It also appears to be concentrated in the shallower areas, particularly around the docks. In the deeper areas of the Harbour it is more difficult to assess.

At present, the shallow near shore areas are where many of the sewage outfalls are located together with their associated local sewage banks. It seems reasonable therefore, to conclude that the remobilization of these sewage banks by shipping is a continuing process within the Harbour. The rate and amount of material eroded by this process is not known. This must be evaluated and compared to the resuspension and remobilization of contaminents within sediments predicted to occur by biological activity under certain proposed sewage treatment scenarios. Remobilization of sediments and their contaminants by shipping may be the dominant process when compared to that predicted by biological activity. This would further suggest that as long as the Harbour is used as a major shipping facility, contaminated sediments which presently occur on the seabed will continue to be resuspended and transported throughout the Harbour. Similar shipping related erosion and resuspension of sediments has been found to occur in Chesapeake Bay.

OTHER FEATURES

Within the Harbour there are many features on the seabed which are not clearly understood. Some may represent debris which has been discarded at sea, while others may possibly represent dense communities of shellfish. One particular series of features occurs at the entrance to the Northwest Arm. They are large shallow depressions on a muddy seabed and resemble pockmarks, which are gas-escape craters. If these depressions are formed by the venting of methane from the subsurface sediments, they are indicators of a process that will affect the mixing of currents and particulates within the water column. Some of the pockmarks have been found to be filled with dense distributions of kelp.

A peculiar linear depression in the inner Harbour, flanked by 3 m muddy berms, is interpreted as the impression of the Trongate, a freighter that was purposely sunk in the Harbour in 1944 because its explosive cargo was on fire. A survey of the seabed in the depression, with a remotely operate vehicle, revealed the presence of many rolls of newsprint and rubber boots. Only a thin dusting of sediment covers the newspaper rolls. Other large depressions in the Harbour bottom are the result of jack-up and semi-submersible oil drilling rigs impacting the seabed.

SUBSURFACE GEOLOGY

In general, the subsurface geology of Halifax Harbour is of more importance to the engineering aspects of sewage system design than environmental considerations. However, several characteristics of the subsurface geology have an important bearing on the mobilization of contaminated sediments. Large areas of Bedford Basin, the inner and outer Harbour, Eastern Passage and the Northwest Arm contain sediments that are gas-charged. The gas seems to appear in sediments that are at least 5 m in thickness. This gas is probably biogenic methane formed within the sediments from the accumulation of organic debris deposited in the Harbour since deglacial time, over the past 10,000 years. This gas is not to be confused with methane gas generated within sewage banks which can be seen bubbling to the sea surface when sewage banks are disturbed. It is, however, methane gas, but occurs at a depth of several metres within the older sediments. In some areas of the Harbour this methane gas appears to be leaking through the seabed. Ship anchoring appears to trigger its release by disturbing the sediments through dragging of anchors across the seabed which produces furrows over several metres in depth. The release of methane gas by this process produces depressions called pockmarks, which are cone-shaped features on the seabed. If the methane gas vents through contaminated sediments containing mercury, for example, methyl mercury is produced and liberated from the contaminated sediments. This is a form of mercury which can be easily adsorbed by the biological community. This is another example of shipping related effects on Harbour water and also must be considered in relation to release of contaminants by increased biological activity from a renewed benthic community. In addition, the construction of seafloor and subsurface facilities for a sewage facility must contend with gas-charged soils as foundation material. The presence of the gas may present problems in this regard. Gas-charging of sediments is widespread and continues seward of the estuary in the channel of the old Sackville River.

Beneath the Holocene muds in the inner Harbour and thin sands in the deeper areas of the outer Harbour, estuarine and/or glaciomarine sediments are present. The surface of these sediments has been eroded during the marine invasion of the Harbour which occurred in postglacial time. From an engineering perspective, the sediments at the present seabed do not reflect the subsurface geology. Boreholes must be taken in ares of the seabed where facilities are to be placed to determine their properties. A similar situation exists with the bedrock. The distribution of varying bedrock lithologies beneath the Harbour is based solely on correlation across the Harbour from the adjacent shores. It would be expected that the bedrock may vary considerably in parts of the Harbour.

SEDIMENT TRANSPORT UNDER WAVES AND CURRENTS

The two disciplines of physical oceanography and marine geology offer a different understanding of the same processes and can shed light on each others problems. The following is extracted from a report by Fader and Petrie, in press, that addresses this aspect of sediment transport. The average water circulation can lead to sediment transport and subsequent deposition in regions of very weak flow. High energy currents from tides, storms or waves can scour some areas of fine-grained sediments leaving behind gravel and bedrock. Sedimentary deposits which reflect water movement over years can tell the physical oceanographers if their short duration current meter records are representative of long term conditions. Information from the two fields of study can be brought together for Halifax Harbour to provide a better understanding of the currents and sediment distributions. Halifax Harbour is an inlet whose mean circulation is known on a broad scale. Areas of strong, variable currents have been identified. Recently, (Miller and Fader, 1988 and Miller et al., 1990), the Harbour has been the subject of thorough marine geological acoustic studies which have provided a regional understanding of the surficial and bedrock geology. In addition, sediment samples have been collected (Buckley and Hargrave, 1989) to provide "ground truth" for the acoustic data and to examine the geochemical changes the Harbour has experienced since the beginning of its use for sewage disposal, shipping and military activities.

AVERAGE CIRCULATION OF THE HARBOUR

Halifax Harbour is an estuary, i.e., a semi-enclosed body of water whose properties are influenced by freshwater runoff from the land. The near surface waters tend to flow towards the ocean becoming saltier as they move down the Harbour. The salt is supplied through mixing with waters from the shelf which move into the Harbour from just below the outgoing near-surface flow to the bottom. In turn, these shelf waters become less salty as they move into the Harbour because of mixing with the shallower, fresher waters.

Salinity measurements in the Harbour confirm this idealized picture of the average circulation and can be used with a model to derive horizontal current strengths and vertical mixing rates. In the surface layer, the weakest outflow, 0.2 cm s^{-1}, which is found in Bedford Basin moves a parcel of water approximately 200 m in 1 day. The currents accelerate to their highest values of about 5 cm s^{-1} in the Narrows, slow to about 2 cm s^{-1} as the Harbour widens in the downtown area, increase slightly with a narrowing off Sandwich Point, and finally slow to about 1 cm s^{-1} before flowing out onto the shelf. The picture is much the same in the lower layer except in the opposite direction, i.e., inflow instead of outflow.

The current meter data generally support this salinity-derived picture of the circulation in the Harbour and, in at least one case, after some additional data. In The Narrows, the instruments recorded the strongest inflows near the bottom of the eastern (Dartmouth) side of the Harbour.

What are the inferences for sediment distribution one would draw from these observations of the circulation? There should be a general tendency for the finer sedimentary particles on the bottom to move towards the head of the Harbour, i.e., towards Bedford Basin. Moreover, sewage particles, which enter the Harbour waters in the surface layer, initially would be carried towards the shelf. However, as they sank, they would be caught up in the deeper inflow and move back up the inlet. One might expect to find sewage derived sediments to be largely confined to the inner Harbour, The Narrows and Bedford Basin, where the major sewage outfalls are located. There may be a tendency for greater sediment transport into the

Basin on the eastern side of the Harbour because of the stronger currents found there.

VARIABLE CURRENTS IN THE HARBOUR

In the Harbour, currents can change rapidly with perhaps the most familiar variation being the tidal flows. Wind also can bring rapid, dramatic changes to the circulation by causing water borne material to cross the Harbour in perhaps an hour or by stirring up the bottom sediments through wave action.

Variable currents are weakest in the Basin with an amplitude of about 3.5 cm s^{-1}. Sediment deposition should occur in this low energy area. The highest values, ranging from 15-35 cm s^{-1}, are found in The Narrows and are largely due to the tides. If there is one area in the inner Harbour that should be scoured of fine sediments, this is it. From Sandwich Point to the Harbour mouth, the time-varying flows have amplitudes equivalent to 5-15 cm s^{-1}, with the lowest values occurring off Herring Cove. These areas, though having lower current variability than The Narrows, are more exposed to ocean waves which can affect sediment transport significantly. No data are available for the Northwest Arm or Eastern Passage but it is anticipated that these areas would have varying currents more like those in the Basin than in The Narrows.

SEDIMENT HISTORY AND SEDIMENT TRANSPORT

The sediments on the seafloor of Halifax Harbour record not only the geological and natural history of the formation of the Harbour, but also its most recent use as a depository of wastes during urban development. In addition, the sediments on the floor of the Harbour have been modified by more direct disturbance. Dredges have scoured and deepened areas; docking facilities have been constructed often including the infilling of shoreline areas; sand and gravel have been mined; dredge spoils, old ships and large quantities of debris have been dumped; ships anchors have been dragged and discharge and intake water pipes have been constructed. All of these anthropogenic activities have interacted with the natural processes of sedimentation and sediment transport in a complex manner to produce the present characteristics of the Harbour bottom. From a study of these characteristics, it is possible to determine the direction of sediment transport, the areas where sediments are being eroded or deposited and areas of non-deposition. This information can be compared with the physical oceanographic data and used to fill in gaps where oceanographic measurements do not exist.

SEDIMENT DISTRIBUTIONS

Areas of coarse sediments are widespread in the Harbour. North of McNabs Island, the most extensive area of coarse sediment is in The Narrows, corresponding to the region with the highest current variance. On the other hand, another area of coarse sediment occurs in the Northwest Arm adjacent to Flemming Park, where strong flows are not expected. The seabed consists of gravel with boulders and outcropping bedrock; fine-grained silts and clays are absent. As both of these areas occur at narrowing restrictions within the inlet, strong currents are interpreted as the responsible mechanism for preventing the accumulation. Other areas of the Harbour are also devoid of fine-grained sediments; the entrance to Bedford Bay, Ives Knoll, the shallow coastal areas to a depth of 10 m, many bedrock shoals in the outer Harbour and vast expanses of the eastern outer Harbour to the southeast of McNabs Island. Wave action may account for the absence of sediment in the outer Harbour and in the shallow coastal areas. In the inner Harbour, to the north of McNabs Island, many small east-west trending ridges of coarse sediment protrude through the muddy seabed. The present distribution of coarse seabed areas, thus has arisen from a combination of relict processes and modern conditions of high energy. The acoustic survey has allowed us to locate these high energy areas economically- it would be virtually impossible to survey the harbour with current meters at this high resolution.

SEDIMENT TRANSPORT INDICATORS

No direct measurement of sediment transport in Halifax Harbour has been undertaken. Such studies require the use of tracers together with subsequent monitoring programs and have only been conducted on Sable Island Bank on the Scotian Shelf (Amos and Nadeau, 1988). However, many other characteristics of seabed sediments can be used as qualitative indicators in an interpretation of the orientation of features with respect to the responsible currents. These include distribution patterns of gravel, sand, silt and clay; bedforms in sand and fine-grained gravel; scour features around seabed obstructions, the distribution of sewage banks, the distribution of geochemical anomalies relative to injection points; the presence of comet marks and the distribution of exposed bedrock.

The most easily identified sediment transport indicators are the bedforms in the outer Harbour. Here the megaripples cover a broad area of the seabed overlying the bedrock channel of the ancestral Sackville River. The megaripples have wavelengths of approximately 4 m and are less than 0.5 m in height. They are flow transverse bedforms and show a moderate coherence in crest spacing. Megaripples usually form at a mean flow velocity of between 40-60 cm s (Amos and King, 1983). Some of the crests of the megaripples are broken into three-dimensional shapes. These features are normally generated under stronger turbulent flow. The shape of the 3-D megaripples indicates bottom sediment transport up the Harbour to the north, i.e., in the direction of the mean current. These megaripples in general are degraded, with less clearly defined crests, suggesting that the event that formed them may have occurred several months to a year previous. Browsing benthic communities often quickly erode and destroy the sharp crests of megaripples.

In many areas, in slightly shallower water adjacent to the megaripples, large areas of gravel ripples are present. These often flank the outcropping bedrock shoals between the bedrock and the megaripples. They are characterized by a wavelength of between 1 and 2 m and wave heights of less than 0.5 m. They do not indicate sediment transport but are formed in situ by oscillatory motion associated with waves. The areas of gravel ripples and megaripples in the outer Harbour indicates that fine-grained silt and clay sediments are not depositing in these areas. Silt and clay sized-sediments discharged there would be transported either further offshore to the inner Scotian Shelf, or transported up the Harbour to the north.

The sidescan sonograms from The Narrows were closely evaluated for sediment transport indicators but none could be found. The presence of large boulders offers the proper setting to preserve comet marks and scour features under strong flow. The seabed in The Narrows consists of coarse gravel and bedrock and silt and clay-sized sediment is absent. Conditions of flow are, however, high enough to prevent deposition of fine-grained sediments indicating a bed shear stress of greater that 1 n. per m squared. Currents of this strength have been observed in fact, to 90 cm per sec in The Narrows.

The distribution of geochemical anomalies in Harbour sediments provides another indicator of sediment transport (Buckley and Hargrave, 1989). Many of these distributions suggest dispersion and settlement of material from the sewage discharge locations along the shores of the Harbour in a northerly direction up the Harbour in agreement with mean flow. Anomalies of mercury suggest that material discharged from the Duffus St. and Tuft's Cove area are transported through The Narrows and deposited on the southeast side of Bedford Basin. In a similar fashion, the Pier A sewage outfalls can be traced up the Harbour to an area north of Georges Island.

The presence of anchor marks on the seabed of the Harbour is an important bench mark that can also be used to assess the history of sedimentation and sediment transport. Large areas of Bedford Basin and the inner Harbour are covered with criss-crossing patterns of anchor marks. Since they occur in most areas of the Basin and in the major shipping channel of the Harbour where anchoring is presently prohibited, they are interpreted as being relict, that is, formed at some time in the past with little subsequent modification or burial. Those in the Basin are interpreted to have largely been developed during assembly of the second world war convoys while those in the inner Harbour may date back even further to the founding of Halifax. Adjacent to the Halifax Harbour shoreline, recent sediment buries the old anchor marked surface. As the relief on the anchor marks is between 1-2 m, this indicates deposition of greater than 2m of sediment to bury the anchor marked surface. The area of buried anchor marks projects up the Harbour from the major sewer outlets and suggests that the material is dispersed in a northerly direction as it settles to the seabed.

SEDIMENT TRANSPORT SUMMARY

Both the oceanographic and geological data are in good agreement that bottom currents move up the Harbour. The distribution of megaripples in the outer Harbour suggests that currents are strongest to the south of Litchfield Shoal. This has prevented the deposition of fine-grained silt and clay sediments. North of Litchfield Shoal, and adjacent to Herring Cove, an area of seabed with a lack of bedforms in sandy sediments agrees with the oceanographic data suggesting lower velocity bottom currents. This local oceanographic anomaly may result from topographic sheltering by Litchfield Shoal. Coarse sediments in The Narrows are predicted from the oceanographic data and the geological information confirms this prediction. In the Northwest Arm adjacent to Flemming Park, a similar lack of fine-grained sediments in a constricting channel suggests the presence of strong currents in an area where no measurements have been made. The eastern part of the outer Harbour is dominated by bedrock and gravel at the seabed. Many of the bedrock outcrops in this area are flanked by rippled gravel deposits which indicate that wave energy is reaching the seabed and that they are zones of high energy. Muddy sediments are confined to the area north of Maugher Beach. Their presence in the inner Harbour, Eastern Passage area and the Northwest Arm reflects lower current velocities. Sediment geochemical anomalies and sewage banks deposited over older anchor marked sediments indicates sediment transport up Harbour even in these areas of lower current velocities.

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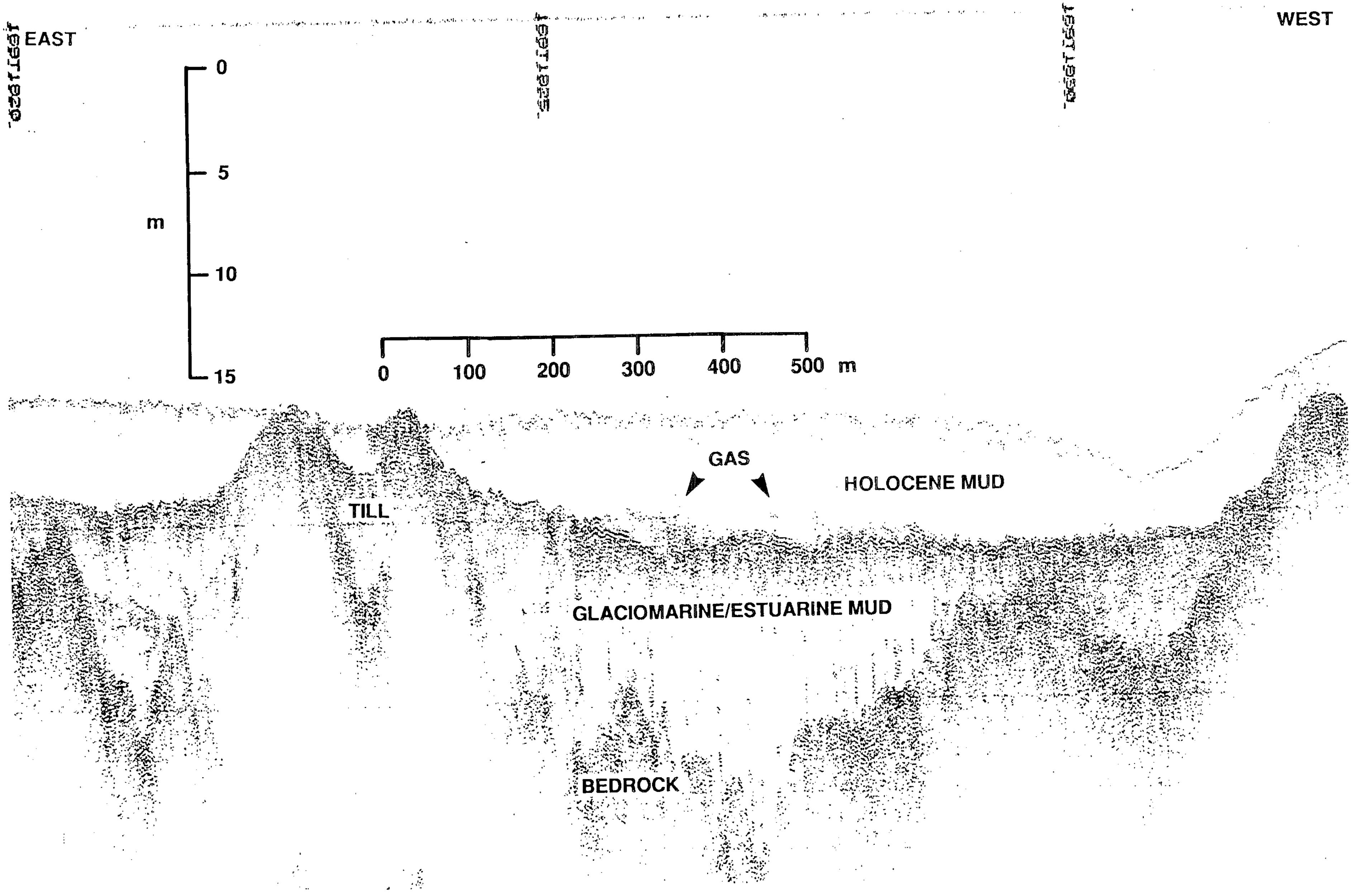


Figure 1 I.K.B. Seistec Boomer high resolution seismic profile from north of Georges Island running East to West showing bedrock, till, glaciomarine/estuarine and Holocene sediments. Note the roughness of the surface of the Holocene mud resulting from the anchor marks.

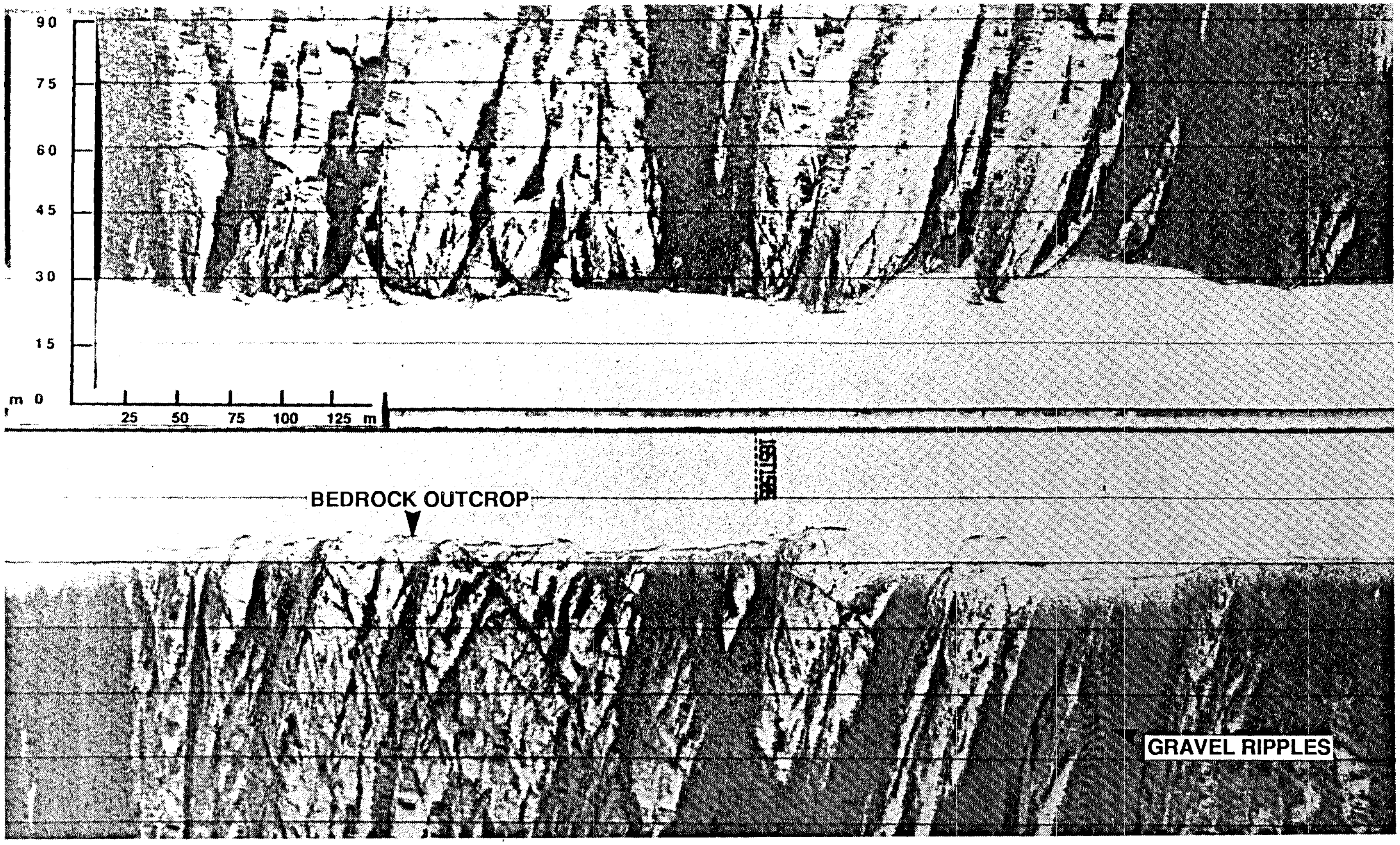
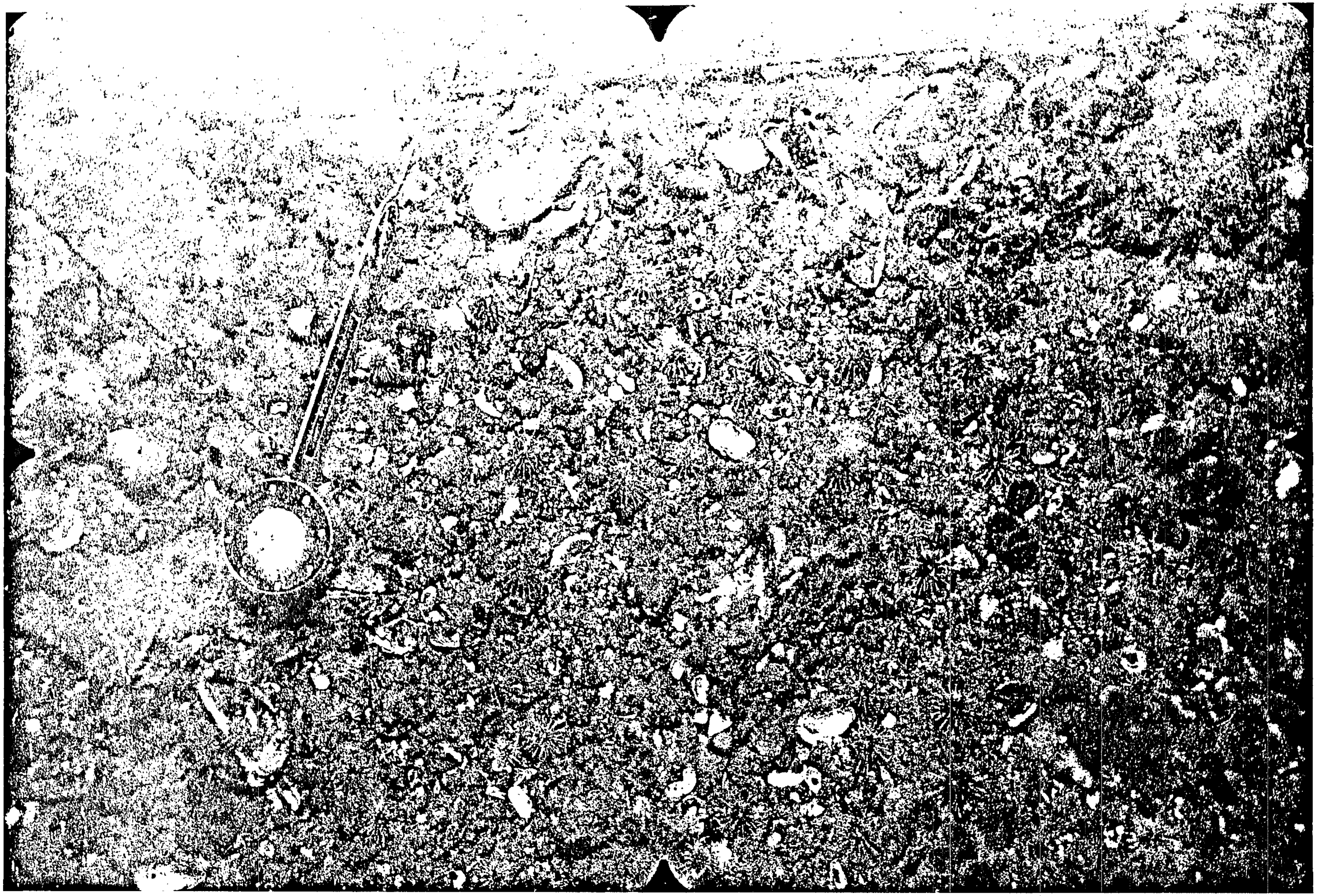


Figure 2 A seafloor area south of the entrance to Halifax Harbour on the inner Scotian Shelf dominated by outcropping bedrock. Note gravel ripples.



