AN EXPERIMENTAL STUDY OF FACTORS AFFECTING CURRENT FLOW AND SEDIMENT STABILITY ON THE FORT ANNE FORESHORE

Final report to

Canadian Parks Service,
Environment Canada
Contract No. HS/SWNS 93-01

by

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1. EXECUTIVE SUMMARY

In order to assess the processes affecting recent erosion of the shoreline adjacent to Fort Anne National Historic Park, a preliminary study of sediment properties and patterns of water flow in Allain River and across the Fort Anne shore was conducted in May and June 1993. Stations were also established for longer term monitoring of changes in bed level of deposited sediments in the intertidal zone, and for indications of rotational slumping of the Fort Anne embankment where cribwork is exposed.

Geotechnical investigations included the obtaining of 2 cores and measurements of sediment consolidation at 5 sites in the intertidal zone. The cores indicate that much of the shore is composed of a stiff, highly plastic red clay of glaciolacustrine origin that extends to the maximum depths of the cores (1.4 and 2.5 m). Penetrometer measurements showed that the sediment is overconsolidated to degrees that correspond to previous burial beneath 1 to 4 m of overburden. The exposed clay surface, however, has softened and lost cohesion as a result of wetting and bioturbation. It is concluded that erosion of this deposit will continue as long as the surface is exposed to tidal water, resulting in continued lowering of the intertidal zone, and further destabilising of the fort embankments.

Current meters installed on the shore for 12 tides indicated that water flows across the shore in a northerly direction during both ebb and flood. This feature is strongly influenced by the pattern of water movement in Allain River, which in part is determined by a man-made constriction near the Highway 1 bridge. A 105 m long, 1 to 1.2 m high barrier temporarily installed down the shore between Fort Anne and the point significantly reduced velocities across the shoreline, particularly on the Allain River side, but did not seem to greatly change the direction of flow. Diminishing current velocity may be a valuable contribution to decreasing erosion on the shore.

Results of the study lead to recommendations including : widening of the Allain River at the highway bridge by removing a rocky constriction left behind from previous construction; re-establishing a stabilising mass at the toe of the western embankment where erosion is very active and the embankment seems to be most unstable; providing immediate protection against erosion of the remaining saltmarsh; conducting further investigations of the load-

bearing properties of the exposed clays, and of the water table within the embankment; and protecting exposed clays against softening of the surface by wetting and bioturbation.

5 August 1993

2. INTRODUCTION

As a result of initial studies by the Acadia Centre for Estuarine Research and the Nova Scotia College of Geographic Sciences, it became apparent that the saltmarsh along the Annapolis Estuary side of Fort Anne was eroding rapidly and thereby removing a significant natural buffer against the normal erosive forces of winds and waves acting on tidal waters. Erosion was a familiar problem to the engineers who built the various forts that occupied the site since the early 17th century (Dunn 1992), but examination of aerial photographs taken since the 1920s suggested that the recent phase of erosion began about the time of construction of the Annapolis Causeway in 1960-61. Since that time, a band of saltmarsh approximately 100 m wide has disappeared, at rates up to 10 $m.yr^{-1}$ (P. Hore - personal communication).

A preliminary study in December 1992 showed that erosion of clays and silts from the intertidal zone, and of the peripheral saltmarsh on the Annapolis side of the fort was occurring as a direct result of wave action during the flooding tide (Daborn *et al* 1993). The results suggested that a great deal of resuspended material was removed from the area up towards the Causeway, or into Allain River (cf. Figure 1), because of the manner in which tidal waters advance over the shore. Measurements of current flow obtained from points on the intertidal zone during the falling (ebb) tide indicated that the predominant flow in this region was northward, along the shore toward the Causeway, although the overall direction of water movement in the Annapolis was toward the sea, i.e., toward the southwest. Field observations in April 1993 reinforced the interpretation that erosion of the fine red clay that predominates on the shoreline (Figure 2) was occurring on almost every tide, even when there was little or no wind, and therefore little or no wave action. Examination of the red clay showed that it was relatively homogeneous -- almost pure clay -- with a very high plasticity, and was at least 1 m thick. It seemed probable that erosion could continue as long as this clay was wetted by the water, producing a steeper beach, and further destabilising both the peripheral saltmarsh that remains, and the walls of the fort.

Close examination of a 1981 aerial photograph showed that in the past a linear structure had extended from the fort to a rocky point in the mouth of Allain River. This structure is represented now by a distinct band of rocks visible as a dark line extending from the rocky point toward the saltmarsh in Figure 3. It was hypothesised that a wharf or seawall in this

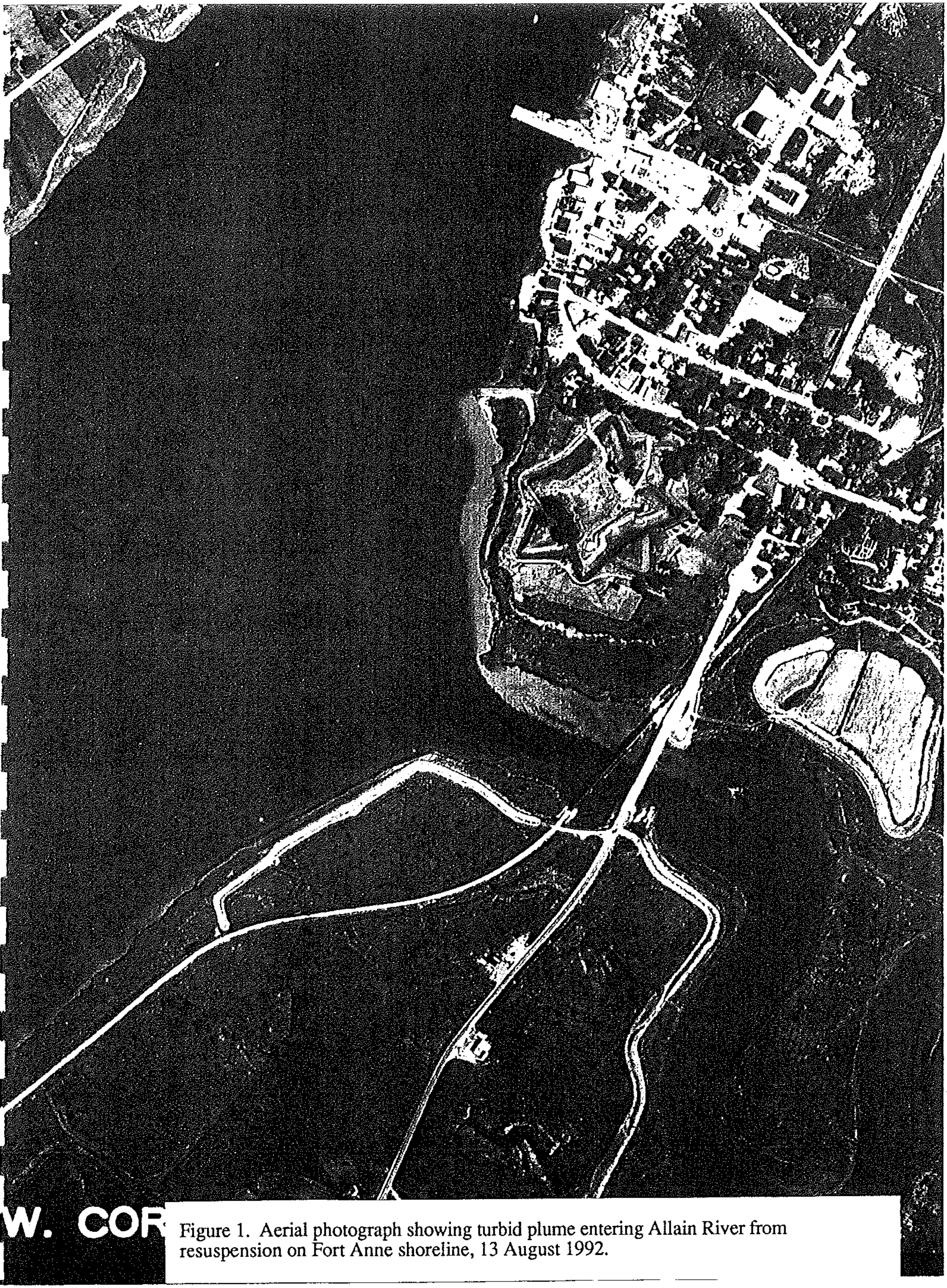

Figure 1. Aerial photograph showing turbid plume entering Allain River from resuspension on Fort Anne shoreline, 13 August 1992.

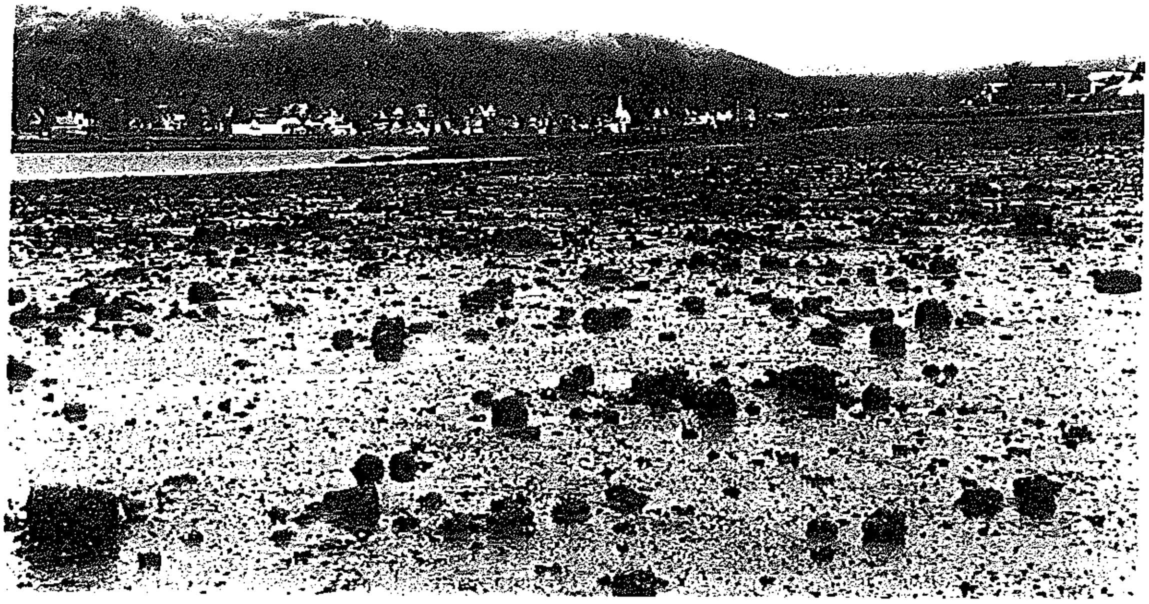

Figure 2. Fort Anne shoreline looking north showing exposed red clay and boulders from exposed embankment foundations.

Figure 3. Fort Anne shoreline looking west toward point showing line of boulders from previous construction, and exposed cribwork in right foreground.

location might have had the effect of reducing any northward flows of water across the fort shoreline, and might therefore have provided a protective function for the fort walls.

A second aspect of investigations in April 1993 related to the stability of the fort walls themselves. Old cribwork that has been exposed for several years toward the western end of the Annapolis shoreline of the fort (and visible in the lower right foreground of Figure 3), is visibly tilted upward, whereas another set of cribwork that has been more recently exposed nearer to Queen's Wharf lies in a horizontal mode. Presumably they were both horizontal when laid down. Without the covering of saltmarsh, boulders that had been laid on top of the crib timbers have begun to move downslope, and are now scattered over the whole shoreline (cf. Figures 2 and 3). These observations suggested that the western portion of the embankment is slumping or has slumped in the past in a rotational manner. Presumably this happened because the load represented by the high embankment is no longer counterbalanced by the mass provided by the boulders and saltmarsh that used to lie at the foot of the slope.

Consequently, protection of the fort against erosion is not just a matter of decreasing wave action, as might be done by construction of a seawall. In order to develop an adequate plan for protection of the fort in the long term, it was deemed necessary to conduct some further specific studies along the shoreline related to current velocities, the depth and characteristics of the fine sediments, and the activity of the slumping embankment.

The Acadia Centre for Estuarine Research was asked by the Canadian Parks Service to conduct studies along the shoreline to provide more comprehensive understanding of the processes at work, and to gather information that would be of assistance to engineers in the design of protective measures. Erosion and deposition of sediments are complex processes that are influenced by oceanographic, atmospheric, geological and biological factors. For this reason, an experimental approach was taken to examine the potential value of recreating a temporary barrier along the line of the historical structure between the fort and the point. In order to minimise costs of the study, labour-intensive activities associated with construction of a temporary barrier against water flow were carried out using volunteers from the Town of Annapolis Royal, the Clean Annapolis River Project, and participants in an Adult Retraining Programme in Digby, N.S. Some materials for construction of the barrier were donated by industries located in the Annapolis Valley. Operating funds were provided under contract HS/SWNS 93-01.

2.1. ACKNOWLEDGEMENTS

The study would not have been as effectively carried out without generous contributions from a number of people. First and foremost are the many volunteers who assisted with construction of the temporary barrier : these individuals included residents of the Town of Annapolis Royal, members of the Clean Annapolis River Project, teachers and participants in the Adult Retraining Programme at Digby, and employees of the National Historic Site. Unfortunately, no record of the volunteers' identities was kept, but we are most grateful for their assistance.

Materials for construction of the barrier were donated by Britex Corporation of Centrelea, and Weavexx Ltd. of Kentville.

Precise geographic locations of sample sites were obtained by J. Kaulback and P. Hore of the Nova Scotia College of Geographic Sciences, Lawrencetown.

Employees of Fort Anne National Historic Site provided valuable assistance during construction and removal of the barrier, and R. Clayton has also undertaken consistent monitoring of the level plates installed on the exposed cribwork.

To all these people we are most grateful.

3. OBJECTIVES

(1) To determine whether the upturned cribwork at the western end of the fort is still rotating as a result of loss of toe stabilisation, and if so, at what rate.

(2) To determine the extent and depth of red clay deposits along the Annapolis shoreline of the fort.

(3) To assess the rate of downslope movement of sediments resulting from erosion of the saltmarsh and an upper grey deposit that overlies the clay.

(4) To examine the potential effects of a barrier across the intertidal zone to limit flow of Allain River water to its own channel on the ebb, and diminish the loss of resuspended sediment into Allain River on the flood tide.

4. FIELD METHODS

4.1. TILT SENSORS

Aluminium base plates were secured to 6 portions of the upturned cribwork toward the SW end of the fort on 12 June 1993, by H. A. Christian. The angle of deviation from the horizontal is being measured on a weekly basis by Parks personnel using an electronic "Smart Level" ™, to determine whether the rotational movement is still active. These measurements will continue as long as the stability of the fort wall is in question.

