ENVIRONMENTAL ANALYSIS AND SEDIMENT INVESTIGATION OF GEORGETOWN HARBOUR, P.E.I.*

by

Grant A. Bartlett

for

Department of Regional Economic Expansion

*[1] Re: Georgetown Seafoods Ltd. Waste Disposal System

Contents

FIGURES

Page

PLATES

TABLES

SUMMARY:

A. The Cardigan Bay estuary is a result of river drowning and is characterized by type B (partially mixed) circulation pattern.

B. Average flow during ebb tide is 3000 cu. m/sec. at the mouth of the estuary.

C. The suspended load varies from 5 mg/l in the surface waters (Station 35m) to 80 mg/l in the bottom waters (Station 34A). Suspended sediment is contributed by the Montague and Brudenell Rivers, shore processes, sewer effluents, marine processes, biological activity and resuspension during periods of excessive turbulence.

D. Dredging operations and longshore drift have contributed significantly to the development of shoals adjoining Thrumcap Spit. The extensive development of these shoals has initiated sediment piracy from the spit.

E. Sediment sources are considered to be external, marginal and internal. Mineralogy, trace element analysis and sediment distribution patterns indicate that the rivers and longshore drift (in conjunction with harbour dredging) are the major contributors. Frequent dredging in harbour environments and the rapid growth of numerous spits, bars and shoals adjoining them substantiate these conclusions.

F. The oscillatory flood and ebb of the tidal currents are the most obvious water motions in the harbour. However, strong winds create a high degree of turbulence and depending upon tidal direction may contribute to, or substract from surface current velocities.

G. The limit of saltwater intrusion (with associated resuspended sediments) migrates upstream and downstream in response to changes in both river flow and tidal penetration.

H. Suspended material in surface waters, which settle into the lower and bottom water layers are returned upstream and commonly accumulate there, rather than downstream from the original source.

I. A short term water chemistry investigation has not shown major trends or provided sufficient information to define specific aspects of chemical pollution within the harbour.

J. The effects of turbidity on microorganisms and bacteria is highly complex. Periodic fluctuations in water movements because of tidal influence may cause sedimentation and resuspension of detritus as well as bacteria and microorganisms. This may account for the sudden decrease in bacterial counts adjoining the sewer outfall.

K. Industrial and municipal effluents daily contribute significant amounts of sediment to Georgetown Harbour. Georgetown Seafoods have an annual flow varying from 300,000 to 700,000 gallons per day. This represents between .02 to .04 cubic meters per second and is a minor contributor to the total flow within the harbour. In addition, the contribution of human waste is assumed to be approximately 0.5 pounds per person per day.

L. The preliminary removal of physical (coarse floating material) pollution from estuaries is desirable because of siltation, aesthetics and fouling of the shoreline.

M. Suspended sediments adjoining the sewer outfall, are contributing significantly to environmental degradation and the development of anoxic hydrogen sulfide-and methane-emitting bottom environments. This region commonly contains significant numbers of bacteria (greater than 100 per ml.) in both the watermass and bottom sediments.

N. Analyses of soils and bottom sediments show that illite, kaolin and chlorite are the dominant clay minerals in Georgetown Harbour.

O. Organic carbon content varies from 0.116% in medium to coarse sand substrates adjoining Thrumcap Spit, to 3.330%, immediately adjoining the sewer outfall. The high concentrations in silts and clays adjoining the outfall indicate inadequate dispersal in the region.

P. Extensive development of shoals adjoining Thrumcap Spit are believed to be primarily a result of river borne sediment and the dumping of dredgings too close to the harbour entrance, and the subsequent "locking in" of the area to the natural longshore drift. Thrumcap Spit is becoming an erosional feature because of "sediment piracy" by the adjoining shoals.

Q. Sediment core analyses indicate that the positive projections of the baymouth bar are receding but that the adjoining shoals are expanding at an ever increasing rate.

R. Specific regions within Georgetown Harbour and environs that are undergoing siltation and environmental degradation are those adjoining the wharves and sewer outfall.

S. Bacterial contamination exists in Georgetown Harbour. However, results have been extremely variable. Positive counts, occasionally greater than 100 ml/l were only obtained at Georgetown Seafoods wharf, Fisherman's wharf and the sewer outfall.

T. The restriction of watermass circulation imposed by Thrumcap Spit and adjoining shoals, projections such as wharves into the estuarine environment, the upstream movement of suspended sediments with both flood and ebb tides and the downstream movement with ebb tides, prohibit sufficient dispersal of effluents and suspended sediments outside of Georgetown Harbour. Consequently, siltation will be directly related to river and effluent flow and the development of the baymouth shoals.

U. Extension of the present outfall to the main river channel will provide more rapid initial dispersal because of increased current velocities. However, two layer and two directional circulation will probably lead to increased transportation upstream with resultant widespread pollution in the harbour and adjoining rivers.

V. The broad extent of the shallows and bar (Thrumcap Spit) indicates that extension of the outfall in this direction will have little long term benefit because the region is apparenlty "locked in" to longshore drift.

W. Fine screening, perhaps secondary treatment in the future, continued dredging with dumping significantly seaward of the harbour entrance and careful planning of future harbour installations in the light of environmental factors are strongly recommended.

X. It is suggested that the present outfall should remain in its present location because of the slight benefit derived from alternatives.

INTRODUCTION:

A water and sediment sampling program was conducted at 18 stations in Georgetown Harbour, Prince Edward Island (Figures 1 & 2, Plates I & II) during the period from October 20 to November 3, 1972, to determine the dispersal of sewer effluents and sediment distribution within the area of Thrumcap Spit (Figure 2). Several current velocity and direction recordings, 20 dye dispersal measurements, 50 suspended load samples, 24 bacteria samples, 24 microorganism samples and 48 samples for sediment size distribution, heavy minerals, organic carbon and clay mineral analyses were obtained. Approximately 100 photographs (35 mm.) of the harbour and environs were obtained with the aid of a helicopter provided by the Department of Transport. Every aspect of the investigation indicates: 1) the tenuous interrelationship of the spit, shoal and sewer outfall, 2) the harmful effects of improper dredging and dumping practices, 3) the need for "in depth" planning of future harbour developments, 4) the immediate necessity of fine screening, 5) the long term and financial impracticality of relocating or extending the existing outfall at present.

ACKNOWLEDGEMENTS:

Special thanks are extended to Arthur Hiscock and St. Clair Murphy, Prince Edward Island Environmental Control Commission for assistance throughout the project. The Department of Transport deserves special mention for the loan of a helicopter. The cooperation of the pilot is greatly appreciated. John Robertson, Queen's University, supervised both the field program and laboratory analyses and is to be highly commended for the quality of his work. Thanks are extended to Dr. K. Rutherford,

clay analysis; T. Hall, zooplankton and phytoplankton analyses; L. Johnson, chemistry of water and sediments; J. Vanderpost, bacteria; G. Holmes, photography and heavy minerals; L. Molinsky, microfauna; and R. Smith, trace element analysis.

OBJECTIVES:

The objectives, as outlined in a letter dated October 18, 1972 to Mr. V. Ulrich, and the statements, as outlined in the formal agreement, page 1, section 2.1, paragraphs, a, b, c, are as follows:

1) To interpret the direction and velocity of currents, utilizing flow devices such as rotation current meters, during a limited period (approximately one week) in the region bounded by Thrumcap Spit, St. Andrew Point and a position approximately eight hundred (800) meters northwest of Gaudin Point.
2) To interpret the dispersal of effluents from the present outfall, utilizing path methods such as Rhodamine B, suspended load, phytoplankton and bacteria.
3) To determine the sediment composition, relative rates of sedimentation, direction of sediment transport and the direction and effect of the movement of sediments associated with Thrumcap Spit.

FIGURE 1: Cardigan Bay and Environs Showing Broad Sample Grid Utilized for the Environmental Control Commission, and the Location of Georgetown Harbour.

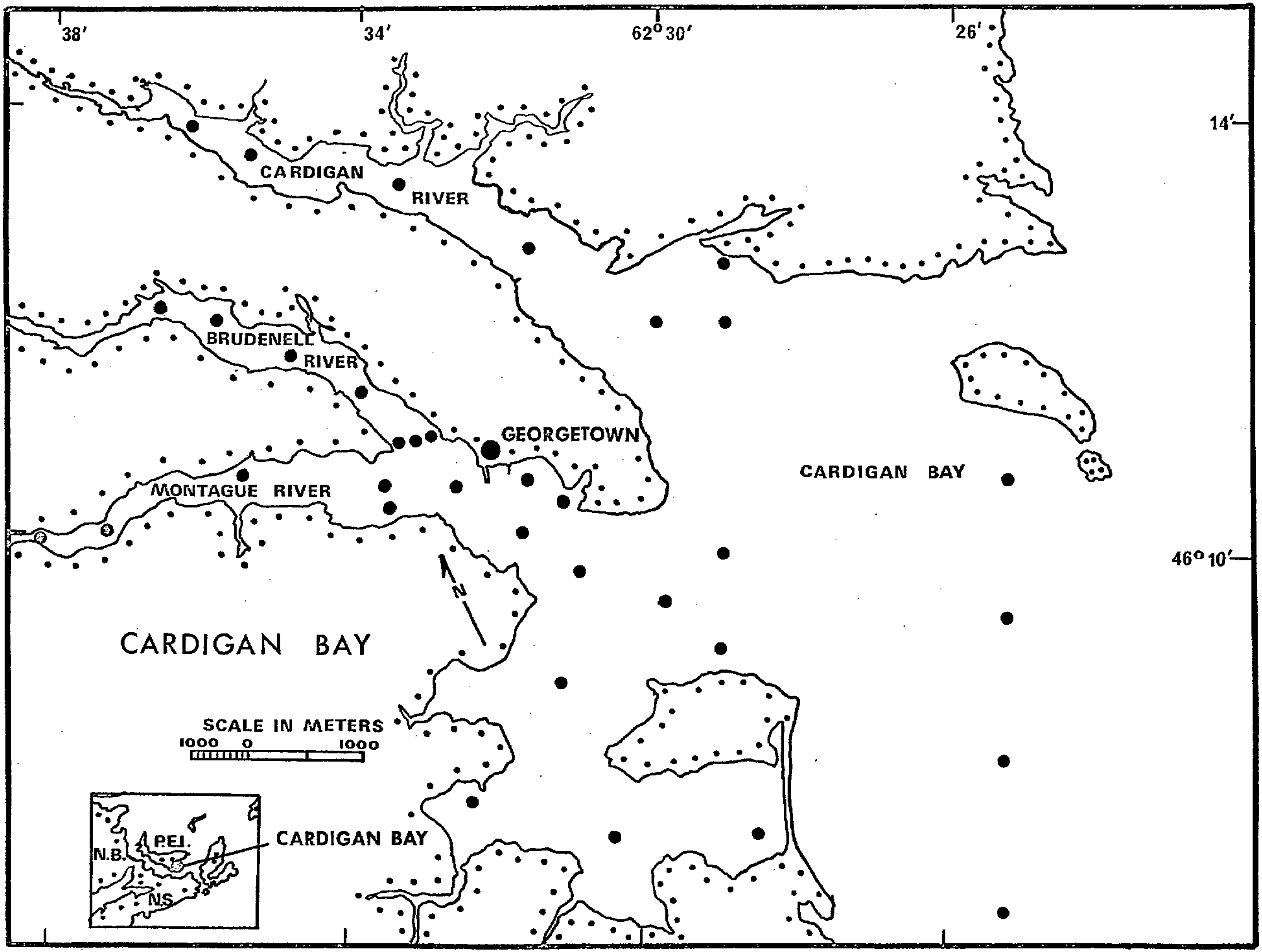
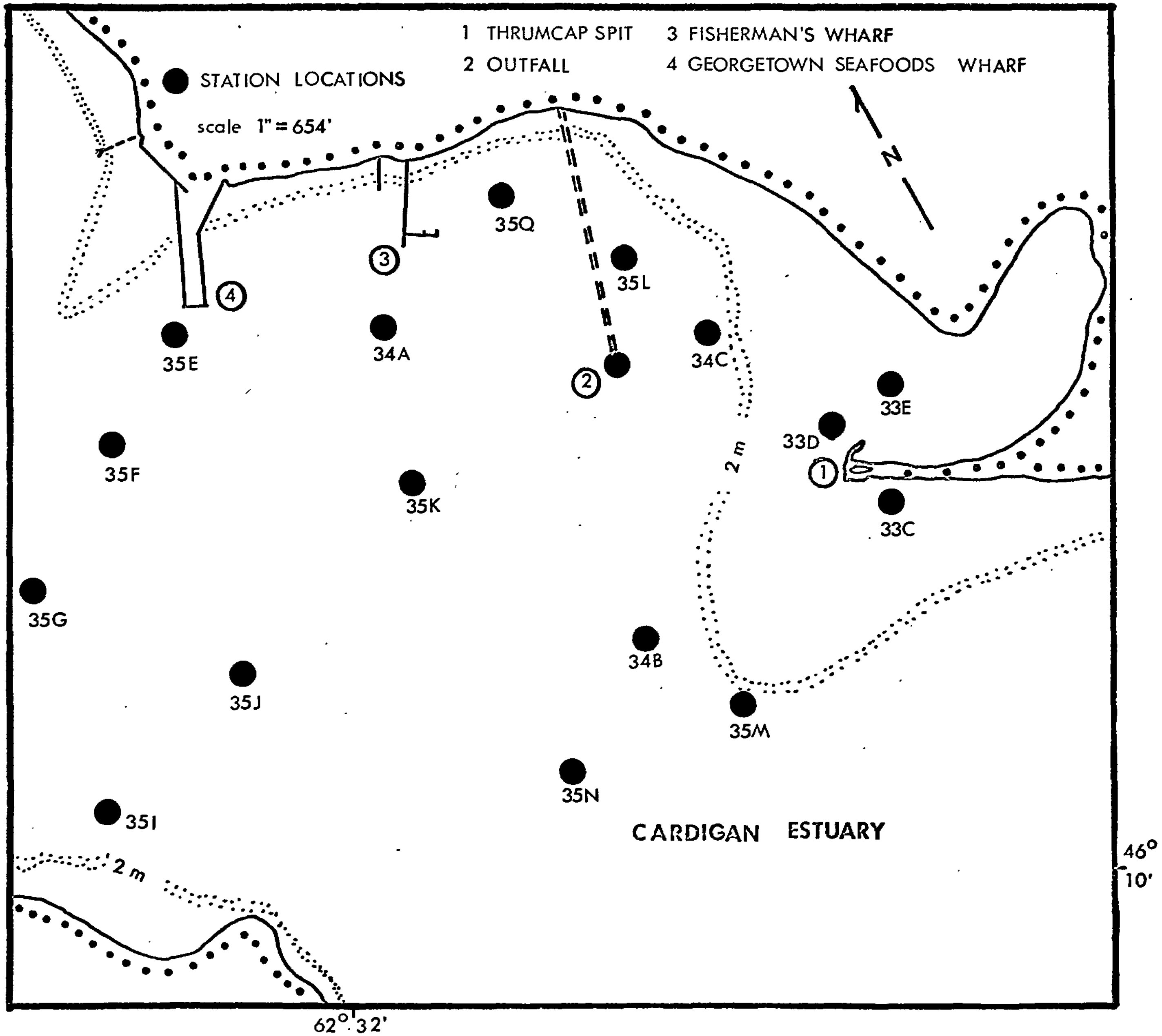