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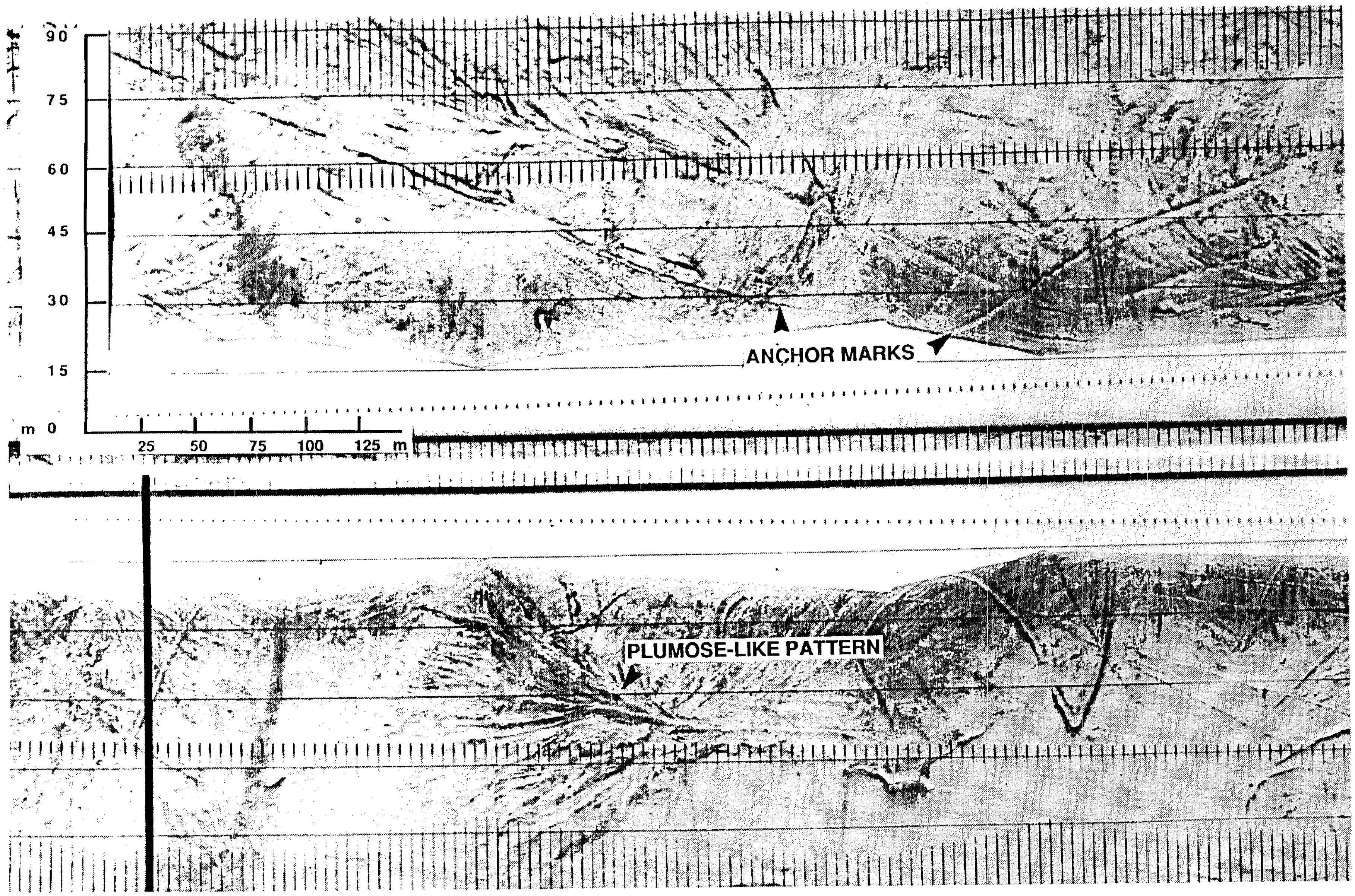

Figure 4. Anchor drag marks on the seafloor of Bedford Basin. Note plumose-like pattern. This pattern is probably caused by ship's anchor chains moving about the seafloor as the ship is moved about by winds and tides.

APPENDIX C. GUIDELINES FOR THE PROTECTION OF THE MARINE ENVIRONMENT AGAINST POLLUTION FROM LAND-BASED SOURCES (MONTREAL GUIDELINES)

Introduction

This set of guidelines is addressed to Governments with a view to assisting them in the process of developing appropriate bilateral, regional and multilateral agreements and national legislation for the protection of the marine environment against pollution from land-based sources. They have been prepared on the basis of common elements and principles drawn from relevant existing agreements and drawing upon experience already gained through their preparation and implementation. Principal among these agreements are the United Nations Convention on the Law of the Sea (Part XII), the Paris Convention for the Prevention of Marine Pollution from Land-Based Sources, the Helsinki Convention on the Protection of Marine Environment of the Baltic Sea Area, and the Athens Protocol for the Protection of the Mediterranean Sea against Pollution from Land-Based Sources.

These guidelines are suggested as a broad framework for the development of similar agreements in those regions where such agreements are called for; for the guidance of Governments in areas which may not presently be covered by any regional agreements; and for the preparation in the longer term, should the need arise, of a global convention on pollution from land-based sources designed to strengthen international institutional arrangements to ensure the harmonization and application of global and regional rules, criteria, standards and recommended practices and procedures and to review the effectiveness of measures taken.

The guidelines are of a recommendatory nature. They are presented as a checklist of basic provisions rather than a model agreement, from which Governments may select, adapt or elaborate, as appropriate, to meet the needs of specific regions. They are without prejudice to the elaboration of cross-sectoral guidelines/principles within the framework of the programme for the development and periodic review of environmental law, as recommended by the UNEP Ad Hoc Meeting of Senior Government Officials Expert in Environmental Law (Montevideo, 1981).

1. Definitions

For the purposes of these guidelines:

(a) "Pollution" means the introduction by man, directly or indirectly, of substances or energy into the marine environment which results or is likely to result in such deleterious effects as harm to living resources and marine ecosystems, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities.

(b) "Land-based sources" means:

(i) Municipal, industrial or agricultural sources, both fixed and mobile, on land, discharges from which reach the marine environment, in particular:

From the coast, including from outfalls discharging directly into the marine environment and through run-off;

Through rivers, canals or other watercourses, including underground watercourses; and

Via the atmosphere.

(ii) Sources of marine pollution from activities conducted on offshore fixed or mobile facilities within the limits of national jurisdiction, save to the extent that these sources are governed by appropriate international agreements.

(c) "Marine environment" means the maritime area extending, in the case of watercourses, up to the freshwater limit and including inter-tidal zones and salt-water marshes;

(d) "Freshwater limit" means the place in watercourses where, at low tide and in a period of low freshwater flow, there is an appreciable increase in salinity due to the presence of sea-water.

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*Ad Hoc Working Group of Experts, Montreal, 11-19 April 1985.

**UNEP/WG. 120/3 (Part IV).

2. Basic obligation

States have the obligation to protect and preserve the marine environment. In exercising their sovereign right to exploit their natural resources, all States have the duty to prevent, reduce and control pollution of the marine environment.

3. Discharges affecting other States or areas beyond the limits of national jurisdiction

States have the duty to ensure that discharges from land-based sources within their territories do not cause pollution to the marine environment of other States or of areas beyond the limits of national jurisdiction.

4. Adoption of measures against pollution from land-based sources

1. States should adopt, individually or jointly, and in accordance with their capabilities, all measures necessary to prevent, reduce and control pollution from land-based sources, including those designed to minimize to the fullest possible extent the release of toxic, harmful or noxious substances, especially those which are persistent, into the marine environment. States should ensure that such measures take into account internationally agreed rules, criteria, standards and recommended practices and procedures.

2. In taking measures to prevent, reduce and control pollution from land-based sources, States should refrain, in accordance with international law, from unjustifiable interference with activities carried out by other States in the exercise of their sovereign rights and in pursuance of their duties in conformity with internationally agreed rules, criteria, standards and recommended practices and procedures.

5. Co-operation on a global, regional or bilateral basis

1. States should undertake, as appropriate, to establish internationally agreed rules, criteria, standards and recommended practices and procedures to prevent, reduce and control pollution from land-based sources, with a view to co-ordinating their policies in this connection, particularly at the local and regional level. Such rules, criteria, standards and recommended practices and procedures should take into account local ecological, geographical and physical characteristics, the economic capacity of States and their need for sustainable development and environmental protection, and the assimilative capacity of the marine environment, and should be reviewed from time to time as necessary.

2. States not bordering on the marine environment should co-operate in preventing, reducing and controlling pollution of the marine environment originating or partially originating from releases within their territory into or reaching water basins or watercourses flowing into the marine environment or via the atmosphere. To this end, States concerned should as far as possible and, as appropriate, in co-operation with competent international organizations, take necessary measures to prevent, reduce and control pollution of the marine environment from land-based sources.

3. If discharges of a watercourse which flows through the territories of two or more States or forms a boundary between them are likely to cause pollution of the marine environment, the States concerned should co-operate in taking necessary measures to prevent, reduce and control such pollution.

6. Duty not to transfer or transform pollution from land-based sources

In taking measures to prevent, reduce and control pollution from land-based sources, States have the duty to act so as not to transfer directly or indirectly, damage or hazards from one area to another or transform such pollution into another type of pollution. (Guideline 6 does not prevent the transfer or transformation of pollution in order to prevent, reduce and control pollution of the environment as a whole.)

7. Specially protected areas

1. States should, consistent with international law, take all appropriate measures, such as the es-

tablishment of marine sanctuaries and reserves, to protect certain areas to the fullest possible extent from pollution, including that from land-based sources, taking into account the relevant provisions of Annex 1.

2. States should, as practicable, undertake to develop, jointly or individually, environmental quality objectives for specially protected areas, conforming with the intended uses, and strive to maintain or ameliorate existing conditions by comprehensive environmental management practices.

8. Scientific and technical co-operation

States should co-operate, directly and/or through competent international organizations, in the fields of science and technology related to pollution from land-based sources, and exchange data and other scientific information for the purpose of preventing, reducing and controlling such pollution, taking into account national regulations regarding the protection of confidential information. They should, in particular, undertake to develop and co-ordinate to the fullest possible extent their national research programmes and to co-operate in the establishment and implementation of regional and other international research programmes.

9. Assistance to developing countries

1. States should, directly and/or through competent international organizations, promote programmes of assistance to developing countries in the fields of education, environmental and pollution awareness, training, scientific research, transfer of technology and know-how, for the purpose of improving the capacity of the developing countries to prevent, reduce and control pollution from land-based sources and to assess its effects on the marine environment.

2. Such assistance should include:

(a) Training of scientific and technical personnel;

(b) Facilitation of the participation of developing countries in relevant international programmes;

(c) Acquisition, utilization, maintenance and production by those countries of appropriate equipment,; and

(d) Advice on, and development of, facilities for education, training, research, monitoring and other programmes.

3. States should, directly and/or through competent international organizations, promote programmes of assistance to developing countries for the establishment, as necessary, of infrastructure for the effective implementation of applicable internationally agreed rules, criteria, standards and recommended practices and procedures related to the protection of the marine environment against pollution from land-based sources, including the provision of expert advice on the development of the necessary legal and administrative measures.

10. Development of a comprehensive environmental management approach

States should undertake to develop, as far as practicable, a comprehensive environmental management approach to the prevention, reduction and control of pollution from landbased sources, taking into account relevant existing programmes at the bilateral, regional or global level and the provisions of Annex 1. Such a comprehensive approach should include the identification of desired and attainable water-use objectives for the specific marine environments.

11. Monitoring and data management

States should endeavour to establish directly or, whenever necessary, through competent international organizations, complementary or joint programmes for monitoring, storage and exchange of data, based, when possible, on compatible procedures and methods, taking into account relevant existing programmes at the bilateral, regional or global level and the provisions of Annex III, in order to:

(a) Collect data on natural conditions in the region concerned as regards its physical, biological and chemical characteristics;

(b) Collect data on input of substances or energy that causes or potentially causes pollution emanating from land-based sources, including information on the distribution of sources and the quantities introduced to the region concerned;

(c) Assess systematically the levels of pollution along their coasts emanating from land-based sources and the fate and effects of pollution in the region concerned; and

(d) Evaluate the effectiveness of measures in meeting the environmental objectives for specific marine environments.

12. Environmental assessment

States should assess the potential effects/impacts, including possible transboundary effects/impacts, of proposed major projects under their jurisdiction or control, particularly in coastal areas, which may cause pollution from land-based sources, so that appropriate measures may be taken to prevent or mitigate such pollution.

13. Development of control strategies

1. States should develop, adopt and implement programmes and measures for the prevention, reduction and control of pollution from land-based sources. They should employ an appropriate control strategy or combination of control strategies, taking into account relevant international or national experience, as described in Annex 1.

2. States should, as appropriate, progressively formulate and adopt, in co-operation with competent international organizations, standards based on marine quality or on emissions, as well as recommended practices and procedures, taking into account the provisions of Annex 1.

3. Where appropriate, States should undertake to establish priorities for action, based on lists of substances from which pollution should be eliminated and of substances from which pollution should be strictly limited on the basis of their toxicity, persistence, bioaccumulation and other criteria as elaborated in Annex, II, or in relevant international agreements.

14. Pollution emergencies arising from land-based sources

States and, as appropriate, competent international organizations should take all necessary measures for preventing and dealing with marine pollution emergencies from land-based sources, however caused, and for reducing or eliminating damage or the threat of damage therefrom. To this end States should, as appropriate, individually or jointly, develop and promote national and international contingency plans for responding to incidents of pollution from land-based sources and should co-operate with one another and, whenever necessary, through competent international organizations.

15. Notification, information exchange and consultation

Whenever releases originating or likely to originate from land-based sources within the territory of a State are likely to cause pollution to the marine environment of one or more other States or of areas beyond the limits of national jurisdiction, that State should immediately notify such other State or States, as well as competent international organizations, and provide them with timely information that will enable them, where necessary, to take appropriate action to prevent, reduce and control such pollution. Furthermore, consultations deemed appropriate by States concerned should be undertaken with a view to preventing, reducing and controlling such pollution.

16. National law and procedures

1. Each State should adopt and implement national laws and regulations for the protection and preservation of the marine environment against pollution from land-based sources, taking into account internationally agreed rules, criteria, standards and recommended practices and procedures, and take appropriate measures to ensure compliance with such laws and regulations.

2. Paragraph 1 is without prejudice to the right of States to take more stringent measures nationally or in co-operation with each other to prevent, reduce and control pollution from land-based

sources under their jurisdiction or control.

3. Each State should, on a reciprocal basis, grant equal access to and non-discriminatory treatment in its courts, tribunals and administrative proceedings to persons in other States who are or may be affected by pollution from land-based sources under its jurisdiction or control.

17. Liability and compensation for pollution damage emanating from land-based sources

1. States should ensure that recourse is available in accordance with their legal systems for prompt and adequate compensation or other relief in respect of damage caused by pollution of the marine environment by natural or juridical persons under their jurisdiction.

2. To this end, States should formulate and adopt appropriate procedures for the determination of liability for damage resulting from pollution from land-based sources. Such procedures should include measures for addressing damage caused by releases of a significant scale or by the substances referred to in guideline 13, paragraph 3.

18. Implementation reports

States, should report, as appropriate, to other States concerned, directly or through competent international organizations, on measures taken, on results achieved and, if the case arises, on difficulties encountered in the implementation of applicable internationally agreed rules, criteria, standards and recommended practices and procedures. To this end, States designate national authorities as focal points for the reporting of such measures, results and difficulties.

19. Institutional arrangements

1. States should ensure that adequate institutional arrangements are made at the appropriate regional or global level, for the purpose of achieving the objectives of these guidelines, and in particular for promoting the formulation, adoption and application of international rules, criteria, standards and recommended practices and procedures, and for monitoring the condition of the marine environment.

2. The function of such institutional arrangements should include:

(a) Periodic assessment of the state of the specific marine environment concerned;

(b) Formulation and adoption, as appropriate, of a comprehensive environmental management approach consistent with the provisions of guidelines 7 and 10;

(c) Adoption, review and revision, as necessary, of the lists referred to in guideline 13;

(d) Development and adoption, as appropriate, of programmes and measures consistent with the provisions of guidelines 10 and 13;

(e) Consideration, where necessary, of the reports and information submitted in accordance with guidelines 15 and 18;

(f) Recommendation of appropriate measures to be taken for the prevention, reduction and control of pollution from landbased sources, such as assistance to developing countries, the strengthening of regional mechanisms of co-operation, consideration of aspects of transboundary pollution, and the difficulties encountered in the implementation of agreed rules; and

(g) Review of the implementation of relevant internationally agreed rules, criteria, standards and recommended practices and procedures, and of the efficacy of the measures adopted and the advisability of any other measures.

Annex 1: Strategies for protecting, preserving and enhancing the quality of the marine environment

Introduction

In controlling marine pollution from land-based sources, an overall approach to the uses and the natural values of the marine environment should be taken, while still considering the needs of populations and industries for waste disposal. It is important to note that for many types of waste, the use of the marine environment is only one option among several. However, in some instances, marine disposal may be a feasible alternative. This document describes a number of strategies which can be employed to protect the marine environment against pollution from land-based sources and, where necessary, restore areas that have been affected. The goal is to protect the marine ecosystem by maintaining its quality within acceptable levels as determined on the basis of scientific, institutional, social and economic factors. It should be recognized that there are many activities competing to derive benefits from the marine environment. None of these activities, save the perpetuation of a marine ecosystem as a vital component of global life support, should be regarded as having guaranteed rights. Compromise and consideration of all alternatives must always be considered. Consequently, in the course of the decision-making process determining the use of a particular sector of the marine environment, social, economic and political factors, as well as natural environmental factors must be taken into account.

Once decision-makers have determined the desired present, interim and long term uses, and associated objectives for a water body, a number of control strategies may be employed to achieve those objectives. Flexibility will be an important consideration in the strategies or regulatory instruments implemented for various water bodies, reflecting their different environmental capacities and other properties and differences in regional socio-economic conditions. The principal strategies in use are based on marine quality standards, on emission standards and on environmental planning. Experience shows that a combination of strategies is often needed. Practical constraints may prevent full implementation of a strategy based on quality standards. Where such an approach cannot be fully implemented, other strategies should be employed.

1.0 Control Strategies

Pollution control strategies in use have been categorized according to:

- those based on marine environmental quality standards,
- those based on emission standards,
- those based on environmental planning.

Priorities for control are often established by the classification of substances into a black and a grey list. Substances are assessed according to the criteria described in Annex II. States undertake to eliminate pollution by those substances in the black list and strictly to limit pollution by those in the grey list.

1.1 Strategies based on marine quality standards

Such strategies relate directly to quality of water, biota or sediments that must be maintained for a desired level of quality and intended use. Several applications of such quality-based strategies exist.

1.1.1 Direct derivation from quality objectives

Technical assessments are conducted to determine the maximum allowable inputs that will ensure the desired levels of environmental quality are met. The assessments consider the fates and effects of various contaminants, amounts of input, and the existing natural characteristics of the relevant marine ecosystem. Numerical standards are then established to which concentrations measured in the receiving environment may be compared. They are usually more restrictive that numbers derived from the technical assessment to allow for monitoring and enforcement capabilities and safety requirements. They may apply to water, sediment, fish or their tissues, health or community composition of organisms in the marine ecosystem.

Monitoring is required to detect changes and compliance with the standards. Changes in the items monitored, after adjustment for natural fluctuation, may signal a need further to reduce inputs and vary existing standards and controls.

1.1.2 No change above ambient

Standards are set based on existing levels which must not be exceeded. This strategy is employed in situations where the aim is to prevent any increase in prevailing specific contaminant levels. It is an interim strategy to allow time to develop a solid scientific base on which more precise quality criteria may be employed for a specific use. It does not imply an existing state of the environment that is satisfactory, nor does it eliminate the need for its improvement.

1.1.3 Dilution

Some contaminants discharged at the source are assumed to attenuate as they spread from that source. Dynamic characteristics of the receiving environment are employed to determine rate and level of dilution. Standards are derived from measured parameters taken at given distances from the discharging source. This strategy may accept short-term or local excess of a potential pollutant at the source of discharge. Application is generally used with effluent that is considered biodegradable, and avoided where scientific evidence suggests that the effluent may accumulate in a given receiving environment.

