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# Change in Sedimentation Following River Diversion in the Eastmain Estuary (James Bay), Canada[1]

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## ABSTRACT

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**Sedimentological changes that occurred in the Eastmain estuary after a 90% reduction in discharge following river diversion in July 1980 were studied during four consecutive summers. Before cut-off, the estuary was kept well flushed of river derived solids. The new sets of physical conditions led to progressive sediment retention. After July 1980, salt migration 8 km inland brought within one year the development of a turbidity maximum zone near the tip of the intrusion. This turbidity zone is unstable: suspended sediments trapped within it tend to be flushed downstream by large fluctuations in the residual flow which are caused by local precipitations or discharge control at the dam. Fine sediments accumulate at rates of 0.02 to 0.05 m per year over the pre-cut-off surface. From sediment trap data and acoustic records, it appears that sediment movement takes place by means of dilute mobile lutite suspensions close to the sediment-water interface, particularly during periods of surge in run-off. Since 1981, there has been a statistically significant rise in turbidity near the bottom, but not in the surface layer, suggesting a general increase in the vertical turbidity gradient. The rates of suspended sediment delivery into James Bay are at least 25 times smaller than they were before 1980.**

**ADDITIONAL INDEX WORDS:** *Eastmain estuary, James Bay, lutite, sedimentation, turbidity zone.*

## INTRODUCTION

Artificial changes in river run-off due to the building of reservoirs or to flow diversion tend to produce rapid and irreversible effects on the sedimentation regime downstream of the project as the river channel and the estuary adjust to the modified flow conditions. These effects are particularly noticeable in the estuarine zone where the circulation is altered as a result of deeper salt water intrusion. An opportunity was found to monitor the physical and sedimentological response of an estuary to changes in run-off after the Eastmain, a large pristine river on the east coast of James Bay in northern Québec (Figure 1), was diverted in 1980.

Before cut-off, the Eastmain was after La Grande River the second largest river along the Québec shore of James Bay, with a mean annual discharge of 900 $m^3s^{-1}$, and a 25 year mean monthly flow in May of 2,480 $m^3s^{-1}$ following an April minimum of 140 $m^3s^{-1}$. Peak flood discharges were up to 35 times that minimum.

The natural drainage basin of the Eastmain covered 50,000 $km^2$. The river extends east-west for 500 km, 150 km of which are carved in a slowly emerging coastal plain consisting of a sequence of post-glacial lacustrine sediments and marine deposits 20 to 30 m thick contemporaneous with the Tyrrell Sea invasion 7,900 years BP. These beds constitute the main source of fine sediments to the river. The climate is subarctic, with temperatures ranging between about −30° C in January and 20° C in July. Ice at the river mouth forms at the end of November, and break-up takes place between the first and the third week of May. Dominant winds are from the west-southwest, thus blowing up channel. The tides are semi-diurnal, with a mean amplitude of .37 m at the entrance to James Bay. Tidal oscillations are propagated as far as the first rapids

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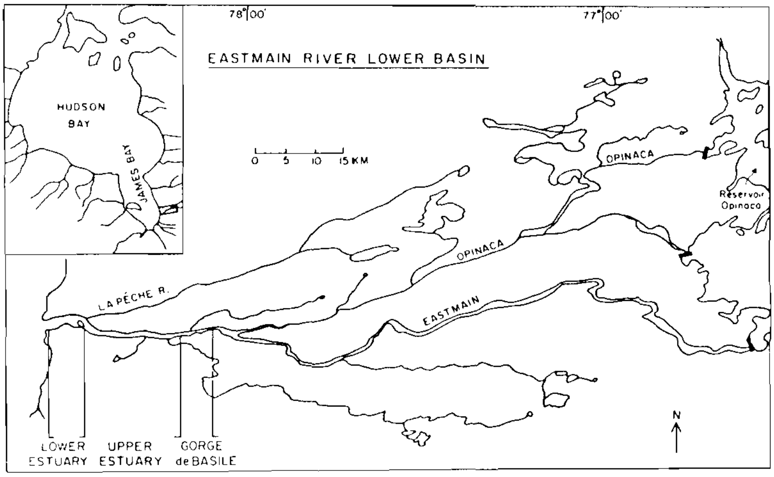

Figure 1. Estuary and lower course of the Eastmain River; diversion dams in black.