38'
34'
62° 30'
26'
14'
46° 10'
CARDIGAN
RIVER
BRUDENELL
RIVER
GEORGETOWN
MONTAGUE RIVER
CARDIGAN BAY
N
CARDIGAN BAY
SCALE IN METERS
1000 0 1000
P.E.I.
N.B.
N.S.
CARDIGAN BAY

FIGURE 1

FIGURE 2: Georgetown Harbour Showing Station Locations Utilized in the October Program.



1 THRUMCAP SPIT
2 OUTFALL
3 FISHERMAN'S WHARF
4 GEORGETOWN SEAFOODS WHARF
STATION LOCATIONS
scale 1" = 654'
N
35Q
35L
35E
34A
34C
2
33E
33D
35F
35K
2 m
1
33C
35G
34B
35J
35M
35N
35I
CARDIGAN ESTUARY
46° 10'
2 m
62° 32'

PLATE I (slide 3-35)/Height: 900'/Direction: NW/Date: Oct. 19/72/Time: 1050

Film: Fujichrome Colour, ASA 100

Plate I: illustrates the relationship of Thrumcap Spit and its submerged shoal to the rest of Georgetown Harbour. Note the arc described by the edge of the shallow sediments traced from the Fisherman's wharf, around the harbour to the right, and past the head of the spit to the point of the shoal. This indicates an active gyre of water flow in the harbour.

Note also the offshore extent of the shoal; it appears to be prograding laterally into, and up the estuary. (Depth of edge <1' at low tide.)

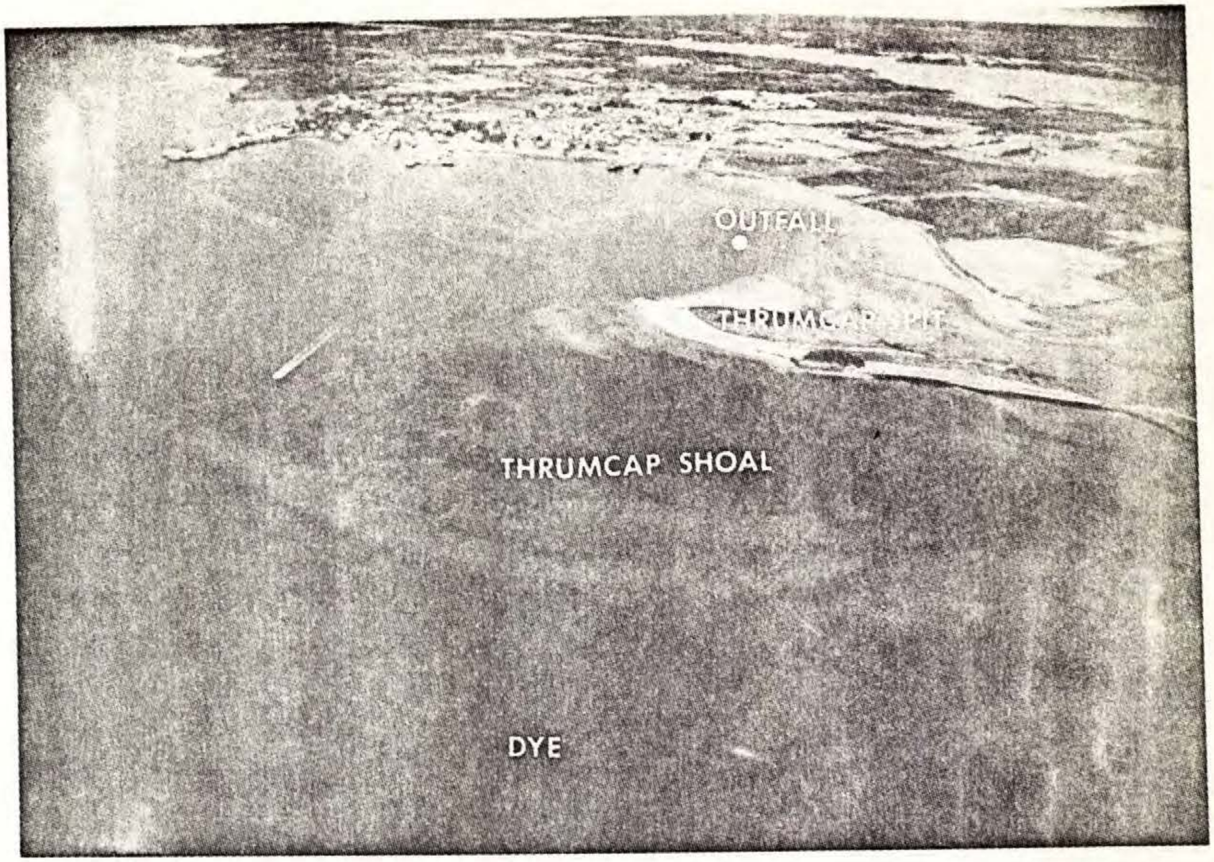
The dye released at station 35 M is faintly discernable at bottom, left of centre, moving to the lower right (downstream).

PLATE II (slide 6-3)/Height: 50'/Direction: W/Date: Oct. 19/72/Time: 1458

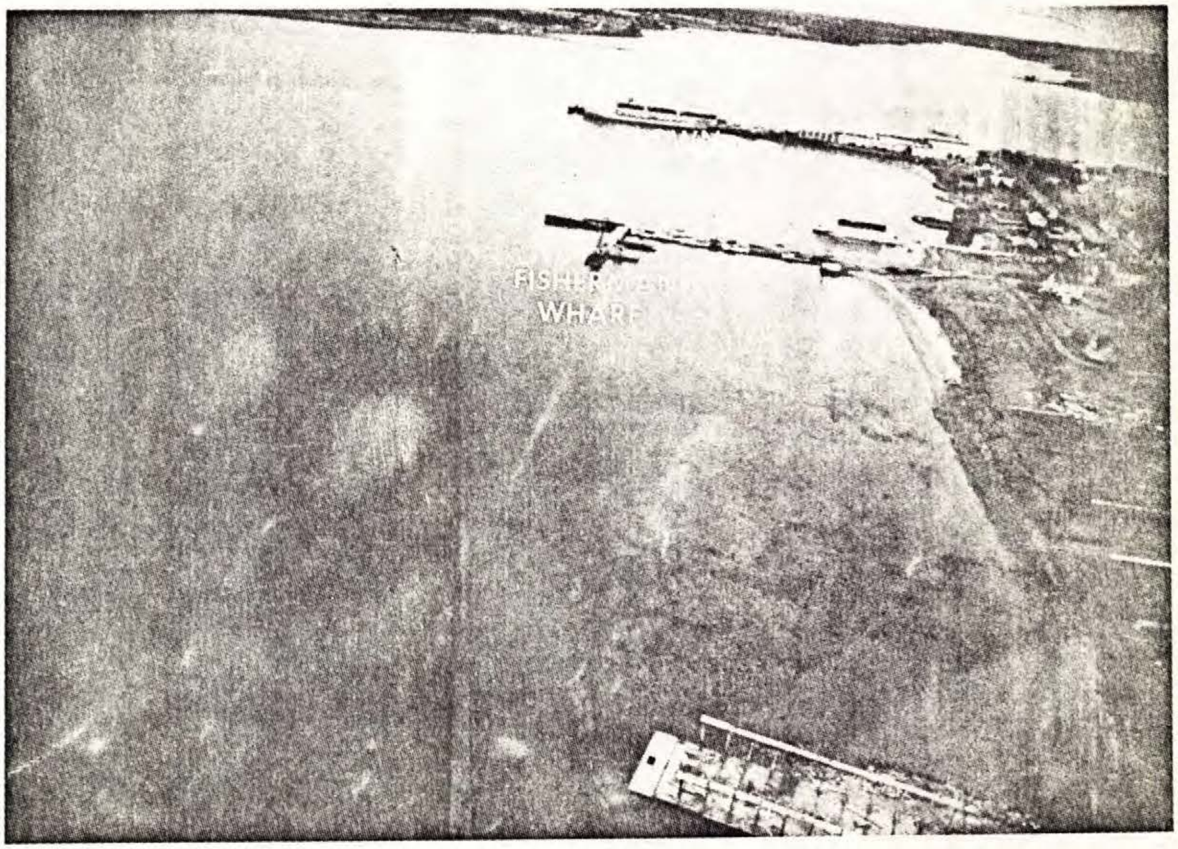
Plate II: Looking west along the harbour toward Montague. At centre, bottom, is the drydock, with the Fisherman's wharf centre and the Georgetown Seafoods wharf at the top of the picture.