1.1.4 Loading allocations

These impose priority of control on the larger sources in consideration of the most cost-effective solution. Allowable discharges are measured in terms of the total allowable for an entire receiving environment regardless of specific site quality. Application is suited to relatively self-contained receiving environments such as lagoons and semi-enclosed bodies of water. It allows flexibility of contaminant output, in that certain sources may emit more than adjacent ones as long as loading limits are not exceeded. All these strategies may employ criteria for water, air or sediment quality, as well as criteria related to specific marine life. Receiving environment quality standards are most prevalent for uses, e.g., swimming, direct harvesting of fish for human consumption, where sound scientific criteria exist to determine levels of harm. Emissions of potential pollutants are usually controlled to ensure that the desired quality is achieved. If the quality needs to be upgraded, additional controls are placed on allowable emissions.

1.2 Strategies based on emission standards

These strategies may be based on:

- a general principle to control pollution,
- achievable technology,
- distribution of control costs,
- enforceability.

They differ from strategies based on marine quality in that the standards set are not primarily determined by the level of contaminant in the environment.

1.2.1 Technology-based standards

These standards are usually applied on a sectoral basis, thus providing a means of imposing similar costs across a particular sector. Alternatively, they may be determined on a case-by-case basis. The standards will need to be reviewed periodically in the light of developing technology.

Standards may be based on:

1.2.1.1 Best practicable technology

This reflects the application of demonstrable and sound treatment technology or spectrum of technologies which is affordable by the sector concerned.

1.2.1.2 Best available technology

This reflects state-of-art technology in use in contaminant control. In general, the standards set would reflect a more stringent level of control as compared to best practicable technology. Application is generally for the control of emissions of the most noxious substances or to protect a sensitive environmental use.

1.2.1.3 As low as reasonably achievable

This is mainly applied to radionuclides and is based on the principle of "optimization." This, as defined by the International Commission on Radiological Protection, requires radiation doses to be kept to levels that are "reasonably achievable," by technological improvements and by suitable choice among alternative options. "Reasonably achievable" takes into account both the ease with which the technology can be applied and the balance between the benefits, in terms of dose reduction, and social and economic costs of its application.

1.2.1.4 Zero discharge

In a situation where stringent protection of a sensitive marine environment is deemed appropriate, consideration may be given to the denial of any release of a contaminant to the environment.

1.2.2 Uniform regional emission standards

Such standards are usually applied in situations where there are existing pollution problems of a similar nature and there is urgent need to reduce pollution. They do not give primary consideration to the nature of sources, their economic base, or the receiving environment.

1.3 Planning strategies

This set of strategies draws in part on those mentioned in sections 1.1 and 1.2 above and will often be used to supplement them (a similar relationship exists vice versa). Planning strategies allow an approach to the management and protection of particular environments which may involve restrictions on, or modification of, activities and sites as well as discharges.

1.3.1 Activity management

Certain activities are deemed inappropriate or inconsistent with the value or use of an environment. Consideration should be given to whether the activity is essential, and if so, whether it can be accommodated elsewhere or in a different manner.

1.3.1.1 Use designation

Use of the receiving environment is the determining factor for pollution control standards as well as the basis for regulations or guidelines affecting other activities. For example, if the desire is to maintain or develop a shellfish harvest (a socio-economic decision) then quality standards and uses are developed with this in mind.

The application may result from a perceived threat to an established economic base, or cultural value, or a conscious effort to change the existing use of a receiving environment.

1.3.1.2 Environmental assessment of activities

Siting of any activity significantly affecting the marine environment is subject to a comprehensive analysis and assessment of:

- the ecological characteristics of the receiving environment,
- the direct and indirect potential effects/impacts of the activity on the environment; and, as appropriate,
- the direct and indirect potential effects/impacts on the environment of any reasonable alternative to the activity.

1.3.2 Regional planning

Plans are drawn up for particular regions, taking into account socio-economic and ecological factors, which are then used as a basis for development.

1.3.2.1 Coastal zone management

The strategy employs planning capabilities to make best use of the coastal zone.

It is not use- or source-specific but area-specific. Potential activities are assessed as components of a coastal zone. Planning is based on regional socio-economic and ecological considerations. Zoning and other land-use restrictions or modifications are major regulatory tools. Many States employ the use of regional planning authorities or councils, given the task to manage overall resource planning within a particular coastal area.

1.3.2.2 Watershed or drainage basin planning

This strategy acknowledges that a large proportion of pollution enters the marine environment via watercourses. It does not necessarily account for inputs via the atmosphere, though air management areas have also been employed for control purposes.

Through consideration of socio-economic and environmental factors utilizing a drainage system as the boundary limit, the desired uses and level of quality that can be attained for any given marine water body are determined.

Pollution via watercourses is controlled through regulation of point and diffuse sources of such pollution within the given watershed.

1.3.2.3 Specially protected areas

This strategy involves the identification of unique or pristine areas, rare or fragile ecosystems, critical habitats and the habitat of depleted, threatened or endangered species and other forms of marine life.

Those areas to be protected or preserved from pollution, including that from land-based sources, are selected on the basis of a comprehensive evaluation of factors, including conservational, ecological, recreational, aesthetic and scientific values.

States should notify an appropriate international organization of the establishment of and any modification to such areas, with a view to that data being included in an inventory of specially protected areas.

2.0 Control Instruments

This section outlines the various types of mechanism which can be invoked to implement control strategies:

2.1 Regulations

Regulations are developed pursuant to establishing legislation and can exist in forms such as:

2.1.1 - Emissions standards (air/water)

Standards based on best practicable technology, best available technology, geographical area, etc.

2.1.2 - Environmental quality standards

Standards for the receiving environment which vary according to its intended use.

2.2 Guidelines/codes of practice

These are descriptions of practices and abatement technologies that may be developed to meet the pollution control needs of various point and non-point sources. They provide a listing of basic requirements that may be implemented or adopted by industry or local authorities.

2.3 Permits

Legislation may require a discharger to have a permit to satisfy the requirements for the release of pollutants. These requirements can be based on standards in the form of emission control regulations, guidelines, codes of practice or specific requirements derived from environmental quality standards prescribed to protect the receiving environment.

2.4 Equipment standards certification

Environmental considerations may be incorporated directly in association with particular equipment. To this end, the equipment, or configuration of equipment may be designed, manufactured, tested and certified to comply with the requirements for source releases of pollutants.

2.5 Product controls

If a particular substance, or assemblage of substances in the form of a commercial product is deemed to be of environmental significance, a restriction on the product in the form of production, use, as well as export/import may be implemented.

2.6 Planning restrictions

Under planning law or practice, restrictions may be placed on the use of certain land.

2.7 Economic measures

These may take a variety of forms, e.g., tax incentives, subsidies and effluent charges. To be effective, the incentive offered must be strong enough or the charge levied high enough to persuade the discharger or user that it is in his own financial interest to limit his discharge or use of the substance concerned.

3.0 Factors Influencing Choice of Strategies and Control Instruments

There is a wide range of strategies and control instruments which can be utilized by a State either individually or in combination to address pollution of the marine environment from land-based sources. A number of factors may influence such a choice. In general terms, they may be categorized as economic, scientific/technical or social/cultural/political.

3.1 Economic

- General economic conditions and trends (deficit, balance of trade, inflation, etc.),
- Availability of public financing,
- Availability of external funding,
- Unemployment,
- Economic viability of various sectors,
- Polluter-pays principle,
- Availability of institutions and infrastructure.

3.2 Scientific/technical

3.2.1 Availability/accessibility of scientific data, including:

- Physical characteristics affecting flushing and mixing.
- Natural nutrient cycles and geochemical cycles,
- Biological processes and nature of communities.

3.2.2 Availability/accessibility of technology, including:

- Basic information on industry types, total effluent releases, and specific data on waste stream constituents.
- Availability of expertise,
- Capability for monitoring,
- Existing engineering infrastructure,
- Experience with implementation of strategies or instruments elsewhere,
- Sensitivity of ecosystems to be affected,
- Climatic considerations,
- Current level of pollution of the receiving environment and identified trends, in municipal, agricultural and industrial waste releases.

3.3 Social/cultural/political

- Infrastructure,
- Existing and proposed uses of the marine environment,
- Political realities,
- Social/cultural awareness of the population,
- Perception of environmental, social and cultural values.

Annex II: Classification of substances

Introduction

Substances may be classified into a black list of those substances pollution from which should be eliminated and a grey list of those substances pollution from which should be strictly limited and reduced.

The basic criteria to be taken into account in allocating substances to one of these lists are:
a) persistence,
b) toxicity or other noxious properties,
c) tendency to bio-accumulation.

These criteria are not necessarily of equal importance for a particular substance or group of substances. Other factors such as location and quantities of the discharge may need to be considered.

1.0 Black List

Substances may be included in this list:
a) because they are not readily degradable or rendered harmless by natural processes; and
b) because they may either:
(i) give rise to dangerous accumulation of harmful material in the food chain, or
(ii) endanger the welfare of living organisms causing undesirable changes in the marine ecosystems, or
(iii) interfere seriously with the harvesting of sea foods or with other legitimate uses of the sea; and

c) because it is considered that pollution by these substances necessitates urgent action.

The substances that fulfill criteria may include:
1.1 Certain organic biocides (e.g., organohalogen compounds and substances which may form such compounds in the marine environment);
1.2 Persistent hydrocarbons of petroleum origin;
1.3 Certain metals and their compounds (e.g., mercury);
1.4 Persistent synthetic materials which may seriously interfere with any legitimate use of the sea;
1.5 Radioactive materials;
1.6 Substances in respect of which it has been proved that they possess carcinogenic properties in or via the aquatic environment;

1.7 Materials in whatever form (e.g., solids, liquids, semi-liquids, gases, or in a living state) produced for biological and chemical warfare.

2.0 Grey List

Substances may be included in this list because, although exhibiting similar characteristics to the substances in the black list and requiring strict control, they seem less noxious or are more readily rendered harmless by natural processes. The substances to which this may apply include:

2.1 Organic biocides not included in the black list;

2.2 Hydrocarbons of petroleum origin and their derivatives not included in the black list;

2.3 Certain elements and their compounds (e.g., fluorides and cyanides);

2.4 Organic and synthetic organic materials, other than those included in the black list, which are likely to produce harmful effects on marine organisms or to make edible marine organisms unpalatable, as well as chemicals which may lead to the formation of such substances in the marine environment;

2.5 Acid and alkaline compounds of such composition and in such quantity that they may seriously impair the quality of the marine environment;

2.6 Substances which, though not producing toxic effects, may become harmful because of the concentrations or quantities in which they are discharged, or which are liable to reduce amenities seriously or to endanger human life or marine organisms or to impair other legitimate uses of the sea;

2.7 Pathogenic micro-organisms which are or may become harmful because of the concentrations and quantities in which they are discharged or which are liable to endanger human life or marine organisms, or to impair other legitimate uses of the marine environment and the coastal waters in particular.

Annex III: Monitoring and Data Management

1.0 Monitoring

In the protection of the marine environment against pollution from land-based sources, monitoring can be defined as the measurement of a pollutant or its effects on either man or elements of the marine resources for the purposes of assessing and controlling exposure to that pollutant. Thus monitoring is used first to assess the need for pollution prevention measures and subsequently the effectiveness of any protection measures introduced. If monitoring is to meet these objectives and be cost-effective it must be carefully designed and implemented.

1.1 Resources to be protected

One of the first things to ascertain is what resources need protecting in the area concerned and the various pollutant sources and ways in which each could possibly be threatened. For example, the well-being of a nature reserve, fish hatchery or fish resource might be threatened by a variety of substances. Similarly, the suitability of fish or shell-fish for human consumption might be affected by other substances such as mercury or arsenic which may adversely affect man, whilst not affecting fisheries.

1.2 Information on Inputs

It is also important at an early stage to establish for each area the activities already practised and the pollutants likely to reach the sea via point, non-point and riverine sources.

A knowledge of the resources to be protected and which pollutants are most likely to affect them will allow attention to be focussed on those substances which appear most likely to be of concern, thereby reducing the amount of effort devoted to establishing a data base on inputs. Information on inputs can also be used to focus environmental monitoring efforts on those pollutants most likely to be encountered in each area. If possible the scale of input should also be established, at least in order of magnitude terms. This will normally be fairly easy but more accurate quantification will require improvements in the quality of data on both concentration and flow.

Information on inputs from direct discharges may be determined from descriptions of unit processes in use. If permit programmes have been established, information on controlled pollutants should be available from the permitting authority. Inputs from non-point sources are generally estimated by employing accepted formulae describing land use in the watershed and the associated runoff. In estimating point and non-point source inputs, the pollutants of concern may include a broad range of substances, for example, toxicants and nutrients.

1.3 Establishing baseline concentrations

Having decided what needs to be monitored, on the basis of what resources must be protected and which pollutants are likely to be of interest, the concentrations actually present in the environment can be established. This information can then be used to assess those protection measures necessary and/or their effectiveness. The need for control measures may be judged either by comparison of the concentrations found with some form of water quality criteria, for example maximum permissible concentration, or with similar data from other areas known not to be contaminated.

When baseline concentrations are being ascertained, the most appropriate substrate should be selected. Three options exist: water, biota and sediments, only rarely should it be necessary to analyze samples of all three. The choice will depend on the pollutant concerned, the water quality criteria selected and the nature of the pathways exposed. For example, water would be most suitable for nutrients, biochemical oxygen demand (BOD), pH and certain metals, but biota would be more appropriate for polychlorinated biphenyls (PCBs) or mercury, and undisturbed sediments can be particularly useful in time or spatial trend assessments.

1.4 Ongoing monitoring

Monitoring will be required to establish the effectiveness of pollution protection measures. Even if no reductions in inputs are deemed necessary it may be desired to check that the situation does not deteriorate. Whatever their purpose, monitoring programmes should be designed to consider the receiving capacity of the environment as well as inputs. This means considering present water quality in relation to the desired quality, and the scale of environmental protection measures taken in relation to the existing concentrations, nature of the pollutants present, the scale of their input and their removal processes. On this basis it will be possible to define what should be monitored and with what frequency.

1.5 Sampling and analysis

The number of samples collected and their nature should represent the substrate being monitored. Water quality, biological tissues and sediments can all be very variable even over short distances and the sampling strategy should, when necessary, be tested statistically to ensure it is sound. The programme design should take account of the hydrographic characteristics of the area so as to avoid sampling the same body of water at different places as it moves under the influence of a current. Finally, the sample collected must be adjusted to the form in which the pollutant occurs in the environment or in the discharge streams.

Once a suitable sampling programme has been designed, it may be possible to bulk samples for analysis in order to reduce the analytical workload and costs. This will inevitably lead to the loss of some information and should only be considered if the complexity of the analytical technique demands it and/or the loss of information can be tolerated or if the monitoring is only to be used to pick up abnormalities such as in compliance monitoring.

1.6 Resource monitoring

In addition to monitoring the pollutants of interest in the selected substrate, it is essential that the state of the resource(s) be monitored. However, if adverse changes do occur it should not be assumed the protection measures taken were inadequate. For example, fish stocks decline due to fishing effort as well as pollution and undesirable plankton blooms occur for reasons other than nutrient enrichment. Biological effects monitoring is desirable but very few techniques can be applied routinely on a wide scale

2.0 Data and Data Management

Before the data from any monitoring programme are used, it is important that confidence limits be established and reported in order to ensure that the confidence with which recorded numbers are handled and interpreted is not misplaced. It is also necessary to decide how the data should be handled for future reference and use.

2.1 Limitations in the data and the extent to which they can be tolerated

The results obtained from any monitoring programme will be subject to errors of accuracy and precision, the size of which must be quantified. If precision is high and accuracy poor then all results for a set of analyses of the same sample will be very close together, for example, differing by no more than one per cent though they may differ from the true result by much more, possibly by as much as an order of magnitude. Some errors will derive from the nature of the samples. These can be minimized by proper statistical design of the sampling procedures and attention to the collection of uncontaminated samples.

All analytical procedures have inherent errors in precision and accuracy. To a greater or lesser extent either or both types of error can be compounded by operator or laboratory errors, which are often not recognized. However, by use of good analytical equipment and methods and by following a rigorous analytical quality assurance scheme, it should be possible to achieve high accuracy and precision for all analytical data, and allow quantification of the scale errors.

2.2 Intercomparability requirements

In most cases where monitoring programmes are operated on a multilateral basis it is essential that the results obtained by all contributors are truly comparable. Establishing comparable monitoring programmes may prove difficult. However, it is desirable that targets be set for comparability of the data.

Analytical comparability is only one aspect of monitoring data. The actual programmes run by different countries must also be comparable. It obviously will not be possible to compare results from three countries if one analyzes water, another a fish species and another sediments. Even when agreement is reached on whether to sample water, biota or sediments it will be necessary to agree, for example, which species of fish should be used, whether the water should be filtered before analysis or whether whole sediment should be analyzed or only a particular size fraction.

2.3 Requirements for analytical quality control

It may be impossible to arrange that all contributors use identical analytical procedures. Even if they do, for the reasons given previously, intercomparability is not guaranteed. To establish whether differences do exist and to minimize them, a programme of intercalibration is essential. Each laboratory should assure the quality of its data by participating in intercalibration exercises and analyzing at intervals reference materials containing certified concentrations of the pollutants of interest in appropriate matrices and concentrations.

2.4 Data storage, retrieval and exchange

Depending on the scale of the monitoring programme various methods of data storage and transfer may be appropriate. It is essential that the design of the storage/retrieval system be carefully worked out to reflect the end use of the data both in its raw and interpreted form. The most efficient method in many respects is to use a computer. It is essential that the limitations of any set of data be instantly recognizable when it is retrieved. To this end, information such as performance in a recognized intercalibration exercise, analysis of reference materials, etc., should be retrievable with the data. Ideally the data should be freely accessible by all contributors and the scientific community in general. However, if a country or group of countries wish certain types of data to be available only to a limited audience that wish must be safeguarded.

2.5 Regions may exhibit different natural background or baseline concentrations, have different resources to be protected and be exposed to different pollutants. As a consequence their monitoring programmes might differ, for example, different fish species might be used as indicators, permissible limits might differ according to exposure patterns and different targets might be set for sampling and analytical accuracy. Therefore it will probably be more practical and effective, at least initially, to organize monitoring programmes and data storage on a regional rather than a global basis.

Once a satisfactory level of regional comparability has been achieved, inter-regional comparability should follow as a logical progression.

APPENDIX D. DIFFUSER DESIGN AND INITIAL DILUTION

Paul Klaamas

Calculations of approximate dilution factors for various outfall options were obtained by the use of the USEPA computer model UMERGE as described in the manual "Initial Mixing Characteristics of Municipal Ocean Discharges : Volume II Computer Programs" by W.P. Muellenhoff et al.

Initial computer runs were made for different receiving water characteristics and it was found that model results were very sensitive to salinities and temperatures. Based on studies carried out by the Bedford Institute over a two year period, data to simulate the greatest stratification in Boxes C and D were used to calculate dilution factors. In Box C an average depth of 20m was used, whereas an average depth of 30m was used for Box D.

Characteristics used for the discharge were a flow rate of 2.14 m^3/s, temperature of 15.0°C and a salinity of 2 ppt. The receiving waters were considered to have a surface salinity of 30.5 ppt and a temperature of 15.0°C and a salinity of 31.5 ppt and a temperature of 4.0°C at depths of 20m and 30m. It was found that if a single port was used, the plumes surfaced in Boxes C and D with a minimum of dilution. The dilution for Box C was approximately 11:1 and for Box D approximately 18:1. If a diffuser was used, the dilution factors increased but the plumes did not surface. A diffuser length of 200m in Box D (depth of 30m) provided an approximate dilution factor of 51:1 but a diffuser length of 600m was required in Box C (depth of 20m) to achieve the same initial dilution.

```
1
  UNIVERSAL DATA FILE: HFX20SIN.UDF

  ***********************************************************
  *    NOTE, THIS IS THE ORIGINAL FILE.                     *
  *    IT DOES NOT REFLECT CHANGES MADE INTERACTIVELY.      *
  *    THOSE CHANGES ARE SHOWN IN THE OUTPUT HEADING.       *
  ***********************************************************

 HALIFAX HARBOUR - 20m DEPTH; SINGLE DISCHARGE
 1,1,1,0,0,0,0,0,
 2.14,1,1.8,0,20,
 .02,90,1000,
 0,5000,150,0,0,0,0,0,0,0,0,0,0,0,
 2,2,15,
 0,30.5,15,.02,
 20,31.5,4,.02,
1 UMERGE VERSION 1.0 AUGUST 1985.
  ..................  ..................  ..................  ..................
  UNIVERSAL DATA FILE: HFX20SIN.UDF
  CASE I.D. HALIFAX HARBOUR - 20m DEPTH; SINGLE DISCHARGE

  RUN TITLE:  HALIFAX HARBOUR - 20m DEPTH; SINGLE DISCHARGE(UMERGE)


  ASPIRATION ENTRAINMENT COEFFICIENT  =       .10    (DEFAULT)
  NUMBER OF STEPS ALLOWED             =   5000
  ITERATION PRINTOUT FREQUENCY        =    150
  PRINT ARRAY AA (0=NO, 1=YES)        =      0       (DEFAULT)
  PRINT ARRAY AB (0=NO, 1=YES)        =      0       (DEFAULT)
  PRINT ARRAY AC (0=NO, 1=YES)        =      0       (DEFAULT)

  INITIAL TEMPERATURE OF THE PLUME    =     15.00    DEGREES CENTIGRADE
  INITIAL SALINITY OF THE PLUME       =      2.00    PPT
  INITIAL DENSITY OF THE PLUME        =      .7050   SIGMAT UNITS
  FROUDE NUMBER                       =      1.3

   DEPTH     SALIN     TEMP     SIGMAT       U
    (M)      (PPT)      (C)                (M/S)

     .00     30.50    15.00     22.54      .020
   20.00     31.50     4.00     25.03      .020

  TOTAL EFFLUENT FLOW                 =      2.1400  CMS
  NUMBER OF PORTS                     =      1
  PORT DIAMETER                       =      1.8000  M
  PORT SPACING                        =   1000.0     M(DEFAULT)
  VERTICAL PORT ANGLE FROM HORIZONTAL =       .0     DEGREES
  PORT DEPTH                          =     20.00    M

  FIRST LINE OF OUTPUT ARE INITIAL CONDITIONS

     X         Z        PLUME     DILU-   DENDIFF   HORIZ     VERT     TOTAL    AMBIENT
                      DIAMETER    TION              VEL       VEL      VEL     CURRENT
    (M)       (M)       (M)              (SIGMAT)  (M/S)     (M/S)    (M/S)     (M/S)

    .00     20.00     1.800      1.00    24.33      .84       .00      .84      .020
    .03     20.00     1.806      1.01    24.16      .84       .01      .84      .020
   4.35     15.69     3.133      2.79     8.32      .31       .71      .77      .020
   7.26      5.01     5.745      7.84     2.04      .12       .63      .65      .020

  COMPUTATIONS CEASE:  PLUMES SURFACE

  PLUMES DID NOT MERGE OR TRAP
  DILUTION =  10.75
```

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1
  UNIVERSAL DATA FILE: HFX20200.UDF

  ********************************************************
  *    NOTE, THIS IS THE ORIGINAL FILE.                  *
  *    IT DOES NOT REFLECT CHANGES MADE INTERACTIVELY.   *
  *    THOSE CHANGES ARE SHOWN IN THE OUTPUT HEADING.    *
  ********************************************************

 HALIFAX HARBOUR - 20m DEPTH;200m DIFFUSER
 1,1,1,0,0,0,0,0,
 2.14,40,.15,90,20,
 .02,90,5,
 0,5000,150,0,0,0,0,0,0,0,0,0,0,0,
 2,2,15,
 0,30.5,15,.02,
 20,31.5,4,.02,
1 UMERGE VERSION 1.0 AUGUST 1985.
  ...................  ..................  ..................  ..................
  UNIVERSAL DATA FILE: HFX20200.UDF
  CASE I.D. HALIFAX HARBOUR - 20m DEPTH;200m DIFFUSER