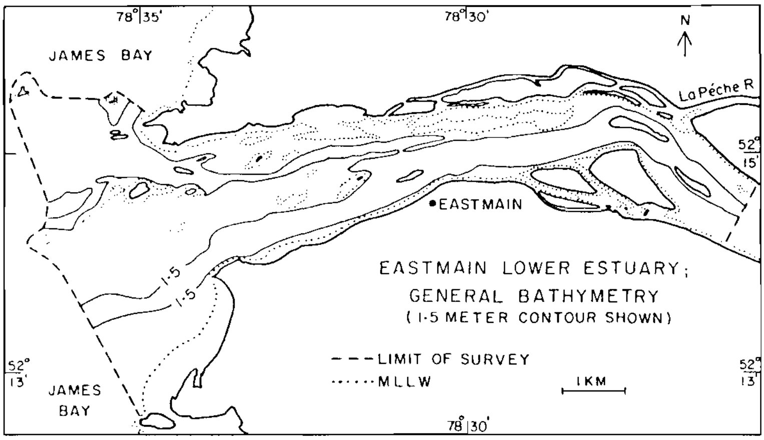

Figure 2. General bathymetry of the Eastmain lower estuary.

(Gorge de Basile), 27 km inland (Figure 1) which marks the upper limit of the estuary.

The diversion of the Eastmain took place on July 19, 1980, 160 km upstream of the river mouth. The main tributary, the Opicana, was previously diverted on April 20, leading to a 55% reduction of the monthly mean discharge for June. After July 19, the mean discharge was reduced to about 90 $m^3s^{-1}$, 10% of the natural one, with monthly extremes of 510 $m^3s^{-1}$ and 50 $m^3s^{-1}$ (PREISENBERG, 1980).

This study focuses on sedimentological changes between 1980 and 1984 in the lower estuary, which extends seaward of the mouth of La Pêche River, a minor tributary, 7 km upstream of James Bay (Figure 1). This region of the estuary received the direct impact of the disruption in discharge since it was exposed to the progressive invasion of salt water. It has the characteristics of a drowned river estuary with a shallow uneven bathymetry dominated by subparallel north and south channels with maximum MLLW depths of 6 m (Figure 2). The natural sedimentation regime in the lower estuary was discussed previously by D'ANGLEJAN (1982).

## MATERIALS AND METHODS

The sedimentological work reported here was part of a comprehensive team program monitoring changes in the estuary after the river diversion. This follow-up survey was done under contract with the Socitété d'Energie de la Baie James (SEBJ). Measurements of the estuarine circulation took place during the summer months in 1979, one year before diversion, and in 1980, 1981, 1982 and 1984. Current meters (Aanderaa RCM-4) were moored at about one meter above the bottom at eight stations in the lower estuary and one outside (Figure 3). These instruments record current speed and direction, as well as salinity, temperature and pressure. Water levels (Foxboro) and tide gauges (Aanderaa) were also installed at several locations in 1980 and 1981. Winter surveys with current meter moorings under the ice took place in March of these 2 years. These observations are discussed by INGRAM (1982) and LEPAGE and INGRAM (1986).

Sampling of sediments and suspended particulate matter (referred to below as SPM) were carried out in 1980, 1981, 1982 and 1984. The time and space distributions of the SPM after July 1980 were studied by nephelometric measurements of the water turbidity on a Hach model 1200A bench turbidimeter. Because of high scatter, it was not possible to quantitatively convert light attenuation values (in NTU or Nephelometric Turbidity Units) into particle weight concentrations (in mg l$^{-1}$1), and the SPM distributions are studied in turbidity units. Two identical sets of measurements were repeated in 1981 and 1982: along-channel transects with near-surface and near-bottom observations taken at a spacing of 1 km were conducted from high-speed launches in order to cover the entire 8 km lower estuary at high or low water slack; semi-diurnal tidal fluctuations in turbidity were studied at 26-hour anchored stations near some of the current moorings, with half-hourly observations in the surface and deep layers. No electronic navigation equipment was available. Positioning was done by compass reference to well-identified shoreline features, sand banks or islands in between the nine moorings which were repeated each year. Accuracy of positioning was well within one hundred meters. Sampling of the near bottom waters for turbidity measurements was done with a contact-triggered van Dorn bottle set to close within 100 cm of the sediment-water interface.