4.2. GEOTECHNICAL INVESTIGATION OF SEDIMENTS

A preliminary site investigation of the depth and strength of the exposed red clay on the Fort Anne shoreline was carried out by Geotechnical Engineer H.A. Christian on 12 to 13 June 1993. Budget limitations necessitated that a small programme be designed that would yield high-quality samples of the materials exposed there for later analysis, as well as determining the *in situ* shear strength profile. The shear strength profile provides considerable information relating both to the geotechnical history of the sediment, and its ability to support loads that might be associated with protective works. Locations of sample sites are given in Figure 4.

A portable percussion corer was used to obtain cores of the stiff red clay at 2 borehole sites (BH1, BH2). The portable framework was designed for erection on site, and does not require a barge for deployment and operation, which enabled costs to be kept to a minimum. Samples were obtained using a thin-walled (TW) Shelby tube coupled to a sliding 50 lb hammer having a drop of 30". Standard CPT rods were used to connect the hammer section to the sampler. The system possessed an internal piston with a one-way valve which ensured good recovery of the core. After recovery, the samples were sealed in the Shelby tubes with beeswax, and shipped to a refrigerated storage facility at the Bedford Institute of Oceanography.

Undrained shear strength (S_u) of the sediments was determined using a miniature cone penetrometer to measure cone resistance (q_c). An N_k factor ranging from 6 to 17 was used to calculate S_u from q_c as given by the formula :

$$S_u = \frac{q_c - \tau_{vo}}{N_k}$$

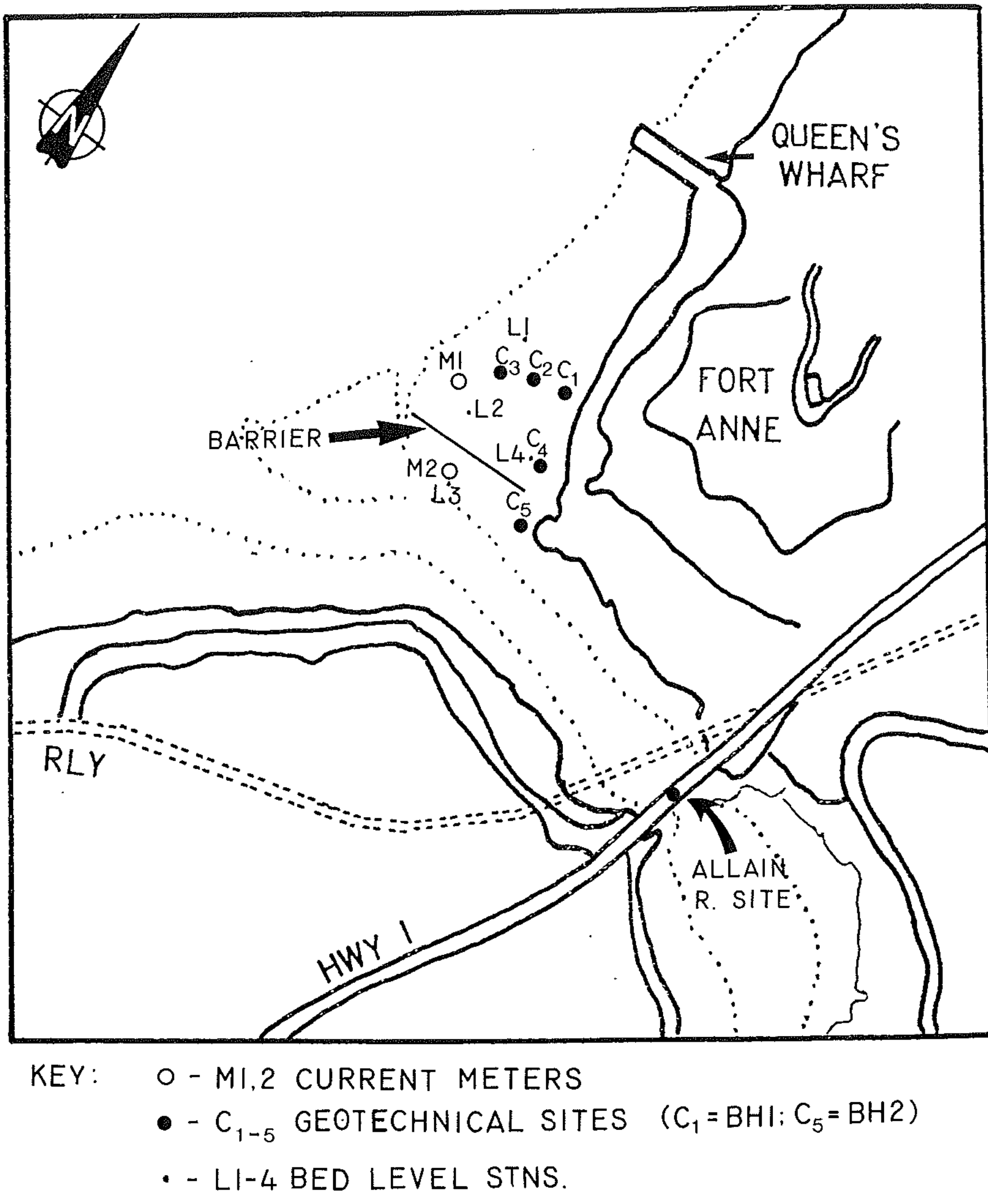

Figure 4. Sampling locations.

where the total overburden stress τ_{vo} was assumed to be zero. The value for N_k was based on *in situ* Pilcon shear vane tests, which measure S_u directly.

4.3. BED LEVEL AND DOWNSLOPE MOVEMENT

Four stations were established on 25 May 1993 to monitor bed level. Locations of sample stations are given in Figure 4. Each station consisted of a pair of posts made from 0.5" reinforcing bar driven approximately 1.5 m into the substrate 1 m apart. During measurement, 0.5" copper T-junctions are installed on each post to act as supporting platforms for a 1 m long mason's level. Liquids in the level are used to ensure that neither of the two posts has moved between measurements, and to ensure that the level remains horizontal during measurement. Depth to the sediment surface midway between the posts is measured to the nearest millimetre using a jig constructed to slide along the mason's level. Measurements were taken at varying intervals, and are continuing.

Six sediment traps constructed out of 0.5" thick plywood, and waterproofed with marine paint were set out on the tidal flat below mean sea level to monitor downslope movement of sediments eroded from the upper shoreline. Four of the traps were open on the up-slope side, whereas the remaining two were walled on all sides. These were designed to act as 'control' traps to investigate the effects of wave-caused resuspension of sediments accumulating in the open traps. All traps were installed in shallow depressions cut into the surface sediment so that the upper surface of the wood was level with the sediment surface.

4.4. CURRENT FLOWS

Two Aanderaa RCM-4 recording current meters (leased from ASL Environmental Sciences Ltd.) were installed on the tidal flat to the WSW of Fort Anne, one on either side of the boulder line extending out toward the point (see Figure 3). Locations of the two meters are given in Figure 4. Each was secured to an aluminium post driven into the substrate to a depth of 1 to 1.5 m, and attached to the posts with hose clamps so that the impeller was 90 cm above the substrate. The instruments were installed during the morning low tide on 25 May 1993, and removed during the afternoon low tide of 31 May, after recording for 12 successive tides. Recordings of current direction and velocity were made at 10-minute intervals. Each instrument was covered by water for approximately 8 h on each tide, and exposed for approximately 4.5 h.

Standard data reduction techniques were applied to the data, yielding time series of rate and true direction. Prior to analysis, the data were examined and edited by hand to remove the data recorded immediately after submergence, and before exposure, in order to eliminate the extreme influence of waves on the rotor. Bad data or 'spikes' were also removed. The time series were then smoothed using a 6-point running mean filter. This provided an hourly mean value of rate and direction for each meter.

In order to test the hypothesis that a barrier installed between the fort and the point would significantly reduce the movement of tidal water across the foreshore between Allain River and the Annapolis, a temporary barrier was constructed during the low tide period of 27 May. The barrier was 105 m in length, 1 to 1.2 m in height, and consisted of 2" x 4" wooden studs set approximately 2 m apart; each stud was 2 m in length, and was driven into the substrate approximately 0.75 to 1.2 m. A woven plastic fabric (donated by Weavexx Co., Kentville, N.S.) was fixed to the studs with galvanized roofing nails. Each vertical stud was tied down to a pair of 2" x 4" stakes driven into the substrate on either side of the barrier for stability. The barrier was laid parallel to, and about 10 m to the west of, the line of boulders representing an older structure (evident in Figure 3). Its orientation was measured at 288^o. Location of the barrier is indicated in Figure 4. The barrier remained in place for more than 2 weeks, but under the effects of strong winds and tidal forces, it began to disintegrate, and was finally removed by Parks personnel during the week of 14 June.

4.5. ALLAIN RIVER TIDAL SERIES

Because initial studies (Daborn *et al* 1993) suggested that a constriction at the Highway 1 bridge over Allain River could be influencing the pattern and strength of flow across the Fort Anne shoreline, an 11-h tidal series of measurements was obtained starting at low water (10.16 h) on 26 May 1993, and ending at 21.00 h near the next low water. At half-hour intervals, vertical profiles of current velocity at each metre of depth were obtained using a TSK Direct Reading current meter. Measurements of salinity, temperature and turbidity were made using an EMP 2000 recording CTD. Location of the sample site is given in Figure 4.

5. EMBANKMENT STABILITY

Measurements of deviation from the horizontal of the six selected timbers have been made at approximately weekly intervals since their installation on 12 June. At the time of writing (3 August 1993), no significant change has been detected (R. Clayton -- personal communication). It is too early to draw any inferences regarding the stability of this embankment, and the measurements are to be continued indefinitely.

6. SEDIMENT CHARACTERISTICS

6.1. SEDIMENT STRATIGRAPHY

Two boreholes were successfully completed during successive daytime low tides on the 12th and 13th June. The clays encountered at sites 1 (including borehole BH1) to 4 were firm to stiff in consistency, but were very stiff to hard at site 5 (BH5). Consequently, coring took a great deal of time : 3.5 h for sampling 2.5 m at BH1, and 1.5 h for 1.4 m at BH5. Outcroppings of hardpan were observed immediately seaward of the point at site 5. Data on the two boreholes are recorded in Table 1.

The local stratigraphy consists of a sequence of at least two saltmarshes with grey reduced clay at the bases. The older (lower) marsh directly overlies the regionally well-developed stiff red clay. This red clay unit is interpreted to be glaciolacustrine in origin (i.e., a freshwater deposit dating back to glacial periods). Bedding in the clay was noticeable in the eroded banks beneath the marsh, dipping towards the south at a low angle (estimated to be between 3 and 5^{o}). The thickness of the marsh was greatest at the point, near site 5, where it is currently being actively undercut at its base. At the location of the exposed tilted cribbing, the red clay appears to continue beneath the ramparts of the fort and directly underlies the wooden footings. At this point, the saltmarsh pinches out against the outcropping clay, suggesting that saltmarsh deposits probably do not lie underneath the fort itself.

Measurements of sediment strength using a Pilcon vane and a miniature cone penetrometer were made at 5 sites, including the two borehole sites. Results are shown in Figure 5. There was a thin veneer of softened clay at the surface of the mudflat, presumably derived from wetting of the exposed clay. Wetting gradually removes cohesion, a process known as 'softening', after which resistance to erosion becomes minimal. Cone penetrometer measurements show that below the surface the sediment is highly overconsolidated, indicating that it has been preconsolidated under a higher overburden pressure in the past. The degree of overconsolidation recorded is consistent with what would exist from the erosion of 1 to 1.5 m of overburden at sites 1 to 4, and 3 to 4 m at site 5.

Table 1. Summary of Borehole Data, Fort Anne, June 1993

Site No.	Sample No.	Top of Sample (m)	Bottom of Sample (m)	Sample Diameter (mm)	Sample Length (mm)	Sample Type	No. of Blows
BH1	1	0.00	0.44	75	440	TW	50
	2	0.44	0.82	75	380	TW	60
	3	1.02	1.40	75	380	TW	50
	4	1.40	1.69	75	340	TW	50
	5	1.69	2.11	75	420	TW	60
	6	2.17	2.51	75	460	TW	50
BH5	1	0.00	0.50	75	500	TW	120
	2	0.60	0.91	75	310	TW	120
	3	1.08	1.41	75	330	TW	100

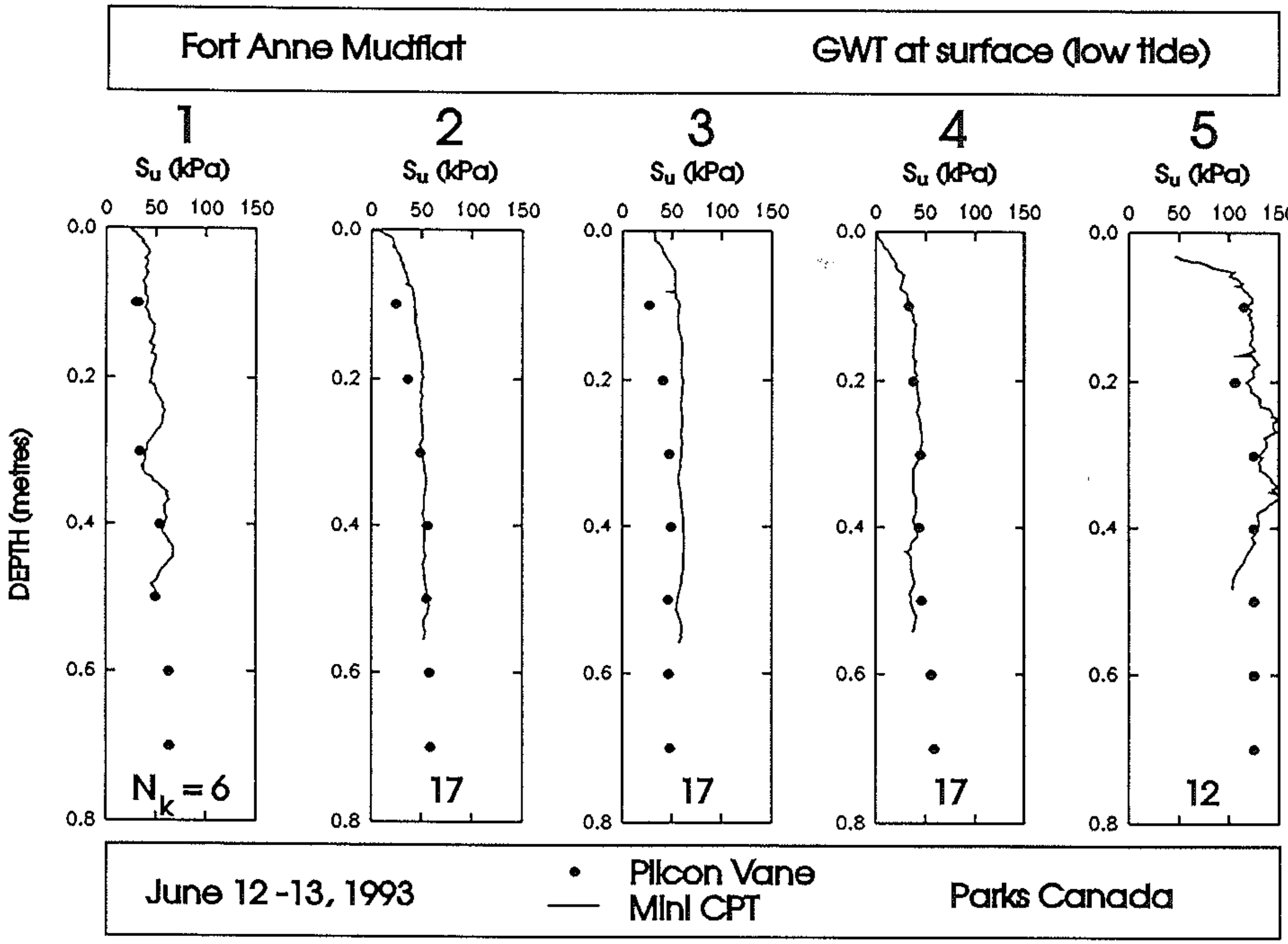

Figure 5. Summary profiles of miniature cone penetration and Pilcon vane tests carried out on the intertidal mudflat at Fort Anne, Annapolis Royal.