Note the areas of dredging near the wharves, and the extent to which the wharves extend directly across the current from the natural shoreline. Such interference with the river and tidal currents creates severe backeddying both upstream and downstream from each wharf, resulting in considerable siltation within the harbour.

I



II



GEOLOGY:

The geology of the Georgetown Harbour area as outlined by Frankel (1966) has been substantiated by the present investigation. Unit B, as proposed by Frankel (1966) is the only rock unit present in the area. Non-pebbly sandstones are the most common rocks in the region. These outcrop occasionally, but are commonly covered by kame and valley edge kame complexes composed of well to poorly sorted sand and gravel, with local areas characterized by washed till. A salt marsh deposit overlying peat and grass occurs inside Thrumcap Spit (Plates III and IV).

Quartz is the dominant mineral in the glacial deposits and the bottom sediments in the harbour. Feldspar (orthoclase, microcline, and sodic plagioclase) is normally present in excess of 10 percent. Muscovite and biotite are the most common accessory minerals. Also present are ilmenite leucoxene, apatite, amphibole, chlorite, magnetite and garnet. Ferruginous material is generally present, both as detrital fragments and as a cementing agent. Manganese oxide is usually present as specks or pods up to 12 inches in diameter. Manganese concentrations are high throughout the harbour waters and bottom sediments.

Unit B (Frankel 1966) outcrops sporadically in Georgetown Harbour area. Conglomerates, conglomeratic sandstones, greywacke, lithic sandstones, arkose, feldspathic sandstones, siltstones, shales, claystones, and calcareous claystone breccias are the dominant rock types. The poorly indurated conglomerate and sandstone beds readily disintegrate, especially when exposed to wave action. The age of Unit B is not known. The only fossils found to date are poorly preserved plant impressions which date the unit as Lower Triassic to Permo-Carboniferous in age.

PLATE III (slide 4-2)/Height: 900'/Direction: SW/Date: Oct. 19/72/Time: 1052

Plate III: illustrates the morphology of the spit, as viewed from above the shore east of Georgetown. As in Plate I, note the recurved nature of the spit, the heavy deposition inshore from the spit, the offshore extent of the shoal and the drainage channels leading out of the salt marsh and lagoon (lower left to lower right). The deflection of the main drainage channel (bottom, centre) parallel to the shoreline suggests a current at ebb tide toward the shore (past the end of the spit and into the harbour). Since the sewer outfall is located just off the end of the spit some of the effluent is evidently carried back into the harbour, and incorporated with the suspended load and sediments.

PLATE IV (slide 4-28)/Height: 250'/Direction: SW/Date: Oct. 19/72/Time: 1300

Plate IV: is a detail of the drainage channels from the lagoon (see Plate III, extreme lower right).

III

IV

The glacial-fluvial deposits (ice-contact, stratified drift) in the area are kames, kame terraces and valley-edge kames. The prominent deposits are the multi-step kame terraces and the valley-edge kames whose heights range from 5 to 100 feet but are generally not more than 30 feet. Well developed, discontinuous deposits occur along the Montague, Cardigan and Brudenell Rivers and provide most of the available sediment to the marine environment. The major components of the glacial material are quartz and feldspar.

WATER CHEMISTRY:

Major elements, minor elements, pesticides and herbicides have been analyzed during the summer months (May 1 - September 30, 1972) and during the October sampling period for the Georgetown Harbour environment. Analysis were completed on the following:

Turbidity	N (total Kjeldahl, nitrate+nitrite diss. ammonia)	SO_4 (diss.)
Colour		SiO_2 (reactive)
pH	O_2 (total chem, demand)	Na (diss.)
C (total, organic)	PO_4 (diss. inorganic)	An (ext., diss.)
Cl (diss.)	P (total)	Hardness
Cu (ext., diss.)	K (diss.)	Sodium Absorption Ratio
F (diss.)	Specific Conductance	% Sodium
Fe (ext., diss.)	$CaCO_3$ (alkalinity acidity, hardness)	Cd (ext.)
Pb (ext., diss.)	Ca (diss.)	Hg
Mg (diss.)	O_2 (consumed)	

TABLE 1

COMPARATIVE WATER CHEMISTRY IN SELECTED ESTUARIES
(in parts per million)

Parameter	Summerside	Charlottetown	Cardigan
Turbidity	2.9	2.9	0.20
Colour	5	<5	5
pH	7.1	7.2	7.1
Carbon: (organic)	1.0	3.5	5.5
Chloride: (dissolved)	15,600	16,400	15,400
Copper: Ext. (Cu)	<0.002	<0.002	0.006
Fluoride: Diss. (F)	2.3	2.6	2.0
Iron: Ext. (Fe)	0.02	0.02	0.08
Iron: Diss. (Fe)	<0.01	<0.01	<0.01
Lead: Ext. (Pb)	<0.002	0.002	0.003
Magnesium: Diss. (Mg)	1080	1080	970
Manganese: Ext. (Mn)	0.030	0.008	0.009
Manganese: Diss. (Mn)	<0.002	<0.002	0.017
Nitrogen: Total Kjeldahl (N)	0.1	0.3	0.1
Nitrogen: Nitrate/Nitrite	0.018	0.010	0.250
Phosphorous: Total (P)	0.003	0.05	<0.003
Phosphorous: Dissolved Inorganic	<0.003	0.025	<0.003
Calcium: Dissolved	320	320	325
Sulphate Dissolved	2111	2209	2254
Silica: Reactive (SiO_2)	0.1	0.5	0.4
Zinc: Dissolved (Zn)	.081	<0.002	<0.001
Cadimium: Ext. (Cd)	<0.002	<0.001	0.001
Mercury: Total (Hg)	.00018	.0005	.0025

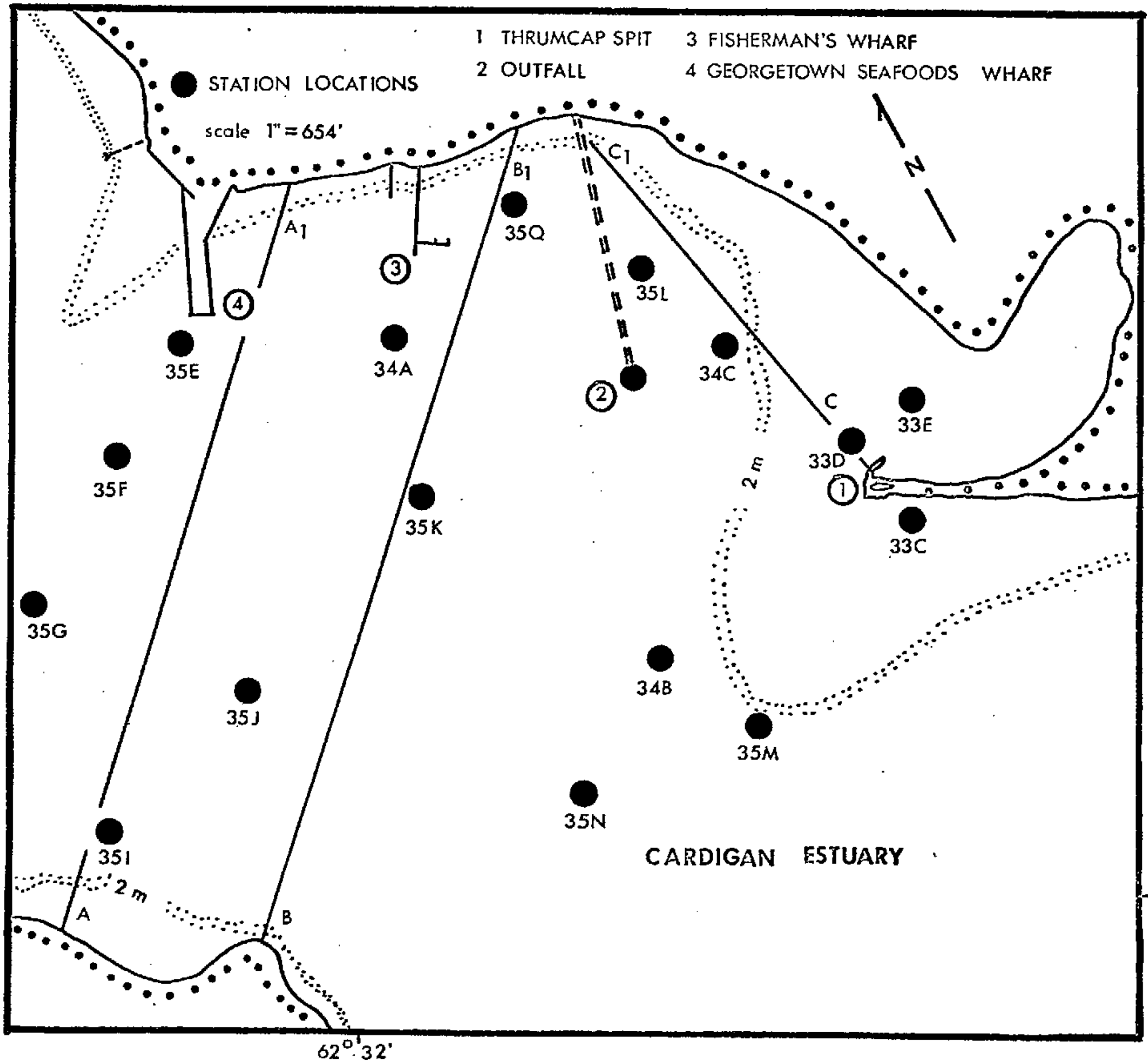
Herbicide and pesticide content are consistently less than .005 micrograms per litre. p,p' - DDT; 2,4-D and 2,4,5-T are always less than 0.010 micrograms per litre and p,p' - methoxychlor is commonly less than 0.050 micrograms per litre.

Lindane	Heptachlor Epoxide	γ-Chlordane	Endrin
Heptachlor	p,p'-Methoxychlor	β-Endosulfan	o,p-DDT
Aldrin	Endosulfan Isomers (α+β)	Dieldrin	2, 4-D
α-BHC		p,p' -DDD	2,4,5-T
	α-Chlordane		
p.p'DDE		p.p'-DDT	

Surface salinities (Figure 4) range from 28.73°/oo (Station 33B). Bottom salinities (Figure 4) range from 29.02°/oo (Station 34C) to 30.02°/oo (Station 35J). Temperatures range from 8.27°C to 8.80°C. During a year-long monitoring program temperatures of 0°C to 20°C were recorded. The hydrogen ion concentration (pH) is always alkaline, ranging from 7.0 to 7.8, although acidic values to 5.6 were recorded immediately (1 cm. to 10 cm.) below the sediment-water interface. Similarly, oxidation-reduction (Eh) readings range from +150 mv to +500 mv. The oxygen content varies from 6 to 9 ml/1, with slight changes between top and bottom waters.

Calcium, Mg, Na and K are almost totally controlled by water depth, rainfall, tide, and varying degrees of mixing caused by tidal changes. In general, Cu, Pb and Cd are relatively constant near the detection limit and are not useful as general pollution indicators. Zinc concentrations are relatively steady in Georgetown Harbour with higher readings in the Montague, Brudenell and Cardigan Rivers. Mn concentrations are very high and relatively constant within the harbour and suggest a strong land influence (see page 6).