In 1982, sediment traps, consisting of 6 liter Niskin cylinders, with no closing mechanism, attached 75 to 100 cm above the bottom to fixed staffs, were moored for two successive periods, July 5 to August 8 and August 8 to 15, at the locations shown on Figure 3. An aspect ratio of 1:4 such as that of the traps (diameter: 15.2 cm; height: 60.9 cm), has been determined not to alter significantly the natural particle settling rates (GARDNER, 1980).

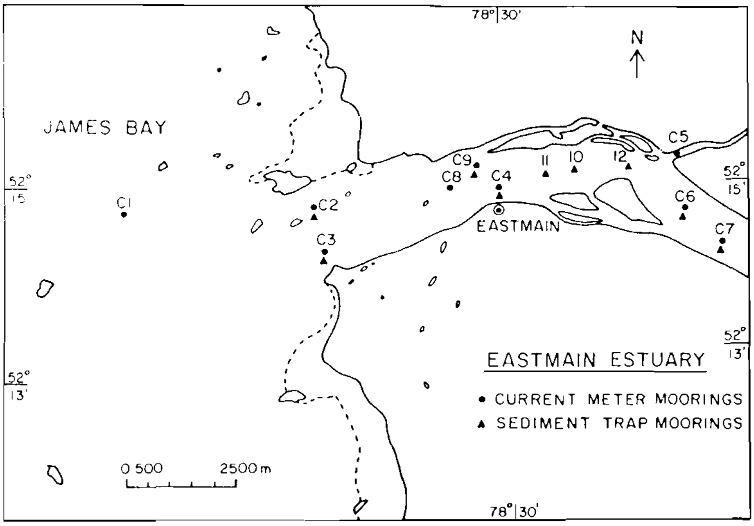

Figure 3. Locations of the current meter moorings and of the anchored stations for turbidity studies.

## PHYSICAL CHANGES INDUCED BY THE DIVERSION

Changes in the stratification and circulation of the lower estuary as a result of the diversion are described by LEPAGE and INGRAM (1986). Before diversion, the salt intrusion reached only 2 km inside the estuary during spring tides in the summer, while penetrating up to 5 km upstream under the ice in winter. Near its mouth, the Eastmain had the strong salinity stratification characteristic of a salt wedge estuary, with a surface freshwater plume extending over 100 km$^2$ into James Bay. After diversion, the river flow velocity downstream of the dam decreased from about 0.35 m s$^{-1}$ to 0.05 m s$^{-1}$ in eight days. In the estuary, at station C4, the mean residual velocities which were 0.45 m s$^{-1}$ and 0.26 m s$^{-1}$ at 2 m and 4 m depths respectively for the month preceeding the closing of the dam, dropped to values of 0.10 m s$^{-1}$ and 0.044 m s$^{-1}$ over the month following it, and to values of 0.06 m s$^{-1}$ and 0.018 m s$^{-1}$ over the next month. With the fall in discharge, the mean water level was depressed by 0.41 m, at the river mouth, and the M2 tidal amplitude increased by about 30%. At C4 and C6, the average M2 tide velocity 2 m below the surface increased during the first month by 75% to 100% respectively to a value of 0.46 m s$^{-1}$. However, it decreased by 40% at 4 meter depth (from 0.23 m s$^{-1}$ to 0.13 m s$^{-1}$ at station C4). The lower estuary evolved rapidly from highly stratified at its mouth before cut-off, to partially mixed or well mixed, in the sense of HANSEN and RATTRAY (1966) after. Based on the horizontal displacement of the zero $^{\circ}/_{oo}$ isohaline, the tidal excursion is about 3 km under present conditions. The salts which rarely entered the lower estuary now reach 8 km inland to station C7.

## REPERCUSSIONS ON SEDIMENTARY PROCESSES

As shown on Figure 4, the closing of the diversion dam was recorded downstream by a sudden surge in river turbidity in mid-August. It remained considerably higher than normal throughout 1981, peaking again in July in spite of the considerable drop in seasonal discharge. Destabilization of Tyrrell clays exposed on the channel banks by the drop in water level as well as stirring of the channel floor by the wind and by the residual discharge are believed to have caused this turbidity increase.