This exposed red clay unit has also become colonised by invertebrates, notably the amphipod *Corophium volutator* which builds U-shaped burrows into the sediment. Attempts to sample the benthic invertebrates occupying the red clay showed that *Corophium* burrows extend down 5 to 10 cm into the clay, and as a result, this upper zone is quite soft. Below this layer of burrows, the clay remains hard and compacted. The activities of common mudflat organisms such as *Corophium*, polychaetes and molluscs may contribute significantly to the weakening of the surficial sediments because their activities introduce water to much greater depths -- a process known as *bioturbation.*

6.2. BED DEPOSITION AND EROSION

Monitoring of bed levels at the four permanent stations has so far shown little consistent pattern except at the highest level in the intertidal zone. Data are shown in Figure 6. Of the four stations, station 3 on the Allain River side of the barrier is the lowest in elevation, being flooded approximately 45 minutes before station 1, and an hour before station 2. Initially, station 3 lost sediment, but its level remained constant while the barrier was in place; with the barrier removed, it appeared that erosion was again dominant, approximately 4 mm having been lost by the end of June. (The station was inaccessible on 27 July.) At station 1, the second lowest and most easterly site (i.e., furthest removed from the barrier), there was a steady gain of sediment, amounting to 7.5 mm over the first 35 days of record, but by the end of July (day 63) this accumulation had been lost. At station 4, which is highest in the intertidal zone, and just near the landward end of the barrier, approximately 5.5 mm was lost by the end of June, and a further 1.5 mm by the end of July. Station 2 has fluctuated between accretion and erosion, gaining while the barrier was in place, and then losing once it was removed.

Sediment traps placed in the lower intertidal zone showed no evidence of accumulation of material eroded from the footings around the fort. In fact, none of the traps collected any sediment; however, erosion occurring in the area around the traps themselves eventually meant that the base of the traps became elevated a fraction above the sediment level itself. The cause of this effective elevation may be partly the increased erosion induced by the traps themselves, and partly the fact that fine sediments in the lower intertidal are being lost through resuspension. Most of the sediment traps are located seaward of (i.e., lower than) the lowermost bed level monitoring stations, and thus it is possible that processes operating at the level of the traps are different from those operating higher up the slope. These

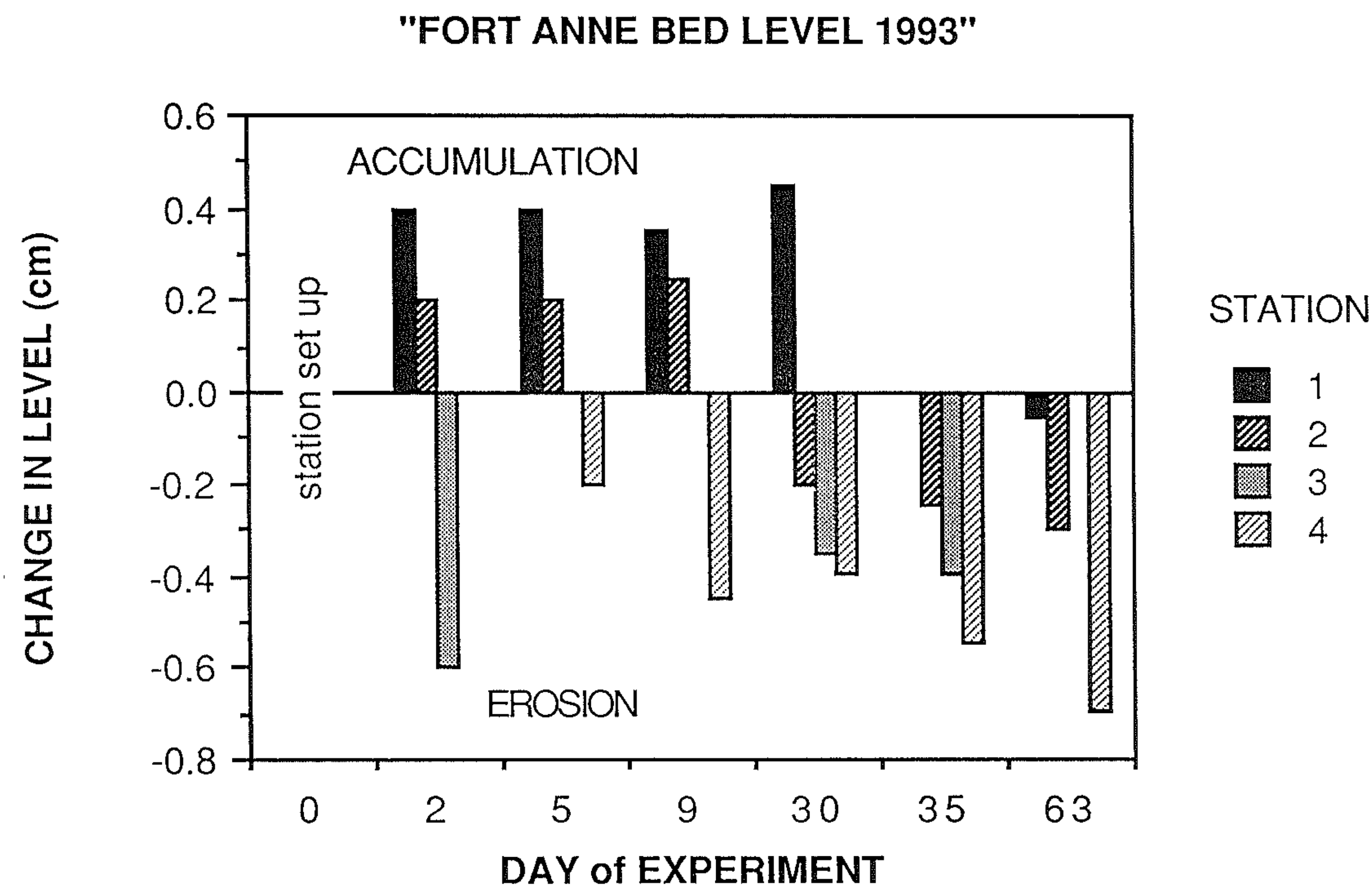

Figure 6. Changes in bed level at four stations on Fort Anne shoreline. Day 0 = 25 May 1993.

sediment trap observations, however, all support the suggestion from the bed level measurements that eroded material that is coarse enough to drop out of suspension and to move as bedload does not travel very far down the slope at this time of year, but rather is temporarily stored in the mid- to upper intertidal. It is normal for intertidal sediments to show accretion patterns during summer months when tidal movements and winds are relatively small. The original accumulation at station 1 during June may be partly due to the downslope movement of material being eroded from the high water level and the upper intertidal where wave-induced erosion is very active against both the saltmarsh and the exposed and underlying clays. It appears that most of the material being eroded from the foot of the fort embankment is moved away from the area in suspension, rather than as bedload.

The processes of accretion and erosion are seasonally very variable, as described above, and are influenced by a wide array of factors such as tides, wind, and living organisms (including humans). Consequently, it is not appropriate to draw firm conclusions about the overall effects based upon 1 or 2 months of record. The sediment traps and bed level monitoring stations have been left in place in order to continue to monitor sediment behaviour on the flat in future months.

7. WATER MOVEMENTS

7.1. CURRENT METER RESULTS

The two current meters were deployed at approximately the same level on the mudflat, meter 2 to the west of the barrier line becoming immersed approximately 20 to 30 minutes before meter 1 on the east side of the barrier. The quality of the data recorded by the instruments was fair to good, except for a recording error that affected directional data from instrument #1. A significant amount of manual editing was required to remove questionable data points (known in the trade as 'spikes') that are common in electrically-recording instruments. The data were recorded at 10-minute intervals, but were then smoothed and reduced to hourly means using a running 6-point mean filter in order to demonstrate the overall tidal pattern. Results are shown in Figure 7. Summary tables of data are included in Appendix 1 in this report.

This smoothing routine eliminated a conspicuous oscillation in current strength that was evident in all tidal cycles and at both meter locations, which is attributed to a *seiche* or internal wave affecting the Annapolis Basin. First order estimates show that a basin 24 km in length and 15 m deep on average will oscillate with a period of about 1 h -- about the same oscillation evident in the raw data. Consequently, the hourly variation in current velocities is probably the result of the natural oscillation of the whole Annapolis Basin in response to tidal forcing. Figure 8 shows plots of current velocities recorded at 10-minute intervals to illustrate the effects of the seiche.

Current velocities for a total of 12 tidal cycles were successfully recorded, 4 of these before the artificial barrier was installed, and 8 afterward. The current meters were removed while the barrier was still in place.

The pattern of flow was reasonably consistent for the first four tides : current velocities were initially high at both current meters when they were first covered on the flooding tide, then declined towards high water. During the ebb tide, meter 2 experienced increasing velocities reaching almost as high as on the flood (and much higher during tide 3), whereas meter 1 to the east of the barrier line tended to show relatively smaller velocities on the ebb than the flood. Velocities at meter 2 near Allain River were almost always greater than at

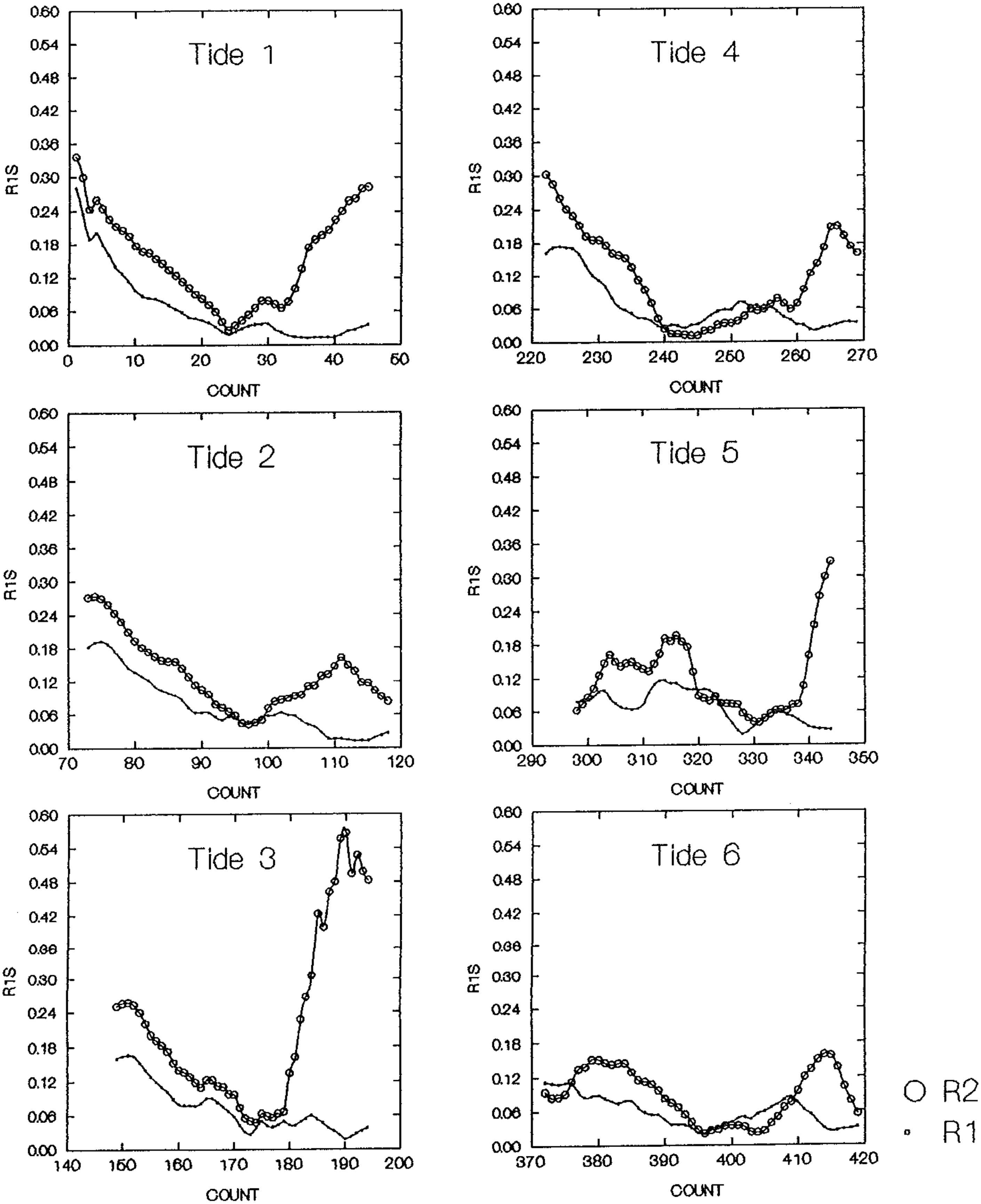

Figure 7. Mean current velocities, Fort Anne, 25 to 31 May 1993.