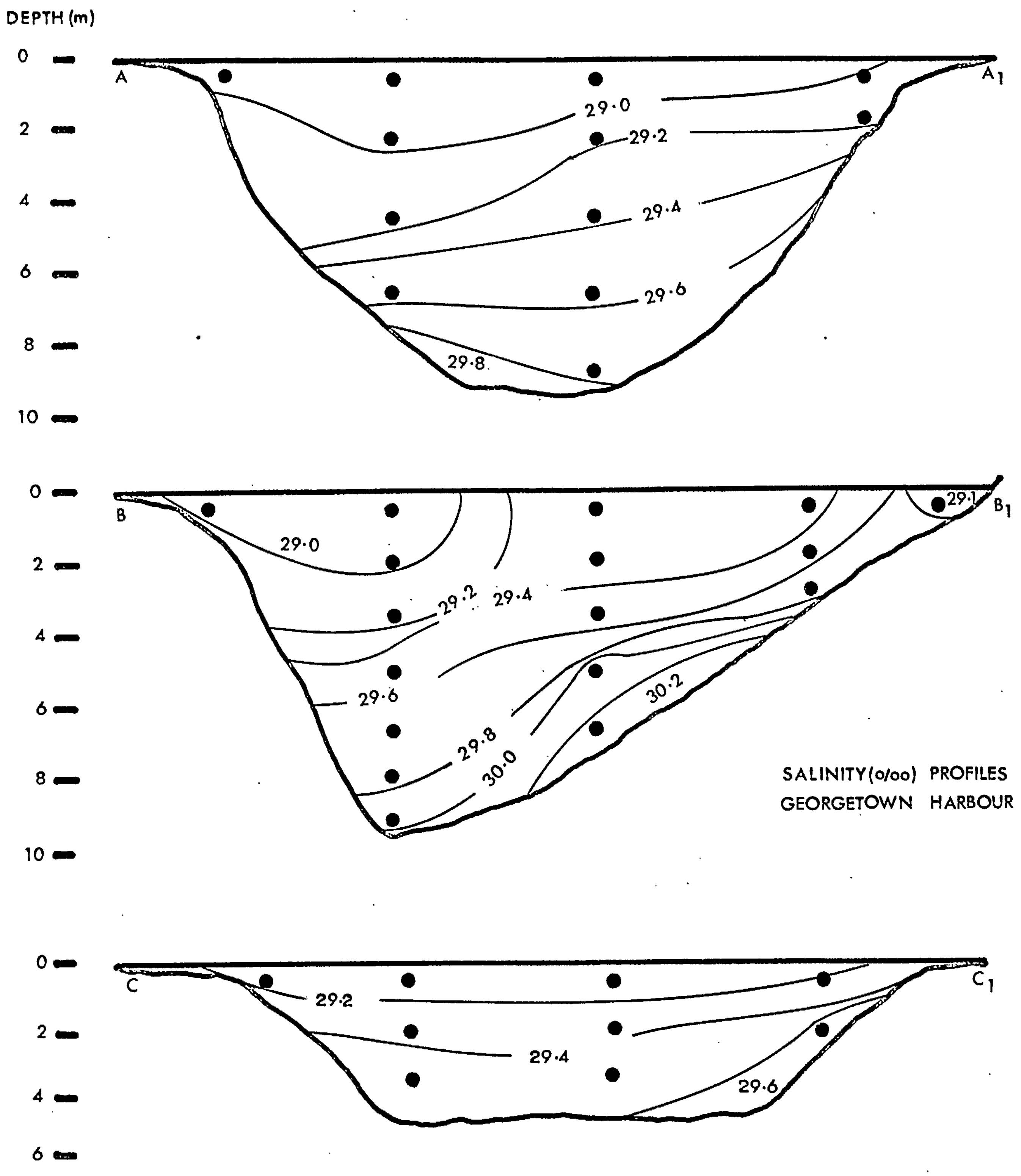
FIGURE 3: Cross Sections Utilized for Salinity Profiles
Shown in Figure 4.



1 THRUMCAP SPIT
2 OUTFALL
3 FISHERMAN'S WHARF
4 GEORGETOWN SEAFOODS WHARF
STATION LOCATIONS
scale 1" = 654'
N
A1
B1
C1
A
B
C
35Q
35L
35E
34A
34C
33E
33D
33C
35F
35K
35G
34B
35J
35M
35N
35I
2 m
2 m
CARDIGAN ESTUARY
46°
10'
62° 32'

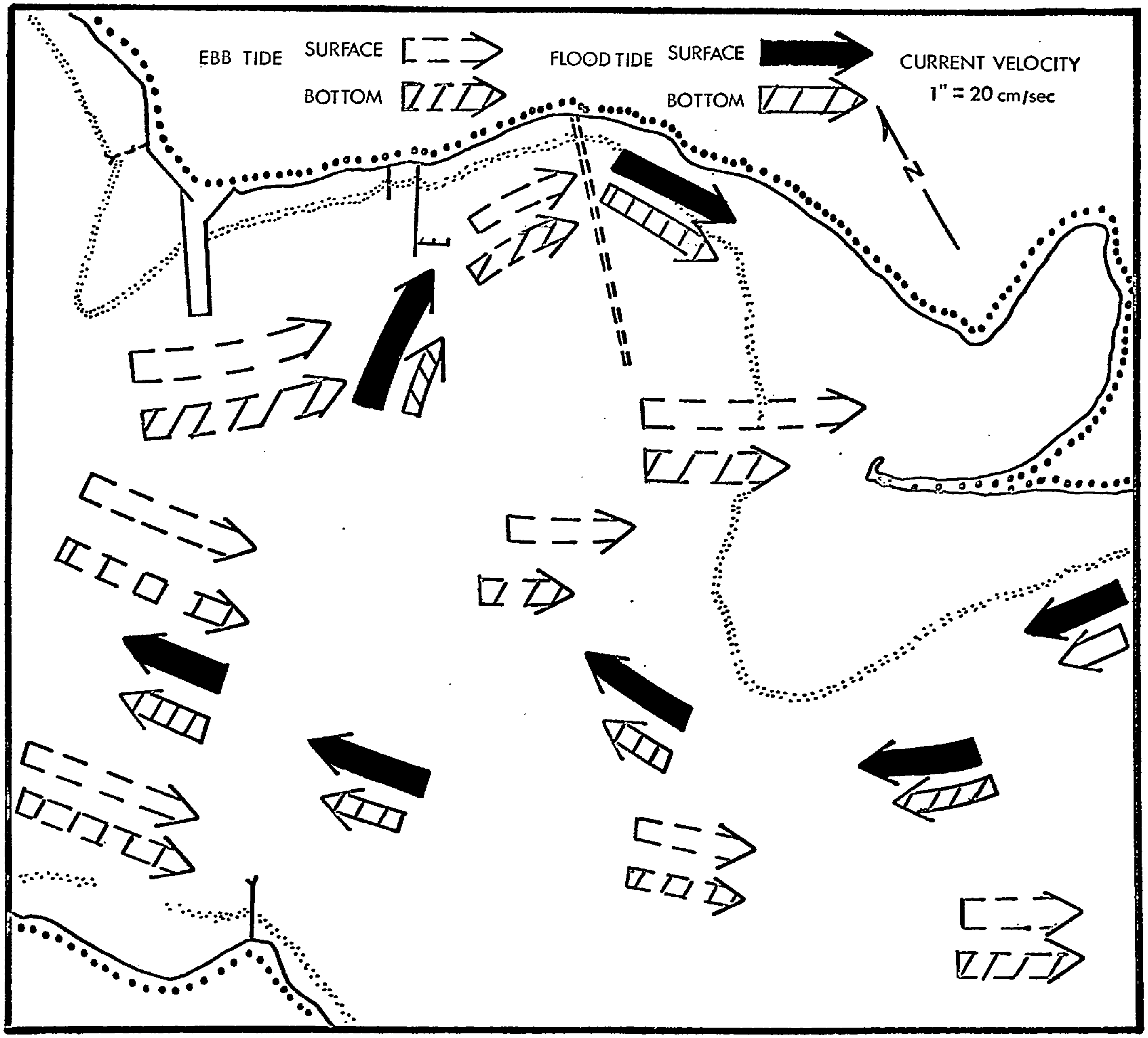
FIGURE 4: Salinity Profiles in Georgetown Harbour.

Note Slight Changes in Salinity with Depth and from Left to Right in Profiles A-A' and B-B'. (A and B represent the right-hand side of the estuary looking seaward)



SALINITY (o/oo) PROFILES
GEORGETOWN HARBOUR

FIGURE 5: Current Flow Patterns during Flood and Ebb Tide. Note the Gyre Effect adjoining the Sewer Outfall, Longshore Drift adjacent to Thrumcap Spit and the flow around the Spit.


EBB TIDE
SURFACE
BOTTOM
FLOOD TIDE
SURFACE
BOTTOM
CURRENT VELOCITY
1" = 20 cm/sec
N

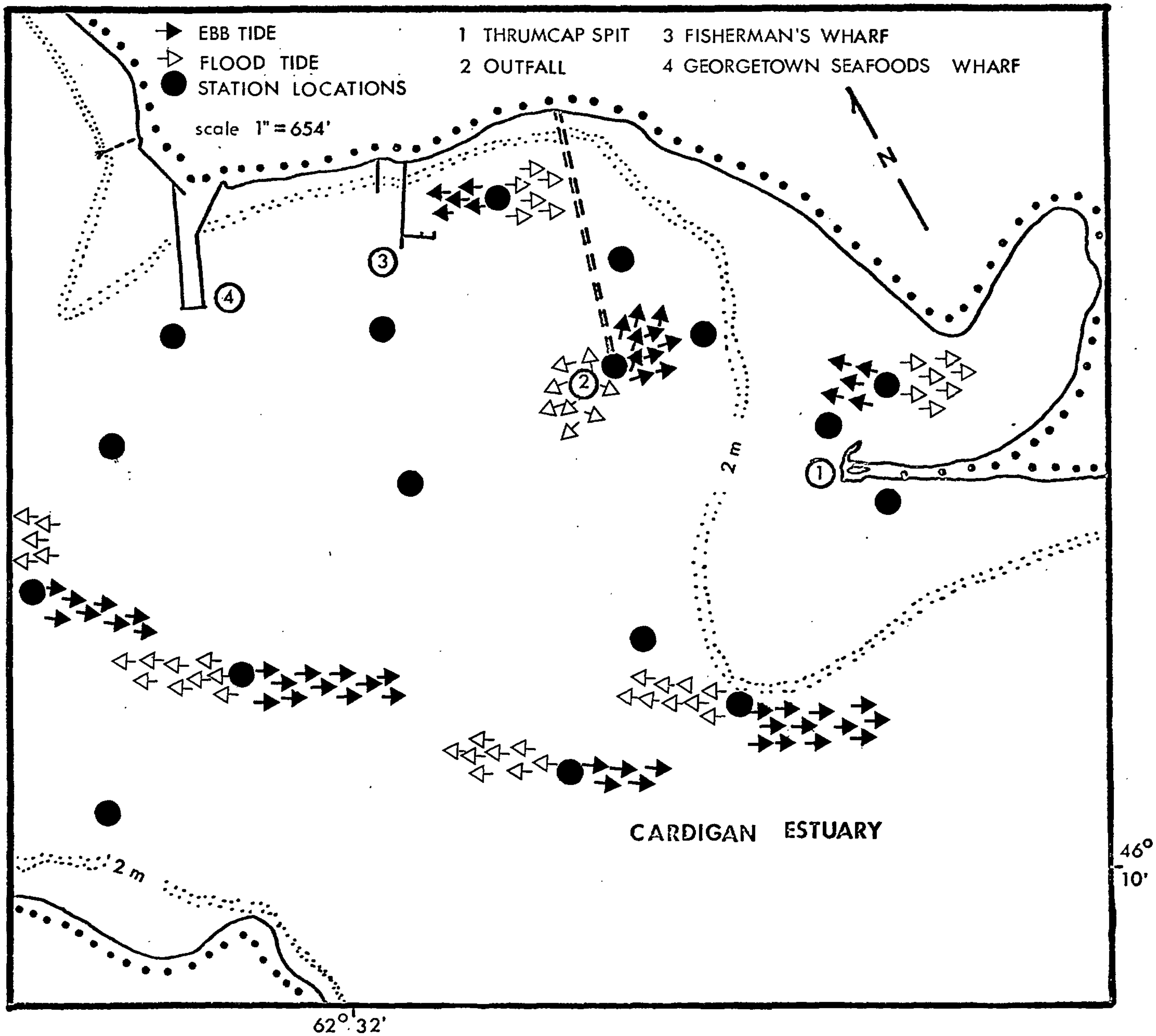
Better background data is required to assess the chemical variations present. This involves the results from more frequent sampling at a larger number of stations to determine the variations that occur on a given day within the harbour. Herbicides and pesticides in all cases are below the detection limit, and due to the time and effort involved, sample numbers should be reduced. In summary, a short-term water chemistry program has not shown major trends or provided information on specific aspects of chemical pollution within the harbour.