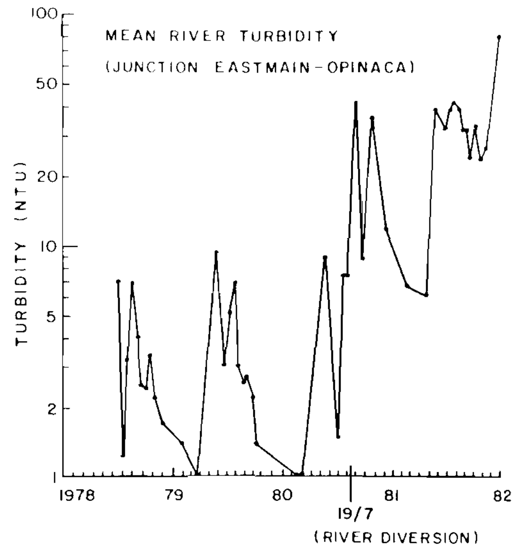

Figure 4. Fluctuations in river turbidity at the Eastmain-Opinaca junction, 32 km upstream of river entrance. June 1978 to December 1982. Integrated midstream measurements (NTU = Nephelometric Turbidity Units). SOCIÉTÉ D'ENERGIE DE LA BAIE JAMES, unpublished data.

### Observations in 1981

A general rise in the SPM concentrations was also noticed in the lower estuary one year after diversion. In March 1981 (mean monthly discharge, $Q_m$ = 12 m$^3$ s$^{-1}$) maximum under-ice values of around 14 mg l$^{-1}$ were twice as high as in the same month of the preceeding year ($Q_m$ = 200 m$^3$ s$^{-1}$). Measurements made at the mouth of the estuary (stations C2 and C3) in late May and early June 1981 ($Q_m$ for May = 225 m$^3$ s$^{-1}$), the normal period of high river flow, indicate a three-fold increase in SPM to values around 30 mg l$^{-1}$, compared to May 1980 ($Q_m$ = 1600 m$^3$ s$^{-1}$). Based on these figures, suspended solid discharges for May would be 42×10$^3$ metric tons and 17×10$^3$ metric tons in 1980 and 1981 respectively, a reduction by more than 50% over one year (D'ANGLEJAN, 1982).

On July 1, 1981, near-synoptic surveys of the distribution of the surface salinity and turbidity in the lower estuary and the region offshore affected by the plume, were conducted at low and high water slacks from two launches running simultaneously. Tides were average on that day. Navigation was by reference to islets identified on a detailed chart and to fixed buoys moored inside and outside the estuary. The results (Figure 5) show the existence of a

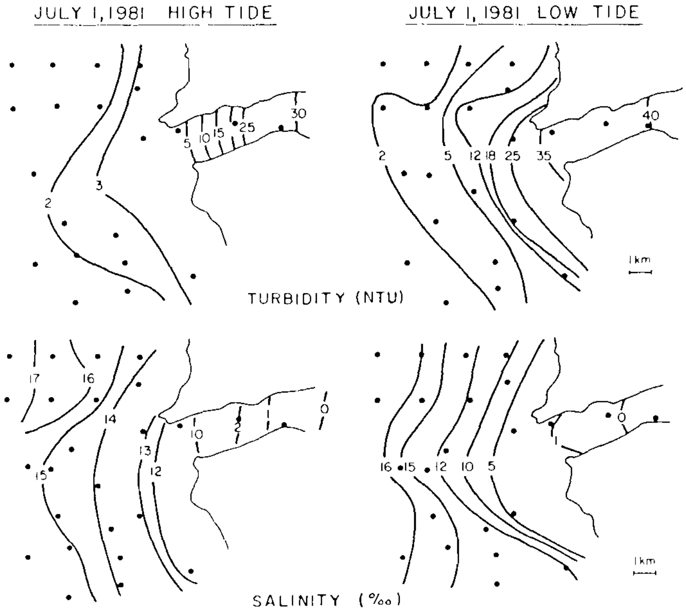

Figure 5. Near-synoptic survey of the turbidity and the salinity near the mouth of the Eastmain River, July 1, 1981; at high and low water; intermediate tide.

turbidity maximum zone (here abbreviated TMZ) landward of the salt intrusion. The river turbidity extended as far as 3 km offshore of the river mouth, the river discharge on that day being approximately 100 m$^3$s$^{-1}$. The tidal displacement of the surface turbidity isopleths was about 5 km which corresponds to mean ebb and flood velocities of about 0.28 m s$^{-1}$, in agreement with the current meter measurements.