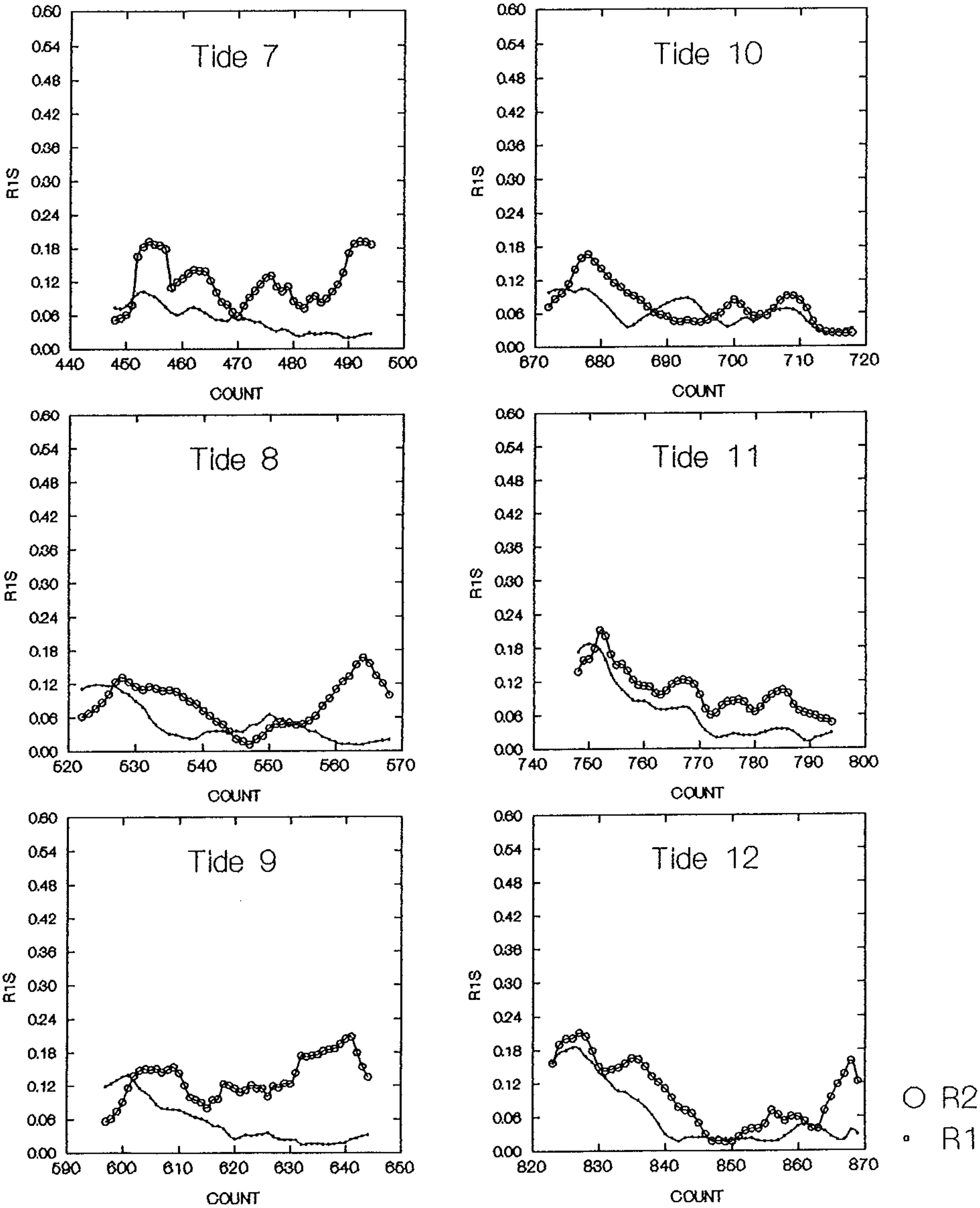

Figure 7 Cont.

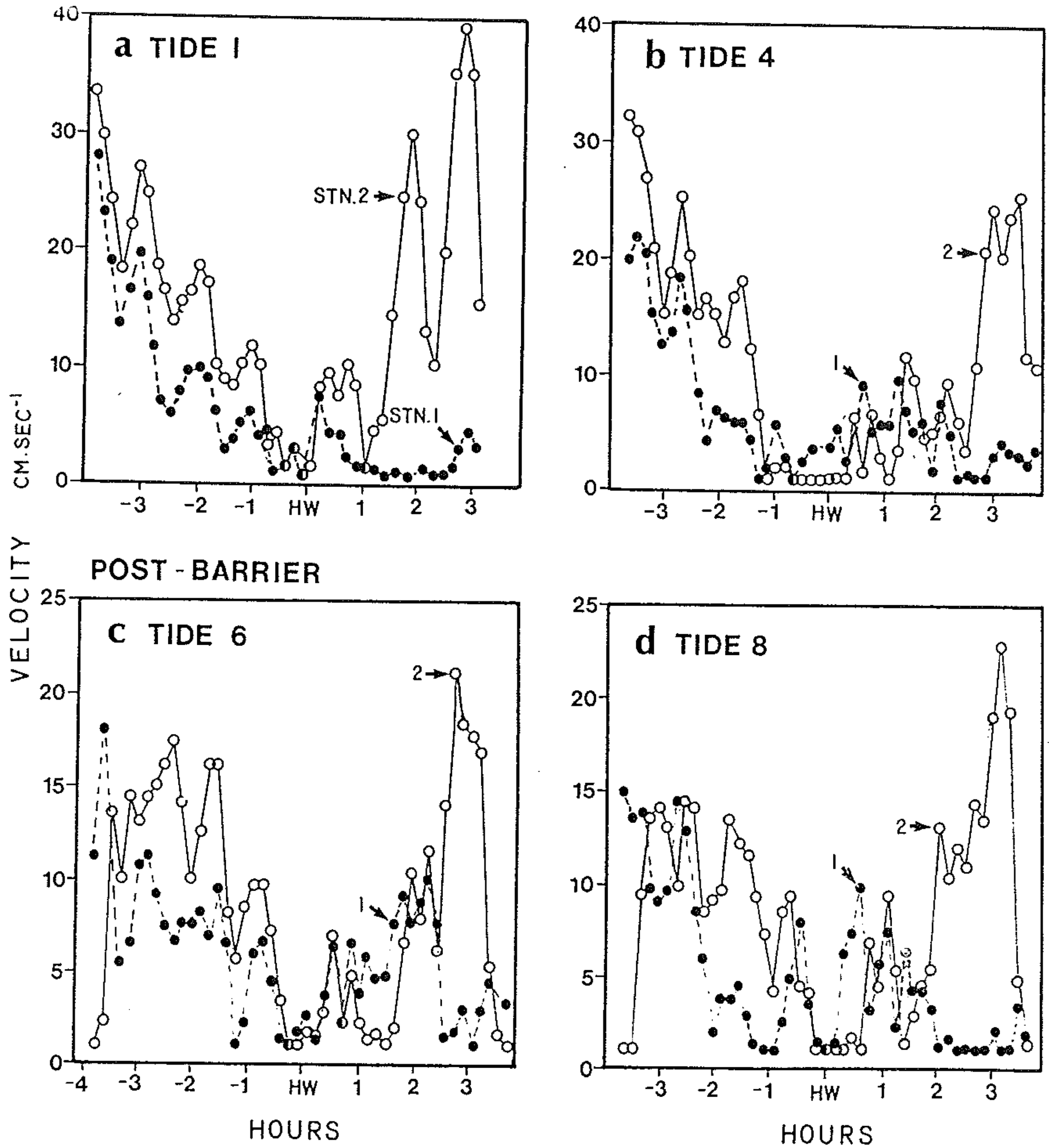

Figure 8. Plots of unedited current velocities for selected tides to illustrate the effect of the internal wave of the Annapolis Basin. Note the differences in scales of the pre-barrier records (upper panels) and the post-barrier records (lower panels). Peak velocities were sharply reduced at both stations after the barrier was constructed.

meter 1, with maximum hourly averages between 25 and 56 $cm.sec^{-1}$, and maximum values > 70 $cm.sec^{-1}$. In contrast, meter 1 averages were 15 to 20 $cm.sec^{-1}$, with a maximum of 28 $cm.sec^{-1}$.

On tide 4, velocities at meter 2 near high water were consistently lower than those at meter 1. There is no clear explanation for this change in pattern, although it may be related to the formation of the major eddy associated with patterns of flow in and out of the Allain River. Because of the constriction at the highway 1 bridge, and the interaction between tides and winds, local current patterns at any point on the Allain River are likely to be quite variable. There is no reason to suspect instrument malfunction in this case.

With construction of the barrier between the fort and the point, the behaviour of currents was dramatically different. The initial high velocities recorded on the flood tide at meter 2 disappeared, so that maximum flood tide flows were encountered during the middle of the flood period, at velocities <20 $cm.sec^{-1}$, at least during tides 5 to 10. Slightly higher flood velocities during tides 11 and 12 might be related to the deteriorating condition of the barrier at this time. With the decrease in flood velocities at meter 2, maximum ebb currents became <u>relatively</u> higher that those on the flood, although still somewhat lower than prior to the barrier. Maximum current velocities were also sharply lower at meter 1, although the mean velocities changed little pre- and post-barrier (cf. Table 2).

Data on direction of water flows at the two current meter stations showed the most surprising results, but ones which generally confirm previous observations. Figure 9 provides 'polar plots' illustrating both direction and velocity of water : the outer ring is scaled to represent a velocity of 40 $cm.sec^{-1}$. It is notable that all the visible arrows for all tides indicate that flow at both locations is consistently northerly; the strongest mean hourly values (represented by the longest vector arrows), were directed to the N or NNE, especially prior to construction of the barrier (tides 1 to 4).

An instrument error in recording direction by the meter 1 (east of the barrier line) resulted in no direction less than 333^{o} being recorded during 11 of the 12 tides. Except for tide 1, when the meter recorded a few values near 330^{o} (approximately NNW), many of the direction readings of later tides were given the value of 333^{o} (cf. Figure 10). According to ASL Environmental Services, the suppliers of the meters, this was due to a problem of recording by the instrument (see Appendix 2), and therefore we are unable to conclude very

Table 2. Effects of barrier on velocity and direction.

	Meter 1 Avg. Velocity $m.sec^{-1}$	Meter 1 Avg. Direction (^{o})	Meter 2 Avg. Velocity $m.sec^{-1}$	Meter 2 Avg. Direction (^{o})
Pre-Barrier (Tides 1-4)	0.06	350.5	0.15	7.7
Post-Barrier (Tides 5-12)	0.05	351.2	0.10	9.2

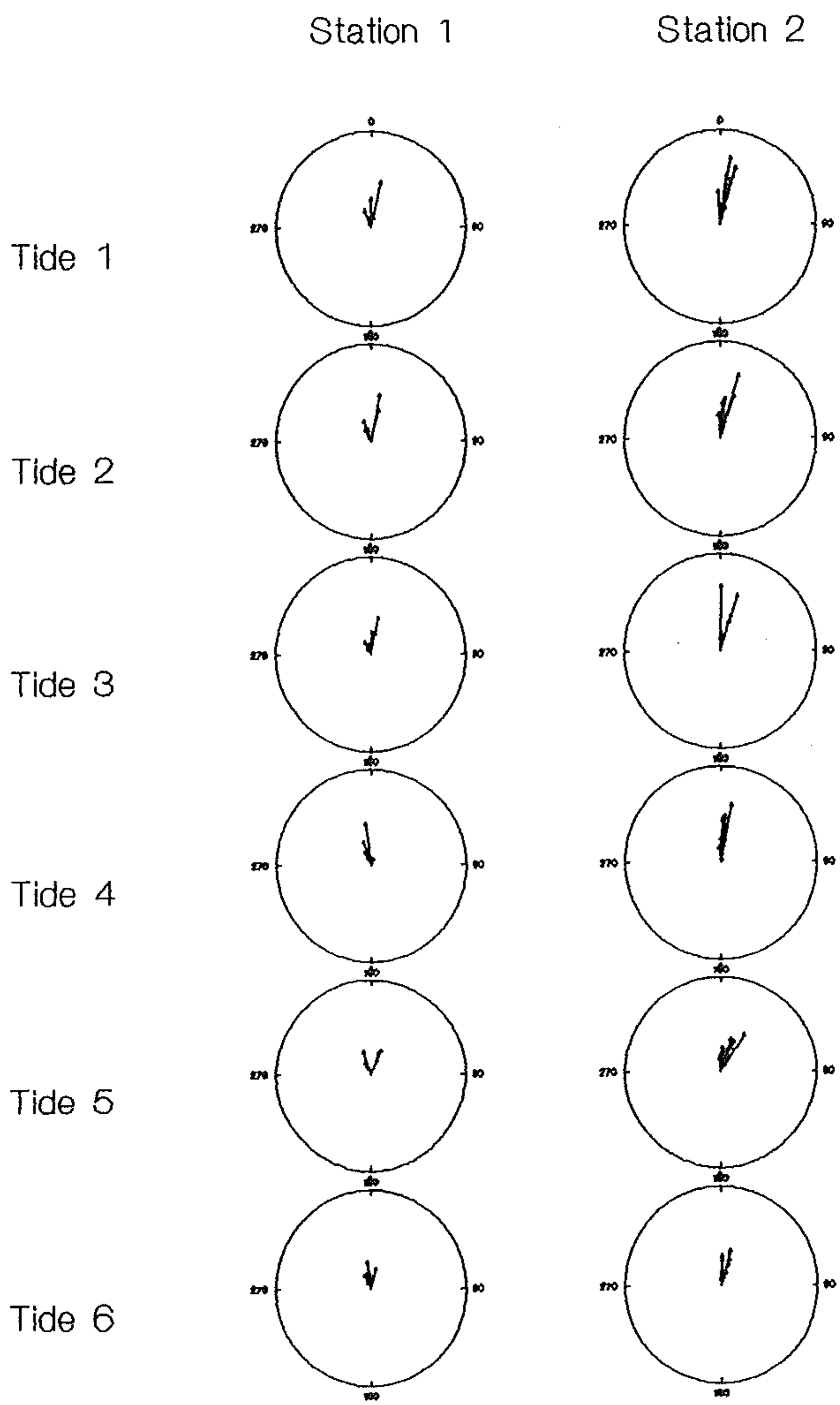

Figure 9. Polar plots of current directions, Fort Anne, 25 to 31 May 1993.