CURRENT CHARACTERISTICS:

The current flow in Georgetown Harbour (Figures 5, 6, Plate VI) during both ebb and flood tides was measured with flow meters, Rhodamine B dye and floats. Current velocity and direction were measured at the surface, in regions with marked changes in salinity, and immediately above the bottom. Measurements were also recorded at specific depths. Dye and float dispersal patterns (Figures 6, Plate VI) were photographed from a helicopter utilizing a 35 mm. camera with Fujichrome film with an ASA of 100.

Current velocities during flood tide ranged from 10 cm. to 25 cm. per second in surface waters and from 12 cm to 25 cm. per second in bottom waters (3 to 15 meters in depth). Surface currents were comparable to, or slightly higher than bottom currents at all stations. Slightly higher or slightly lower readings were recorded at intermediate depths (3 m to 5 m) below the surface and were commonly associated with salinity differences related to two layer circulation. The net volume transport during flood tide is toward the harbour in a north-northeasterly direction. An intermittent anticlockwise gyre was noted in the region of stations 34A, 35K and 35Q, with a resultant two-directional pluming effect at the outfall. Flood currents sweep around Thrumcap Spit and deposit sediments derived from a

FIGURE 6: Dispersion Patterns of Rhodamine B Dye in Georgetown Harbour during Flood and Ebb Tide.



EBB TIDE
FLOOD TIDE
STATION LOCATIONS
scale 1" = 654'
1 THRUMCAP SPIT
2 OUTFALL
3 FISHERMAN'S WHARF
4 GEORGETOWN SEAFOODS WHARF
N
2 m
2 m
CARDIGAN ESTUARY
46° 10'
62° 32'

seaward direction in this region. Sediments dumped during a dredging operation were immediately transported along the spit and those that were not deposited on the shoals were transported back into the harbour.

Current velocities in surface waters during ebb tide (Figure 5) ranged from 12 cm. (Station 35J) to 30 cm. per second (Station 34C), whereas bottom velocities ranged from 18 cm. per second at a depth of 8 meters immediately outside Thrumcap Spit (Station 33B) to over 60 cm. per second at a depth of 12 meters near the right bank of the main channel (Station 35J). Maximum velocities would be expected in this region during ebb tide. Velocities were uniform from the surface to the bottom (10 cm.) at Station 35C-the most Shoreward station used during the study. The greatest change from top to bottom was recorded at the most westerly station (35J) where the surface velocity was 12 cm. per second and bottom velocity was 60 cm. per second.

Currents associated with the ebb tide (Figure 5) flow in an east-south-easterly direction or in the opposite direction toward Cardigan Bay. In the inner harbour, adjoining the outfall and at station 34C, the main current trends are along shore, southeast to south, and east to northeast, with a "piling up" inside of Thrumcap Spit. This movement entraps river borne sediment, harbour refuse and sewer effluent in the small inlet and salt marsh formed originally as a result of the development of Thrumcap Spit (Plates I, II, III, IV).

The dispersion patterns of Rhodamine B dye (Figure 6; Plate V & VI) substantiate the current meter readings. Two-directional flow is associated with the sewer outfall whereas unidirectional flow depends on the state of

PLATE V (slide 2-35)/Height: 250'/Direction: NE/Date: Oct. 19/72/Time: 0945

Plate V shows the relationship of the lagoon and salt marsh as a whole to the spit. Note the shoal in the foreground, and the width of the peninsula on which Georgetown is situated (see also: Plate I). The extreme offshore edge of the shoal is covered with only about 0.03 meters of water at low tide. Landward, this depth increases to about two meters, and then shallows to less than 0.03 meters toward the spit. Moving offshore from the shoal break, the water depth increases rapidly to about 6 or 7 meters.

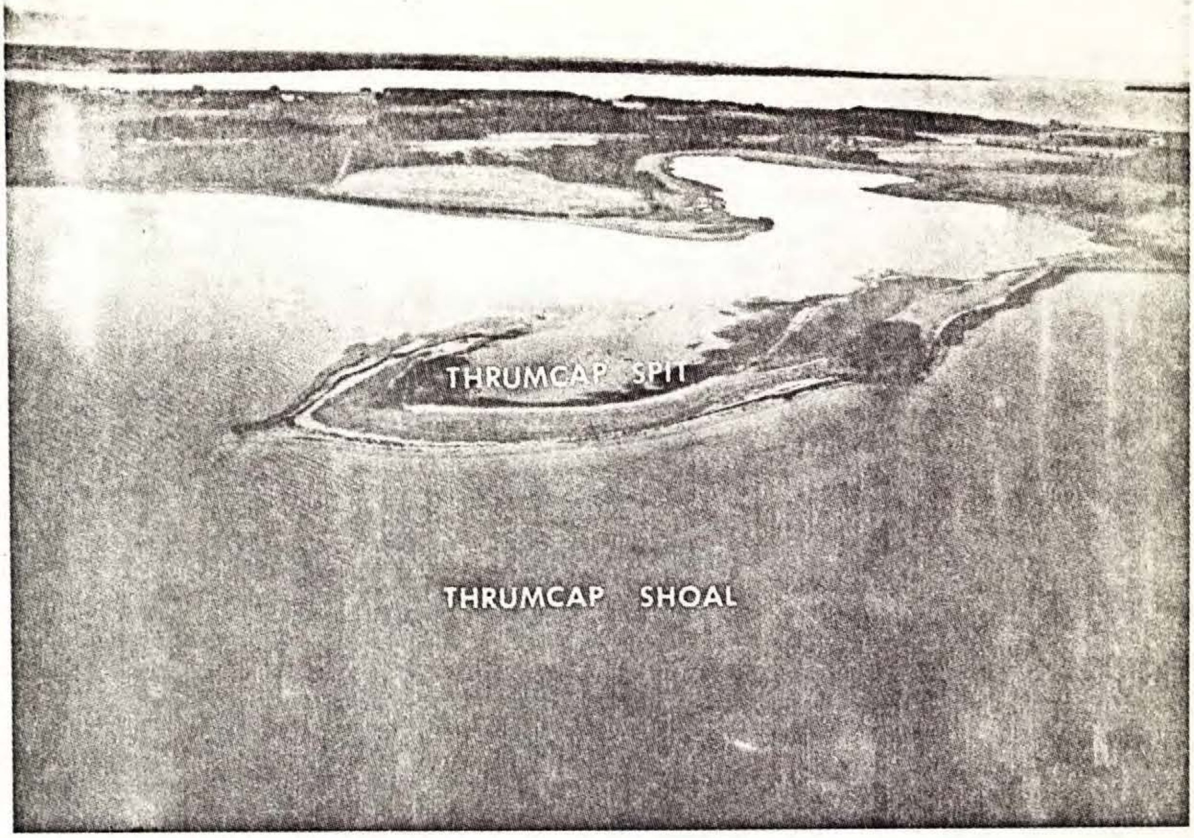
PLATE VI (slide 3-21)/Height: 250'/Direction: S/Date: Oct. 19/72/Time: 1025
Tide: Ebb

Positioned over Thrumcap shoal, looking offshore, this photograph shows the shoal break (mentioned in conjunction with Plate V) and the dye released at Station 34B.

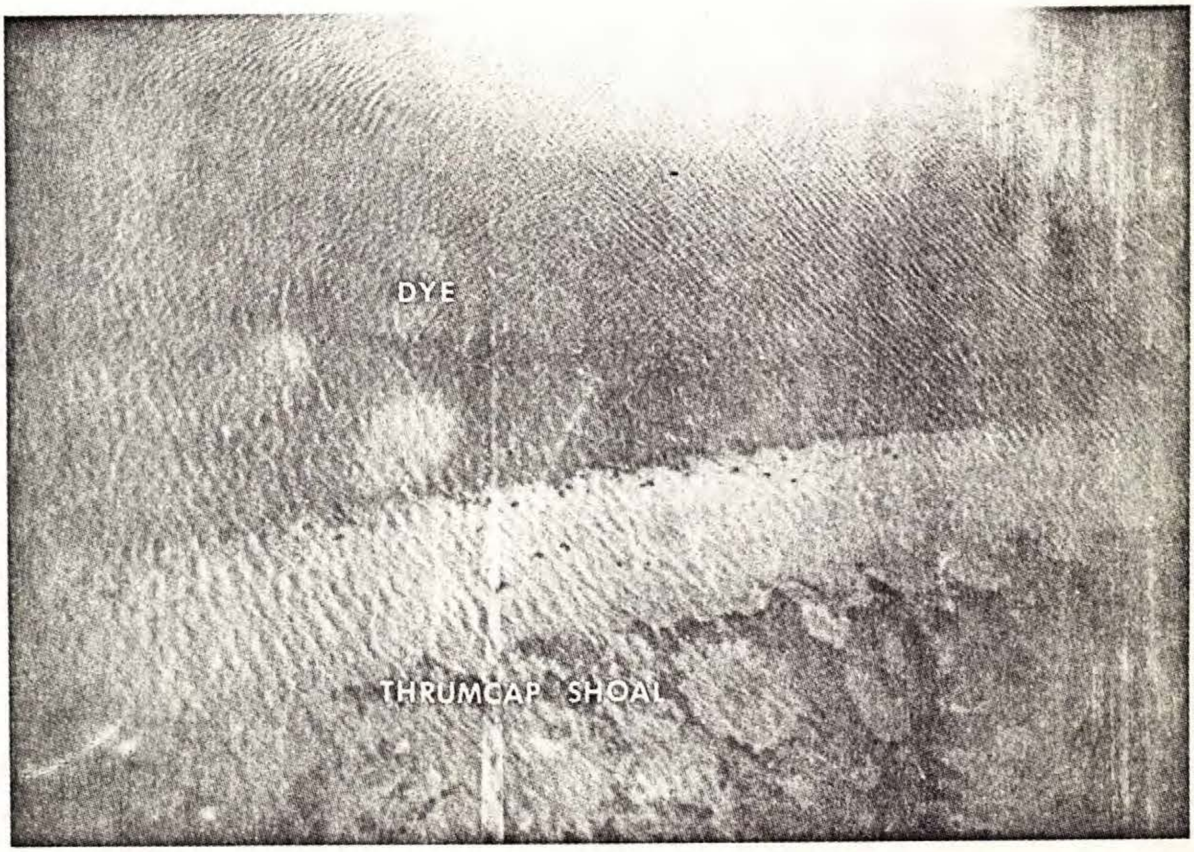
The light coloured sand on the shoal break is at a depth of approximately 0.5 meters and is a recent addition. From this point, the shoal drops off steeply to 6 or 7 meters at Station 34B, which is shown in the photograph by a small, white, anchored buoy just right of centre. The dark coloured area shows encroachement of marine plants and stabilization of the shoals. Sediment piracy of Thrumcap Spit is evident in Plate III.

The red dye in the photograph was released at the buoy at 1000 hours. In 25 minutes, it has moved about 80 meters downstream (eastward, toward the left of the picture). This movement indicates the effect of the river and ebb currents seaward. The dye has remained in a fairly consolidated mass, whereas dye dropped in the centre of the channel rapidly dispersed linearly downstream, travelling about 4 times the distance in the same time period.

V



VI



ebb or flood tide. Initial dispersion is relatively slow, although complete dispersion occurs within forty-five minutes of introduction.