  RUN TITLE:  HALIFAX HARBOUR - 20m DEPTH; 200m DIFFUSER


  ASPIRATION ENTRAINMENT COEFFICIENT  =       .10    (DEFAULT)
  NUMBER OF STEPS ALLOWED             =   5000
  ITERATION PRINTOUT FREQUENCY        =    150
  PRINT ARRAY AA (0=NO, 1=YES)        =      0       (DEFAULT)
  PRINT ARRAY AB (0=NO, 1=YES)        =      0       (DEFAULT)
  PRINT ARRAY AC (0=NO, 1=YES)        =      0       (DEFAULT)

  INITIAL TEMPERATURE OF THE PLUME    =    15.00     DEGREES CENTIGRADE
  INITIAL SALINITY OF THE PLUME       =     2.00     PPT
  INITIAL DENSITY OF THE PLUME        =      .7050   SIGMAT UNITS
  FROUDE NUMBER                       =    16.0

   DEPTH     SALIN     TEMP    SIGMAT       U
    (M)      (PPT)      (C)               (M/S)

     .00     30.50    15.00     22.54      .020
   20.00     31.50     4.00     25.03      .020

  TOTAL EFFLUENT FLOW                 =     2.1400   CMS
  NUMBER OF PORTS                     =    40
  PORT DIAMETER                       =      .1500   M
  PORT SPACING                        =     5.00     M
  VERTICAL PORT ANGLE FROM HORIZONTAL =    90.0      DEGREES
  PORT DEPTH                          =    20.00     M

  FIRST LINE OF OUTPUT ARE INITIAL CONDITIONS

     X         Z       PLUME     DILU-    DENDIFF    HORIZ     VERT     TOTAL    AMBIENT
                      DIAMETER   TION                 VEL       VEL      VEL     CURRENT
    (M)       (M)       (M)              (SIGMAT)   (M/S)     (M/S)    (M/S)     (M/S)

     .00     20.00      .150     1.00     24.33       .00      3.03     3.03      .020
     .00     20.00      .151     1.01     24.16       .00      3.01     3.01      .020
     .00     19.33      .413     2.78      8.57       .01      1.10     1.11      .020
     .05     17.54     1.062     7.83      2.92       .02       .47      .47      .020
     .29     13.81     2.377    22.12       .70       .02       .27      .28      .020
  ****NOMINAL TRAPPING LEVEL REACHED
     .64      9.09     3.740    39.59      -.01       .02       .10      .10      .020
  ****MERGING BEGINS
     .94      6.64     5.090    50.11      -.30       .02       .13      .13      .020
    1.35      4.99    17.574    62.56      -.45       .02       .03      .04      .020

  COMPUTATIONS CEASE:  VERTICAL PLUME VELOCITY IS LESS THAN 0

  PLUMES MERGED AFTER TRAPPING LEVEL REACHED
  TRAPPING LEVEL =    9.09 M BELOW SURFACE;  DILUTION =  39.37
```

```
1

  UNIVERSAL DATA FILE: HFX20400.UDF

  ******************************************************
  *    NOTE, THIS IS THE ORIGINAL FILE.                *
  *    IT DOES NOT REFLECT CHANGES MADE INTERACTIVELY.   *
  *    THOSE CHANGES ARE SHOWN IN THE OUTPUT HEADING.    *
  ******************************************************

 HALIFAX HARBOUR - 20m DEPTH;400m DIFFUSER
 1,1,1,0,0,0,0,0,
 2.14,80,.15,90,20,
 .02,90,5,
 0,5000,150,0,0,0,0,0,0,0,0,0,0,0,
 2,2,15,
 0,30.5,15,.02,
 20,31.5,4,.02,
1 UMERGE VERSION 1.0 AUGUST 1985.
  ..................  ..................  ..................  ..................
  UNIVERSAL DATA FILE: HFX20400.UDF
  CASE I.D. HALIFAX HARBOUR - 20m DEPTH;400m DIFFUSER

  RUN TITLE:  HALIFAX HARBOUR - 20m DEPTH; 400m DIFFUSER


  ASPIRATION ENTRAINMENT COEFFICIENT  =      .10    (DEFAULT)
  NUMBER OF STEPS ALLOWED             =  5000
  ITERATION PRINTOUT FREQUENCY        =   150
  PRINT ARRAY AA (0=NO, 1=YES)        =     0       (DEFAULT)
  PRINT ARRAY AB (0=NO, 1=YES)        =     0       (DEFAULT)
  PRINT ARRAY AC (0=NO, 1=YES)        =     0       (DEFAULT)

  INITIAL TEMPERATURE OF THE PLUME    =    15.00    DEGREES CENTIGRADE
  INITIAL SALINITY OF THE PLUME       =     2.00    PPT
  INITIAL DENSITY OF THE PLUME        =      .7050  SIGMAT UNITS
  FROUDE NUMBER                       =     8.0

   DEPTH     SALIN     TEMP     SIGMAT        U
    (M)      (PPT)      (C)                 (M/S)

     .00     30.50     15.00     22.54      .020
   20.00     31.50      4.00     25.03      .020

  TOTAL EFFLUENT FLOW                 =     2.1400  CMS
  NUMBER OF PORTS                     =    80
  PORT DIAMETER                       =      .1500  M
  PORT SPACING                        =     5.00    M
  VERTICAL PORT ANGLE FROM HORIZONTAL =    90.0     DEGREES
  PORT DEPTH                          =    20.00    M

  FIRST LINE OF OUTPUT ARE INITIAL CONDITIONS

     X          Z       PLUME     DILU-    DENDIFF    HORIZ     VERT      TOTAL     AMBIENT
                      DIAMETER    TION                 VEL       VEL       VEL      CURRENT
    (M)        (M)       (M)               (SIGMAT)   (M/S)     (M/S)     (M/S)      (M/S)

     .00      20.00      .150      1.00      24.33      .00      1.51      1.51       .020
     .00      20.00      .151      1.01      24.16      .00      1.50      1.50       .020
     .01      19.35      .396      2.73       8.57      .01       .60       .60       .020
     .07      17.73      .902      7.83       2.94      .02       .33       .33       .020
     .21      14.34     1.806     22.12        .00      .03       .23       .23       .020
  ****NOMINAL TRAPPING LEVEL REACHED
     .75       9.20     3.106     46.43       -.01      .02       .15       .15       .020
    1.16       7.57     4.888     62.55       -.20      .02       .10       .10       .020
  ****MERGING BEGINS
    1.19       7.41     5.145     63.86       -.30      .02       .08       .08       .020

  COMPUTATIONS CEASE:  VERTICAL PLUME VELOCITY IS LESS THAN 0

  PLUMES MERGED AFTER TRAPPING LEVEL REACHED
  TRAPPING LEVEL =  10.02 M BELOW SURFACE;  DILUTION =  46.17
```

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1

  UNIVERSAL DATA FILE: HFX20500.UDF

  *************************************************************
  *    NOTE, THIS IS THE ORIGINAL FILE.                       *
  *    IT DOES NOT REFLECT CHANGES MADE INTERACTIVELY.        *
  *    THOSE CHANGES ARE SHOWN IN THE OUTPUT HEADING.         *
  *************************************************************

 HALIFAX HARBOUR - 20m DEPTH;500m DIFFUSER
 1,1,1,0,0,0,0,0,
 2.14,100,.15,90,20,
 .02,90,5,
 0,5000,150,0,0,0,0,0,0,0,0,0,0,0,
 2,2,15,
 0,30.5,15,.02,
 20,31.5,4,.02,
1 UMERGE VERSION 1.0 AUGUST 1985.
  .................  .................  ..................  ..................
  UNIVERSAL DATA FILE: HFX20500.UDF
  CASE I.D. HALIFAX HARBOUR - 20m DEPTH;500m DIFFUSER

  RUN TITLE:  HALIFAX HARBOUR - 20m DEPTH; 500m DIFFUSER


  ASPIRATION ENTRAINMENT COEFFICIENT  =       .10    (DEFAULT)
  NUMBER OF STEPS ALLOWED             =   5000
  ITERATION PRINTOUT FREQUENCY        =    150
  PRINT ARRAY AA (0=NO, 1=YES)        =      0       (DEFAULT)
  PRINT ARRAY AB (0=NO, 1=YES)        =      0       (DEFAULT)
  PRINT ARRAY AC (0=NO, 1=YES)        =      0       (DEFAULT)

  INITIAL TEMPERATURE OF THE PLUME    =     15.00    DEGREES CENTIGRADE
  INITIAL SALINITY OF THE PLUME       =      2.00    PPT
  INITIAL DENSITY OF THE PLUME        =       .7050  SIGMAT UNITS
  FROUDE NUMBER                       =      6.4

   DEPTH     SALIN     TEMP     SIGMAT       U
    (M)      (PPT)      (C)                (M/S)

     .00     30.50     15.00     22.54      .020
   20.00     31.50      4.00     25.03      .020

  TOTAL EFFLUENT FLOW                 =      2.1400  CMS
  NUMBER OF PORTS                     =    100
  PORT DIAMETER                       =       .1500  M
  PORT SPACING                        =      5.00    M
  VERTICAL PORT ANGLE FROM HORIZONTAL =     90.0     DEGREES
  PORT DEPTH                          =     20.00    M

  FIRST LINE OF OUTPUT ARE INITIAL CONDITIONS

     X         Z       PLUME    DILU-   DENDIFF   HORIZ    VERT     TOTAL    AMBIENT
                     DIAMETER   TION              VEL      VEL      VEL      CURRENT
    (M)       (M)      (M)              (SIGMAT)  (M/S)    (M/S)    (M/S)    (M/S)

    .00     20.00      .150     1.00     24.33      .00     1.21     1.21      .020
    .00     20.00      .151     1.01     24.16      .00     1.20     1.20      .020
    .01     19.35      .386     2.78      8.57      .01      .51      .51      .020
    .08     17.82      .841     7.83      2.94      .02      .30      .30      .020
    .31     14.70     1.653    22.12       .82      .02      .22      .22      .020
  *****NOMINAL TRAPPING LEVEL REACHED
    .72     10.36     3.019    49.07       .00      .02      .14      .15      .020
   1.07      8.54     4.100    62.54      -.21      .02      .10      .10      .020
  *****MERGING BEGINS
   1.25      7.81     5.145    69.40      -.29      .02      .07      .07      .020

  COMPUTATIONS CEASE:  VERTICAL PLUME VELOCITY IS LESS THAN 0

  PLUMES MERGED AFTER TRAPPING LEVEL REACHED
  TRAPPING LEVEL =  10.37 M BELOW SURFACE;  DILUTION =  48.97
```

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1

  UNIVERSAL DATA FILE: HFX20600.UDF

  ***********************************************************
  *    NOTE, THIS IS THE ORIGINAL FILE.                     *
  *    IT DOES NOT REFLECT CHANGES MADE INTERACTIVELY.      *
  *    THOSE CHANGES ARE SHOWN IN THE OUTPUT HEADING.       *
  ***********************************************************

 HALIFAX HARBOUR - 20m DEPTH;600m DIFFUSER
 1,1,1,0,0,0,0,0,
 2.14,120,.15,90,20,
 .02,90,5,
 0,5000,150,0,0,0,0,0,0,0,0,0,0,0,
 2,2,15,
 0,30.5,15,.02,
 20,31.5,4,.02,
1 UMERGE VERSION 1.0 AUGUST 1985.
  ...................  ..................  .................  ..................
  UNIVERSAL DATA FILE: HFX20600.UDF
  CASE I.D. HALIFAX HARBOUR - 20m DEPTH;600m DIFFUSER

  RUN TITLE:  HALIFAX HARBOUR - 20m DEPTH; 600m DIFFUSER


  ASPIRATION ENTRAINMENT COEFFICIENT  =       .10     (DEFAULT)
  NUMBER OF STEPS ALLOWED             =   5000
  ITERATION PRINTOUT FREQUENCY        =    150
  PRINT ARRAY AA (0=NO, 1=YES)        =      0        (DEFAULT)
  PRINT ARRAY AB (0=NO, 1=YES)        =      0        (DEFAULT)
  PRINT ARRAY AC (0=NO, 1=YES)        =      0        (DEFAULT)

  INITIAL TEMPERATURE OF THE PLUME    =     15.00     DEGREES CENTIGRADE
  INITIAL SALINITY OF THE PLUME       =      2.00     PPT
  INITIAL DENSITY OF THE PLUME        =      .7050    SIGMAT UNITS
  FROUDE NUMBER                       =      5.3

   DEPTH     SALIN     TEMP     SIGMAT       U
    (M)      (PPT)      (C)                (M/S)

     .00     30.50    15.00     22.54      .020
   20.00     31.50     4.00     25.03      .020

  TOTAL EFFLUENT FLOW                 =      2.1400   CMS
  NUMBER OF PORTS                     =    120
  PORT DIAMETER                       =      .1500    M
  PORT SPACING                        =      5.00     M
  VERTICAL PORT ANGLE FROM HORIZONTAL =     90.0      DEGREES
  PORT DEPTH                          =     20.00     M

  FIRST LINE OF OUTPUT ARE INITIAL CONDITIONS

    X         Z        PLUME     DILU-    DENDIFF    HORIZ     VERT      TOTAL     AMBIENT
                     DIAMETER    TION                 VEL       VEL       VEL      CURRENT
   (M)       (M)       (M)               (SIGMAT)   (M/S)     (M/S)     (M/S)     (M/S)

    .00     20.00      .150      1.00     24.33       .00      1.01      1.01      .020
    .00     20.00      .151      1.01     24.16       .00      1.00      1.00      .020
    .01     19.36      .376      2.78      8.57       .01       .45       .45      .020
    .08     17.90      .790      7.83      2.95       .02       .28       .28      .020
    .21     14.99     1.527     22.12       .04       .02       .21       .21      .020
  ****NOMINAL TRAPPING LEVEL REACHED
    .79     10.66     2.894     51.51       .00       .02       .14       .14      .020
   1.01      9.31     3.636     62.54      -.16       .02       .10       .11      .020
  ****MERGING BEGINS
   1.29      8.17     5.127     74.30      -.27       .02       .06       .06      .020

  COMPUTATIONS CEASE:  VERTICAL PLUME VELOCITY IS LESS THAN 0

  PLUMES MERGED AFTER TRAPPING LEVEL REACHED
  TRAPPING LEVEL =  10.67 M BELOW SURFACE;  DILUTION =  51.48
```

```
1
  UNIVERSAL DATA FILE: HFX30SIN.UDF

  ***********************************************************
  *    NOTE, THIS IS THE ORIGINAL FILE.                     *
  *    IT DOES NOT REFLECT CHANGES MADE INTERACTIVELY.      *
  *    THOSE CHANGES ARE SHOWN IN THE OUTPUT HEADING.       *
  ***********************************************************

 HALIFAX HARBOUR - 30m DEPTH; SINGLE DISCHARGE
 1,1,1,0,0,0,0,0,
 2.14,1,1.8,0,30,
 .02,90,1000,
 0,5000,150,0,0,0,0,0,0,0,0,0,0,0,
 2,2,15,
 0,30.5,15,.02,
 30,31.5,4,.02,
1 UMERGE VERSION 1.0 AUGUST 1985.
  ..................  .................  .................  .................
  UNIVERSAL DATA FILE: HFX30SIN.UDF
  CASE I.D. HALIFAX HARBOUR - 30m DEPTH; SINGLE DISCHARGE

  RUN TITLE:  HALIFAX HARBOUR - 30m DEPTH; SINGLE DISCHARGE(UMERGE)


  ASPIRATION ENTRAINMENT COEFFICIENT  =       .10    (DEFAULT)
  NUMBER OF STEPS ALLOWED             =   5000
  ITERATION PRINTOUT FREQUENCY        =    150
  PRINT ARRAY AA (O=NO, 1=YES)        =      0       (DEFAULT)
  PRINT ARRAY AB (O=NO, 1=YES)        =      0       (DEFAULT)
  PRINT ARRAY AC (O=NO, 1=YES)        =      0       (DEFAULT)

  INITIAL TEMPERATURE OF THE PLUME    =    15.00     DEGREES CENTIGRADE
  INITIAL SALINITY OF THE PLUME       =     2.00     PPT
  INITIAL DENSITY OF THE PLUME        =      .7050   SIGMAT UNITS
  FROUDE NUMBER                       =     1.3

   DEPTH     SALIN     TEMP     SIGMAT       U
    (M)      (PPT)      (C)               (M/S)

     .00     30.50     15.00     22.54      .020
   30.00     31.50      4.00     25.03      .020

  TOTAL EFFLUENT FLOW                 =     2.1400   CMS
  NUMBER OF PORTS                     =     1
  PORT DIAMETER                       =     1.8000   M
  PORT SPACING                        =   1000.0     M(DEFAULT)
  VERTICAL PORT ANGLE FROM HORIZONTAL =       .0     DEGREES
  PORT DEPTH                          =    30.00     M

  FIRST LINE OF OUTPUT ARE INITIAL CONDITIONS

     X         Z       PLUME     DILU-   DENDIFF   HORIZ     VERT     TOTAL    AMBIENT
                      DIAMETER   TION               VEL       VEL      VEL     CURRENT
    (M)       (M)       (M)              (SIGMAT)  (M/S)     (M/S)    (M/S)     (M/S)

     .00     30.00     1.800     1.00     24.33      .84      .00      .84      .020
     .03     30.00     1.806     1.01     24.16      .84      .01      .84      .020
    4.35     25.69     3.129     2.78      8.42      .31      .71      .77      .020
    7.21     15.07     5.659     7.84      2.45      .12      .65      .67      .020

  COMPUTATIONS CEASE:  PLUMES SURFACE

  PLUMES DID NOT MERGE OR TRAP
  DILUTION =   17.54
```

```
1
  UNIVERSAL DATA FILE: HFX30200.UDF

  **********************************************************
  *    NOTE, THIS IS THE ORIGINAL FILE.                    *
  *    IT DOES NOT REFLECT CHANGES MADE INTERACTIVELY.     *
  *    THOSE CHANGES ARE SHOWN IN THE OUTPUT HEADING.      *
  **********************************************************

 HALIFAX HARBOUR - 30m DEPTH;200m DIFFUSER
 1,1,1,0,0,0,0,0,
 2.14,40,.15,90,30,
 .02,90,5,
 0,5000,150,0,0,0,0,0,0,0,0,0,0,
 2,2,15,
 0,30.5,15,.02,
 30,31.5,4,.02,
1 UMERGE VERSION 1.0 AUGUST 1985.
  ..................  ..................  ..................  ..................
  UNIVERSAL DATA FILE: HFX30200.UDF
  CASE I.D. HALIFAX HARBOUR - 30m DEPTH;200m DIFFUSER
  RUN TITLE:  HALIFAX HARBOUR - 30m DEPTH; 200m DIFFUSER


  ASPIRATION ENTRAINMENT COEFFICIENT   =       .10    (DEFAULT)
  NUMBER OF STEPS ALLOWED              =   5000
  ITERATION PRINTOUT FREQUENCY         =    150
  PRINT ARRAY AA (0=NO, 1=YES)         =      0       (DEFAULT)
  PRINT ARRAY AB (0=NO, 1=YES)         =      0       (DEFAULT)
  PRINT ARRAY AC (0=NO, 1=YES)         =      0       (DEFAULT)

  INITIAL TEMPERATURE OF THE PLUME     =    15.00     DEGREES CENTIGRADE
  INITIAL SALINITY OF THE PLUME        =     2.00     PPT
  INITIAL DENSITY OF THE PLUME         =      .7050   SIGMAT UNITS
  FROUDE NUMBER                        =    16.0

   DEPTH    SALIN    TEMP    SIGMAT       U
    (M)     (PPT)     (C)               (M/S)

     .00    30.50    15.00    22.54      .020
   30.00    31.50     4.00    25.03      .020

  TOTAL EFFLUENT FLOW                  =     2.1400   CMS
  NUMBER OF PORTS                      =    40
  PORT DIAMETER                        =      .1500   M
  PORT SPACING                         =     5.00     M
  VERTICAL PORT ANGLE FROM HORIZONTAL  =    90.0      DEGREES
  PORT DEPTH                           =    30.00     M

  FIRST LINE OF OUTPUT ARE INITIAL CONDITIONS

    X        Z       PLUME     DILU-    DENDIFF    HORIZ     VERT      TOTAL     AMBIENT
                    DIAMETER   TION                 VEL       VEL       VEL      CURRENT
   (M)      (M)       (M)              (SIGMAT)    (M/S)     (M/S)     (M/S)      (M/S)

    .00    30.00      .150     1.00     24.33       .00      3.03      3.03       .020
    .00    30.00      .151     1.01     24.16       .00      3.01      3.01       .020
    .00    29.33      .413     2.78      8.59       .01      1.10      1.11       .020
    .05    27.54     1.061     7.83      2.97       .02       .47       .47       .020
    .28    22.33     2.310    22.12       .86       .02       .28       .28       .020
 *****NOMINAL TRAPPING LEVEL REACHED
    .06    16.64     4.422    51.34       .00       .02       .18       .18       .020
 *****MERGING BEGINS
   1.03    15.19     5.060    58.05      -.11       .02       .15       .15       .020
   1.17    14.20     5.764    62.54      -.19       .02       .13       .13       .020