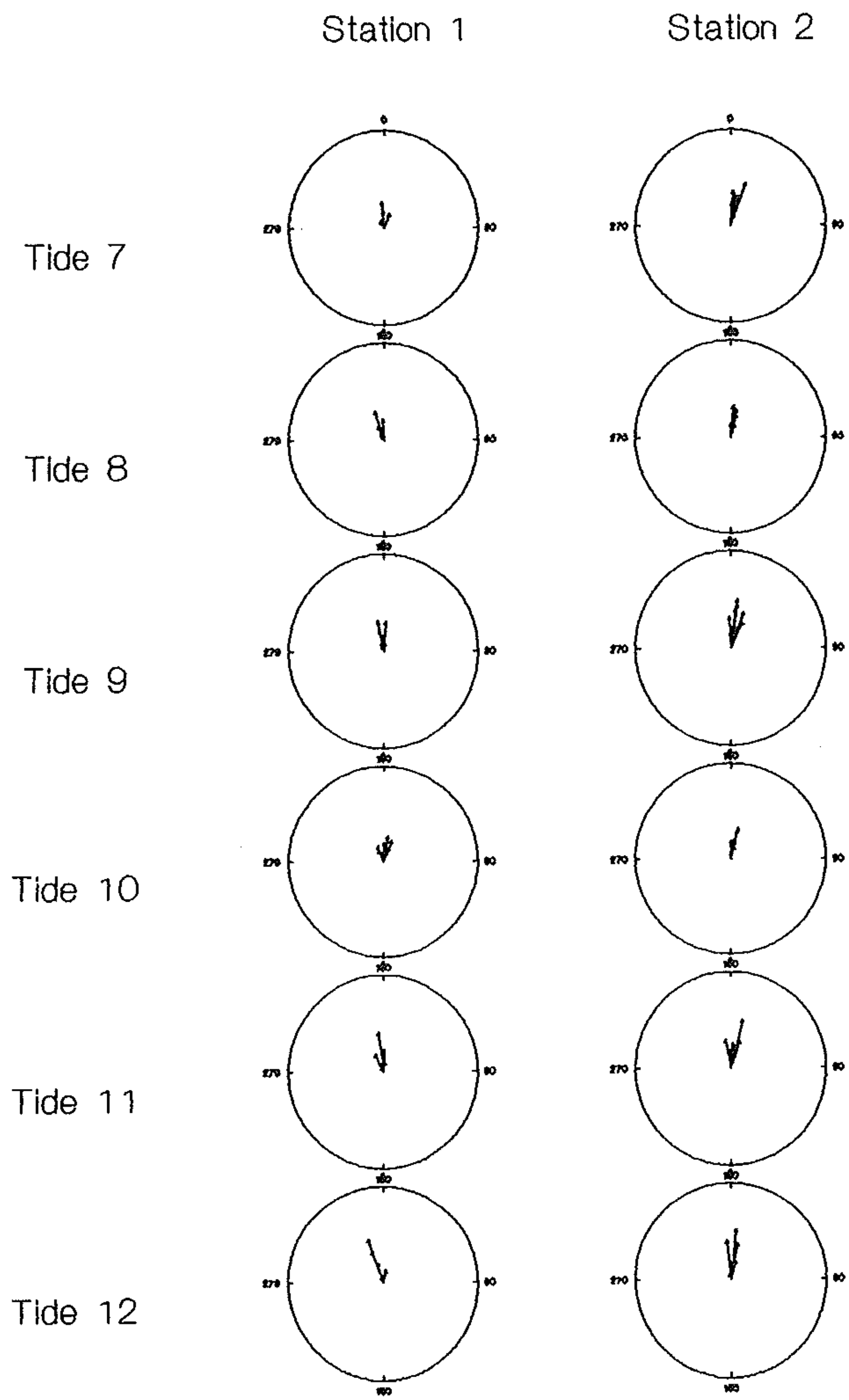

Figure 9 Cont.

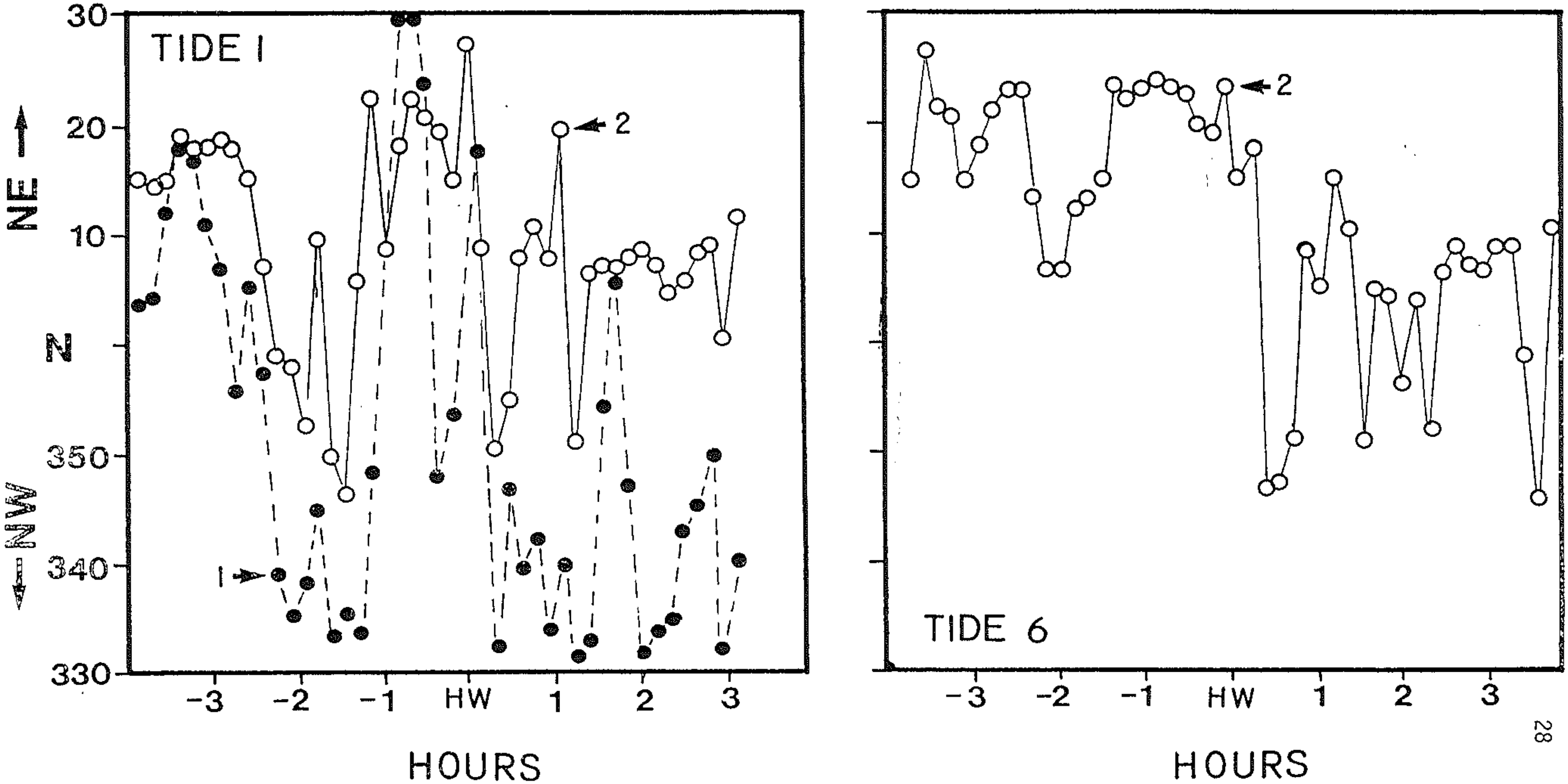

Figure 10. Plots of unedited current direction data for two selected tides, Fort Anne, 1993.
(N.B. Data for meter #1 on tide 6 are in error and omitted.)

much from this location about the directions of flow for most of the deployment. However, our own observations on several occasions, together with the results for tide 1 when the instrument appears to have been recording correctly (see Appendix 2), indicate that flows were generally distributed northward along the shore towards Queen's Wharf.

At meter 2, the direction was consistently northerly, ranging between 345° and 15 to 20°. At no time did the current meter on the Allain River side show any indication that water was flowing from the Fort Anne shore into the Allain River, which would have been a direction of 180 to 200°. These data suggest unequivocally that at all times when the Fort Anne foreshore is covered by water, the water tends to flow in a northerly direction, removing any resuspended material from the zone; the currents do not reverse in such a way that suspended material will be returned to the shore.

Construction of the barrier had no significant effect on the direction of flow at meter 2 (cf. Table 3). Because of the corrupted data from meter 1, it is not possible to draw a firm conclusion for this location. However, our several observations of orientation of the meter vane always indicated a northward direction. Consequently, we conclude that although the velocities were sharply reduced by the barrier, particularly during the flood, the direction of flow was always across or along the Fort Anne shore from Allain River toward the Queen's Wharf and the Annapolis Causeway, regardless of the presence or absence of the barrier.

7.2. ALLAIN RIVER TIDAL SERIES

Results of CTD measurements taken over a tidal sequence from the Highway 1 bridge over Allain River are shown in Figure 11. Initial measurements indicated that the water was vertically well-mixed at all stages of the tide, and thus the average values shown in Figure 11 can be taken as representative of all water depths.

Salinity near low water was 20 to 22 ‰, rising to 27 to 28 ‰ near high water. Water temperature remained between 10 and 13°C, being slightly higher during the afternoon ebb tide as a result of solar heating. Turbidity was consistently low throughout the tidal cycle, primarily because the turbid plume seen during the flood tide (see below) was constrained to the northeastern side of the river, and did not intersect the sample point in the middle of the highway bridge.

Table 3. Summary of current velocities and direction for each tide.

STATION	STATISTIC	TIDE 1	TIDE 2	TIDE 3	TIDE 4	BARRIER	TIDE 5	TIDE 6	TIDE 7	TIDE 8	TIDE 9	TIDE 10	TIDE 11	TIDE 12
-----1-----	MINIMUM	0.01	0.02	0.03	0.02	*	0.03	0.03	0.02	0.01	0.02	0.03	0.01	0.02
...VELOCITY...	MAXIMUM	0.19	0.19	0.15	0.17	*	0.11	0.11	0.10	0.12	0.12	0.10	0.16	0.10
.....M/SEC....	MEAN	0.08	0.08	0.07	0.06	*	0.07	0.06	0.05	0.06	0.08	0.06	0.06	0.05
	STD. DEV.	0.06	0.06	0.04	0.05	*	0.03	0.03	0.03	0.04	0.04	0.03	0.05	0.06
-----2-----	MINIMUM	0.05	0.05	0.06	0.01	*	0.06	0.03	0.08	0.03	0.08	0.02	0.06	0.02
...VELOCITY...	MAXIMUM	0.28	0.27	0.50	0.24	*	0.19	0.15	0.18	0.12	0.19	0.13	0.20	0.20
.....M/SEC....	MEAN	0.16	0.13	0.21	0.11	*	0.11	0.09	0.12	0.06	0.13	0.07	0.11	0.10
	STD. DEV.	0.09	0.07	0.17	0.08	*	0.05	0.04	0.03	0.04	0.05	0.03	0.05	0.06
-----1-----	MINIMUM	338.90	333.11	333.40	333.53	*	333.00	333.53	333.40	332.38	337.23	333.80	333.13	333.27
..DIRECTION..	MAXIMUM	12.00	14.65	12.25	18.60	*	22.90	13.02	22.90	356.73	8.98	23.18	8.22	11.96
.....(O)......	MEAN	352.38	347.00	355.13	347.33	*	358.28	348.77	354.63	341.53	351.14	0.33	347.29	349.73
	STD. DEV.	14.31	16.17	16.37	14.20	*	24.00	13.22	20.72	9.65	11.27	18.41	14.40	14.98
-----2-----	MINIMUM	357.02	350.72	0.92	352.18	*	354.02	0.95	2.57	3.20	357.62	2.27	349.32	350.70
..DIRECTION..	MAXIMUM	18.80	18.32	17.80	17.60	*	50.03	21.90	19.53	17.06	20.13	17.35	19.00	15.27
.....(O)......	MEAN	9.12	7.39	9.07	5.19	*	12.10	10.00	11.10	9.39	10.49	9.93	5.02	4.89
	STD.DEV.	6.53	7.20	7.52	7.59	*	12.45	8.77	6.53	8.05	9.69	5.22	10.05	8.09

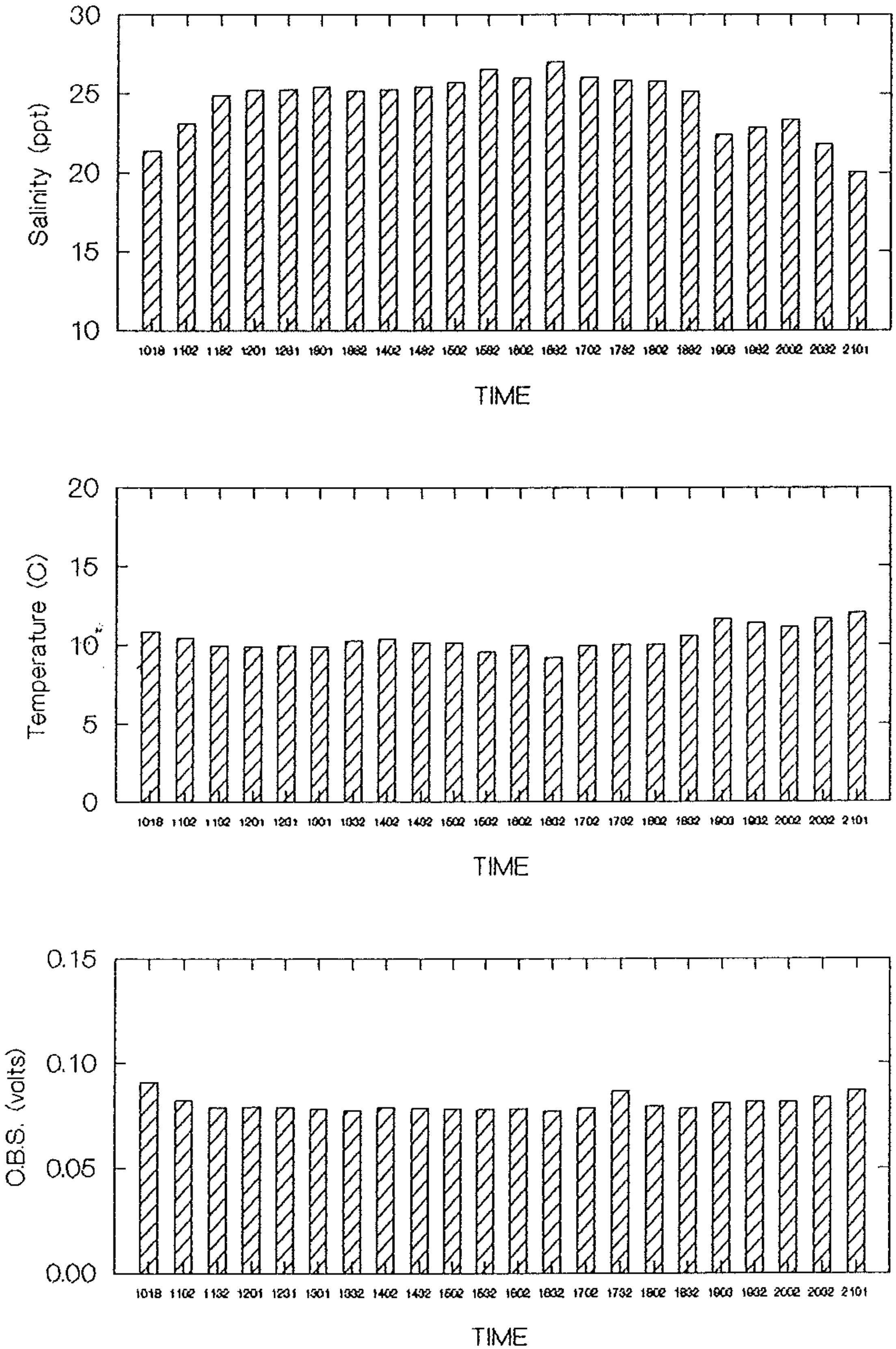

Figure 11. Tidal variations in salinity, temperature and suspended sediments (as O.B.S. volts) at Highway 1 bridge, Allain River, 26 May 1993.