Current velocity readings at selected stations through a complete tidal cycle substantiated short term readings at individual stations.

The oscillatory flood and ebb of the tidal currents are the most obvious water motions in the harbour. However, strong winds create a high degree of turbidity in the shallower inshore regions. The tidal currents provide the energy for the mixing of the ocean water and freshwater in the harbour. It is believed that a net non-tidal circulation pattern is superimposed on the oscillatory tidal currents. This is characterized by a seaward flow in the upper layers (above 4 meters) and a flow directed up the estuary below this level. However, waters are quite well mixed within the harbour and the development of characteristic two-layer circulation is concentrated upstream in the Montague and Brudenell Rivers.

In order to preserve continuity, water which flows into the harbour in the deeper layers must be returned seaward in the upper layers. Consequently there must be a net vertical flow upward. This flow, which is believed to be quite small in this area, requires further study and cannot be determined at present.

The surface of no net motion varies across the harbour and is deeper on the western than on the eastern side. Consequently, the layer of net seaward drift extends to greater depths on the western side of the harbour, while layers with a net flow upstream in the harbour extend nearer the surface on the eastern side of the harbour. This has important bearing on distribution of river and marine borne sediments and sewage within the harbour. Circulation and sedimentation is discussed in a later section (page 25). The harbour varies from Pritchards' (1971), Type B, partially mixed to his Type C, vertically homogeneous estuary. In both instances the Mixing Index (M.I.) is less than 1.

1. The Mixing Index*[1] is defined as: $\dfrac{\text{volume of freshwater entering during a half tidal period}}{\text{volume of salt water entering during a flood tide}}$

In this respect the limit of salt intrusion (and sediments) moves upstream and downstream in response to changes in both river flow and tidal penetration. Suspended material in the surface layers which settles into the lower layers will be returned upstream and may accumulate there rather than downstream from the original source.

SUSPENDED LOAD:

Samples for suspended sediment concentration were collected at meter intervals from the water surface to the sediment-water interface at all stations. Analyses were conducted on suspended sediment concentration (mg/l) and organic carbon. Suspended sediment is contributed by the Montague and Brudenell Rivers, shore processes, sewer outfall, marine processes, biological activity and resuspension during periods of excessive turbulence. Maximum concentrations of suspended sediments are anticipated during spring freshet and periods of heavy rainfall with associated erosion. Therefore, the present sample period (October) should represent turbidity minima. However, during the September sampling period dredged material was dumped immediately outside the harbour entrance (Station 33B) which increased

---

[1] Schubel, J.R. 1971: "Estuarine Circulation and Sedimentation", <u>in</u> The Estuarine Environment, A.G.I., Chapter VI, page 2.

PLATE VII. Photograph of sediment substrate (sand) on Thrumcap Shoals. Note especially the well developed unidirectional and variably directed ripple markings.

suspended load by 100 X to 300 X. It is believed that dredging practices have contributed significantly to development of Thrumcap shoal. Similarly, heavy rains and strong winds may have contributed to increased suspended load (greater than normal) during October, although the content was low.

Suspended load in Georgetown Harbour during the year varied from 5 mg/l in the surface waters (Station 35M.) to 80 mg/l in the bottom waters (Station 34A). Areas shoreward from the main harbour had concentrations ranging from 20 mg/l to 60 mg/l. Surface waters at all except the main channel stations had lower concentrations than bottom waters. Rivers adjoining the harbour had concentrations of 8 mg/l to 90 mg/l in surface waters and 40 mg/l to 90 mg/l in surface waters and 40 mg/l to 90 mg/l in bottom waters.

During the October sampling period the suspended load was considerably reduced. During flood tide surface concentrations ranged from 1 mg/l (Station 35K) to 12 mg/l (Station 35G) and bottom concentrations were comparable, 3 mg/l (Station 34A) to 11 mg/l (Station 35L). Concentrations at intermediate depths (saltwater wedge) were also variable. Suspended loads were higher within the main harbour than immediately upstream.

During ebb tide suspended load concentrations were also low with surface readings ranging from 4 mg/l (Stations 35N) to 8 mg/l (Station 35P). Bottom concentrations ranged from 2 mg/l (Station 33A) to 10 mg/l (Station 33b). Suspended loads at intermediate depths were lower (1 mg/l to 2 mg/l) at all stations.

According to Schubel (1971) flocculation cannot produce "turbidity maxima" in the lower reaches of estuaries. The zone of high suspended sediment concentration is produced by a combination of physical processes -

the periodic local resuspension of bottom sediments by tidal scour and the sediment trap produced by the net non-tidal estuarine circulation which entraps much of the sediment both resuspended and newly introduced. Thrumcap Spit and Thrumcap Shoal form effective regions of entrapment during both flood and ebb tide. Dredging and dumping practices and construction of wharves within the harbour have contributed significantly to siltation and turbidity in this region (Plates I-VI).

SEWAGE DISCHARGE

Industrial and municipal effluents daily contribute significant amounts of sediment to Georgetown Harbour. It has been shown (Bridgeo, 1966; Rambow and Hennessy, 1965; Redfield and Walford, 1951; Wheatland et. al. 1964) that the capacity of marginal marine waters to degrade and dilute waste material depends upon waste volume flow, freshwater flow, tidal currents, wind conditions, temperature, basin size and shape and numerous other factors. The combination of these effects changes constantly at any one area. Consequently, an analyses of the "record" as well as short term monitoring is essential for proper analysis.

The region adjoining the sewer outfall at Georgetown (Plate VII) contains highly organic oozes, high concentrations of white to grey organic and inorganic suspensions and large quantities of fish remains (2.5 X 30 cm. to 15 X 30 cm.). Sea gulls feed constantly in this area, and local inhabitants report that it is an extremely favourable area for smelt fishing. The flow of effluent from Georgetown Seafood Products varies from 300,000 to 700,000 gals. per day. Human waste contribution is commonly calculated at 0.5 lb per person per day. Major concentrations of both suspended and coarse floating material were recorded during the daylight hours (8 a.m. - 5 p.m.) which apparently coincided with plant operation at Georgetown Seafoods.

Sea gulls removed most of the coarse floating material; however, the finely suspended material was transported into the salt marsh area bounded by Thrumcap Spit, onto and beyond Thrumcap shoal and toward the Fisherman's wharf in the inner harbour (Plates III & IV).

The removal of physical (coarse floating material) pollution is desirable from the point of view of aesthetics and fouling of the shoreline. Because of the enclosed nature of the harbour, the fine suspended material is contributing significantly to pollution and the development of an anoxic hydrogen sulphide and methane-emitting bottom environment with the introduction of significant numbers (commonly greater than 100 per ml.) of bacteria (see page 34) to the watermass and bottom sediments. Each operation must be examined critically to insure that effluent is correctly treated, and that the disposal site is properly chosen in relation to environmental characteristics, to protect fishing and recreational areas and other interests which could be adversely affected.

It has been shown by Bridgeo (1966) and other authors that sewage discharged into the marine environment is diluted in two stages: 1) the first occurs in the immediate vicinity of the outfall (Plate VIII) as the sewage rises to the surface in the form of a stream and its kinetic and potential energy is dissipated by turbulent mixing; 2) the second occurs as the sewage drifts from the outfall and is dispersed laterally and vertically by currents which are critical in the mixing of surface and deeper water layers (see page 10). The second phase of sewage and sea water mixing in Georgetown Harbour is limited to the upper 2 m to 5 m and dilution rates are extremely slow, because of the relatively slow current movements within the harbour. More rapid dilution would require an extension of the outfall to the main channel or significantly outside Thrumcap Spit in Cardigan Bay. Lower layer circulation within the channel would move significant quantities upstream (back into the harbour). The extension of the outfall beyond the spit is believed to be financially unreasonable at the present time. Dumping harbour dredgings and sewer effluent farther seaward appears more practical at present.

BOTTOM SEDIMENTS:

Sediments in Georgetown Harbour (Figure 6, Plate VII, Table 2) are introduced by the Montague and Brudenell Rivers, natural and man-induced shore erosion, dredging and dumping practices, biological activity and the sea. Sources therefore, may be considered as external, marginal and internal. At present, the amount of sediment derived from each source is not quantitatively known but is under investigation. However, mineralogy and sediment characteristics indicate that the rivers and long shore drift are the major contributors. The need for frequent dredging and the rapid growth of Thrumcap Spit (as interpreted from a comparison of hydrographic charts, air photos and sediment cores) and regions immediately adjoining it substantiate these conclusions. A thorough discussion of sedimentation in other coastal zone environments may be found in Bartlett, 1966; Greer, 1969; Guilcher, 1963; Meade, 1969; Postma, 1967; Rusnak, 1967; Schubel, 1968, 1969, 1971; and Van Stratten 1960; to name only a few. Yalin (1972) has thoroughly discussed the mechanics of sediment transport.

DISTRIBUTION

The sediments in Georgetown Harbour vary from fine grained silty clays

TABLE 2

SEDIMENT SIZE DISTRIBUTION IN GEORGETOWN HARBOUR

Station 8	Sand%	Silt%	Clay%
35A	57	8	35
35C	5	34	61
35D	45	15	60
35E	79	4	17
35G	5	37	58
35J	20	25	55
35L	44	25	31
35M	65	1	34
35N	25	10	65
33C	92	3	5
33D	96	1	3
33E	100	0	0

PLATE VIII (slide 5-8)/Height: 250'/Direction: E/Date: Oct. 19/72/Time: 1413

Tide: Ebb

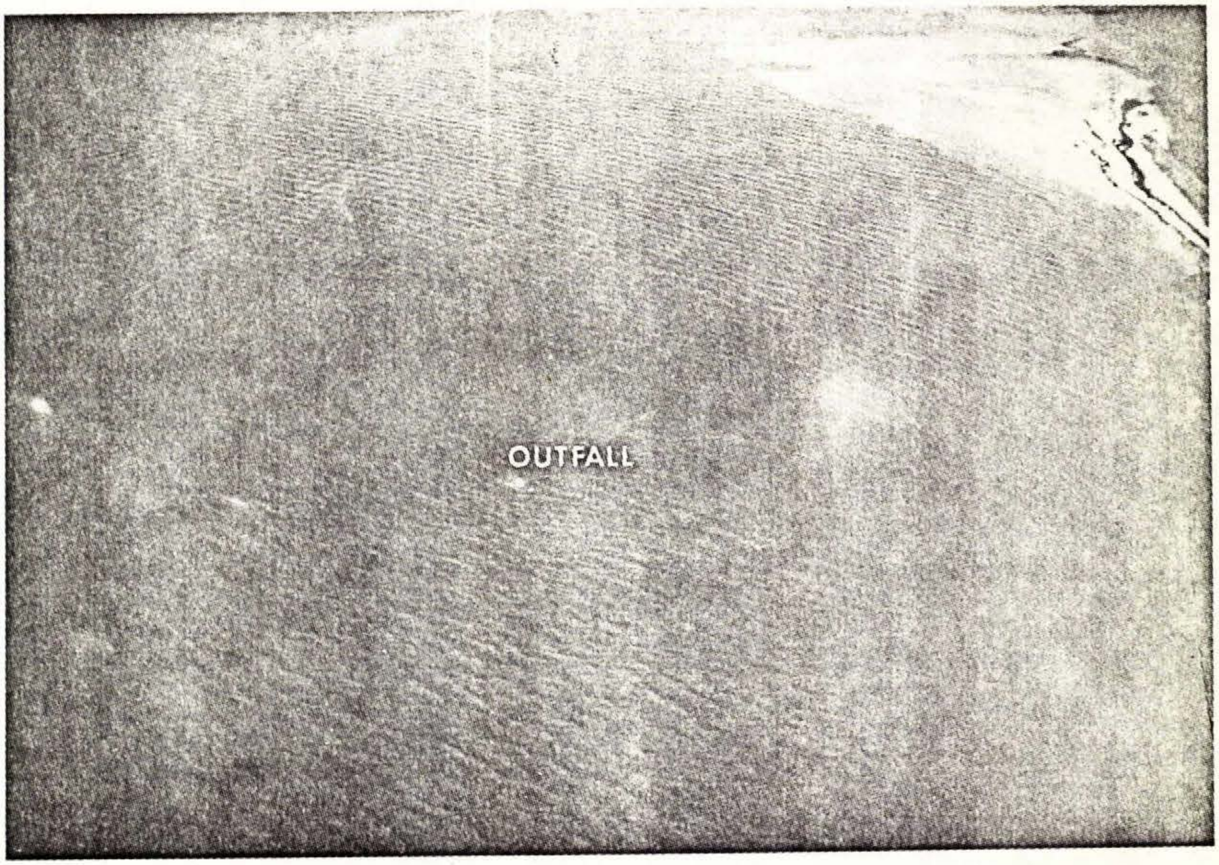
This photograph was taken from a position over the centre of the harbour, looking toward the recurved limb of Thrumcap Spit.