  COMPUTATIONS CEASE:  VERTICAL PLUME VELOCITY IS LESS THAN 0

  PLUMES MERGED AFTER TRAPPING LEVEL REACHED
  TRAPPING LEVEL =  16.64 M BELOW SURFACE;  DILUTION =  51.34
```

APPENDIX E. INFORMATION ON LONG LIST OF POTENTIAL SITES FOR FACILITIES

PRELIMINARY LOCATION AND EVALUATION OF SEWAGE TREATMENT PLANT SITES

1. Eastern Passage

- Approximately 73 hectares
- Harbour Box C
- Potential for expansion
- Frontage on collector road
- Frontage on rail line
- Municipal services available
- Bordered by industrial uses on one side, residential on two sides, and more vacant land outside study boundaries
- 396 m from shore (Eastern Passage) at closest
- Flat, elevations ranging from 20 to 35 m above sea level
- Site bisected by stream
- Quartzite bedrock with Lawrencetown till sheet 1.5 to 4.5 m thick
- Low visual impact
- Eastern Passage upwind

2. Shearwater

- Approximately 53 hectares
- Limited potential for expansion
- Site bisected by collector road
- Frontage on rail line
- Municipal services available
- Bordered by Shearwater, residential, and industrial uses
- 700 m from shore (Eastern Passage) at closest point
- Very flat, elevations ranging from 24 to 30 m above sea level
- Stream on site
- Quartzite bedrock with Lawrencetown till sheet 1.5 to 4.5 m thick
- Low visual impact
- Eastern Passage upwind

3. Esso Refinery South

- Harbour Box C
- Approximately 16 hectares
- No potential for expansion
- Collector road frontage
- Near rail access
- Municipal services available
- Bordered by residential uses on two sides, refinery on two sides

- 450 m from shore at closest point
- Moderate slopes, elevations ranging from 9 to 24 m above sea level
- Stream on site
- Quartzite bedrock with Lawrencetown till sheet 1.5 to 4.5 m thick
- Low visual impact
- Residential land upwind

4. Esso Refinery North

- Harbour Box C
- Approximately 32 hectares
- Limited potential for expansion
- No collector road or rail access
- Municipal services available
- Bordered by refinery and Shearwater
- 1000 m from shore at closest point
- Moderately steep, elevations ranging from 30 to 75 m above sea level
- Stream and wetland on site
- Quartzite bedrock with thick Lawrencetown till
- Low visual impact
- Shearwater downwind

5. Woodside Industrial Park

- Harbour Box C
- Approximately 40 hectares
- Industrial Park
- Potential for expansion outside study area
- Located in industrial park
- Frontage on collector and arterial roads
- No rail access
- Access to common-user pier
- Municipal services available
- Bordered by industrial, residential, and vacant lands
- 1100 m from shore at closest point
- Flat to very steep: the industrial park has been graded, adjacent slopes very steep
- 39 to 60 m above sea level
- Quartzite bedrock with thick Lawrencetown till
- Moderate visual impact
- Some residential land downwind

6. Dartmouth Cove

- Approximately 32 hectares of water less than 10 m deep
- Limited adjacent land area
- No potential for expansion
- Access to collector road
- Frontage on rail line
- Access to sea
- Municipal services available bordered by residential lands, active and derelict industrial lands
- High visual impact
- High heritage value: site of early settlement in Dartmouth and entrance to Shubenacadie Canal system
- Residential land downwind

7. Tufts Cove

- Approximately 6 hectares of water less than 10 m deep
- Harbour Box B
- Limited adjacent land area, no potential for expansion
- Access to collector road
- Access to rail line
- Access to sea
- Municipal services available
- Bordered by industrial and residential uses
- High visual impact
- Residential lands downwind

8. Halifax Rail Yards

- Approximately 20 acres
- Limited potential for expansion
- Harbour Box C
- Frontage on truck route
- Access to rail and sea
- Municipal services available
- Bordered by residential and industrial lands
- Flat, approximately 3 m above sea level
- Moderate visual impact
- Harbour downwind

9. Williams Lake Road Quarry

- Approximately 24 hectares
- No potential for expansion
- Frontage on collector road
- No rail or sea access
- Municipal services available
- Bordered on three sides by residential uses, one side by park land
- 790 m from shore (Northwest Arm) at closest point
- Rough terrain, elevations ranging from 24 to 70 m above sea level
- Wetland on site
- Slate bedrock near contact with granite, thin granite till
- High visual impact
- Residential lands downwind
- Potential for park expansion

10. Purcells Cove Backlands

- Approximately 525 hectares
- Access to collector road
- No rail or sea access
- No sewer or water available
- Bordered by residential uses along Purcells Cove Road
- Approximately 450 m to shore (Harbour Box C or D) at closest point
- Flat to steep, elevations range from 4 to 500 m above sea level
- Bedrock controlled terrain characterized by bedrock ridges and bogs
- Granite bedrock with very thin till
- Low visual impact
- Purcells Cove Road residential areas and Harbour downwind

11. Sandwich Point

- Approximately 24 hectares
- Harbour Box D
- Owned by Department of National Defence (DND)
- Frontage on collector road
- No rail access
- Limited sea access
- Bordered by residential sites and park land, existing DND uses on site
- Very steep, elevations range from 0 to 80 m above sea level

- Granite bedrock, very thin till
- Moderate visual impact
- Harbour downwind

12. Purcells Cove

- Approximately 6 hectares
- Harbour Box C
- No potential for expansion
- Frontage on collector road
- No rail access
- Sea access
- No municipal sewer or water
- Bordered by residential lands and the Northwest Arm
- High visual impact
- Northwest Arm and Harbour downwind

13. Head of Northwest Arm

- Approximately 6 hectares
- Drainage to Northwest Arm
- No potential for expansion
- Frontage on collector road
- No rail access
- Limited sea access
- Municipal services available
- Bordered by residential uses and Northwest Arm
- High visual impact
- Residential uses downwind

14. Pleasant Shoal

- Approximately 20 hectares of water less than 10 m deep
- Harbour Box C
- No potential for expansion
- No direct access to collector road
- No rail
- Good sea access
- Municipal services available
- Bordered by park land, Northwest Arm, and Harbour
- Very high visual impact
- Harbour downwind

15. Ives Knoll

- Approximately 16 hectares of water less than 10 m deep
- Harbour Box C
- Limited potential for expansion to McNabs Island
- No access to road or rail
- Good sea access
- High visual impact
- Harbour downwind

16. McNabs and Lawlor Islands

- Approximately 970 hectares of land and water less than 10 m deep
- Drainage to Eastern Passage, Box C, D, or E
- No road or rail access
- Road access possible
- Limited to good sea access
- Existing interpretation and recreational uses
- Hilly terrain, elevations range from 0 to 40 m above sea level
- Quartzite bedrock with thick Lawrencetown till
- Low to very high visual impact
- Eastern Passage downwind
- Many significant archaeological sites
- Regional Park designation
- Sensitive wildlife habitat

APPENDIX F. TASK FORCE NEWSLETTERS #1-3

Halifax Harbour Task Force

Number 1 July, 1989

1568 Argyle Street,
Halifax, Nova Scotia B3J 2B6
423-8629

Newsletter

Letter From Bob Fournier

In February Premier John Buchanan appointed the Halifax Harbour Task Force under my chairmanship. Its task is to review the current level of knowledge about the harbour in relation to sewage treatment options. We have been meeting on a weekly basis since the end of April, and this newsletter is our first attempt to explain our mandate, who we are, what we have done so far, and what our intentions are.

The Environmental Control Council's report identified the need for public consultation as a key issue in future harbour clean-up activities. The Task Force believes that hearing from local residents, community groups and other harbour users is as important as reviewing scientific and engineering reports. We are inviting you to participate in planning the future of Halifax Harbour by attending the Task Force Open Meeting on July 24, or one of the community and harbour user workshops to be held in September, or by sending in a written brief - or by doing all three.

Sewage treatment is just one step in cleaning up Halifax Harbour, but it is a very important investment in a sustainable future. We can't afford to make uniformed decisions. Please get involved.

Robert O. Fournier
Chair,
Halifax Harbour Task Force

Background To The Task Force

Every day Metro Area residents and businesses discharge 40 million gallons of sewage effluent into Halifax Harbour. Eighty percent of this is untreated. The remaining 20 percent is treated at two small plants operated by the County of Halifax at Mill Cove and Eastern Passage.

Over the past 20 years many pollution abatement studies have been carried out, both by individual municipalities and on a regional basis. The most recent study was started by MAPC (Metropolitan Area Planning Commission) in 1984. It included the development of a water quality model, which indicated that bacterial contamination of harbour waters was increasing and that this was likely to threaten recreational uses in the North West Arm and Bedford Basin.

The MAPC study developed a series of sewage treatment scenarios. It recommended that the best option would be a single regional plant to be located at Sandwich Point, providing primary treatment. A federal/provincial funding agreement provided federal assistance to the proposed project in order to encourage the adoption of sludge-to-oil technology at a full-scale plant. To date, this technology has only been used at the pilot plant level.

This sewage treatment proposal was challenged by a number of interest groups, and particularly by the residents of Herring Cove, who were very concerned about the local impact of a single regional outfall discharging 40 million gallons of effluent daily into their part of the harbour.

The Environmental Control Council (ECC) was asked to review these and other concerns. The ECC's report, issued in February of this year, concluded that, in order to make long-term decisions about appropriate sewage treatment, Metro residents and harbour users need to develop clearer objectives for the future of the harbour. The report also stated that insufficient knowledge existed about the biophysical environment in the harbour to determine the impacts of different treatment scenarios.

The Nova Scotia Minister of Environment accepted the findings of the report, and the Fournier Task Force was established to assist in carrying out some of its recommendations.

You are invited to the first..

Halifax Harbour Task Force Open Meeting

Monday, July 24 Public
Archives of Nova Scotia
(Robie and University Avenue)

7.00 pm Open House

7.30 pm Presentations by Task Force Members

8.30 Discussion

The meeting will provide an opportunity to meet the members of the Task Force, and discuss progress so far and Task Force plans for the future.

(For more information, call 423-86

Who's Who On The Task Force

Robert Fournier, *Chair*, is Associate Vice-President of Research Services at Dalhousie University, and an oceanographer by training.

Ray Côté teaches environmental studies and marine affairs programs at Dalhousie, and is interested in toxicology and marine environmental protection strategies.

Gordon Fader is a marine geologist with the Geological Survey of Canada at the Bedford Institute of Oceanography (BIO), studying the history and distribution of sediments off the East Coast.

Donald Gordon is a marine ecologist at BIO. He has studied diverse environmental issues in coastal waters, and has been a long-standing member of the Dartmouth Lakes Advisory Board.

Jill Grant teaches environmental planning at the NS College of Art and Design. Her research focuses on public participation and urban planning

Paul Klaamas is Head of Municipal Wastes, Food and Technology Transfer, with Environment Canada. He reviews plans for wastewater treatment facilities and for the transfer of technology in the wastewater treatment field.

Brian Nicholls is Head of the Marine Assessment and Liaison Division with the Department of Fisheries and Oceans at BIO, and also chairs the federal Science Advisory Committee on Halifax Inlet Sewage Disposal.

Peter Pelham chairs the Herring Cove Ratepayers Association, and is a long-term resident of the Cove. He is a cameraman with CBC, a keen environmentalist, and very active in outdoor recreation.

Brian Petrie is a physical oceanographer at BIO. He has studied the mean, wind-driven and tidal flows on the continental shelf and in coastal embayments.

Stanley Purdy is a resident of Eastern Passage and has been a commercial fisherman over forty years. He is the Secretary-Treasurer of the Eastern Shore Fishermen's Association.

Donald Waller is the Director of the Centre for Water Resources Studies at TUNS. His experience includes determining waste water loadings and planning sewerage systems.

Frank Potter is an environmental engineer and Chief of Government Programs at the NS Department of Environment. He provides the liaison between the Task Force and the federal-provincial Technical Advisory Group on the Halifax Harbour Clean-up.

Lesley Griffiths and **Anne Muecke** with Griffiths Muecke Associates are acting as the secretariat to the Task Force.

Terms of Reference

The Mandate of the Task Force is to draw together a group of knowledgeable and experienced persons to consider marine environmental and associated socio-economic issues pertaining to sewage treatment in Halifax Harbour, resulting in recommendations to the Nova Scotia Minister of Environment.

The Task Force will therefore:

Recommend Harbour use objectives related to water quality.

Examine existing engineering and scientific information.

Identify important information gaps and recommend studies needed to fill them.

Recommend, where appropriate, outfall siting criteria, treatment levels or other strategies.

Achieve the above goals with public participation.

Task Force Progress So Far

Since its first meeting on April 21, the Task Force has been reviewing reports, such as the MAPC study; listening to presentations (for example, the commercial fishery in the harbour, and the Environmental Control Council hearings); sharing information and experiences between Task Force members; and working on the Terms of Reference and the public consultation process.

The Task Force has also:

reviewed the harbour circulation study taking place this summer and recommended increasing its scope (the recommendations have been accepted)

asked the NS Department of Environment to prepare a booklet on sewage treatment

started to collect information on current uses of the harbour

had three members visit the Boston Harbour project

requested the Minister of Environment to undertake a sewage treatment plant siting study to complement the work being carried out by the Task Force on the Marine environment.

Future plans include consulting with the public, reviewing all relevant environmental and engineering information, a tour of the harbour and local sewage treatment plants, and looking at similar projects and problems elsewhere. The final report should be completed early in 1990.

Issues

Many issues relating to sewage treatment and the harbour have already been identified through the public meetings held by the Environmental Control Council in November, 1988. The mandate of the Task Force is to look primarily at the impacts of sewage treatment on the marine environment and associated uses in the Harbour. Therefore the Task Force will be focusing on certain issues.

Concerns that fall within the terms of reference of the Task Force include:

Location of outfall(s)
Outfall design
Lack of oceanographic studies
Residual currents
Nutrient enrichment
Fouling of nets
Stormwater management
Threat to fisheries
Safety of shellfish harvesting
Danger to wildlife
Impact on recreation uses
Impact on tourism
Shoreline aesthetics
Impacts on whales
Level of treatment
Single vs multi plant scenarios
Lack of public consultation
Need for regional sludge management program
Hazardous wastes in sewage and sludges
Lack of water quality objectives
Contamination of sediments
Overall objectives of Harbour clean-up

Other concerns identified but not within the terms of reference of the Task Force include:

Location of treatment plant
Tunneling
Construction of run-off
Impact on York Redoubt
Private wells
Trucking of sludge and septage
Noise at plant
Odour at plant
Aesthetics at plant
Effects on property values
Disposal of tunnelling wastes
Financing project
Sludge to oil technology (petro-poop)

Harbour Studies

A number of scientific studies on the harbour have recently been completed or are currently underway (marked with an asterisk*). For more information on any of these studies (unless otherwise indicated), contact Brian Nicholls at Bedford Institute of Oceanography (BIO) 426-3246.

***Sedimentological Investigations** (Buckley and Hargrave)
Two hundred seafloor sediment samples taken from Halifax Harbour and analyzed for a variety of parameters including organic carbon, nitrogen content, oxygen uptake and heavy metals. Results will be included in the BIO Report on the Harbour to be issued this summer.

***Physical Oceanographic Study of the Outer Harbour** (ASA Consulting)
Measurements of current speed and direction, water temperature and salinity taken during June and July this summer, using fixed current meter moorings located both at the surface and near the bottom at seven sites. Several thousand surface and bottom drifters will also be released and tracked to determine dispersion rates in the outer harbour. This report is due in November.

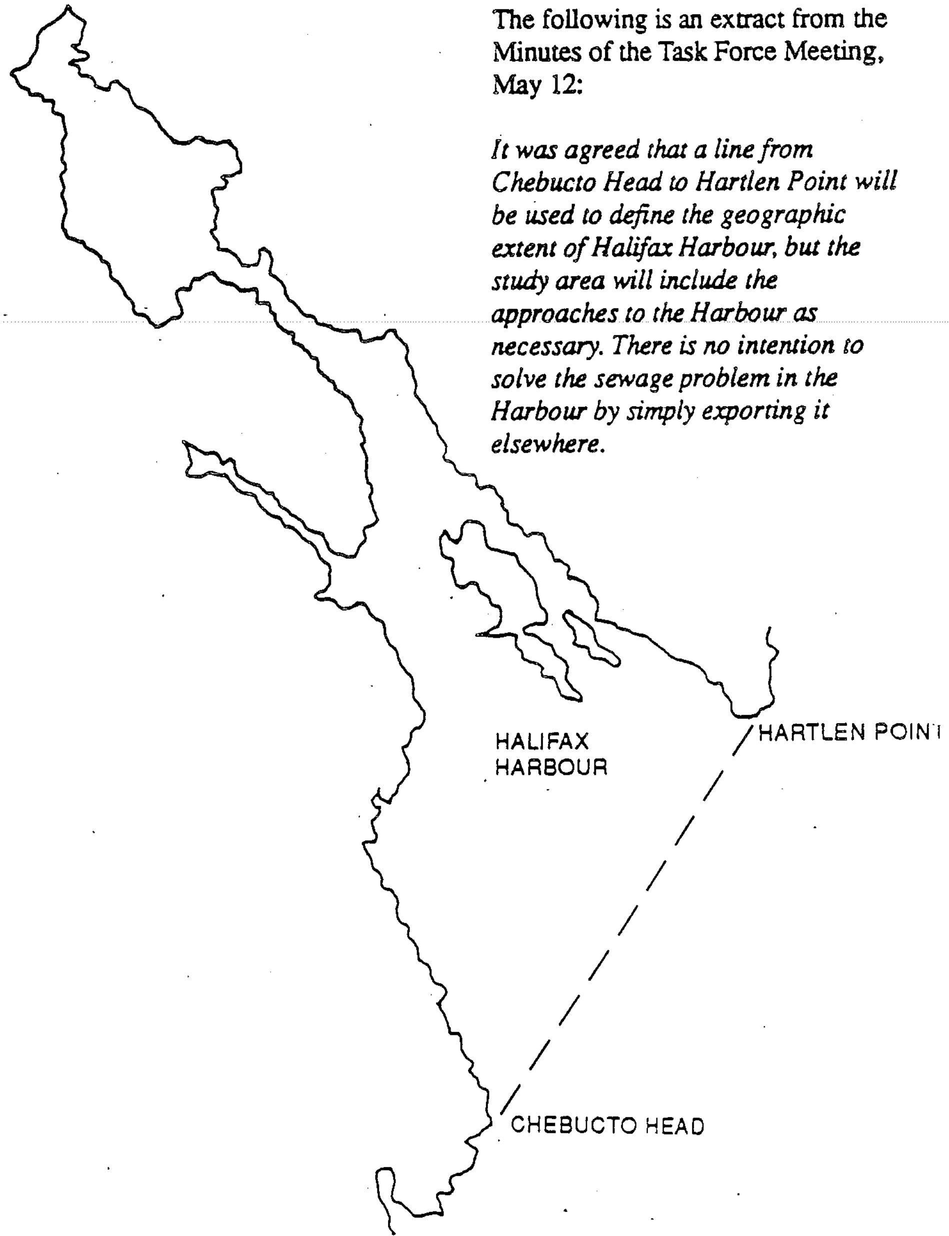
***Halifax Harbour Geological-Geophysical Survey** (Fader)
A survey, using seismic reflection and sidescan sonar data, to map sediments, bedrock and other seabed features; to study mineral and aggregate potential; and to provide a regional geological assessment as part of the Harbour clean-up program.

What is Halifax Harbour?

The term Halifax Harbour means different things to different people. The Task Force has agreed that, for the purpose of their work, the term will take in the area north of a line drawn from Chebucto Head to Hartlen Point..

The following is an extract from the Minutes of the Task Force Meeting, May 12:

It was agreed that a line from Chebucto Head to Hartlen Point will be used to define the geographic extent of Halifax Harbour, but the study area will include the approaches to the Harbour as necessary. There is no intention to solve the sewage problem in the Harbour by simply exporting it elsewhere.



***Trace Metals and Health Data for Mussel Populations** (Ward)
A study of contaminants in mussels in the harbour by a graduate student at the School for Resources and Environmental Studies. (For more information, contact Ray Côté, 424-3632).

Benthic Biological Investigations
(Hargrave, Peer and Wiele)
An underwater photographic survey (late 1987) with some sediment sampling to assess the environmental impact of the sewage outfall at Tribune Head.

Trace Metal Concentrations
(Dalziel, Yeats and Loring)
Water samples collected at seven locations (January 1989) and analyzed for heavy metals in both the water and the suspended particulate matter.

Heavy Metal, PAH and PCB Concentrations in Lobsters
(Uthe, Chou, Prouse and Musial)
Investigation of lobsters caught in three areas of the harbour, January 1989.

Microbiological Examination of Lobsters
Investigation of microbiological quality of lobsters captured in the summer of 1988, with respect to their use as food.

BIO Report on the Harbour

BIO will shortly be publishing a report entitled Investigations of Marine Environmental Quality in Halifax Harbour, describing research carried out by three federal departments. The report will include results from several of the studies mentioned above, and will also contain a discussion of environmental quality issues relevant to sewage treatment in the harbour..

Halifax Inlet Research Workshop

November 9, 1989
Bedford Institute of Oceanography

Sponsored by the federal Science Advisory Committee on Halifax Inlet Sewage Disposal

An informal forum to present and discuss research results and plans relating to the Harbour, including issues relating to sewage treatment proposals. The forum is open to any interested persons. For more information, call 428-3559.

Public Consultation

The Environmental Control Council flagged the need for public information and consultation in developing a sewage treatment strategy for Halifax Harbour. In order to carry out its work effectively, the Task Force wants to share information, and get feedback from the public throughout the process. In order to do this, the Task Force is planning the following:

Newsletters

This is the first of several newsletters to be distributed to interested groups, businesses, agencies and individuals, to report on Task Force activity.

Open Task Force Meeting #1, Public Archives, July 24

An opportunity to meet the Task Force and discuss what it plans to do. (see notice on page 1)

Community Workshops