Current velocities are recorded in Table 4 and illustrated in Figure 12. Because of the time required to take readings, velocity was measured at each half hour at the surface, and then at depths of 1, 2, 3, 5 and 7 m, depending upon the available depth of water. During the flood tide, maximum velocities of 0.68 $m.sec^{-1}$ (68 $cm.sec^{-1}$) were encountered during the middle of the flood, when water depth was <8 m. At this stage, the flooding water is advancing through the very narrow channel left between boulder piles remaining from an earlier bridge construction; after this time, the flood velocity decreased to <40 $cm.sec^{-1}$, partly because width of the channel increased sharply once the boulder piles were covered. These moderate velocities continued through high water. During the ebb, velocities rose steadily as the water level fell, primarily because of the constriction presented at the bridge. Higher velocities continued to be achieved as water depth decreased, reaching more than 2 $m.sec^{-1}$ (i.e., >200 $cm.sec^{-1}$) at the time the study was terminated. The measurement series ended at 21.00 h (5 h after High Water) because at this time the narrowness of the channel meant that the strong jetting outflow wandered apparently erratically from side to side in the channel, and a mean value for current velocity could not be obtained.

Observations made during these measurements indicate very strongly that the pattern of flow through the bridge over Allain River has a great deal of influence upon the flows across the Fort Anne shoreline. The pattern of flow during the early flood results in formation of a shear line running diagonally across the river channel between the southwest shore at the mouth of the river, and the eastern shore of the river at the level of the railway bridge. Associated with this shear line is a major clockwise eddy that constrains water advancing into Allain River to follow the eastern side, i.e., beside Fort Anne.

By 12:00 h, at an early stage of the flood, it was apparent that water advancing over the Fort Anne shoreline was very much more turbid than the rest of the flooding water, because of immediate resuspension of clays from that shoreline. This resulted in a distinct turbid plume that passed into Allain River as a narrow band along the eastern shore, constrained there by the eddy described above. The plume never intersected the location of the CTD, which was suspended from the middle of the road bridge. These phenomena precisely match the conditions recorded in an aerial photograph taken on 13 August 1992 (see Figure 1).

Table 4. Current velocities at Highway 1 bridge, Allain River, 26 May 1993.

REAL TIME	TIDE TIME	SURFACE CV	CV @ 3M	CV @ 5 M	CV @ 7 M	WATER DEPTH
10:16	-5.7	0.06	-	-	-	4
11:00	-5.0	0.13	-	-	-	4
11:30	-4.5	0.30	0.42	0.45	-	5
12:00	-4.0	0.28	0.54	0.48	-	6.5
12:30	-3.5	0.68	0.68	0.51	-	7
13:00	-3.0	0.55	0.61	0.59	-	7.5
13:30	-2.5	0.61	0.53	0.47	-	8
14:00	-2.0	0.47	0.38	0.37	-	9
14:30	-1.5	0.46	0.45	0.40	-	9.5
15:00	-1.0	0.27	0.21	0.21	-	10.5
15:30	-0.5	0.29	0.33	0.26	-	10.5
(HW)16:00	0	0.33	0.27	0.29	-	11.0
16:30	+0.5	0.33	0.18	0.00	0.00	10.25
17:00	+1.0	0.60	0.57	0.40	0.02	10
17:30	+1.5	0.48	0.45	0.37	0.19	9.5
18:00	+2.0	0.74	0.69	0.65	0.61	8.75
18:30	+2.5	1.15	1.11	0.89	-	7.75
19:00	+3.0	1.05	0.84	0.41	0.18	7
19:30	+3.5	1.20	0.38	0.22	-	6.5
20:00	+4.0	1.79	1.91	2.01	-	6
20:30	+4.5	1.60	1.50	-	-	5.5
21:00	+5.0	2.15	1.87	-	-	5

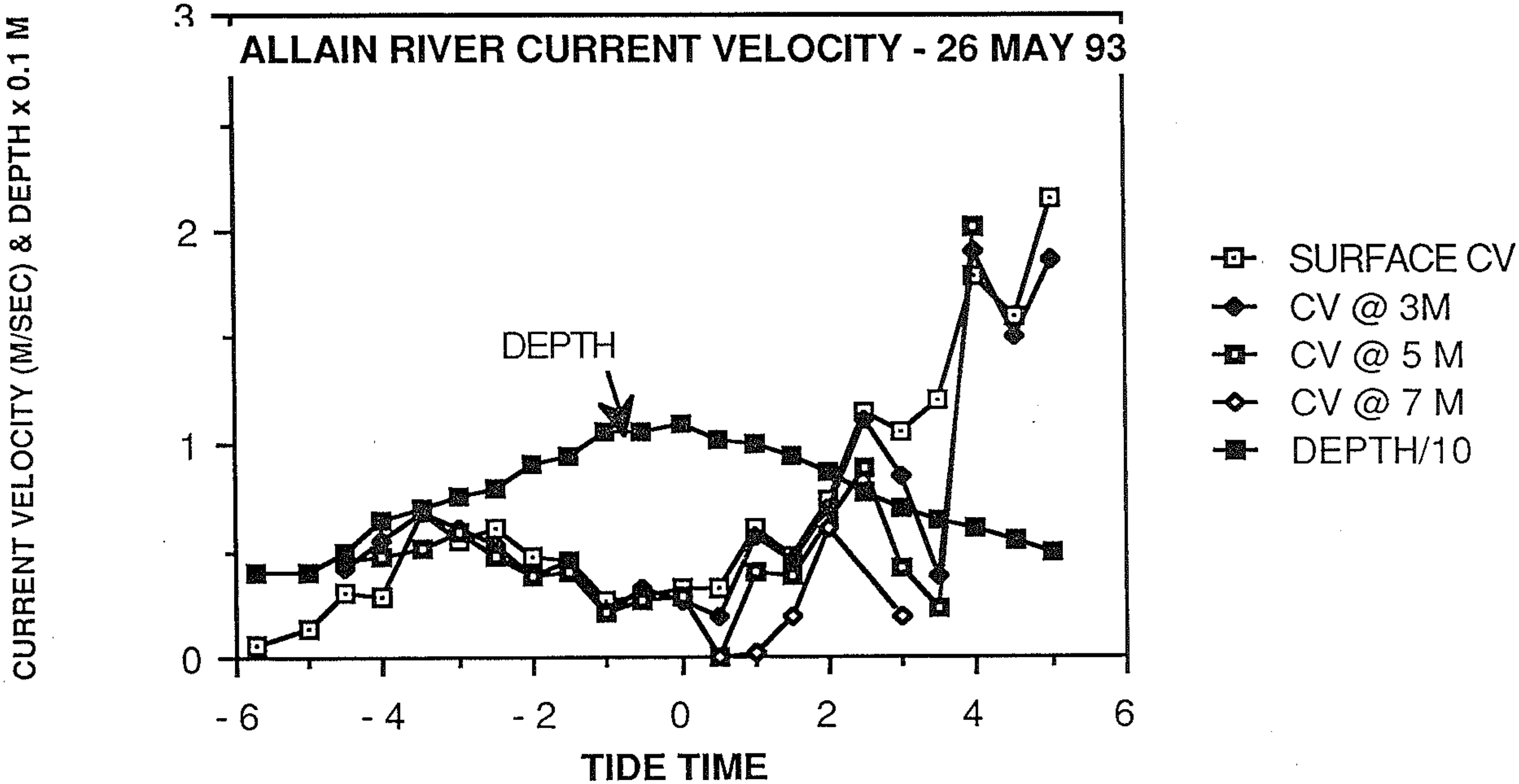

Figure 12. Current velocities and water depth, Highway 1 bridge, Allain River, 26 May 1993.

It was noticeable that no resuspension occurred as flooding water advanced over the grey-coloured clays that are exposed along the southwestern bank of the Allain River. Clearly this deposit, which appears similar to that underlying the Fort Anne saltmarsh, but overlying the red clay, has quite different resuspension properties from the red clay itself.

During the ebbing tide, flow was maximal toward the western side of the channel, and resulted in formation of a major clockwise gyre or eddy that maintained at least a surface flow toward the Fort Anne shore. At its most extreme development, just before the study was concluded, outflow from the Allain River was strongly concentrated on its southwestern side, with a backward, or upstream flow on the northeastern side resulting from the gyre.

These observations confirm the directional information derived from the fixed current meters. It supports the contention that direction of flow on both flood and ebb is consistently northerly across the Fort Anne shore, except for a relatively narrow band of turbid water that passes upstream in Allain River along its eastern shore. The dynamics of flow in the Allain River are quite clearly related to the constriction formed by the highway bridge. Figure 13 is an attempt to represent the flow conditions observed, and in part measured, in Allain River during this study.

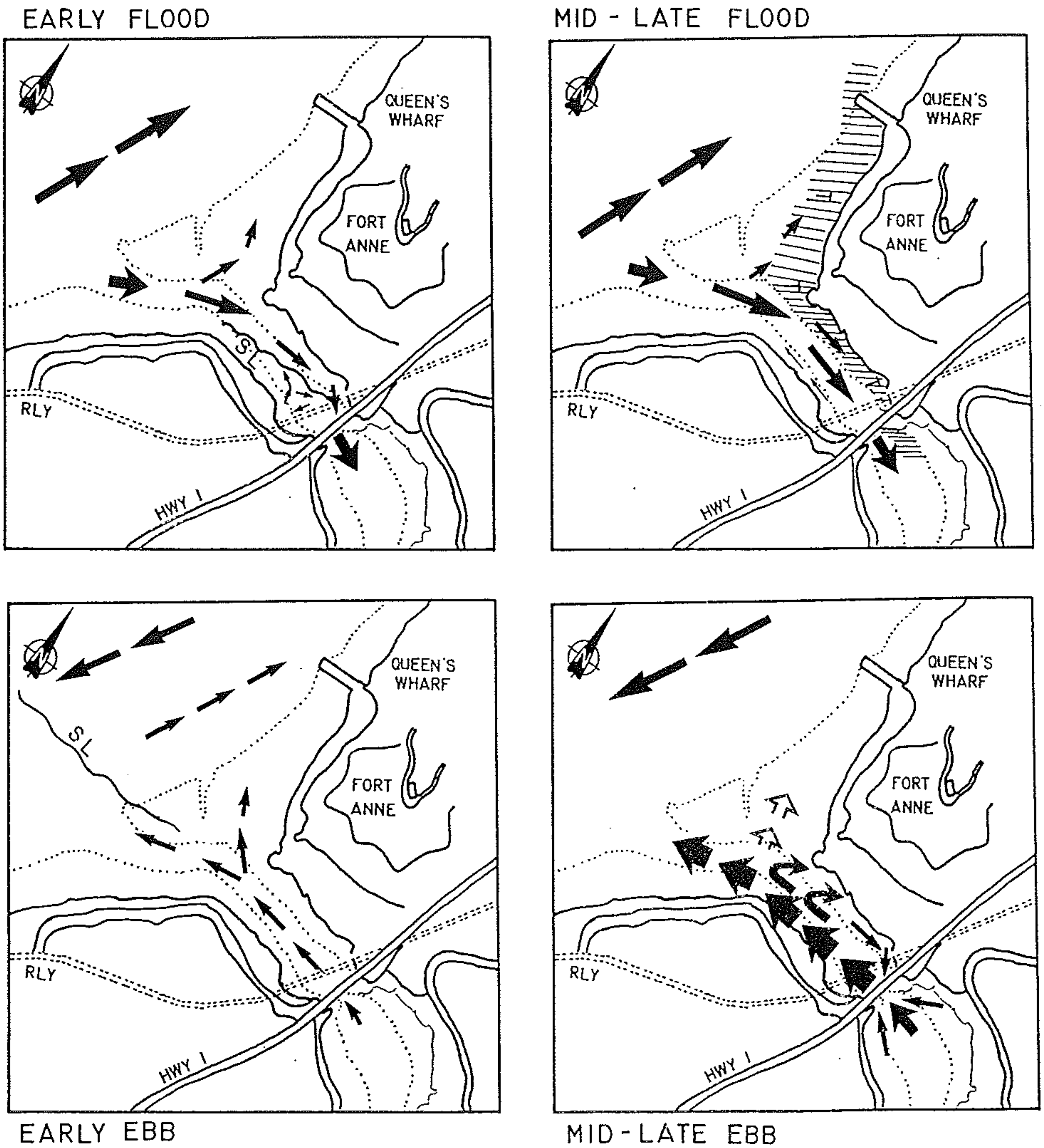

Figure 13. Patterns of current flow in Allain River. T = turbidity plume, SL = shear line.

8. INTERPRETATION

8.1. EMBANKMENT STABILITY

Our present results regarding the orientation of the upturned timbers toward the western end of the Fort Anne foreshore do not indicate that the embankment is slumping sufficiently rapidly to be recorded within a month, but it must be recognised that the time series of measurements is very short. In addition, movements of an inherently unstable embankment are likely to be episodic, responding to strong short-term effects rather than longer-term processes. The fact that the timbers toward the western end are tipped upward indicates that at some time in the past the embankment has experienced a rotational slip. Figure 14 provides a representation of the processes and forces involved in slipping phenomena. It is quite possible that most activity occurs in the late winter and spring, when heavy rainfall occurs, raising the water table and decreasing the shear strength of the soil. At this time also, cyclic loading from higher tides could induce more forceful drawdown of the ground water table at the foot of the embankment. Percolation of water from the top of the embankment might also contribute to the ease with which the soils may undergo slippage. It is essential to continue the present set of measurements on the cribwork, so that any significant movements can be detected.

Nonetheless, all indications are that the embankment is unstable, and that the absence of a sufficient mass at the toe of the slope is part of the reason. Present stratigraphic information suggests that the fort may be underlain by a plastic clay that seems to have sufficient strength to support the embankment as long as it remains intact and unweathered. Permitting the present disintegration of the embankment may well lead to intrusion of water into this layer and hasten its failure.