The sewer outfall is almost centered in the photograph, and shows up as a white upwelling in the water. The water depth over the outfall is 5 to 6 meters. An oval of lighter coloured water can be seen in the photograph, indicating to some extent the multidirectional dispersal of the waste material. The water immediately about the outfall, when viewed from a boat, is filled with waste debris, and large numbers of gulls constantly feed on the large pieces of fish remains in the area.

Dye was released in the outfall at approximately 1400 hours. As shown in the photograph and Figure 6, the lateral dispersal of dye near the outfall is bilobal; past the spit and along the shoal break (lower right), and back into the harbour (at upper left).

Reference to Plate I illustrates the position of the outfall relative to the rest of the harbour (near the point of Thrumcap Spit). Apparently, river currents, deflected while passing the ends of the wharves, strike the end of the spit resulting in erosion at the spit point, and subsequently transfer of the sediments into the harbour (along the lagoon opening) and out along the shoal break toward the channel. It was probably the original deflection of these currents toward the spit that resulted in its recurved nature, before continued sedimentation protected the limb of the spit. The offshore shoals are believed to be primarily a result of dumping of dredgings too close to the harbour entrance and the subsequent "locking in" of the area to the natural longshore drift. The spit is becoming an erosional feature because of "sediment piracy" by Thrumcap Shoal.

VIII



to medium grained sand and gravel. The colour is consistently 5YR 3/4 to 5YR 4/4 on the GSA colour chart. Sediments at every station contained dead grass and worm tubes comparable to Cistenides. All substrates were reduced and emitted hydrogen sulphide or methane from layers 0.5 to 2.0 cm. below the oxidized surface layer. Channel deposits ranged from sandy silt to silty clay, whereas nearshore deposits were composed of silty sand, sand and gravel. The sediments in Georgetown Harbour have been derived from internal (rivers), external (sea) and marginal (shoreline) sources. Volume and character have varied with time, tidal regime and source.

Franck (1971) has referred the sediment in Northumberland Strait immediately outside of Cardigan Bay to her Unit 5b; mainly sandy gravel with more than 5% gravel.

Bottom sediments have been analyzed for 1) sand-silt-clay distribution; 2) clay mineralogy; 3) heavy minerals; 4) organic carbon; 5) trace elements; and 6) pesticides. The confinement of fine grained sediments in all marginal marine environments has an important selective effect on the grain size distribution of the deposits and the retention of potential pollutants.

A major investigation of the soil profile has been completed in regions adjoining both the watershed and the estuary proper (Table 2). This information has indicated that the rivers and sewer effluent are the major source of the clay minerals and suspended sediments within the harbour. Our analysis included the following:

Cultivated Soils:	Sample	1	0-5 cm.
	"	2	5-10 cm.
	"	3	10-15 cm.
	"	4	35-40 cm.

Virgin Soils:	Sample	1	whole of organic horizon
	"	2	whole of A_2 horizon
	"	3	first 5 cm. of B horizon
	"	4	5-10 cm. of B horizon
	"	5	35-40 cm.

Whether fine grained or coarse grained material is more important in an estuary depends on the shape of the estuary, the strength of tidal currents and river flow, and the amount of fine grained suspended material available in the source areas.

CLAY MINERALS:

Illite, kaolin and chlorite are the dominant clay minerals in Georgetown Harbour. Illite, chlorite, kaolin and mixed layers of montmorillonite, illite and chlorite are present at every station.

Preliminary soil analysis show that illite, chlorite and kaolin are also the predominant minerals in the soil profiles. This suggests that the clay minerals are land derived. The apparent absence of montmorillonite in the harbour, seems questionable. However, montmorillonite weathers out of the A horizon and changes to the more stable form of illite in the marine environment. It has been shown by Milne and Earley, Johns and Grim in Grim (1968) that illite and chlorite form from montmorillonite in the marine environment due to the absorption of K^+ and Mg^+ with the consequent collapse of the montmorillonite structure. While changing, the mineral passes through the mixed layer stage recorded in the present investigation.

The only difference between stations is in the concentration of the individual minerals. Illite is the most abundant with a mean of 36.42%; kaolin is second most abundant with a mean of 26.85%; chlorite has a mean of 12.49%. It is apparent that the distribution and abundance ratio is

3:2:1. However, no major trends in concentration in this small area could be determined during the present investigation.

ORGANIC CARBON:

Organic carbon content (Table 3) varied from 0.116% in medium to coarse sand substrates adjoining the baymouth bar to 3.330% immediately adjoining the sewer outfall. Carbonate varied from 1.527% to 9.421% at these same localities. The organic and inorganic content in the sediments at the outfall were the highest recorded in the harbour environment and indicate inadequate dispersal. Concentrations of 2.460% were recorded near the Fisherman's wharf and concentrations of 2.965% were recorded in sediments adjoining the tidal flat-salt marsh, shoreward from Thrumcap Spit.

Most marginal marine sediments contain several percent of organic matter (organic matter = 1.7 X organic carbon). It is composed of a number of substances which include: humic acids, amino acids, bitumens, hydrocarbons, lipids, porphyrins and lignin. Organic matter in the environment is extremely important because it exerts a strong control over the kind of diagenetic change which occurs in marine sediments subsequent to their deposition. Consequently, it is essential to understand the general relationship between the organic matter in marginal marine sediments and its environment of deposition. The relationship in Georgetown Harbour is as follows: 1) the organic matter content is highest in finer grained sediments which are dark grey to black in colour; 2) the organic carbon content is commonly higher

TABLE 3

Organic Carbon in Georgetown Harbour Sediments

Station	%Total Carbon	%Organic "C"	%Inorganic "C"
35A	1.298	0.880	0.418
35C	3.443	1.860	1.583
35D	3.770	1.450	2.320
35E	2.860	0.100	2.760
35G	3.330	1.600	1.730
35J	1.650	0.560	0.890
35K	2.550	2.240	1.990
35L	1.710	0.340	1.370
35M	3.410	1.141	2.269
35N	2.580	2.240	0.340
33E	0.190	0.059	0.400
33D	0.210	0.030	0.180
33C	1.580	0.050	1.530

on tidal flats and in sewer effluent areas than in the main tidal channels; 3) the type of organic matter varies from area to area; 4) the total content of organic matter decreases seaward and in coarser sediments. The extent to which organic matter is preserved in a sediment depends largely on the rate of deposition of the total sediment components.

All organic matter, both particulate and dissolved, plays a vital role in marine ecology since it provides part of the energy, food, vitamin and other requirements for bacteria, plants and animals. The high organic matter content in estuaries causes a rapid depletion of the oxygen and permits the development of anoxic H_2S emitting environments below (0-10 cm.) the surface "life Zone". Factors which are dominant in causing the observed carbon distribution patterns appear to be the energy of the environment and the inorganic oxidation of organic matter because of a plentiful supply of dissolved oxygen.

RATES OF SEDIMENTATION:

On the North Shore of Prince Edward Island and New Brunswick, sedimentation rates in the outer lagoons, estuaries and baymouth barrier regions range from .027 cm. to .750 cm. per year. In the inner bay regions rates of sedimentation range from .053 cm. to .950 cm. per year. The "natural" rate of sedimentation during the past 7500 years, based on Carbon 14 dating of sediment cores, ranged from .027 cm. to .068 cm. per year. In the Northumberland Strait region "natural" sedimentation rates during the past 6600 years have been as follows:

Colville Bay	.048 cm. per year
Cardigan Bay	.045 cm. per year
Hillsborough Bay	.030 cm. per year
Bedeque Bay	.036 cm. per year

In the area under investigation, man-induced siltation (through dredging, cultivation, deforestation, wharf and highway construction) has increased rates of sedimentation in the range of 1 to 10 cm. per year. This represents an increase of 20 to 400 times that attributed to natural causes. Sediment core analyses indicate that the positive (extending) projection of the baymouth bar is receding and the adjoining shoals are expanding at an ever increasing rate.

Large river flow does not necessarily mean that sediment discharge will be high. There must not only be a transporting mechanism, but also an available supply of sediment. Thrumcap Shoals have apparently "locked in" to the natural longshore drift and may require constant dredging in the immediate future to prevent adverse effects within the harbour and eliminate hazards to navigation.

MICROFAUNA:

The outer bay faunas of Cardigan Bay are dominated by the arenaceous species *Ammotium cassis*, *Saccammina atlantica* and *Reophax scorpiurus*. The inner harbour *Elphidium* and *Trochammina* faunas are commonly depauperate, dwarfed, malformed and possess degenerate shells in regions adjoining the wharves and sewer outfall.

The microfaunas in Cardigan Bay are typical of an inner shelf environment. They have not changed drastically in either numbers or species during the five years that the area has been monitored. The Montague River which empties into Georgetown Harbour was in a highly polluted and deteriorated condition until October 1971, when a marked improvement in microfaunal assemblages and the consistent presence of oxidized sediments was noted. The improvement is attributed to the installation and operation of sewage treatment facilities at Montague.

Specific regions within the harbour and environs that are polluted and undergoing degradation are the main wharf areas and the sewer outfall. This degradation is directly attributed to man-induced processes of harbour development and sewage disposal techniques in a partially enclosed estuarine environment.

On a bioindex scale of 1 to 10 (unfavorable to favorable habitat) the harbour rates 6 to 7 compared to 1 to 2 for the majority of Summerside Harbour and 4 to 6 for Charlottetown Harbour.

Foraminifera were analyzed with the electron microprobe to determine if the trace elements Sr, Fe, Mg and/or Mn had been biogenetically included in the $CaCO_3$ lattice of their tests. Results are inconclusive, but it is hoped that an additional, sensitive control for measuring seasonal and annual variation in coastal zone water chemistry can be established.

Most of the measurements computed in this study consisted of values of less than .05%. Concentrations varied considerably between different positions in the individual specimens. The number of positive measurements suggests that trace elements are present and detectable. This research is continuing.

PHYTOPLANKTON AND ZOOPLANKTON:

The phytoplankton species form part of a natural succession or series depending upon open water influence and currents. Dinoflagellates and diatoms predominate during the summer but decrease in October and November. Populations are very low in winter and many species form spores. With spring breakup, colonial and filamentous diatoms and silicoflagellates become very abundant.

The Coscinodiscaceae are characterized by species of Skeletonema, Thalassosica and Coscinodiscus. The Solinoidaceae are represented by species of Rhizosolinia, Heptocylindrus and Corethron. At least three species of Chaetaceros were recognized as well as Asterionella, Thalassiothrix, Lycomopha, Striatella, Nitzachia, Bacillaria, Amphora, Pleurosigma, Novicula and Diploneis. The Dinoflagellata were represented by Pholacroma, Dinophysis, Goniaulax and Peridinium. Species of Crysonionadales were also recognized.