A series of community workshops will be held in the fall to ask you -- local residents -- to share your knowledge about the harbour and the way it is used, and to discuss the role that sewage treatment can play in cleaning it up.

Workshops are scheduled at the following times (locations to be announced later):

Eastern Passage Thursday, September 14
Dartmouth Monday, September 18
Bedford Thursday, September 21
Halifax Tuesday, October 3
Herring Cove Thursday, October 5

Harbour User Workshop

A workshop for commercial, industrial and government harbour users will also be held in the fall (time and place to be announced later).

Written Submissions

Written submissions on any aspect of sewage treatment and the marine environment will be received by the Task Force at any time. A formal request for briefs will be made in the fall.

Open Task Force Meeting #2

Before the Task Force writes its final report, a second Open Task Force Meeting will be held to discuss the draft recommendations, so that public feedback can be incorporated.

Read All About it!

A collection of the major reports on sewage treatment and the harbour (including the Environmental Control Council Report and the three volumes of the MAPC Study) is being placed in the reference collections at the following libraries:

Halifax City Regional Library
Main Library

Dartmouth Regional Library
Wyse Road

Halifax County Regional Library
Bedford Branch, Sunnyside Mall

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printed on recycled paper

Halifax Harbour Task Force

Newsletter

Number 2 Nov., 1989
1568 Argyle Street,
Halifax, Nova Scotia B3J 2B6
423-8629

Letter from Bob Fournier

In this, our second newsletter, we are attempting to present to the public some of the problems we have been wrestling with over the past few months. Ultimately, the debate regarding the future of Halifax Harbour comes down to a question of water quality objectives. In other words, what do we expect of our Harbour? Sewage treatment is simply one means of achieving that objective.

What we have tried to present below is a brief summary of the various activities which are routinely conducted in the Harbour on any given day. It covers the full gamut from an appreciation of its visual aesthetics, to active recreational participation, on up to full commercial use of its waters as a coolant for turbines or as a medium to transport shipping.

The dilemma that faces all groups attempting to reconcile a multi-use environment is the realization that all the above mentioned uses are valid and must in some way be accommodated.

Six scenarios are provided which demonstrate the choice of options before us — or to be more precise — the limited choices. At the low end of the spectrum, the absence of any action is an unconscionable choice; while at the upper end, insufficient dollars exist in Canada to return the Harbour to its pre-1749 virginal state. So a range of choices does exist, but they are much narrower than one might expect.

Building on this newsletter, we will be holding a second public meeting — in the form of a workshop — in December. At that time we will invite community comment on these options and welcome any suggestions that might be useful in assisting ongoing Task Force deliberations.

Robert O. Fournier
Chair
Halifax Harbour Task Force

Task Force Diary

July

Interest in the first Task Force Open Meeting on July 24 was greater than anticipated — our apologies to those who had to stand. We heard some excellent questions and comments. Issues brought up included treatment plant siting, industrial toxics, stormwater problems, incorporating harbour planning into municipal planning and vice versa, sludge management, what might happen to existing treatment facilities, public education and participation.

Based on the feedback from the meeting, the Task Force decided to postpone the community workshops until the New Year to give us more time to develop a range of sewage treatment options. But don't miss the Workshop on Harbour Use and Water Quality Objectives, December 5.

August

Summer holidays! Task Force members no doubt hard at work studying background reports at the cottage or the beach.

September

The Task Force considered a request from the Minister of Environment to include plant siting in our Terms of Reference. It was agreed that the main focus of the Task Force will still be on water quality, treatment levels and outfall locations, but we will address the plant siting issue as time and resources allow.

Observers from the Ecology Action Centre Harbour Committee start attending Task Force meetings. Other observers are welcome to attend, but please give us a call first at 423-8629.

The Task Force took a tour of the Harbour, courtesy of BIO, and visited most of the major outfalls. Time was spent developing an outline for the final report, and a subcommittee was formed to look at developing harbour use objectives.

October

The Task Force listened to presentations by Don Waller on stormwater management, Dale Buckley on sediments

The Halifax Harbour Task Force
Invites You to Attend

A Workshop on Harbour Use and Water Quality Objectives for Halifax Harbour

7.00 to 9.30 pm

Tuesday, December 5,

Dartmouth High School
Audio Visual Room

The purpose of the Workshop is to get feedback from the public on the harbour use information and the harbour use and water quality objectives outlined in this newsletter.

[For more information, call 423-8629]

in the harbour, Don Lawrence on preliminary results of the ASA oceanographic study, and Frank Potter on managing toxics at source.

The Task Force toured the Eastern Passage and Mill Cove sewage treatment plants.

November

The Task Force made plans for the newsletter and the December workshop, and a visit was made to the Deer Island sewage treatment plant in Boston and a secondary treatment plant in Providence, Rhode Island. Several members of the committee made presentations at the first BIO workshop on the Halifax Harbour Inlet.

The Task Force wrote to the Halifax Harbour Clean Up Corporation expressing its opinion that outfall extensions, such as the proposed Historic Properties project, should not be funded by the Corporation until harbour use and water quality objectives have been determined.✠

More Reading

Three more reports of interest have been released and will be deposited at the Halifax City Regional Library (Main Branch), the Dartmouth Regional Library (Wyse Road) and the Halifax County Regional Library (Bedford Branch, Sunnyside Mall). Just ask to see the Halifax Harbour Task Force collection.

UMA Engineering Ltd. July 1989

Halifax Harbour Cleanup Project: Sludge Management Study

A study evaluating different options for the use or disposal of sludge from a regional sewage treatment system.

Nicholls, H.B. (Ed). 1989

Investigations of Marine Environmental Quality in Halifax Harbour.

A collection of six papers, with an introductory discussion, and a bibliography, written and compiled by people working at the Bedford Institute of Oceanography. (For information on obtaining a copy of this report, contact Brian Nicholls at BIO, 426-3246).

Porter Dillon Ltd. September, 1989.

City of Dartmouth: Burnside Industrial Park Special Waste Transfer Station Market Assessment Study.

A survey of special wastes generated in Burnside which are currently not handled properly (in other words, some of it is going straight down the sewer into the Harbour). The study recommends strengthening compliance enforcement to create demand for appropriate special wastes facilities.

How We Are Using The Harbour Today

Swimming

Metro residents swim at several Harbour beaches, despite occasional closings due to bacteria levels. Black Rock Beach in Point Pleasant Park accommodates 5,000-6,000 bathers during the summer. The Dingle Beach on the Northwest Arm has 3,000-4,000 users. It's unknown how many swimmers use Maughers Beach on McNab's Island or the beach at Bedford Lions Park on the Basin.

Within recent memory, people swam at Eastern Passage, Horseshoe Island, Admiral Cove, Long Cove, Fairview Cove, Purcell's Cove and Herring Cove, but sewage contamination and port activity now limit swimming in those areas. Dartmouth and Halifax County have no Harbour beaches currently in regular use.

Scuba Diving

The Nova Scotia Underwater Council reports that the Harbour is a popular diving area, with approximately 75 people in the water on a pleasant summer weekend. The most heavily used areas include Ketch Harbour, around Chebucto Head, and into the Northwest Arm. Thrumcap Shoal, George's Island, Back Cove and the ferry landing at McNab's Island are also well-used. Winter diving in the deep clear waters off Sandwich Point is a significant industry, worth approximately $5 million per year.

Boating and Windsurfing

Little windsurfing activity currently takes place in the Harbour because of concerns about water quality. The school in Mill Cove closed in recent years, and competitions now occur on the lakes.

There are approximately ten boat clubs and marinas around the Harbour, with both sailing and motorboating being popular. Several of the clubs have sailing schools that operate within the Harbour. The clubs and marinas have moorings and berths for approximately 1,000 boats. Residents of the Metro area can also use the public boat launches at Horseshoe Island, the Dingle, end of Jubilee Road, Seaview Park, McKay Bridge, Dartmouth Marina, and Lion's Park (in Bedford).

Recreational and competitive sailing takes place throughout the months of pleasant weather. Halifax Harbour is a popular port of call for visiting boats, and the finishing line for the annual Marblehead Race.

Other boating activities include canoeing, kayaking, and rowing. Years ago boat clubs held rowing races in the Harbour, but rowing regattas now occur on the lakes. For the last few years Dartmouth has hosted a speedboat race in the Harbour, and in 1984 the port welcomed the Tall Ships.

Other Recreational Activities

Many local residents enjoy the simple pleasures of walking along the waterfront, or watching the birds and other animals which may visit the Harbour. All along the waterfront we can enjoy the spectacular views that help to define the character of our communities. In some winters, parts of the Harbour freeze over, and are used for skating.

Port

As the busiest port on the Canadian Atlantic seaboard, Halifax lands cargo for transhipment to points west. Within the Harbour there are eight designated anchorages, including two used for oil rigs waiting re-assignment. Twenty four line services use Port Corporation facilities at the Fairview and Pier C container terminals, and the general ocean terminals. Many ships visit the National Gypsum Pier, the Autoport, and the petroleum refineries in Dartmouth. The port receives over 12,000 ships annually, including several pleasure cruisers.

In order to accommodate large vessels, the Port Corporation has a maintenance program which involves dredging and blasting channels in various locations in the Harbour. Over the years dredges have dumped their contents into Bedford Basin, leaving the bottom spotted with dredge spoils.

In the fall of 1989 the Bedford Waterfront Development Corporation will dredge about 200,000 cubic metres of sediments now clogging Bedford Bay around the mouth of the Sackville River (the result of erosion upstream); the sediments will help create new land for development along the Basin near Mill Cove.

Public Transportation

In 1988, 1.5 million passengers rode the Dartmouth ferry, while 422,000 travelled between Halifax and Woodside. Two bridges cross the Harbour. Each carries in excess of 45,000 vehicles a day.

Mining

Sand and gravel were dredged near McNab's Island as recently as the mid-1970's, and some mining companies have filed claims to mine other areas of the Harbour approaches. At the height of the McNab's operation, up to 1,000 tons of sand and gravel were removed each day for use in local construction. This activity has left large pits in the seabed which have not filled in.

Military

As Canada's major eastern port, Halifax hosts a large proportion of the Canadian navy. The Department of National Defence uses the Harbour in a variety of ways: for readying ships for sea, for training divers and sailors, and for military exercises. The presence of numerous DND facilities in and around the Harbour attests to the importance of Halifax in Canada's naval defences.

Additional military uses of the Harbour include the transhipment of live ammunition, visits from foreign ships and submarines, and firing of shells and missiles into the ocean in demarcated ranges just outside the approaches. Certain parts of the Harbour have been declared "off limits" for diving and anchoring because of concerns for live ammunition on the Harbour floor, or for reasons of military security. The munitions depot occupies most of the undeveloped shoreline on Bedford Basin.

During the Second World War, Bedford Basin provided a staging area for convoys of ships headed for Europe. Many ships anchored in the Basin are believed to have dumped ballast, leaving unusual materials in the sediments.

Waste Discharges

Some forty sewer outfalls discharge approximately 40 million gallons of untreated domestic and industrial sewage from Halifax and Dartmouth into the Harbour each day. In addition, two Halifax County treatment plants, Mill Cove in Bedford and Eastern Passage, release treated effluent from Bedford and areas of the County. A number of facilities have their own sewage treatment facilities: for example, Bedford Institute of Oceanography, both oil refineries, the Nova Scotia Hospital, and some Department of National Defence locations.

Water Intakes

Several industrial, commercial and institutional facilities take water out of the Harbour for cooling or other purposes and return it processed. The Nova Scotia Power Corporation uses Harbour water for cooling. Seafood product retailers and wholesalers use sea water from the Harbour to hold live products prior to sale. Scientific establishments use Harbour water to maintain marine life in experimental programs.

Tourism

Approximately 750,000 people visit the waterfront each year bringing thousands of dollars into our communities. Many take Harbour tours, providing revenues for local boating operators. Several noteworthy tourist attractions, such as the Citadel and Point Pleasant Park, offer impressive views of the Harbour.

All of the municipalities around the Harbour have committed themselves to improving the waterfront. The Waterfront Development Corporation in Halifax and Dartmouth, and the Bedford Waterfront Development Corporation are investing millions of dollars in improvements to make the waterfront areas attractive and usable. In spite of these changes both Metro residents and tourists often comment about water quality. Smells and debris have made the major outfall near Historic Properties infamous.

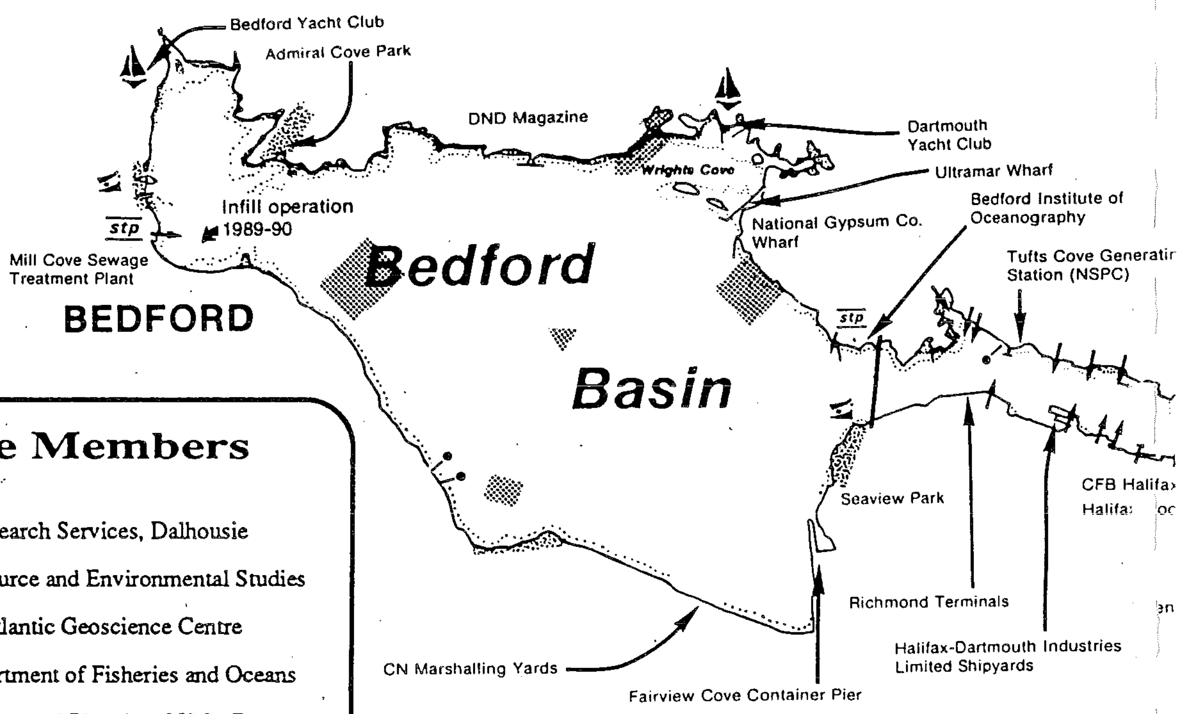
Fishing

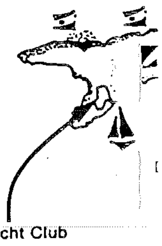
Historical accounts tell of the bountiful fish stocks which once filled Halifax Harbour. Today, fishing is limited to recreational activity and a seasonal commercial fishery for finfish and lobsters.

Many commercial fishing vessels operate out of the Harbour: from Eastern Passage or Herring Cove, for instance. Up to 100 fishermen work the Harbour at various times of the year. They have moved their primary fishing grounds further off in recent years due to declining catches, and problems with fouled nets. Nevertheless, mackerel, cod, haddock, gaspereau, and (until recently) herring, have been taken in commercial numbers. More than one hundred lobster pots may be set many times within the Harbour during the course of a year.

Land Infilling

The original Harbour shoreline had a very different shape than the current shoreline. With the pre-Confederation grants of shoreland in Halifax went rights to "water lots". The owners of water lots may fill those lots to create "reclaimed land", as many already have. A considerable amount of the Harbour could be filled in this way, altering circulation patterns in the water.





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DON WALLER, Centre for Water Resources Study

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Key

⛱	Beaches
◪	Scuba Diving
⛵	Yacht Club or Marina
⛴	Boat launch
stp	Sewage Treatment Plant
→	Sewage Outfall
▨	Waterfront Parks
⚓	Anchorages
✴	Lighthouse
◌	5 meter depth contour
▩	DND
—●	Water Intake
⁄	Ferry Routes

Berths and moorings at boat clubs and marinas in Halifax Harbour

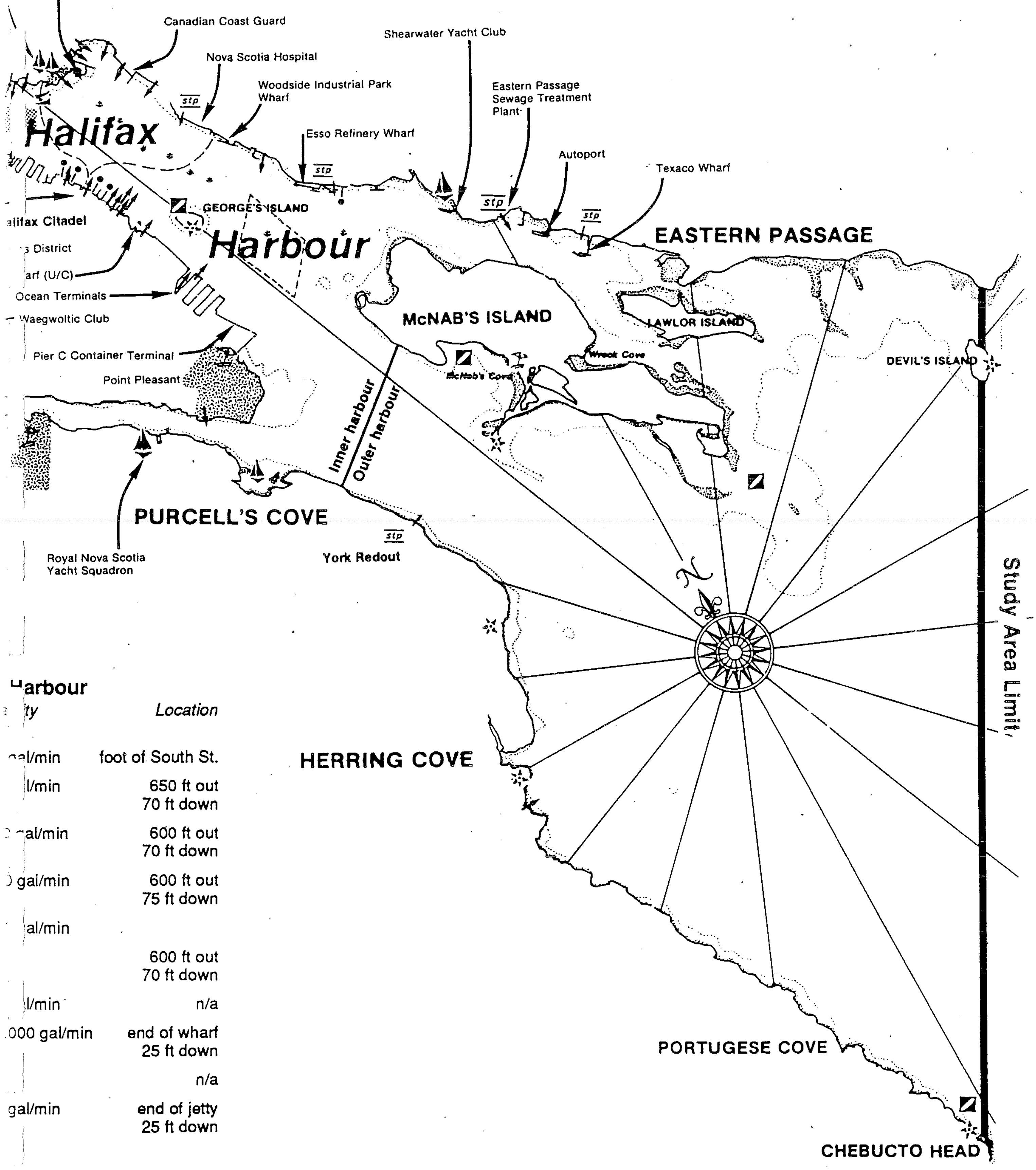
Club	*Berth*	*Moorings*
Waegwaltic	–	150
Armdale Yacht Club	120	75
Royal Nova Scotia Yacht Squadron	114	70
Shearwater Yacht Club	17	48
Dartmouth Marina	56	–
City of Dartmouth	12	–
Dartmouth Club	106	55
Bedford Basin Club	–	115
Irvin Boutlier's Marina	n/a	n/a
Purcell's Cove Marina	3	–

Water Intakes in 'a

User
Dalhousie University Oceanography
DFO Labs, Water St.
Purdy's Wharf 1
Purdy's Wharf 2
Imperial Oil Refinery
Fisherman's Market
Walker's Wharf
NSPC (Tuft's Cove)
Clearwater Lobster Lt
Bedford Institute of Oceanography

Halifax Harbour

Harbour Use - 1989



arbour

ty	Location
al/min	foot of South St.
l/min	650 ft out 70 ft down
al/min	600 ft out 70 ft down
gal/min	600 ft out 75 ft down
al/min	
	600 ft out 70 ft down
l/min	n/a
000 gal/min	end of wharf 25 ft down
	n/a
gal/min	end of jetty 25 ft down

Underwater Cables and Structures

Numerous cables run under the Harbour connecting Halifax to Dartmouth, and linking the Harbour islands to the mainland. While many of the underwater cables now lie useless, Maritime Telephone and Telegraph, the Department of National Defence, and the Nova Scotia Power Corporation have active cables.

The remains of old bridges still rest on the bottom in the Narrows, and the supports of the McKay and MacDonald Bridges stand supported by rock buttresses.

Research and Development

Because it is convenient and accessible, the Harbour is frequently used by establishments such as the Bedford Institute of Oceanography for research on the marine environment. Marine and oceanographic equipment is also often tested here by local companies which develop and manufacture oceanographic instruments.

Setting Harbour Use and Water Quality Objectives for Halifax Harbour

The activities we will all be able to enjoy in Halifax Harbour in the future will depend upon the water quality which we achieve and maintain. First we need to set harbour use objectives — what it is we want to be able to do in the Harbour. Then we will need to define water quality standards.

Halifax Harbour is a busy multi-use waterway. Plans to improve water quality must recognize that conflicts may occur. Even with our best efforts, we may not be able to guarantee that harbour use objectives can be met at all times. Some uses may take priority over others, thereby limiting our choices.

The following section outlines, in general terms, a range of possible harbour use and water quality objectives for public discussion. The various scenarios do not address specific treatment levels or outfall locations because these cannot be determined until the scientific and technical studies are complete. We are also not able to put price tags on the various scenarios. We know that the higher the level of water quality desired, the greater will be the cost to Metro taxpayers. But, as the scenarios point out, these are not the only costs which need to be considered.

Harbour Use and Water Quality Objectives - Some Scenarios

Objective A.

To use Halifax Harbour as a receptacle for untreated wastes, relying on dilution and tidal flushing action.

Action: No action required.

Consequences: Existing pollutants will continue to enter the Harbour and future development will add new pollutants. Beaches close more often, and for longer periods. Commercial fishing in the Harbour would probably come to an end. Recreational boating could be dangerous in some areas.

While this option has no direct costs, there are economic and environmental costs over the long term. Tourism could suffer as the waterfront becomes less attractive for business and leisure activities. The fisheries will lose revenue. At the same time, the Harbour ecosystem would deteriorate, as many species cannot thrive in such polluted conditions. If seriously contaminated, the water could pose a serious health hazard for those accidentally in contact with it.

This objective does not, in the opinion of the Task Force, merit serious consideration.

Objective B.

To preserve water quality at existing levels so that present uses can continue.

Action: residential and industrial development would not be able to discharge their wastes into the Harbour. This would require expensive treatment systems and might discourage further development.

Consequences: If we meet this objective, then current uses of the Harbour waters could continue. Swimming areas such as Black Rock Beach would be open except when bacteria levels increase after heavy rainfalls. A limited fishery for finfish and lobster would be possible, but shellfish harvesting would still be banned. Complaints about water quality would continue as existing outfalls spilled wastes into the Harbour.