8.2. SEDIMENT PROPERTIES

Our preliminary study shows that the sediment now exposed over much of the intertidal zone, which contributes to the marked turbidity of the water on each rising tide, is a stratified deposit of highly plastic red clay. Its behaviour results in resuspension of the upper surface on every tide, apparently because the consolidated clay loses its cohesion upon wetting. Observations indicate that this clay is colonised by several invertebrate

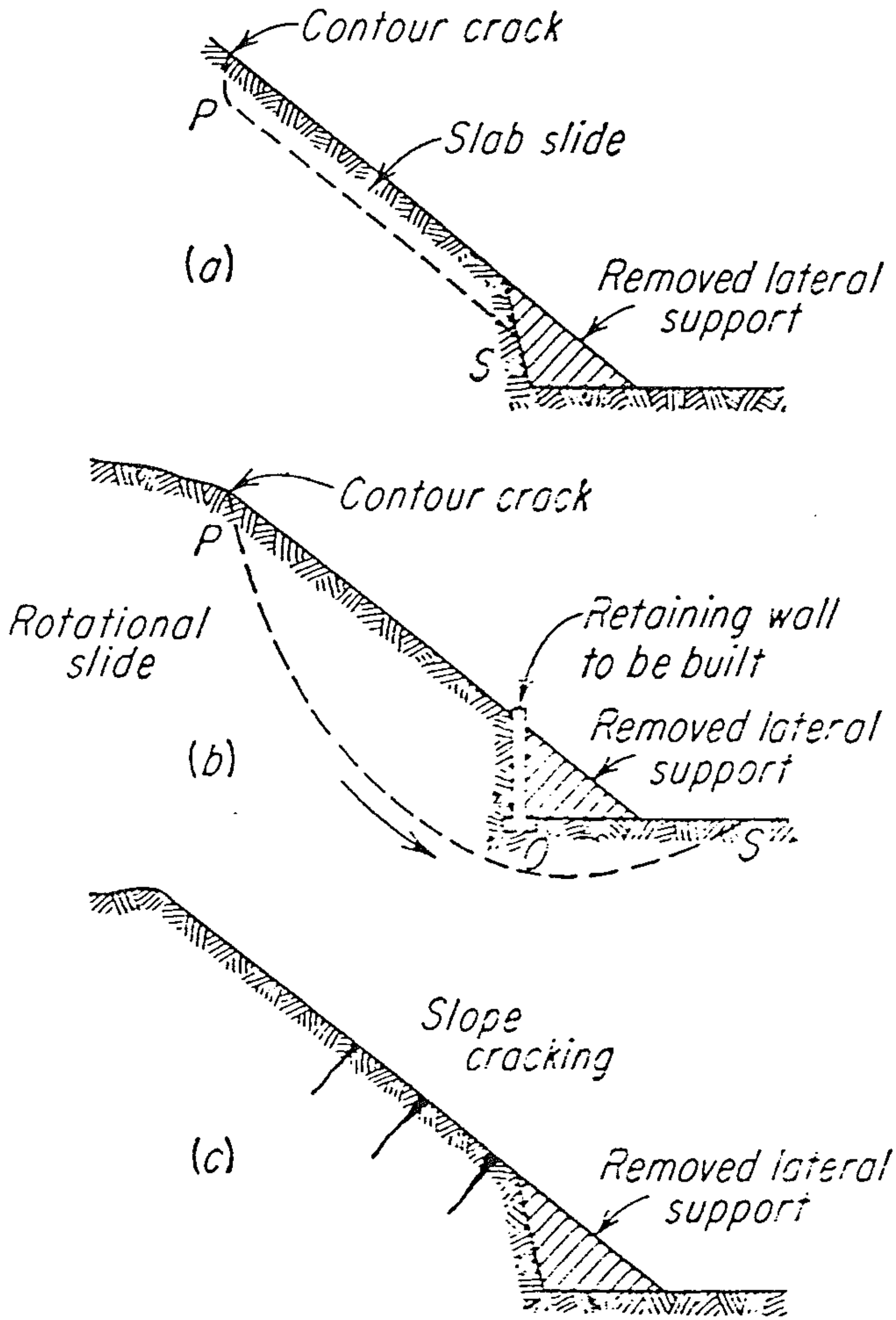

Figure 14. Sliding caused by the removal of lateral support.

From: Krynine, D.P. and W.R. Judd. 1957. Principles of Engineering Geology and Geotechnics. McGraw-Hill, N.Y., p. 640.

organisms that burrow into the sediment and thereby increase the potential for its resuspension and erosion directly by bioturbation, and indirectly by introducing water to greater depths. Comparison of the behaviour of this clay with the fine grey muds lining other parts of the Annapolis Estuary and Allain River (see above) seems to indicate that it must have been protected by an overlying band of more erosion-resistant material, such as that which underlies the saltmarsh. Aerial photographs from 1942 (low tide) and 1963 (high water) suggest that a cap of saltmarsh and more stable muddy substrate probably overlay the presently-exposed red clay at these times. Shear strength measurements point to a degree of consolidation in this red clay consistent with it being buried beneath 1 m or more of overburden.

Since coring studies indicate that this clay deposit extends relatively unchanged for depths of 1.4 to 2.5 m -- and probably more -- it seems likely that the present process of loss of sediment by resuspension will continue more or less indefinitely.

The bed level measurements conducted as part of this study suggest that, at least during the summer months, material eroded from the saltmarsh and upper shore is being stored in the middle or upper intertidal zone, as is typical in temperate estuaries. Failure to capture sediments moving downslope into the sediment traps supports this conclusion. However, temperate estuaries generally release sediment during the more dynamic wave-dominated periods of the winter, and it is to be expected that the material now being accumulated on the shore will disappear during next winter. There seems to be no reason to expect that the eroded material will remain on the Fort Anne shore. Consequently, the shoreline next spring should indicate a loss of the material that has been eroded during the past months. Without accumulation of eroded material in the intertidal zone, the marsh and footings of the fort are open to continued assault by waves.

These observations point unequivocally to two essential measures: (1) protection of the embankment footings and marsh against continued wave attack, and (2) protection of the exposed red clay deposit against wetting and consequent resuspension and loss.

8.3. WATER MOVEMENTS

Measurements of water movements using moored current meters, and observations made during the tidal series at the highway bridge over Allain River, confirm previous observations that water flows consistently northward over the foreshore in front of Fort Anne. This consistent orientation of water flow is highly peculiar : one usually expects that flood and ebb flows would be in opposite directions. The effect is that all material resuspended on the rising tide from the intertidal zone is moved away from the site of resuspension --- mostly upstream toward the Annapolis Causeway, although some moves along the northeast bank of the Allain River. There appears to be no mechanism for it to return.

Resuspension of surficial sediments is in part a function of the stress applied by water moving over its surface, and therefore is a function of current velocity. Our experiment with the temporary barrier showed that limiting flow across the line between the fort and the point could significantly reduce current velocities on both sides, although the difference was much greater on the Allain River side, where much of the present marsh erosion is taking place. Current velocities at meter 2 were almost 30% less than prior to construction of the barrier. It should be noted that the barrier was only 1 to 1.2 m in height, whereas the current measurements were made at a height of 0.9 m, quite a distance away from the barrier. The barrier clearly had a major effect on the strength of current flows across this zone, although it seems to have had little or no effect on the directions of flow.

It seems an inescapable conclusion that on the rising tide, water tends to move across the Fort Anne shoreline after passing south of the point, and then divides into two flows, one of which continues northward across the Fort Anne intertidal, and another which travels along the northeastern shore of Allain River. At no time did the current meter installed at meter 1, northeast of the barrier, indicate flows of water to the east or south (i.e., onto the shore from the Annapolis River side). Although instrument errors might be partly responsible for this, our own visual observations support the persistent northerly flow. On the ebb, flow is still toward the north or northeast, because of a very strong gyre set up in Allain River as a result of the flow pattern caused primarily by the constriction above the highway bridge. Thus, it seems that the flow across the Fort Anne shore is primarily determined by the present morphometry of Allain River. During the flooding tide, the shear line indicates that flow is directed primarily onto the Fort Anne shore, whereas on the ebb the major eddy formed downstream of the constriction at the highway bridge results again in flow directed toward the Fort Anne shore.

9. CONCLUSIONS

(1) Waves remain the dominant short-term force causing erosion of saltmarsh and sediments in the upper intertidal zone.

(2) Destabilisation of the embankment of the fort is a result : (a) of the loss of saltmarsh by undercutting at its base; (b) of the continued erosion of intertidal sediments that increases the slope of the beach, and hence the exposure of the marsh and footings; and (c) potential weak clays underlying the base of the embankment.

(3) Continued erosion of the exposed red intertidal clay results from softening (loss of cohesion upon wetting) and resuspension. It is expected to continue as long as this deposit is exposed to tidal waters and wave action.

(4) Flows across the intertidal zone that contribute both to erosion and export of resuspended sediment are related to the dynamics of the Allain River, and are strongly influenced by the narrow constriction just above the highway bridge.

(5) A barrier across the intertidal zone along the line of a historic structure would significantly reduce currents on the Allain River side, but have less effect on the Fort Anne shore. It may have negligible effect on the direction of water flows, unless it is more than 1 m in height.

10. RECOMMENDATIONS

(1) **Remove the boulder piles upstream of the Highway 1 bridge over Allain River.**

This narrowing of the channel results in a very significant increase in the ebb velocities out of the Allain River, and changes the pattern of flow in the stretch downstream of the highway bridge. Although not in itself responsible for the present erosion of the Fort Anne shore, it exacerbates the problem by causing flows across the shoreline to persist in a northerly direction so that eroded material is continuously exported from the area. Widening of the Allain River at this point will decrease resistance to flow on both flood and ebb, and therefore should decrease the velocities experienced on the southwestern portion of the Fort Anne shore where erosion is presently most active.

A secondary benefit of removing the obstruction at the Highway 1 bridge would be a reduction of the scouring forces that presently act on the railway and highway bridge supports, and hence enhance the stability of the bridges themselves. The material to be removed might also contribute in a small way to protective works for the Fort itself, although additional material would also be required.

(2) **Monitor flows across the Fort Anne shore for a period of at least 4 tides following removal of the constriction at the highway bridge on Allain River, by installing current meters at the sites previously used.**

This should confirm that current velocities are indeed diminished by widening of Allain River, and detect any effective change in eddy formation, especially on the ebb tide, and on direction of flow across the Fort Anne shore.

(3) **Reinstall the counterbalancing mass at the toe of the embankment where upturned cribwork is exposed, in order to assist the stabilisation of this part of the fort.**

This could be done by providing extensive riprap as part of a protection against wave action. The rocks removed from the Allain River bridge area could be used for this purpose.

(4) **Provide protection of the remaining saltmarsh against the effects of waves to prevent further loss.**

This could be achieved by a number of different techniques, including the use of riprap, or a seawall of various materials.

(5) **Maintain the integrity of the soils on the top of the embankment to prevent percolation of water into the structure.**

This may require cessation of archeological work until such time as the water table characteristics are determined and reseeding of exposed areas.

(6) **Install piezometers in the embankment wall and monitor water levels and pressures to examine the status of the water table.**

This is a necessary step in any future geotechnical assessment of appropriate remedial works and should be done in combination with analytical studies discussed in item 3.

(7) **Protect the exposed red clay occurring on the lower shore from resuspension by preventing wetting and decreasing bioturbation.**

One obvious measure would be to cover the clay with less erodible material such as sand and gravel. It will be necessary to provide a shallow seaward barrier along the lower intertidal zone to prevent downslope movement of the covering material.

(8) **Continue the geotechnical examination of the sediment properties started during this study to assess the shear strength behaviour of the red clay deposits.**

This information will be required for selection of the best engineering solution(s) to the problems of erosion. Analysis of the percussion samples obtained during this study for shear strength would provide an initial basis for selecting an improved site investigation program; a necessary step before designing a seawall and for providing input data for embankment stability analyses.

* * *

All of the above activities are, in our view, critical for the long-term protection of Fort Anne against erosion. However, some of these actions are extremely urgent, and should not be delayed longer than absolutely necessary. These high priority items include recommendations 4, 3 and 1. Other recommendations need to be initiated in order to make sound judgements on alternative remedial measures (e.g., recommendations 6 and 8), or to provide a longer time for appropriate planning (e.g., recommendation 5).

11. REFERENCES CITED

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Dunn, B. 1992. A preliminary look at the history of erosion at Fort Anne. Internal Report, Atlantic Regional Office, Canadian Parks Service. 32 p.

12. APPENDICES

Appendix 1. Hourly means of velocity and direction, Fort Anne, 25 to 31 May 1993.

A. Meter 1

B. Meter 2

A.

		DA	HR	MIN	TIDE	D1	R1	D1S	R1S
CASE	1	25.000	12.000	0.000	1.000	372.000	0.190	12.000	0.190
CASE	2	25.000	13.000	0.000	1.000	365.100	0.069	359.217	0.113
CASE	3	25.000	14.000	0.000	1.000	333.500	0.063	336.883	0.070
CASE	4	25.000	15.000	0.000	1.000	389.500	0.048	11.483	0.039
CASE	5	25.000	16.000	0.000	1.000	332.400	0.076	356.000	0.033
CASE	6	25.000	17.000	0.000	1.000	331.700	0.014	339.267	0.016
CASE	7	25.000	18.000	0.000	1.000	333.800	0.020	342.717	0.013
CASE	8	25.000	19.000	0.000	1.000	340.400	0.035	341.512	0.035
CASE	9	26.000	0.000	0.000	2.000	368.500	0.218	10.734	0.192
CASE	10	26.000	1.000	0.000	2.000	377.900	0.122	14.500	0.129
CASE	11	26.000	2.000	0.000	2.000	333.800	0.094	339.033	0.086
CASE	12	26.000	3.000	0.000	2.000	333.800	0.091	333.117	0.051
CASE	13	26.000	4.000	0.000	2.000	333.800	0.097	337.100	0.054
CASE	14	26.000	5.000	0.000	2.000	333.800	0.073	344.850	0.049
CASE	15	26.000	6.000	0.000	2.000	333.800	0.011	339.083	0.016
CASE	16	26.000	7.000	0.000	2.000	333.800	0.011	337.557	0.023
CASE	17	26.000	13.000	0.000	3.000	377.900	0.122	12.250	0.152
CASE	18	26.000	14.000	0.000	3.000	382.900	0.066	11.250	0.088
CASE	19	26.000	15.000	0.000	3.000	372.700	0.060	2.883	0.090
CASE	20	26.000	16.000	0.000	3.000	356.000	0.011	1.267	0.042
CASE	21	26.000	17.000	0.000	3.000	333.800	0.073	351.500	0.039
CASE	22	26.000	18.000	0.000	3.000	333.000	0.069	333.400	0.054
CASE	23	26.000	19.000	0.000	3.000	333.800	0.014	333.400	0.025
CASE	24	27.000	1.000	0.000	4.000	376.900	0.153	352.083	0.172
CASE	25	27.000	2.000	0.000	4.000	333.000	0.045	340.933	0.100
CASE	26	27.000	3.000	0.000	4.000	333.000	0.011	350.033	0.042
CASE	27	27.000	4.000	0.000	4.000	382.900	0.035	18.600	0.025
CASE	28	27.000	5.000	0.000	4.000	333.800	0.091	347.267	0.058
CASE	29	27.000	6.000	0.000	4.000	333.000	0.051	333.533	0.058
CASE	30	27.000	7.000	0.000	4.000	333.800	0.014	339.083	0.029
CASE	31	27.000	8.000	0.000	4.000	333.800	0.032	337.100	0.033
CASE	32	27.000	14.000	0.000	5.000	333.800	0.088	341.200	0.098
CASE	33	27.000	15.000	0.000	5.000	382.900	0.073	21.667	0.065
CASE	34	27.000	16.000	0.000	5.000	382.900	0.116	22.900	0.111
CASE	35	27.000	17.000	0.000	5.000	382.900	0.116	20.333	0.100
CASE	36	27.000	18.000	0.000	5.000	333.800	0.011	341.717	0.026
CASE	37	27.000	19.000	0.000	5.000	333.000	0.057	333.000	0.055
CASE	38	27.000	20.000	0.000	5.000	333.000	0.035	333.000	0.038
CASE	39	28.000	2.000	0.000	6.000	333.800	0.054	350.450	0.109
CASE	40	28.000	3.000	0.000	6.000	382.900	0.066	13.017	0.083
CASE	41	28.000	4.000	0.000	6.000	356.000	0.066	354.933	0.058
CASE	42	28.000	5.000	0.000	6.000	333.800	0.014	359.283	0.036
CASE	43	28.000	6.000	0.000	6.000	333.000	0.063	340.800	0.038
CASE	44	28.000	7.000	0.000	6.000	333.000	0.048	333.533	0.060
CASE	45	28.000	8.000	0.000	6.000	333.800	0.076	338.950	0.062
CASE	46	28.000	9.000	0.000	6.000	333.800	0.045	339.217	0.028
CASE	47	28.000	15.000	0.000	7.000	333.800	0.141	353.233	0.102
CASE	48	28.000	16.000	0.000	7.000	333.000	0.073	356.383	0.061
CASE	49	28.000	17.000	0.000	7.000	382.900	0.048	22.900	0.058
CASE	50	28.000	18.000	0.000	7.000	382.900	0.085	21.233	0.053
CASE	51	28.000	19.000	0.000	7.000	333.000	0.038	341.717	0.031
CASE	52	28.000	20.000	0.000	7.000	333.800	0.017	333.400	0.028
CASE	53	28.000	21.000	0.000	7.000	333.800	0.014	333.533	0.020
CASE	54	29.000	3.000	0.000	8.000	356.000	0.097	341.200	0.118