A longitudinal transect of the lower estuary was made out at low tide for an intermediate tide on June 29, 1981 in order to determine the turbidity at the surface and near the bottom. It confirms the presence of a TMZ with values above 40 NTU (50 to 60 mg l$^{-1}$) in both the surface and the deep layers near station C4 (Figure 6). Within the TMZ, at C4, low tide turbidities were found to be twice as high for spring as for neap tides (45 NTU, on 5/7/81; 20 NTU on 14/7/81), winds being low (10 km hr$^{-1}$ or less) in both cases.

At anchored stations occupied next to the current meter moorings, the along-channel oscillations of the turbidity are recorded by sharp increases in turbidity toward the end of the ebb. Tidal turbidity fluctuations are in opposition of phase with the salinity, indicating that downstream advection of turbid river waters rather than local resuspension is the main cause of this increase. Progressive velocity vector diagrams were computed from half-hourly data covering one semi-diurnal tide at stations C8 and C4 (Figure 7). To simulate the suspended particle transport trajectories, transport vectors (T) were also determined by using the cross-product of the mean instantaneous velocity at time t ($V_t$) and the ratio of the turbidity at t($C_t$) over its mean tidal value (C): $T = V_t \times C_t / C$. These results suggest that in response to the newly established estuarine circulation, the residual near bottom transport is close to zero inside the TMZ (C4), and seaward of it (C8) is directed upstream, as expected in a partially mixed estuary.

Particle volume measurements were obtained with a Coulter Electronic particle size counter (model TA) on 11 surface and bottom SPM samples collected at C4 on June 24 at different phases of the tide. These samples were brought back to the laboratory under refrigeration and treated in an ultrasound bath for 5 minutes, long enough to break down most flocs or aggregates. Each sample was analyzed using tubes of 50 micron and 220 micron openings, and the distributions were overlapped. Results indicate no difference between surface and

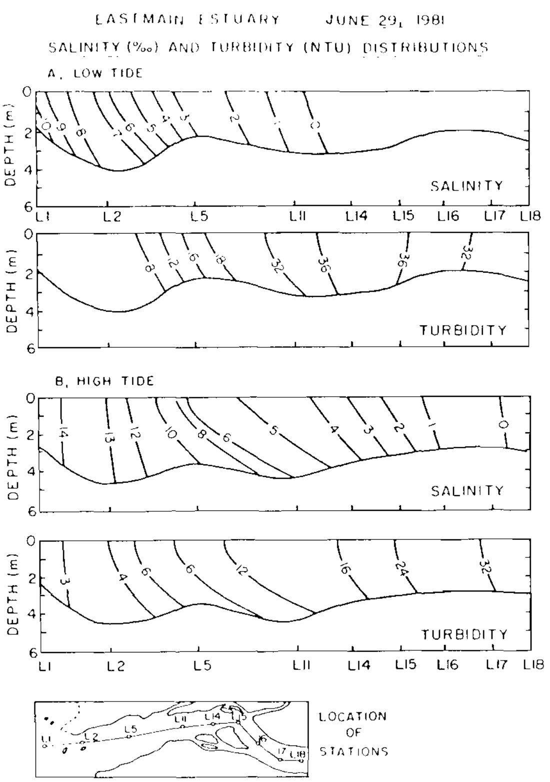

Figure 6. Distribution of the salinity and of the turbidity at high and low water in the lower estuary for an intermediate tide; June 29, 1981.

bottom SPM samples, and about equal partitioning between particles in the less than 2 microns and in the 2 to 10 microns range (about 48% in each class), with a median size (Md) between 2 and 4 microns. Distributions are identical to those obtained on Tyrrell clay core samples from the channel (analyzed by the pipette method; D'ANGLEJAN, 1982).