While this scenario does not require construction of a regional system to deal with existing sewage wastes, it could still prove relatively expensive. Municipalities would have to provide treatment plants for new development, or limit their own expansion. Wastes would continue to pour into the water, adversely affecting tourism, fishing, and recreational opportunities.

Because this objective does not address existing environmental problems created by untreated sewage wastes entering the Harbour, the Task Force does not believe it is an appropriate choice.

Objective C.

To achieve both aesthetic and limited water quality improvement.

Action: This objective might possibly be achieved by pre-treating some industrial discharges, screening of floatable materials and large objects from existing outfalls, and relocating some outfalls to deeper water.

Consequences: Screening out the most obvious floating debris and removing chemical slicks would reduce some of the smells and visible evidence of wastes in the Harbour. It would not reduce the amount of raw sewage entering the Harbour.

Some uses of the Harbour could expand under this scenario, but the benefits would be for shoreline uses and boating. The Northwest Arm and parts of Bedford Basin might improve so that body contact sports could occur in presently contaminated areas. However, the areas around the outfalls would continue to suffer severe environmental problems.

This strategy simply shifts the waste problem from one area to another. Extending or putting screening devices on 40 outfalls would be an expensive undertaking for limited gain. If the volume of waste continues to grow, the outfalls may require further extension in the future. Opportunities for commercial and recreational fishing within the Harbour will continue to be limited. Tourists standing at Historic Properties, however, would probably be less offended by the smell and appearance of the water than they are today.

Because this objective does not remedy the problems of environmental degradation, but simply relocates them, the Task Force does not recommend it.✠

Objective D.

To achieve a substantial level of water quality improvement so that body contact sports and fishing can occur in designated areas at most times.

Action: Some level of sewage treatment of all wastes entering the Harbour would be required to achieve this objective. It probably would also require pre-treatment of industrial wastes to reduce the input of toxic materials.

Consequences: With this objective we might expect to increase recreational activities in priority areas, such as McNab's Island or the Northwest Arm. Fishing and lobster harvesting could continue, and might even expand into some new areas as water quality improves. Sewage plumes from certain outfalls would disappear, and the loading of new contaminants would diminish. The water would appear "cleaner" most of the time.

Some problems would remain, however. Following moderate to heavy rainfalls system overflows might cause beach closures and some aesthetic problems. Some areas could remain off-limits because of contaminated sediments. The immediate area of the outfall(s) would not be suitable for body-contact recreation or fishing.

This scenario would prove quite costly, as tunnels, plant(s), and outfall(s) would have to be constructed. It would substantially improve water quality, but would not totally eliminate environmental problems.✠

Metropolitan Area Planning Commission studies dealing with sewage treatment options for Halifax Harbour have adopted water quality objectives similar to this one.

The Task Force believes that this objective can be achieved, and is appropriate for consideration.✠

Objective E.

To achieve a high level of water quality so that body contact sports and fishing can occur 90-95% of the time in most parts of the Harbour.

Action: This scenario assumes pre-treatment of industrial wastes, a suitable level of sewage treatment, and appropriate outfall location(s). The system would need the capacity to accommodate a significant level of stormwater flow. Some treatment or removal of contaminated sediments may be required.

Consequences: If we achieved this objective people could swim, boat or fish through most of the Harbour most times of the year. Only very large rainstorms would place limits on swimming activities around the outfall(s) or overflow(s). Fishing and lobster harvesting could expand, and the Harbour would be considered aesthetically acceptable by all conventional standards.

Some areas of the Harbour would remain off-limits for recreation because of shipping lanes or military activities. If contaminated sediments were to remain and release toxins or heavy metals, then some uses would be limited.

The costs of implementing this objective would considerably exceed that of Objective D, as it requires more treatment and greater capacity within the system.

The Task Force believes that this objective can be achieved, and is appropriate for consideration.✠

Objective F.

To improve water quality significantly so that people could harvest shellfish for direct consumption.

Action: This objective would require a high level of treatment of all industrial and domestic wastes, capacity to handle all storm flows, and cleanup of existing sediments. It might be necessary to limit port and military activities.

Consequences: Shellfish harvesting requires virtually pristine water conditions, with very low bacteria and toxic chemical levels. If the Harbour were clean enough for shellfish harvesting, then it would be suitable for all body contact sports. However, swimming might have to be limited near shellfish areas to protect this resource from human contamination.

This scenario probably cannot be achieved, even if governments were willing to spend billions of dollars. A multi-use Harbour such as ours cannot guarantee the pristine conditions necessary for shellfish harvesting. Sediments deposited over two hundred years cannot be removed. Even with the best preventative programs, shipping accidents, sewage treatment system breakdowns, or freak storms that exceed system capacity may still occur.

The Task Force believes that it is not technically feasible to return the Harbour to pristine conditions while continuing to use it, so this objective is not appropriate for consideration.✠

What's Next?

Workshop on Harbour Use and Water Quality Objectives

7.00 pm, December 5, Dartmouth High School. Everyone welcome to attend.

Newsletter #3

The next newsletter will contain information about current environmental conditions in the Harbour, and about what sewage treatment can and cannot do.

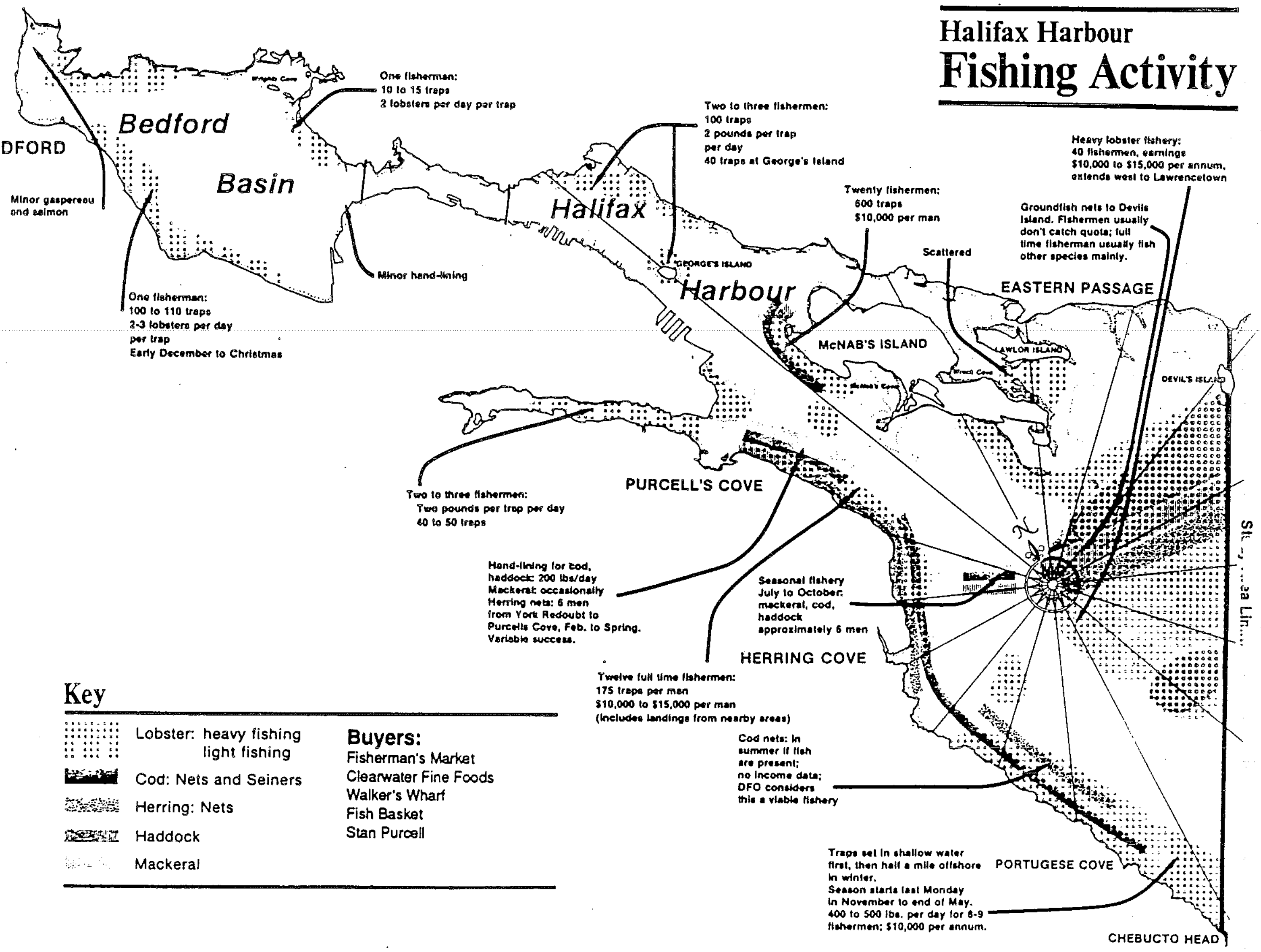
Community Workshops

These workshops, originally to be held in Eastern Passage, Dartmouth, Bedford, Halifax and Herring Cove in September, will be rescheduled early in the New Year.

Final Report

The Task Force will be producing its final report in April.

Halifax Harbour
Fishing Activity



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Halifax Harbour Task Force

Newsletter

Number 3 Feb., 1990
1568 Argyle Street
Halifax, Nova Scotia B3J 2B6
423-8629

Letter from Bob Fournier

Our last newsletter pulled together information on harbour uses, and put forward for discussion a range of harbour use and water quality objectives. About 80 people attended the December workshop in Dartmouth, and provided us with excellent feedback (summarized in this newsletter). We have also received written briefs from over 20 individuals and groups.

In Newsletter #3 we are sharing some basic information we have on the current state of the Harbour and the range of sewage and stormwater management options available. Together with the harbour use information, this covers most of the basic "building blocks" needed to develop an appropriate regional sewage management strategy.

In February we are holding five community meetings around the Metro area, this time to present some general sewage treatment scenarios for the harbour, to talk about their pros and cons, and to get more feedback from the public. Please plan to attend if you can. If you can't, we are always happy to get letters.

One more thing: we now have a mailing list of about 500 people and groups, but we are well aware that 250,000 people are sending their sewage (treated or untreated) into the Harbour, so we'd like to reach many more people. If you know someone who is — or should be — interested in the future of the Harbour, ask them to contact us so we can send them information. We still have copies of Newsletter #1 and #2 on hand.

Robert O. Fournier
Chair
Halifax Harbour Task Force

Task Force Diary

December

The Task Force spent time planning for the December 5 workshop at Dartmouth High School, and then reflecting on the feedback. Brian Petrie, with assistance from colleagues at BIO, and using new information about the movement of water in the Harbour, started looking at how different outfall locations might affect aspects of water quality not covered by the ASA oceanographic model.

The Harbour Use subcommitee met with representatives from DND. Other meetings are planned for January and February. Several members also gave talks to various public groups on the activities of the Task Force and the research underway.

In response to a letter from the Task Force, The Halifax Harbour Clean Up Corporation indicated that they will not be funding any part of the Historic Properties outfall extension until they know for sure that it would be needed as part of the new regional system.

January

Alan Ruffman joined the Task Force as a temporary replacement for Peter Pelham, who was convalescing after an operation.

Task Force members met with the Marine Advisory Committee for the Halifax Port Corporation, which has representatives of all major commercial harbour users. ✠

The Halifax Harbour Task Force invites you to attend

Community Meetings on Sewage Treatment Scenarios for Halifax Harbour

All meetings begin at 7.00 pm

February 20
Eastern Passage Junior High School, Caldwell Road, Eastern Passage

February 21
Lion's Den, LeBrun Centre, Bedford

February 22
St Paul's Church Hall, Herring Cove

February 26
Audio-Visual Theatre, Dartmouth High School, Dartmouth

February 27
Room 172, Loyola Building, Saint Mary's University, Halifax

The purpose of the meetings is to discuss the advantages and disadvantages associated with various sewage treatment scenarios.

(For more information call 423-8629)

What you told us at the December Workshop

Eighty seven people signed in: including 39 from Halifax, 29 from Dartmouth, 14 from the County, and 2 from Bedford. Only about half were already on our mailing list. After brief presentations by Task Force members, participants broke into five discussion groups to talk about harbour uses and locations, and objectives for the future. The following is a sampling of issues raised. A 7-page summary of the workshop was sent to all participants. If you would also like to have one, call the Task Force at 423-8629.

“

Harbour Uses

The Task Force needs to put more emphasis on maintaining the Harbour as part of a healthy marine ecosystem. Humans are not the only users of the Harbour. More attention also needs to be paid to the Harbour as wildlife habitat.

At the very least, we should maintain the existing commercial and recreational fishery.

We need more specific objectives for swimming, which is already limited by access and water temperature as well as by water quality. People were divided as to what priority should be given to swimming in the Harbour.

We should concentrate on existing parks and recreation areas, but should also recognize that new areas could be viable as water quality improves.

Water quality has an impact on the appeal and value of shoreline development.

Don't underestimate the aesthetic contribution made to our lives by the Harbour. A major function of the inlet is the setting it provides for walking, fishing and viewing the water.

Objectives

We should deal with problems in our own backyard, not export them to someone else's backyard.

No area in the Harbour should get any worse because of the sewage treatment system.

Development should be geared to available treatment capacity.

Think into the future. Don't make decisions today that might unnecessarily limit future options.

There is more to harbour management than sewage treatment. We must consider other uses (industry, the military etc).

The public needs to be able to compare costs and benefits in some detail, in order to evaluate different objectives.

The Task Force should consider a combination of scenarios, recognizing that even though water is always moving, water quality may never be the same throughout the whole Harbour.

”

Our Mistakes

The Port of Halifax is busy, but not quite as busy as we suggested in Newsletter #2. The Halifax Port Corporation wrote to say that about 2,000 ships enter the Harbour annually, not 12,000. They also pointed out that the Harbour, unlike most major ports, does not require maintenance dredging.

Esso Petroleum Canada also informed us that the Imperial Oil Refinery at Eastern Passage uses 22,000 gallons/minute of harbour water, not 1,900 gallons/minute.

Harbour Uses

Different parts of the Harbour have different patterns of use. Here is a summary based on input from harbour users and the general public meetings.

The Task Force is usinmg this information to develop environmental quality criteria for each area of the harbour These criteria wsed to evaluate different sewage treatment options.

Bedford Basin (A)

A multi-use area for:
- ✓ swimming
- ✓ boating
- ✓ port activities
- ✓ anchorage
- ✓ military uses
- ✓ shipping lanes
- ✓ ship trials
- ✓ sport fishing (from boats and piers)
- ✓ commercial fishing (where possible)
- ✓ wildlife
- ✓ research (seawater supply)

As much as possible, the deep water of the Basin should be protected from unnecessary organic enrichment because of a natural stagnation process caused by infrequent flushing.

Narrows (B)

The uses for this area are limited to:
- ✓ port activities
- ✓ industry
- ✓ military uses
- ✓ shipping lanes

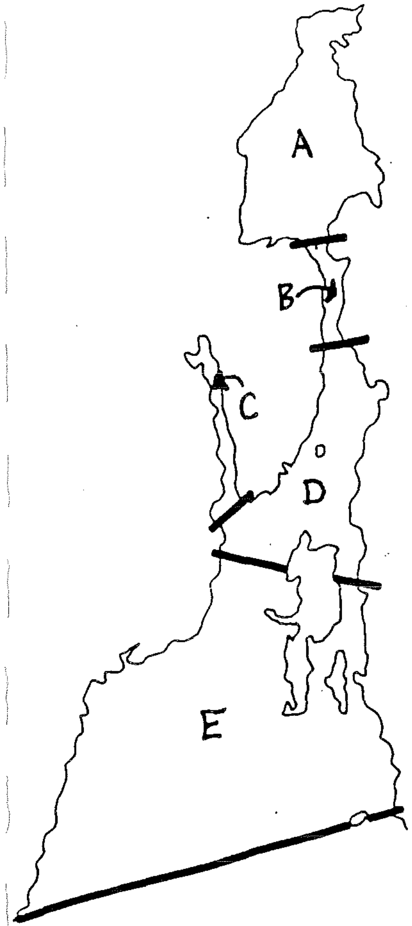
The Narrows are not used much for recreation or fishing, but the area must still be safe for fish and other marine life to pass through between the Inner Harbour and Bedford Basin. This area is also an important transportation route for commercial shipping, the military. and pleasure boats.

Northwest Arm (C)

Recreation is the priority in this area. Important uses include:
- ✓ swimming
- ✓ boating
- ✓ sport fishing (from boats and piers)
- ✓ wildlife
- ✓ research (seawater supply)

There are no port, industrial or military uses in the Arm.

HALIFAX HARBOUR



Inner Harbour (D)

A multi-use area for:

- ✓ ferries
- ✓ port activities
- ✓ industry
- ✓ anchorage
- ✓ shipping lanes
- ✓ sport fishing (from boats and piers)
- ✓ commercial fishing (where possible)
- ✓ swimming (where practical)
- ✓ boating
- ✓ wildlife
- ✓ research (seawater supply)
- ✓ viewing (this is the part of the Harbour that most residents and visitors alike most frequently see at close range)

Outer Harbour (E)

An area in which natural resource use is emphasized:

- ✓ commercial fishing (both fixed and mobile gear)
- ✓ sport fishing (from boats, piers and shore)
- ✓ shellfishing
- ✓ swimming/diving
- ✓ boating
- ✓ shipping lanes
- ✓ wildlife
- ✓ research

✠

Halifax Harbour as we know it today is a series of drowned lakes and river valleys which were flooded as the sea-level rose after the last ice age. The water in Halifax Harbour is comparatively deep, and does not need to be routinely dredged for shipping. The deepest part of the Harbour (70 m) is found in Bedford Basin. Elsewhere, depths range from 20 to 30 m, except in the North West Arm (10-15 m), Eastern Passage (less than 10 m) and the shoals in the Outer Harbour. As a comparison, in Boston they are having to take their new outfall pipe out for 15 km in order to reach 30 m depths.

Fresh Water, Salt Water

The Harbour is an estuary. The fresh water draining from the land mixes with salt water from the ocean. This mixing makes estuaries biologically productive. Over half of the fresh water comes from small streams and storm runoff. The major single source is the Sackville River. Sewage flow contributes about half as much freshwater as the Sackville, but unlike the river its input remains fairly constant throughout the year. In the summer months the river and sewage outfalls contribute about the same amount.

How Water Circulates in the Harbour

The freshwater does not immediately mix with the saltwater, but forms a separate layer on the surface. Typically in estuaries this results in a two-layer circulation. The upper fresh layer flows out towards the ocean, gradually becoming more salty as it mixes with the lower salt layer which is moving inwards. From time to time, however, this situation may reverse for periods lasting a few hours or even days.

Salinity and temperature measurements throughout the Harbour help us understand how water moves in the Harbour, and can help to predict where sewage effluent from an outfall would travel.

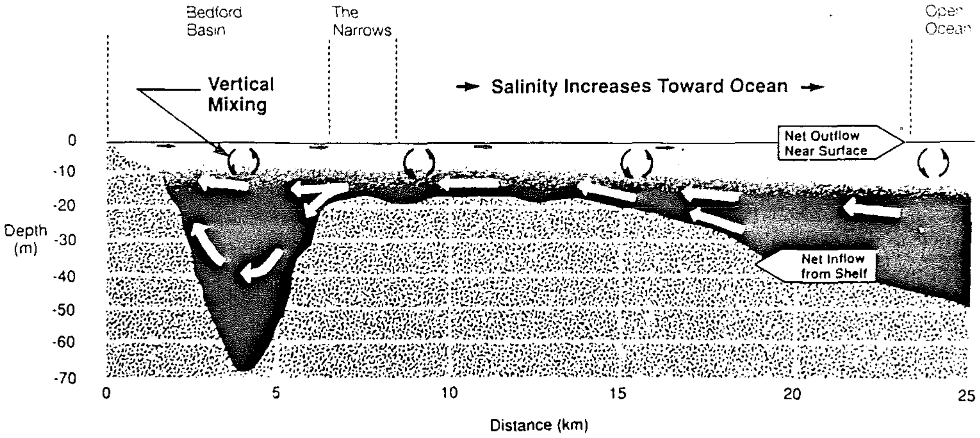
The Harbour Floor

The harbour floor can tell us about events which have happened in the past in and around the Harbour.For example, it is possible to date different sediments by identifying the first appearance of coal fragments (shortly after the founding of Halifax in 1748) or plastics (the 1950's). Dredge spoils and scour marks made by anchors show the influence of port related activities on surface sediments.

Sediments can also show the strength and direction of currents in the Harbour. In some parts of the inlet the bedrock is swept clean. In other areas, currents are slower allowing sediments to settle to the bottom.

The Outer Harbour area beyond Maugher's Beach on McNab's Island consists of sand, gravel and bedrock. The sand is only found on the western side in a deep channel originally formed by the Old Sackville River. The floor of the Inner Harbour is covered with mud, except where stronger currents forcing their way through the Narrows have scoured the bottom, leaving sand and gravel.

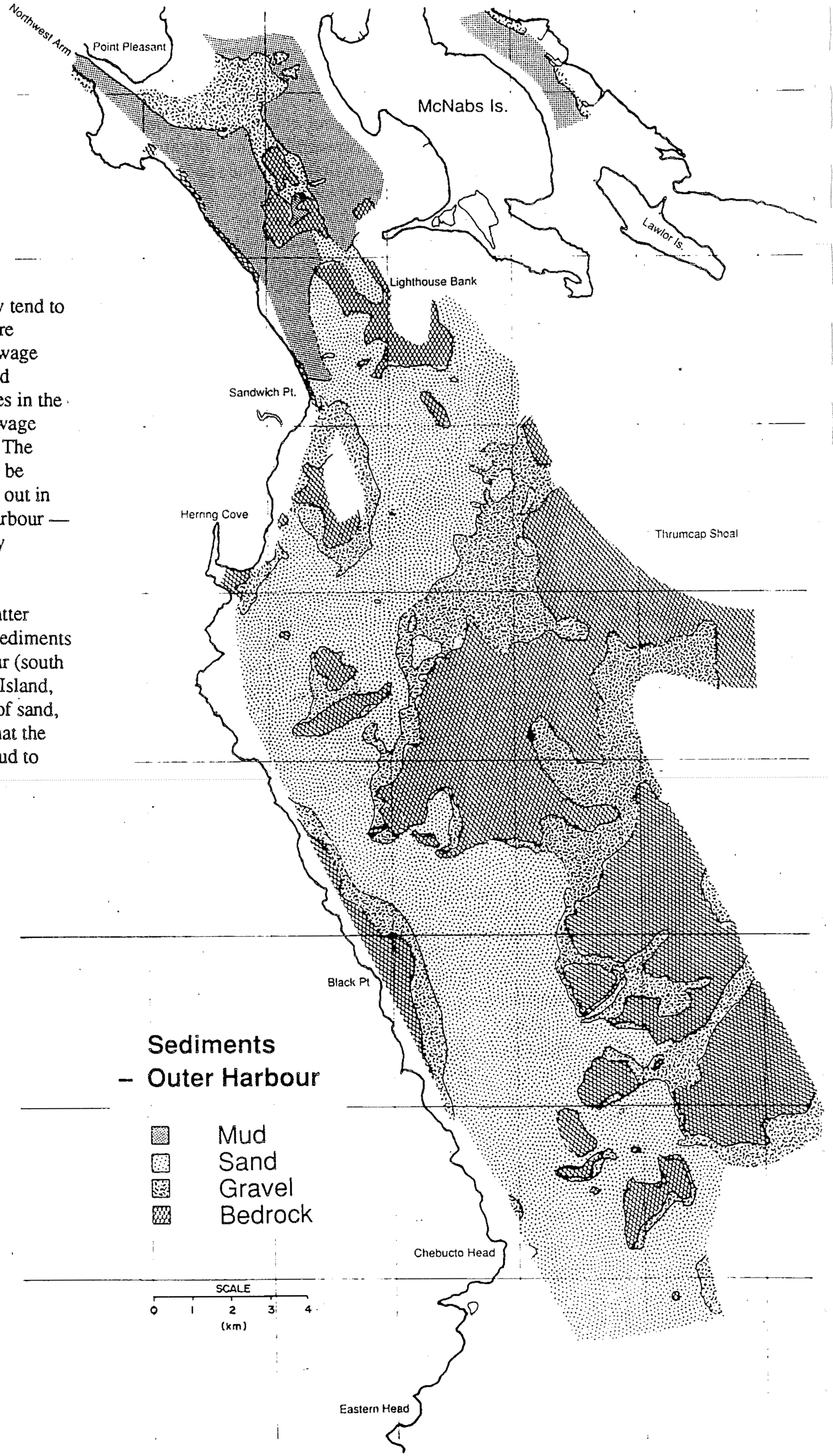
Circulation in Halifax Harbour



Where Sediments Settle

Knowing where sediments already tend to collect will help us to predict where sediments from a new regional sewage system would go. Treatment would remove many of the larger particles in the raw sewage, which formed the sewage "banks" close to existing outfalls. The remaining smaller particles would be carried away, eventually dropping out in the more sheltered areas of the Harbour — in other words, those areas already covered by mud.

We know, for example, that no matter where an outfall is located, finer sediments will not settle in the Outer Harbour (south of Maugher's Beach on McNab's Island, because the bottom now consists of sand, gravel and bedrock. This shows that the currents are too strong to allow mud to drop out of the water.



Current State of the Harbour

A headline in the Toronto Star last year referred to "The Horror of Halifax Harbour". An article in the The Chronicle Herald talked about "a cancer cess pool". Just how bad is the situation? Does water quality in the Harbour threaten public health? What about the overall health of the Harbour as a marine ecosystem? What do we know, and what don't we know about the Harbour?

Unfortunately we cannot present a comprehensive report on environmental quality in the Harbour, because an integrated program of research has not been carried out. What we do know suggests that there is no call for panic, but nor is there room for complacency.

Water Quality

Sewage related "floatables" and general garbage dumped into the Harbour from the shore or from ships are an eyesore and a hazard to marine life. As might be expected with raw sewage flowing into the Harbour, high bacteria levels occasionally cause beaches to be closed in the summer.

In general water quality is fairly good, except for local problem areas particularly around outfalls. Dissolved oxygen levels are high, which is a good sign of a healthy marine environment. A recent survey showed that concentrations of dissolved metals and organic chemicals are no higher in the Harbour than in other inshore waters along the Canadian east coast. The one exception was zinc in certain parts of the Harbour, but even in this case the concentrations are well below levels suggested by guidelines to protect marine aquatic life.

Sediment Quality

Research on sea floor sediments, on the other hand, shows that concentrations of metals and organic chemicals such as PCBs have built up in parts of the Harbour. These metals have come from domestic sewage, industry and leaking waste dumps. Right now it seems as though most of these contaminants are contained quite securely in the sediments, although in some areas port activity (ship movements, anchoring, dredging) may stir up the mud on the bottom, allowing some of the contaminants to get back in the water.