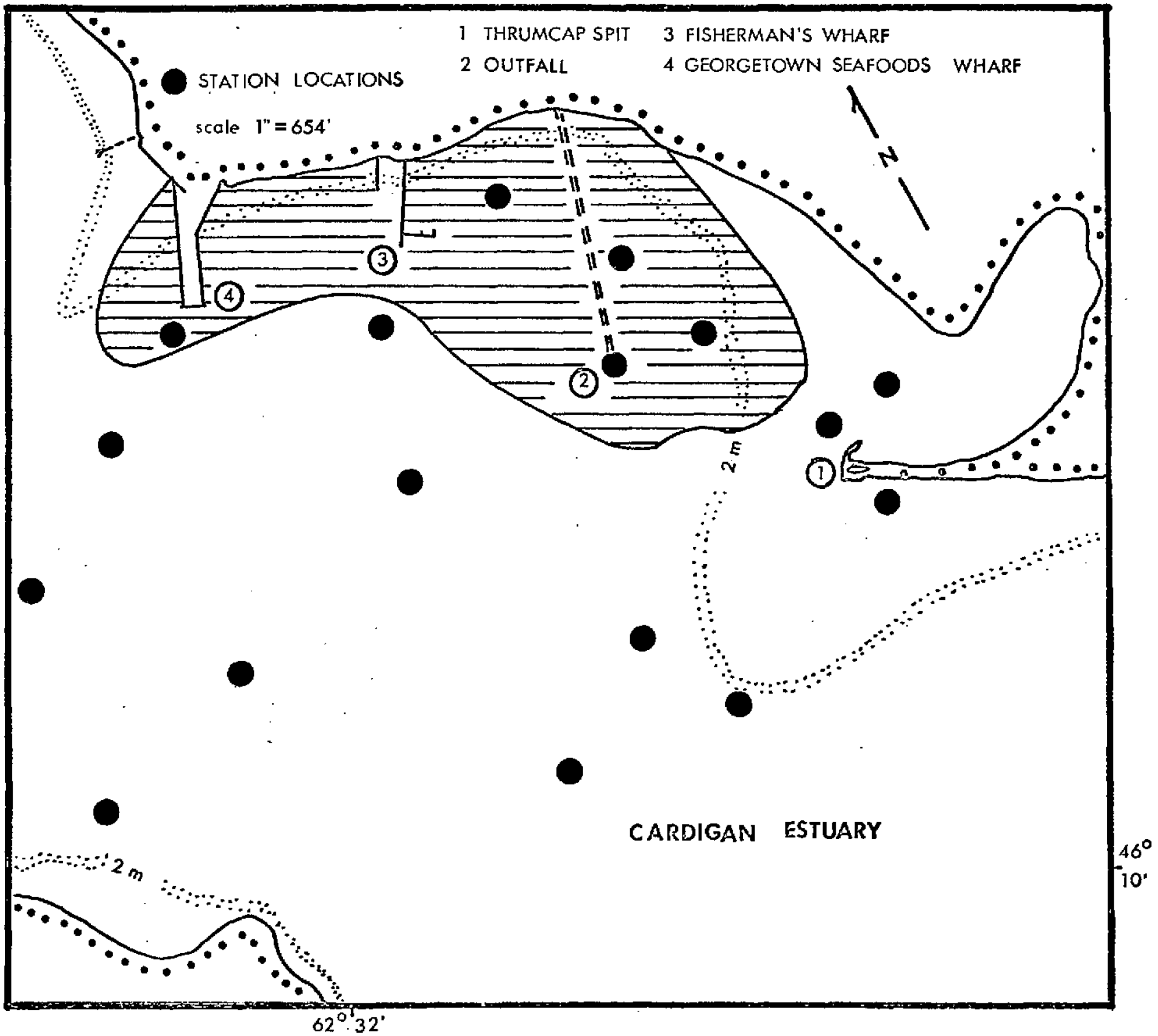
The biomass and productivity of phytoplankton populations is an important factor in determining: 1) the nutrient richness of the water; 2) the number of trophic levels that can be supported; 3) the amount of organic matter being contributed to the sediments, which may possibly cause the buildup of organic matter and the development of anoxic conditions.

The zooplankton is dominated by calanoid copeopods, naplius larvae, gastropod larvae and Lamellibranchiatae. The overall productivity and distribution of phytoplankton and zooplankton in Georgetown Harbour requires further study in relation to effluents, suspended load and current characteristics.

BACTERIA:

The primary objectives of the total bacteriological studies in Prince Edward Island (Bartlett et al. 1972) are: 1) to delineate bacteriological baselines, 2) to indicate those areas which do or may have bacteriological pollution problems in the future, 3) to interpret seasonal variation in

Figure 7: Polluted and deteriorated areas in Georgetown Harbour as indicated by the bacteria content in surface and bottom water and bottom sediment.



1 THRUMCAP SPIT
2 OUTFALL
3 FISHERMAN'S WHARF
4 GEORGETOWN SEAFOODS WHARF
STATION LOCATIONS
scale 1" = 654'
N
2 m
2 m
CARDIGAN ESTUARY
46°
10'
62° 32'

the populations, 4) to determine diurnal or hourly variations, 5) to monitor direction of flow of polluted waters using certain bacteria as tracers, 6) to assess differences in bacterial numbers between surface and bottom waters and the relation of these to water depth, and 7) to interpret the relationship of certain bacterial biotype populations in sediment to determine the degree of pollution of the overlying water.

The organisms monitored include coliforms, facal coliforms, fecal streptococci, organic sulfur-reducing bacteria and nitrigying bacteria.

The results (Figure 7) from the majority of stations sampled in Cardigan, Brudenell and Montague Rivers and in Cardigan Bay show these water bodies to be very clean bacteriologically, having zero coliform, facal coliform and facal streptococci counts, and low standard plate counts (Bartlett et al. 1972). Positive counts were obtained in Georgetown Harbour at stations 35E, 34A, 35Q, 35L, 34C and for some distance surrounding the sewer outfall.

No seasonal pattern was observed for the variation in bacterial counts in Cardigan Bay, and a 10 hour survey in August did not reveal conclusive results as to the direction of flow away from the outfall. Bacterial contamination does exist in the Georgetown Harbour area; however, results have been extremely variable. Further water and sediment samples should be analyzed during a complete tidal cycle and during minimum and maximum effluence from the outfall.

DISCUSSIONS AND RECOMMENDATIONS:

An environmental analysis of Georgetwon Harbour, P.E.I. utilizing water chemistry, current characteristics, suspended load, sediment distribution, microfauna, phytoplankton, zooplankton and bacteria indicate that the harbour is in a state of degradation (but is healthy with respect to Charlottetown and Summerside harbours) because of sewer effluents, siltation from natural and man-induced processes and the rapid growth of Thrumcap Shoal because of natural sedimentation, dredging and dumping practices. If the spit and shoals have "locked in" to longshore drift which is apparent from several photographs (Plates I-V), then the present trend and resultant damage is irreversible and rapid siltation within the inner harbour is anticipated. Projections such as wharves into the estuarine environment provide barriers for river and tidal currents and consequent deposition of sediment in both upstream and downstream directions. The restriction imposed by the bar, the upstream movement with flood tides and downstream movement with ebb tides prohibit sufficient dispersal of effluents and suspended load outside the harbour. Consequently, siltation will be directly related to effluent outflow and rapidity of barrier growth. Extension of the outfall to the main channel will provide more rapid initial dispersal, but two directional circulation will probably lead to increased transportation of salt, bottom water upstream with resultant widespread pollution in the harbour and adjoining rivers. The broad extent of the shallows and bar adjoining Thrumcap Spit indicates that extension of the outfall in this direction will have little long term benefit and the cost is doubtlessly prohibitive. Fine screening, perhaps secondary treatment in the distant future, continued dredging, with dumping significantly seaward and careful planning of future harbour installations in the light of environmental factors are essential.

It is evident that information derived from the October investigation suggests that the present outfall could remain in its present position (because of the anticipated slight environmental benefit derived from alternatives) until more long term monitoring can be completed.

Similarly, present dredging and dumping practices must be carefully assessed. It is apparent that dumping from harbour dredging has contributed substantially to the buildup of Thrumcap Shoal, the "sediment piracy" from Thrumcap Spit, the "locking in" to longshore drift and the consequent increased siltation and confinement of effluents and other suspended matter within the harbour.

REFERENCES

BARTLETT, G.A.
1966: Distribution and Abundance of foraminifera and thecaemoebina in Miramichi River and Bay, Rept. B.I.O. 66.2, 107 p.

BARTLETT, G.A., JOHNSTON, L. & VANDERPOST, J.
1972: "Environmental Analysis, Ecology and Nutrient Study of Cardigan Bay and Environs, Charlottetown Harbour, Souris Harbour and Summerside Harbour, P.E.I."; Environmental Control Commission, 40 pages.

BRIDGEO, W.A.
1966: "Ocean Disposal of Wastes"; IPC, Background Paper B17-1-4, p. 1-8.

FRANKEL, L.
1966: "Geology of Southeastern Prince Edward Island"; Geol. Survey Canada, Bull. 145, 70 pages.

GREER, S.A.
1969: "Sedimentary Mineralogy of the Hampton Harbour Estuary, New Hampshire and Massachusetts"; SEPM, Coastal Research Group, p. 403-414.

GRIM, R.E.
1968: "Clay Mineralogy"; McGraw-Hill 582 pages.

GUILCHER, A.
1963: "Estuaries, Deltas, Shelf, Slope", in The Sea V. 3, M.N. Hill (ed.), Wiley & Sons, 963 pages.

KRANCK, K.
1971: "Surficial Geology of Northumberland Strait", Geol. Survey of Canada, Paper 71-53, 10 pages.

MEADE, R.
1969: "Landward Transport of Bottom Sediments in Estuaries of the Atlantic Coastal Plain", Jour. Sed. Pet., V. 39, N. 1, p. 222-234.

POSTMA, H.
1967: "Sediment Transport and Sedimentation in the Estuarine Environment"; in Estuaries, G. Lauff (ed.), Amer. Assoc. Adv. Sci., p. 158-179.

PRITCHARD, D.W.
1971: "Estuarine Circulation Patterns"; in The Estuarine Environment-Estuaries and Estuarine Sedimentation J.R. Schubel (ed.), AGI, Section IV, p. 1-7.

RAMBOW, C.A. & HENNESSY, P.V.
1965: "Oceanographic Studies for a Small Wastewater Outfall"; Water Pol. Cont. Fed., V. 37, N. 11, p. 1471-1480.

REDFIELD, A.C. & WALFORD, L.A.
1951: "A Study of the Disposal of Chemical Wastes at Sea", Publ. 201, Nat. Res. Coun., Natl. Acad. Sciences.

RUSNAK, G.A.
1967: "Rates of Sediment Accumulation in Modern Estuaries", in Estuaries, G.H. Lauff (ed.) Amer. Assoc. Adv. Sci., p. 180-184.

SCHUBEL, J.R.
1968: "Suspended Sediment Discharge of the Susquehanna River at Havre de Grace, Maryland, during the period 1 April 1966 through 31 March 1967"; Ches. Science, V. 9, p. 131-135.

1969: "Distribution and Transportation of Suspended Sediment in the upper Chesapeake Bay"; Ches. Bay. Inst. Tech. Rept. 60, The johns Hopkins University, 29 pages.

1971: "Sources of Sediments to Estuaries"; in The Estuarine Environment-Estuaries and Estuarine Sedimentation, J.R. Schubel (ed.) AGI, Section V, p. 1-19.

VON STRATTEN, L.M.
1960: "Transport and Composition of Sediments" in Symposium Ems-Estuarium, Nordsee. Verhandel. Koninkl. Med. Geol. Mynbouwk. Genoot. Geol. Ser., V. 19, p. 279-292.

WEATLAND, A.B., AGG, A.R. & BRUCE, A.M.
1964: "Some Observations on the Dispersion of Sewage from Sea Outfalls", Reprint No. 452, Water Pollution Research Laboratory, Elder Way, Stevenage, Herts.

YALIN, M.S.
1972: "The Mechanics of Sediment Transport", Pergamon Press.