## Observations in 1982

The first deployment of the sediment traps in July 1982 (from 5/7 to 5/8) coincided with an interval of increase in run-off induced by a close succession of large rain storms. Total recorded precipitation for the month was 116 mm, more than three times that for July 1981. In five days, between July 7 and 11, the river discharge more than doubled to levels above 200 $m^3$ $s^{-1}$ (Figure 8). This is approximately equivalent to low flow conditions before the diversion. One consequence was the reinforcement of the ebb velocities over the flood velocites near the bottom. Mean values between July 3 and August 5 were 0.33 m $s^{-1}$ and 0.19 m $s^{-1}$ at station C3 for ebb and flood respectively. The mean of the along-channel component (u) of the residual velocity for that period rose correspondingly by a factor of two to three over its 1981 values, from 0.03 m $s^{-1}$ or less, to more than 0.06 m $s^{-1}$, the flow direction being reoriented parallel to the channel axis and downstream (280° T) as it was before the run-off event.

The surge in run-off during July caused a seaward retreat of the salt intrusion by about 6 km: station C8 was in fresh water for one week following July 14 and salinity reached zero on July 16 at the mouth (C3). This resulted in the westward migration of the turbidity maximum zone, which is indicated by very large rates of sediment accumulation in the traps moored at C2 and C3 at the mouth of the estuary: rates exceeding 90 mg $cm^2$ $day^{-1}$ were reached at these two stations in July (Table 1). For the entire month, more than 20 cm of sediments with an 80% water content accumulated in the traps. These rates are 2.5 times as high as those recorded at the same stations during the second mooring of the traps in August (from 6/8 to 12/8: less than 40 mg $cm^2$ $day^{-1}$; Table 1) after conditions returned to normal.

Thus under the new regime, sudden peaks in precipitation or, potentially, flow manipulations at the diversion dam can create large oscillations around the much reduced mean discharge. These in turn will tend to cause large fluctuations in salt and suspended sediment distributions in the lower estuary.

A reconnaissance survey by gravity coring, in the north and south channels, indicated only a discontinuous uneven layer, 0.10 m to 0.15 m in maximum thickness, of fine poorly consolidated muds recently deposited on top of the hard clay or coarse sand bottom noted previous to diversion (D'ANGLEJAN, 1982). These observations suggest mean rates of deposition between 0.02 m and 0.05 m per year in

Table 1. *Eastmain estuary. Rates of accumulation in sediment traps, July and August 1982 (sites shown on Figure 3).*

| Stations | Mooring No. 1<br>(5/7/82 to 5/8/82) | Mooring No. 2<br>(6/8/82 to 12/8/82) |
|---|---|---|
| C 2 | 94.0 | 23.0 |
| C 3 | 83.6 | 38.4 |
| C 4 | 65.0 | 48.6 |
| C 6 | 24.3 | 22.4 |
| C 7 | 28.3 | — — |
| C 8 | 27.0 | 22.4 |
| C10 | 49.0 | 55.6 |
| C11 | — | 38.5 |
| C12 | - — | 35.3 |

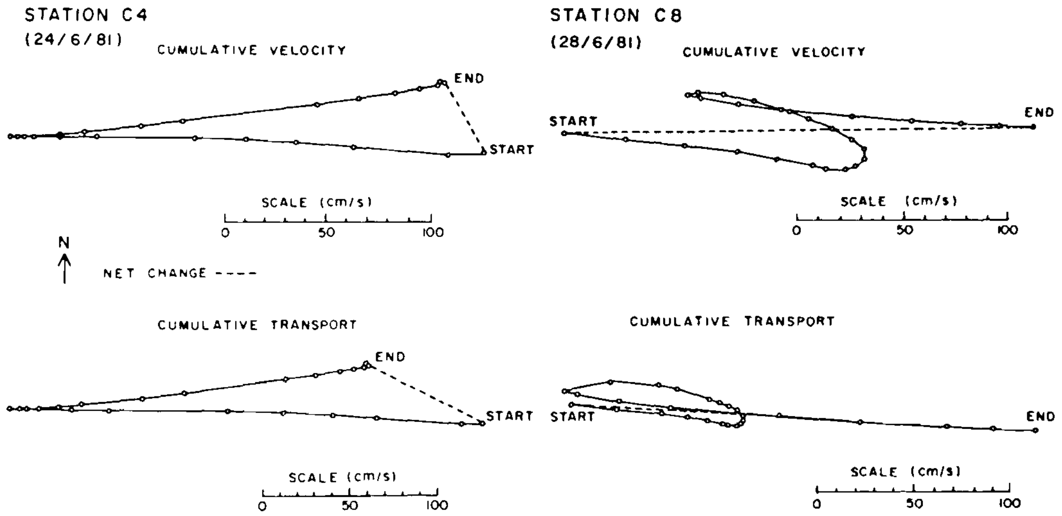

Figure 7. Progressive vector diagrams for current velocity and for suspended matter flux at stations C4 (24/6/81) and C8 (28/6/81) small circles are half-hourly measurements at one meter above the bottom.