There is a concern that, by removing a lot of the solids from the sewage, treatment could introduce oxygen into these contaminated sediments. This could cause chemical changes which might release the metals back into the water. They might then be picked up by organisms, possibly accumulating through the food chain, and becoming a threat to human health. More research is needed to know just how fast this could happen, and how significant the effect would be.

Marine Life

Limited research has been done into possible effects of pollution on animals living in or moving through the Harbour. Like many bays and estuaries in Nova Scotia, the whole inlet is closed to shellfish harvesting because of bacterial contamination. Concentrations of metals and organic chemicals in Harbour lobsters are low and the fishery remains open. Tumours on finfish - an indicator of pollution - have not been documented. Mussels in the Harbour, however, do show elevated levels of metals. It is not yet clear how significant these accumulations are.

What all of this adds up to is that the Harbour is certainly showing the effects of 240 years of waste disposal, but has not deteriorated severely. In most of the Harbour, most of the time, people and fish can both swim quite safely. Most of the existing problems should respond quickly to preventive and remedial measures, including sewage treatment.

More research is now being done on the Harbour with a major contribution by the Bedford Institute of Oceanography. Two tasks which deserve priority are:

- ✓ developing a current "health of the harbour" report as a baseline against which to measure changes (hopefully improvements)
- ✓ continuing work on the contaminated sediments, looking particularly at organic chemicals.

A Sewage Management Strategy: What are the Priorities?

In simple terms, a sewage management strategy answers four big questions: (1) What will be allowed into the sewer pipe — inasmuch as that can be controlled (2) How much will it be treated (3) Where and how will it be discharged, and (4) What to do with the sludge.

To answer those questions in the Metro Area we first have to establish what level of environmental quality we want to maintain in the Harbour (and beyond, where applicable), and then work backwards from there.

Concerns about the effects of sewage on environmental quality can be grouped into five categories.

AESTHETICS Sewage which is poorly treated (or not at all), and discharged in the wrong way, is offensive. Metro residents and visitors are all too familiar with the smells, discoloured sewage "boils", and floating objects which result.

ACUTE RISK TO PUBLIC HEALTH
People could become sick very quickly (with gastroenteritis and other infections) from swimming in waters or eating shellfish contaminated by pathogens from sewage.

ACUTE RISK TO AQUATIC LIFE
Sewage could cause immediate fish kills due to low dissolved oxygen or the presence of acute toxins.

CHRONIC RISK TO PUBLIC HEALTH
Over a much longer period of time, it is possible that people could develop cancer

or other diseases by eating heavily contaminated seafood or by swimming frequently in a contaminated area.

CHRONIC RISK TO AQUATIC LIFE Long exposure to toxic contaminants could also cause cancers and other diseases in marine life, and perhaps change species composition.

Please note that we have no indication of chronic risk to public health in Halifax Harbour, or of acute or chronic risk to aquatic life. Nevertheless, we need to be aware of the full range of possible repercussions should we allow the Harbour to become grossly polluted.

What's in Sewage

Sewage is 99.9 percent water and 0.1 per cent solids (which doesn't sound like much, but soon adds up when the daily flow is 40 million gallons).

There are different types of contaminants with different implications.

OBJECTS Used toilet tissue, tampon applicators, condoms, hair. Many of these objects float and have a tendency to gather at the surface and blow towards shore, where they collect along the high water mark.

GREASE Grease and oils which can be of petroleum, vegetable or animal origin. Grease may clump into balls at the surface and collect at the shoreline. Oil may form slicks.

MICROORGANISMS Sewage contains a range of microscopic plants and animals. We are most concerned about pathogens - the bacteria and viruses which cause diseases. It would be difficult to identify all of these pathogens so fecal coliform bacteria, which are themselves harmless but numerous and easily tested, are used to indicate whether pathogens are present.

SUSPENDED SOLIDS These can discolour or cloud the water. They also carry pathogens and toxic materials.

BIOCHEMICAL OXYGEN DEMAND (BOD) As the organic material in the sewage decomposes, it consumes dissolved oxygen in the receiving waters — possibly depleting it to an unacceptably low level, although this is rarely a problem in ocean waters. Plants and animals cannot live in the water without good levels of dissolved oxygen.

NUTRIENTS Nutrients act as fertilizers encouraging the growth of algae and other plants, which may in turn use up the oxygen as they die and decompose. Excessive nutrient input may also promote toxic phytoplankton blooms. In marine waters nutrient enrichment is usually only a problem where large amounts of sewage are discharged into relatively sheltered areas.

PERSISTENT TOXICS These can come from domestic sewage or from industry. They are difficult to remove by treatment, and indeed can upset the operation of a biological (secondary) treatment process.✠

Sewage Treatment Options

While we normally speak about sewage treatment as being at primary, secondary and tertiary levels of treatment, there are many variations possible within these categories, so it helps to break out the different treatment options. (See **Types of Treatment**, for more details).

CONTROL AT SOURCE This simply means not allowing certain contaminants into the sewage in the first place. A range of approaches are needed to keep toxics out of our sewers: public education, legislation, enforcement, and providing alternative recycling or disposal options. For many toxic contaminants, this is the only real option because conventional treatment processes have little or no effect on them.

PRELIMINARY TREATMENT This removes or reduces the size of objects and solids, such as sand and gravel, oil and grease, and large pieces of garbage or fecal matter, which could subsequently interfere with other treatment processes.

PRIMARY SEDIMENTATION Sewer pipes are designed so that the sewage will always flow fast enough to keep solids from settling out. At the treatment plant, the object is the reverse - to slow down the flow, allowing plenty of time for the settleable solids to sink and the floatable solids to gather at the surface. The former are drained out of the bottom as sludge, the latter are skimmed off the surface.

ADVANCED PRIMARY SEDIMENTATION Adding chemicals such as aluminum sulfate, ferric chloride, lime or certain polymers, will cause small sewage particles to clump together and sink more rapidly than the separate particles would. More sludge is generated, both because more solids are removed and because a chemical sludge is formed.

BIOLOGICAL SECONDARY TREATMENT The effluent from the primary sedimentation process contains dissolved and fine particles of organic matter. In secondary treatment a bacterial culture converts this organic matter to new cell growth, which eventually settles to the bottom as sludge. Secondary sludge is very watery.

NUTRIENT REMOVAL (TERTIARY TREATMENT) Conventional primary and secondary treatment removes only a small percentage (0-30%) of the nutrients. Nitrogen is the nutrient of most concern in marine waters, and phosphorus in freshwater. Either or both can be removed by adding another step to the treatment process.

OTHER TERTIARY TREATMENT PROCESSES Tertiary treatment is a catch-all term referring to processes added to primary and secondary treatment in order to improve or "polish" the quality of the effluent, or to solve particular problems. Besides nutrient removal, tertiary treatment can include processes to remove specific metals or more solids.

DISINFECTION The purpose of disinfection is to kill as many pathogens as possible and prevent the spread of diseases through contact with sewage effluent. Disinfection is usually (but not always) the final step in the treatment process. It works better with a more highly treated effluent. Chlorine is by far the most commonly used disinfectant, because of its effectiveness and reliability. But chlorine in certain concentrations can also be toxic to marine life, and can form toxic chlorinated compounds with other components of the effluent.

DISPERSAL IN THE ENVIRONMENT It might be strange to see dispersal listed as a treatment option. "The solution to pollution is dilution" is a much discredited slogan. However, dispersal does play a legitimate role in treatment for those pollutants which, given time, can decay without causing harm.

We need, however, to be very careful about natural processes which may reverse the effects of dispersal: floatables carried by the tides collecting again at the shoreline, small particles clumping together and settling to the bottom, or toxics accumulating in aquatic organisms.

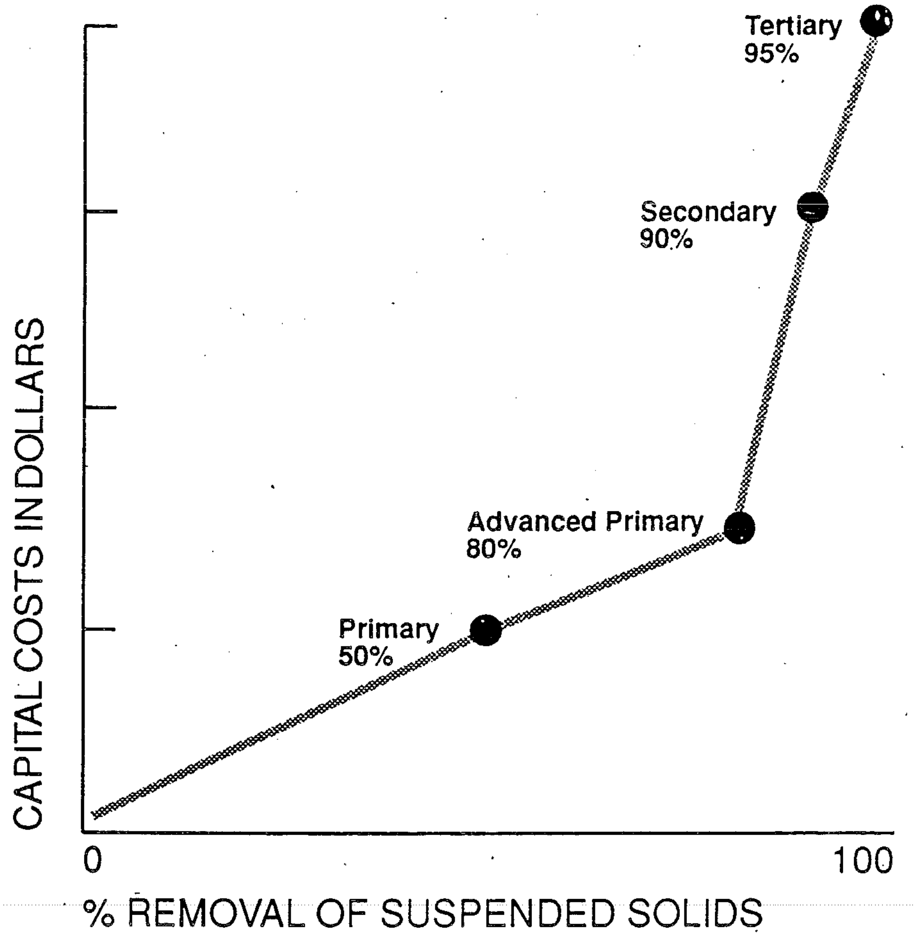
SLUDGE TREATMENT, USE AND DISPOSAL All sewage treatment produces sludge as well as effluent, although sometimes this tends to get forgotten. Higher levels of treatment remove more solids, and therefore generate more sludge on a dry weight basis. Before dewatering, the volume is even greater because secondary sludge contains four times as much water as primary sludge.

There are many ways to treat sludge, including conditioning and dewatering, anaerobic digestion, composting, heat drying, incineration, and the new sludge-to-oil process. In other parts of North America, sewage sludge has been spread on land, landfilled by itself or with municipal garbage, put in lagoons, dumped at sea, burnt, or sold as fertilizer.

✠

What you get for your money

Costs rise rapidly as treatment levels increase



More Reading . . . .

Two recent publications from the U.S. of general interest. Both will be deposited with the Halifax Harbour Task Force collection in the reference departments of the Halifax Main Library, Dartmouth Library, and Halifax County, Bedford Branch.

Saving Bays and Estuaries: A Primer for Establishing and Managing Estuary Projects
U.S. Environmental Protection Agency
EPA / 503 / 8-89-001, August, 1989
Covers topics such as management frameworks, problem definition, comprehensive conservation plans and public participation.

The Gulf of Maine: Sustaining our Common Heritage
Maine State Planning Office, November, 1989
No . . . Halifax harbour is not in the Gulf of Maine, but this beautifully illustrated report provides an excellent introduction to the challenges of protecting marine environment.

Types of Treatment

Please note that actual treatment efficiencies, sludge generation rates, costs and land requirements depends on the specific purpose, design and location of the treatment plant.

The estimates are provided just for the purposes of comparison.

Primary Treatment

Removal of settleable and floating solids	90-95 %
Removal of suspended solids	40-60 %
BOD removal	25-35 %
Heavy metal removal	0-40 %
Nutrient removal	0-20 %
Sludge generated per million liters treated	120 kg dry weight
Approximate cost of a plant to treat 180 million liters/day	
Capital costs	$ 35 million[1]
Operating costs/year	$ 2 million[1]
Land required for plant to treat 180 million liters/day	8 hectares[2]

[1] *(Based on estimates in CBCL Phase III report, 1987 dollars)*

[2] *(Based on estimates in CBCL Phase III report)*

Advanced Primary Treatment

Removal of settleable and floating solids	90-95 %
Removal of suspended solids	75-85 %
BOD removal	60-70 %
Heavy metal removal	20-65%
Nutrient removal	10-30 %
Sludge generated per million liters treated	Depends on process used, probably slightly less than secondary treatment
Approximate cost	Depends on process used, between primary and secondary
Land required	Slightly more than primary

Secondary Treatment

Removal of settleable and floating solids	95 % plus
Removal of suspended solids	85-95 %
BOD removal	85-95 %
Heavy metal removal	20-65 %
Nutrient removal	0-30 %
Sludge generated per million liters treated *(total from primary and secondary treatment processes)*	240 kg dry weight
Approximate cost	
capital costs	1.5 to 2 times the cost of primary
operating costs	2 to 2.5 the cost of primary
Land required	1.5 times as much land as primary

Tertiary Treatment

Removal of settleable and floating solids	95-100 %
Removal of suspended solids	95 %
BOD removal	95 %
Heavy metal removal	80-95 %
Nutrient removal	80-95 %
Sludge generated per million liters treated *(total from primary,secondary and tertiary processes)*	360 kg dry weight
Approximate cost	
capital costs	2.5 to 5 times the cost of primary
operating costs	4 to 6 times the cost of primary
Land required	Twice as much as primary

Stormwater

COMBINED AND SEPARATE SEWER SYSTEMS

Until early this century all sewer systems used the same pipes to carry sanitary sewage (domestic, commercial and industrial wastewater) and stormwater. The older parts of Metro - Halifax Peninsula and downtown Dartmouth - have combined sewer systems, while more recent developments have separate systems. In a separate system sanitary sewage is carried in one set of pipes to a treatment plant, while stormwater is carried in another set of pipes or by way of natural drainage directly into a river, a lake or the sea.

COMBINED SEWER OVERFLOWS

When a sewage treatment system has to use combined sewers, problems can arise during rainstorms. Typically, interceptor pipes are sized to hold anywhere from 2 to 7 times the average dry weather flow. But a surge of runoff during a storm can easily exceed the capacity of the interceptors and the mixture of stormwater and sewage must then be released into a watercourse through direct outfalls called combined sewer overflows.

Other communities have found that providing sewage treatment has not solved all their problems, because combined sewer overflows, some of which may be near beaches and other recreational areas, periodically pour out a mixture of raw sewage and contaminants washed off the streets.

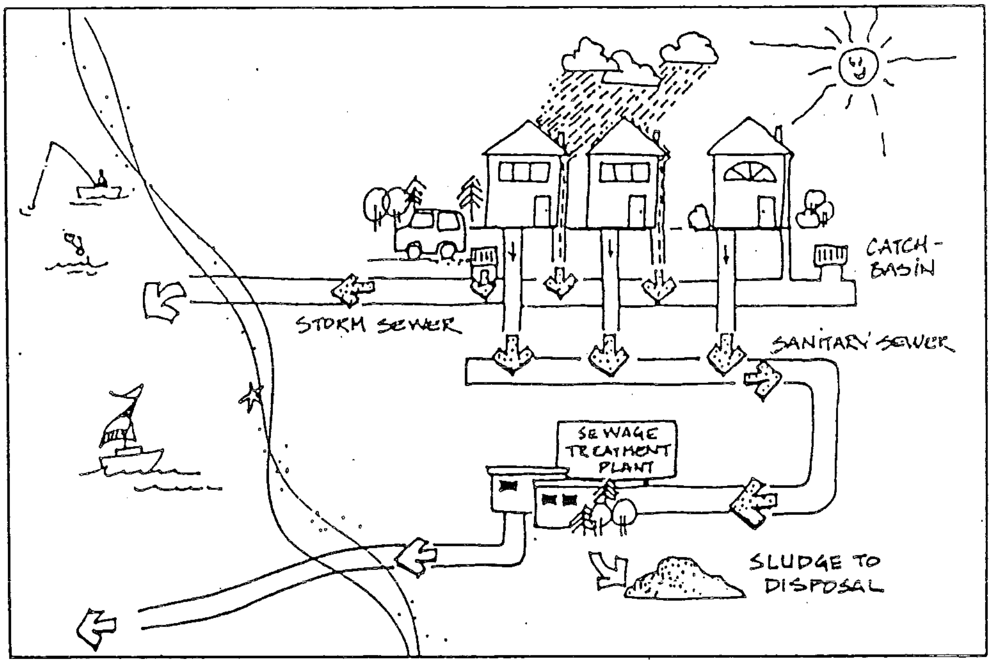
In theory, a separate sewer system would ensure that no raw sewage was ever discharged, because it should be possible to make the pipes and the treatment plant large enough to cope with just sanitary sewage. In practice, leaking pipes and illegally connected roof drains may add large quantities of water to the sewer pipes, making it necessary for the excess flows to bypass the treatment plant during very wet weather. This is currently a problem in the Bedford-Sackville area.

SEPARATING COMBINED SYSTEMS

The first solution that comes to mind - and one which many Metro residents have brought up in meetings with the Task Force - is to eliminate combined systems.

New sewer systems are always separate, but no North American city with a significant amount of combined sewers has opted to rebuild existing combined systems. Cost and disruption are obvious drawbacks. People often suggest that combined sewers could be separated on a piecemeal basis as a part of routine maintenance, and that this would reduce costs, but the whole collection system would still have to operate as a combined system until the last pipe was replaced. This could take many years.

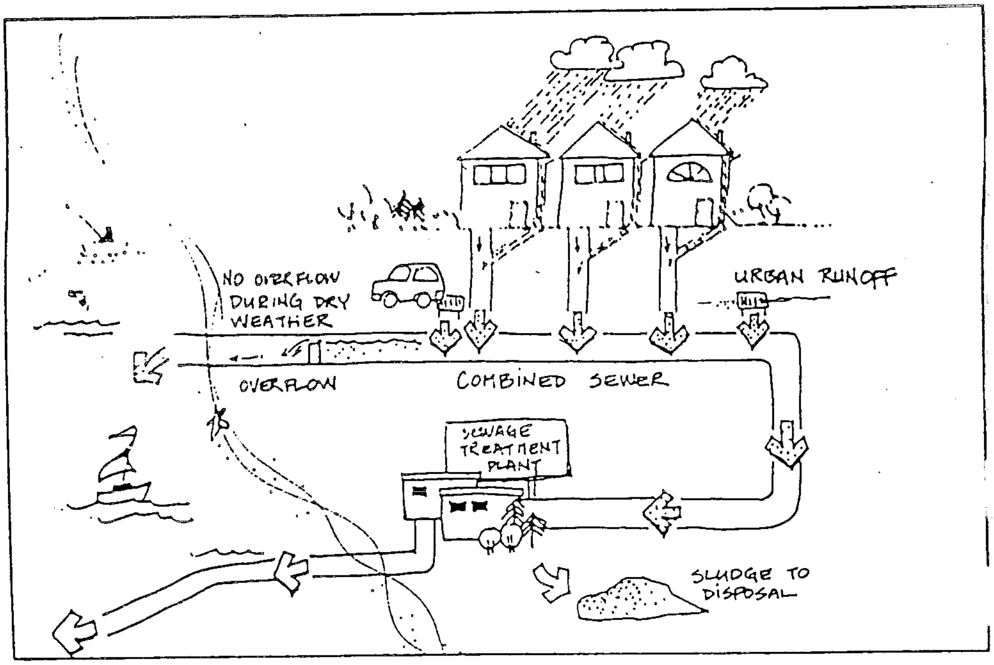
Perhaps more importantly, separating combined systems may not accomplish very much. With a combined system some raw sewage mixed with runoff enters the Harbour during storms, but the rest of the time the runoff will be treated with the sewage at the sewage treatment plant. We now know that runoff is not as clean as we once thought. Stormwater carries with it whatever it can wash off the streets and parking lots, contributing bacteria, nutrients, heavy metals and toxics to the Harbour.



The separate sewer system

STORAGE AND TREATMENT

Cities attempting to deal with the problem of combined sewer overflows have instead opted to use storage and treatment. Stormwater and sewage can be stored in large underground tanks, deep tunnels or oversized interceptors during storm periods, and then allowed to go on to the treatment plant when the storm subsides. When a storm is too big even for this storage (which will inevitably happen at some time), some form of treatment, perhaps screening and chlorination, can be provided for the resulting overflows.



The combined sewer system

The Federal-Provincial Agreement for Metro

Metro municipalities have been carrying out pollution control studies for over twenty years, but still 80 percent of our sewage goes into the Harbour untreated. A major stumbling block was cost, especially when the Federal government stopped providing financial assistance for municipal infrastructure such as sewer and water systems in 1980.

This problem was at least partly solved in 1988, when a Federal-Provincial Subsidiary Agreement for the Metro Area was signed. The Agreement covers a number of development projects, but most of the money is for sewage treatment facilities. Subsequently the Province, Halifax, Dartmouth and the County also signed an agreement setting out a regional approach.

Highlights of the Agreements

✓ The purpose of the Federal-Provincial Agreement is to undertake key initiatives in support of economic development, resource management and improvement of the environmental well-being of the Halifax-Dartmouth Metropolitan Area.

✓ S195.7 million are earmarked for sewage treatment, to be shared as follows:

Federal government	37.5 %
Provincial government	37.5 %
Municipalities	25 %

✓ The municipal portion of the total cost is about S49 million, to be shared as follows:

City of Halifax	66.6 %
City of Dartmouth	32.8 %
Halifax County	0.6 %

✓ Both parties to the Federal-Provincial Agreement agree to employ sludge-to-oil technology.

✓ There is to be a joint assessment of the possibility of the private sector getting involved in building and running sewage treatment facilities.

✓ Halifax Harbour Clean Up Inc.(Chief Executive Officer, Paul Calda) has been formed to oversee the design and construction of the regional sewage treatment system.

✓ The Board of the Corporation is chaired by Cathy MacNutt, Deputy Minister of the NS Department of Consumer Affairs. The Board has representation from the Province and the three municipalities, with three federal observers.

✓ A Technical Advisory Group, co-chaired by representatives from Environment Canada and NS Department of Environment, provides scientific and technical assistance to the Corporation.✠

WHAT'S NEXT?

Community Meetings

Long awaited, finally scheduled: February 20 to 27 in Eastern Passage,Bedford, Herring Cove, Dartmouth and Halifax. For dates, times and locations, see notice on the first page of this newsletter. The purpose of these meetings is to get feedback on different sewage treatment options.

Final Report

The Task Force will be producing its final report in April.

Task Force and friends tour the harbour during warmer weather.

APPENDIX G. PEOPLE AND ORGANIZATIONS MAKING WRITTEN SUBMISSIONS TO THE TASK FORCE

Councillor Randy Ball, District 5, Halifax County

Peter C. Barr, Canadian Surfing Association

D. A. Bayer, Planning and Development Department, City of Dartmouth

D.F. Bellefontaine, Halifax Port Corporation

R. G. Belliveau, Herring Cove Ratepayers Association

Arden Burns, Sherbrooke

Jim B. Carson, Esso Petroleum Canada

Norval Collins, Community Planning Association of Canada

City of Dartmouth, Planning Department

Peter M. Dunn, ViolinWorks

John Edmonds, Edmonds Landscape Services

M. Lynn Gallant, Nova Scotia Underwater Council

Commodore J.E. Green, Commander Maritime Command, FMO Halifax

Richard C. Hale, Professional Project Engineering Limited

Harbour Cleanup Committee, Ecology Action Centre

Hugh S. Harper, Halifax Sheraton

John Jenkins, The Friends of McNab's Island

Michael Kennedy, Halifax

Ronald H. Loucks, Halifax

Susan McEachern, Dartmouth

Alan McIver, Bedford Waters Advisory Committee

David J. Miller, Halifax

Roland Morrison, Nova Scotia Underwater Council

Peter Pelham, Herring Cove Ratepayers Association

R.T. Pentland, Halifax Port Corporation

Alan Ruffman, Geomarine Associates Ltd.

Mayor John Savage, City of Dartmouth

Valerie Spencer, Department of Planning and Development, Halifax County

Bill Stanbrook, District 6 Ratepayers Association, Eastern Passage

Colin Stewart, Conservation Issues Committee, Halifax Field Naturalists

Deborah Wallace, Boutilier's Point

W.A. Waugh, Waugh Associates Ltd.

Charlie Weatherby, Recreation Advisory Board, City of Dartmouth

APPENDIX H. REFERENCES CONSULTED DURING PREPARATION OF ENVIRONMENTAL QUALITY GUIDELINES

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