ISE	55	29.000	4.000	0.000	8.000	382.900	0.060	356.733	0.079
SE	56	29.000	5.000	0.000	8.000	333.800	0.014	333.800	0.025
CASE	57	29.000	6.000	0.000	8.000	333.000	0.035	355.450	0.036
ISE	58	29.000	7.000	0.000	8.000	333.800	0.097	337.233	0.056
ISE	59	29.000	8.000	0.000	8.000	333.000	0.042	341.933	0.046
CASE	60	29.000	9.000	0.000	8.000	333.000	0.011	333.517	0.012
CASE	61	29.000	10.000	0.000	8.000	330.000	0.035	332.363	0.018
ISE	62	29.000	15.000	0.000	9.000	333.800	0.135	347.673	0.119
ASE	63	29.000	16.000	0.000	9.000	359.200	0.153	4.233	0.115
CASE	64	29.000	17.000	0.000	9.000	333.800	0.110	346.317	0.077
ISE	65	29.000	18.000	0.000	9.000	382.900	0.088	357.983	0.056
ISE	66	29.000	19.000	0.000	9.000	383.600	0.017	8.983	0.028
CASE	67	29.000	20.000	0.000	9.000	347.700	0.023	342.183	0.029
ISE	68	29.000	21.000	0.000	9.000	333.000	0.020	337.233	0.015
ISE	69	29.000	22.000	0.000	9.000	333.000	0.017	344.500	0.017
CASE	70	30.000	4.000	0.000	10.000	377.900	0.094	9.950	0.103
CASE	71	30.000	5.000	0.000	10.000	333.800	0.042	1.250	0.072
ISE	72	30.000	6.000	0.000	10.000	382.900	0.063	23.183	0.056
ISE	73	30.000	7.000	0.000	10.000	382.900	0.094	22.900	0.087
CASE	74	30.000	8.000	0.000	10.000	333.800	0.073	356.683	0.035
ISE	75	30.000	9.000	0.000	10.000	356.000	0.038	337.500	0.063
ISE	76	30.000	10.000	0.000	10.000	333.800	0.029	333.800	0.045
CASE	77	30.000	11.000	0.000	10.000	333.800	0.023	357.350	0.029
ISE	78	30.000	17.000	0.000	11.000	333.800	0.141	352.250	0.160
ISE	79	30.000	18.000	0.000	11.000	367.100	0.082	1.700	0.086
CASE	80	30.000	19.000	0.000	11.000	333.000	0.073	333.133	0.073
CASE	81	30.000	20.000	0.000	11.000	333.800	0.011	333.267	0.034
ISE	82	30.000	21.000	0.000	11.000	333.800	0.017	348.800	0.025
ISE	83	30.000	22.000	0.000	11.000	382.900	0.035	8.217	0.033
CASE	84	30.000	23.000	0.000	11.000	333.800	0.011	333.667	0.014
ISE	85	31.000	5.000	0.000	12.000	333.800	0.187	340.020	0.180
ISE	86	31.000	6.000	0.000	12.000	333.000	0.131	338.950	0.130
CASE	87	31.000	7.000	0.000	12.000	367.100	0.076	342.917	0.078
CASE	88	31.000	8.000	0.000	12.000	382.900	0.032	6.267	0.023
ISE	89	31.000	9.000	0.000	12.000	367.100	0.011	3.633	0.018
CASE	90	31.000	10.000	0.000	12.000	356.000	0.017	340.800	0.016
CASE	91	31.000	11.000	0.000	12.000	382.900	0.066	11.983	0.046
ISE	92	31.000	12.000	0.000	12.000	333.000	0.011	333.267	0.019

B.

		DA	HR	MIN	TIDE	D2	R2	D2S	R2S
CASE	1	25.000	12.000	0.000	1.000	375.000	0.243	15.000	0.243
CASE	2	25.000	13.000	0.000	1.000	375.000	0.166	12.517	0.195
CASE	3	25.000	14.000	0.000	1.000	349.800	0.104	357.017	0.134
CASE	4	25.000	15.000	0.000	1.000	382.500	0.035	18.800	0.071
CASE	5	25.000	16.000	0.000	1.000	350.500	0.085	7.433	0.054
CASE	6	25.000	17.000	0.000	1.000	351.200	0.048	7.267	0.077
CASE	7	25.000	18.000	0.000	1.000	367.300	0.135	6.933	0.207
CASE	8	25.000	19.000	0.000	1.000	371.800	0.159	8.143	0.282
CASE	9	26.000	0.000	0.000	2.000	375.000	0.293	16.189	0.269
CASE	10	26.000	1.000	0.000	2.000	379.400	0.181	18.317	0.181
CASE	11	26.000	2.000	0.000	2.000	355.400	0.169	3.900	0.144
CASE	12	26.000	3.000	0.000	2.000	360.300	0.116	7.833	0.072
CASE	13	26.000	4.000	0.000	2.000	356.800	0.100	8.083	0.051
CASE	14	26.000	5.000	0.000	2.000	346.600	0.116	356.717	0.095
CASE	15	26.000	6.000	0.000	2.000	365.500	0.135	7.450	0.162
CASE	16	26.000	7.000	0.000	2.000	368.700	0.128	0.624	0.092
CASE	17	26.000	13.000	0.000	3.000	377.600	0.203	17.500	0.239
CASE	18	26.000	14.000	0.000	3.000	378.000	0.150	16.933	0.152
CASE	19	26.000	15.000	0.000	3.000	381.000	0.090	16.383	0.122
CASE	20	26.000	16.000	0.000	3.000	375.000	0.016	5.017	0.073
CASE	21	26.000	17.000	0.000	3.000	348.000	0.109	1.733	0.055
CASE	22	26.000	18.000	0.000	3.000	371.100	0.280	0.917	0.266
CASE	23	26.000	19.000	0.000	3.000	366.600	0.652	5.000	0.556
CASE	24	27.000	1.000	0.000	4.000	378.700	0.209	10.350	0.241
CASE	25	27.000	2.000	0.000	4.000	357.500	0.166	2.483	0.176
CASE	26	27.000	3.000	0.000	4.000	373.200	0.066	10.200	0.094
CASE	27	27.000	4.000	0.000	4.000	378.700	0.011	17.500	0.012
CASE	28	27.000	5.000	0.000	4.000	346.300	0.017	3.617	0.033
CASE	29	27.000	6.000	0.000	4.000	345.600	0.097	352.817	0.059
CASE	30	27.000	7.000	0.000	4.000	353.300	0.035	359.117	0.095
CASE	31	27.000	8.000	0.000	4.000	354.300	0.255	5.417	0.193
CASE	32	27.000	14.000	0.000	5.000	375.000	0.175	15.467	0.147
CASE	33	27.000	15.000	0.000	5.000	382.500	0.209	21.633	0.142
CASE	34	27.000	16.000	0.000	5.000	392.700	0.317	30.633	0.186
CASE	35	27.000	17.000	0.000	5.000	375.000	0.051	16.333	0.083
CASE	36	27.000	18.000	0.000	5.000	365.500	0.045	1.850	0.072
CASE	37	27.000	19.000	0.000	5.000	364.800	0.038	354.617	0.055
CASE	38	27.000	20.000	0.000	5.000	375.000	0.097	4.600	0.106
CASE	39	28.000	2.000	0.000	6.000	380.400	0.100	19.383	0.091
CASE	40	28.000	3.000	0.000	6.000	373.200	0.175	15.550	0.145
CASE	41	28.000	4.000	0.000	6.000	383.200	0.082	18.167	0.112
CASE	42	28.000	5.000	0.000	6.000	380.100	0.035	21.983	0.054
CASE	43	28.000	6.000	0.000	6.000	347.000	0.069	0.950	0.034
CASE	44	28.000	7.000	0.000	6.000	350.800	0.011	5.050	0.025
CASE	45	28.000	8.000	0.000	6.000	366.200	0.063	2.267	0.119
CASE	46	28.000	9.000	0.000	6.000	358.500	0.054	3.083	0.102
CASE	47	28.000	15.000	0.000	7.000	378.700	0.162	19.533	0.182
CASE	48	28.000	16.000	0.000	7.000	358.900	0.120	7.483	0.120
CASE	49	28.000	17.000	0.000	7.000	380.400	0.110	16.633	0.122
CASE	50	28.000	18.000	0.000	7.000	371.100	0.032	15.467	0.076
CASE	51	28.000	19.000	0.000	7.000	371.800	0.100	11.867	0.111
CASE	52	28.000	20.000	0.000	7.000	366.600	0.051	2.567	0.088
CASE	53	28.000	21.000	0.000	7.000	363.100	0.128	4.117	0.136
CASE	54	29.000	3.000	0.000	8.000	379.000	0.135	15.250	0.087

SE	55	29.000	4.000	0.000	8.000	378.000	0.085	11.950	0.110
SE	56	29.000	5.000	0.000	8.000	373.200	0.094	7.900	0.097
CASE	57	29.000	6.000	0.000	8.000	381.100	0.042	17.350	0.048
CASE	58	29.000	7.000	0.000	8.000	350.500	0.011	8.833	0.027
SE	59	29.000	8.000	0.000	8.000	377.600	0.029	3.200	0.048
CASE	60	29.000	9.000	0.000	8.000	365.500	0.110	5.750	0.124
CASE	61	29.000	10.000	0.000	8.000	344.500	0.048	4.884	0.121
SE	62	29.000	15.000	0.000	9.000	348.000	0.035	0.318	0.057
SE	63	29.000	16.000	0.000	9.000	379.000	0.190	20.883	0.148
CASE	64	29.000	17.000	0.000	9.000	355.000	0.153	7.183	0.154
SE	65	29.000	18.000	0.000	9.000	385.000	0.125	14.600	0.079
SE	66	29.000	19.000	0.000	9.000	394.100	0.110	26.133	0.108
CASE	67	29.000	20.000	0.000	9.000	375.000	0.110	357.600	0.119
CASE	68	29.000	21.000	0.000	9.000	368.300	0.228	9.083	0.172
SE	69	29.000	22.000	0.000	9.000	368.000	0.246	8.100	0.195
CASE	70	30.000	4.000	0.000	10.000	377.600	0.190	13.150	0.114
CASE	71	30.000	5.000	0.000	10.000	366.600	0.110	14.400	0.127
SE	72	30.000	6.000	0.000	10.000	367.300	0.082	12.850	0.071
SE	73	30.000	7.000	0.000	10.000	380.100	0.032	17.350	0.047
CASE	74	30.000	8.000	0.000	10.000	351.900	0.069	7.150	0.073
SE	75	30.000	9.000	0.000	10.000	363.800	0.023	6.967	0.055
SE	76	30.000	10.000	0.000	10.000	347.700	0.020	2.267	0.069
CASE	77	30.000	11.000	0.000	10.000	352.200	0.011	5.305	0.022
CASE	78	30.000	17.000	0.000	11.000	375.000	0.203	13.850	0.202
SE	79	30.000	18.000	0.000	11.000	380.100	0.131	19.000	0.114
CASE	80	30.000	19.000	0.000	11.000	346.600	0.110	349.317	0.115
CASE	81	30.000	20.000	0.000	11.000	373.900	0.073	0.967	0.072
SE	82	30.000	21.000	0.000	11.000	375.000	0.113	11.250	0.087
SE	83	30.000	22.000	0.000	11.000	363.800	0.162	5.933	0.096
CASE	84	30.000	23.000	0.000	11.000	351.200	0.042	354.817	0.064
CASE	85	31.000	5.000	0.000	12.000	357.100	0.290	6.189	0.201
SE	86	31.000	6.000	0.000	12.000	378.700	0.135	12.083	0.142
CASE	87	31.000	7.000	0.000	12.000	358.200	0.190	354.333	0.151
CASE	88	31.000	8.000	0.000	12.000	379.700	0.094	15.267	0.071
SE	89	31.000	9.000	0.000	12.000	345.600	0.023	350.700	0.016
SE	90	31.000	10.000	0.000	12.000	369.000	0.048	7.800	0.047
CASE	91	31.000	11.000	0.000	12.000	357.100	0.097	0.850	0.052
SE	92	31.000	12.000	0.000	12.000	369.000	0.237	10.317	0.135

Appendix 2. Letter from ASL Environmental Sciences

ASL ENVIRONMENTAL SCIENCES
Unit 59, 201 Brownlow Ave., Dartmouth, N.S. Canada B3B 1W2
Tel: (902) 468-8871
Fax: (902) 468-5341
a member company of Sea Nova Oceanographic Inc.

FAX IN

FAX COVER SHEET
PAGE 1 OF 1 PAGES

July 19, 1993
our ref: 95-data (93-3)

Centre for Estuarine Research
Acadia University
Wolfville, N.S.

FAX 542-3466

ATTN: Dr. Graham DaBorn

RE: direction channel of RCM4 current meter data from Annapolis

I am faxing to answer your inquiry re the above-mentioned data. I performed the translation and processing of this data. Subsequent to your telephone conversation with Bruce Batstone, I plotted the direction channels for both current meters TCM2 and 6353 (this was not done before because a separate direction time series is not plotted during standard data processing procedures).

The direction channel in current meter 6353 seems to have worked fine. However, current meter TCM2 did have some problems. The data seems fine for the most part on the first day, but from there on in it is highly suspect. We are quite sure that this was a physical problem with the current meter, and not with the data processing. The fault did not show up in pre-deployment bench testing, or in subsequent checks since it has been returned. At this point, we are unable to relate the cause of the fault. However, this does not help you. I am sorry, but at this point there is little we can do about the problem with your data, as the data was erroneous the moment it was written to tape in the machine.

Again, I am sorry if this causes you any problems, and am available if you have any further comments or questions.

Ferne Welsman

Ferne Welsman
Marine Data Specialist