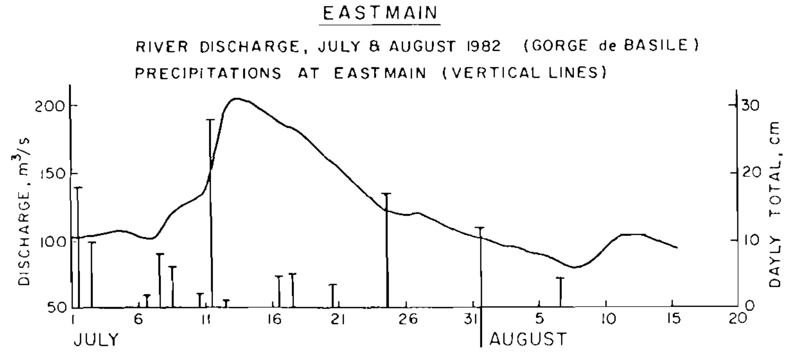

Figure 8. Precipitations (cm) at Eastmain and river discharge (m$^3$ s$^{-1}$) (Gorge de Basile), in July and August 1981.

the channels since July 1980. Profiling of the channels in early July with a high frequency (220 kHz) echo sounder (Ross model 805) also failed to reveal any significant new sediment deposition, but occasionally recorded discontinuous mid-water multilayer reflectors (Figure 9) which at several places intersect the bottom. As the salinity stratification is weak, these reflectors can only be attributed to mud suspensions. These observations as well as the evidence from coring suggest that with increasing SPM concentrations in the estuary, near-bottom low-density suspension layers are developing by particle settling, while only a fraction of the bottom settled muds has begun consolidating.

Along-channel turbidity profiles made in August, after the discharge had returned to normal, demonstrate that the near bottom values were relatively low with no indication of suspension layers of that time. One exception occurred during the spring tide of August 8: bottom water turbidities at C4 exceeded 80 NTU (estimated concentration: 150 mg l$^{-1}$) at high tide, the near surface values being less than 20 NTU. This large vertical turbidity gradient, over less than a 4 m water depth maintained in spite of strong northerly winds, again suggests that the settled muds on the bottom have reached shear strength large enough to partly overcome dispersion by the tides and the winds.

The particulate matter settled in the traps as well as in the cohesive mud layer on the bottom were found to consistof 47% clays and 53% silts mostly in the two to ten micron range. This agrees with size measurements on the SPM and on Tyrrell clays reported above. A charasteristic difference with this latter material, however, is that the newly deposited muds are three times as rich in particulate organic carbon, ranging from 1.8 to 2.5%. High C/N ratios (more than 20) indicate that this organic matter must be of terrestrial and not of marine origin. Measurements in the river demonstrate a more than two-fold increase in particulate organic carbon after cut-off, with values of the C/N ratio above 50 (SOCIÉTÉ D'ENERGIE DE LA BAIE JAMES, unpublished data).

## Observations in 1984

Observations of turbidity and sediment deposition taken by the firm LOGIMER (1984) for the SEBJ in the estuary on this year confirmed those of 1982. The thickness of the post-diversion mudlayer was found to be highly variable, occasionally reaching 20 cm inside depressions of the lower estuary channels, perhaps as a result of gravity flow, but being less than 5 cm in shallower areas, as well as in the upper estuary. Average depositional ratios of 0.02 m to 0.05 m per year again are indicated.

Between September 13 and 19, the discharge was raised experimentally to 922 m$^3$ s at the dam, in order to determine the effects of a sharp rise in river flow on downstream sedimentation. In four days (September 15 to 19) the discharge at Gorge de Basile (Figure 1), 27 km inland rose to nearly 2,000 m$^3$ s$^{-1}$, twice the mean natural flow (INGRAM *et al.*, 1986). The SPM concentrations monitored in the upper estuary 14 km upstream of James Bay

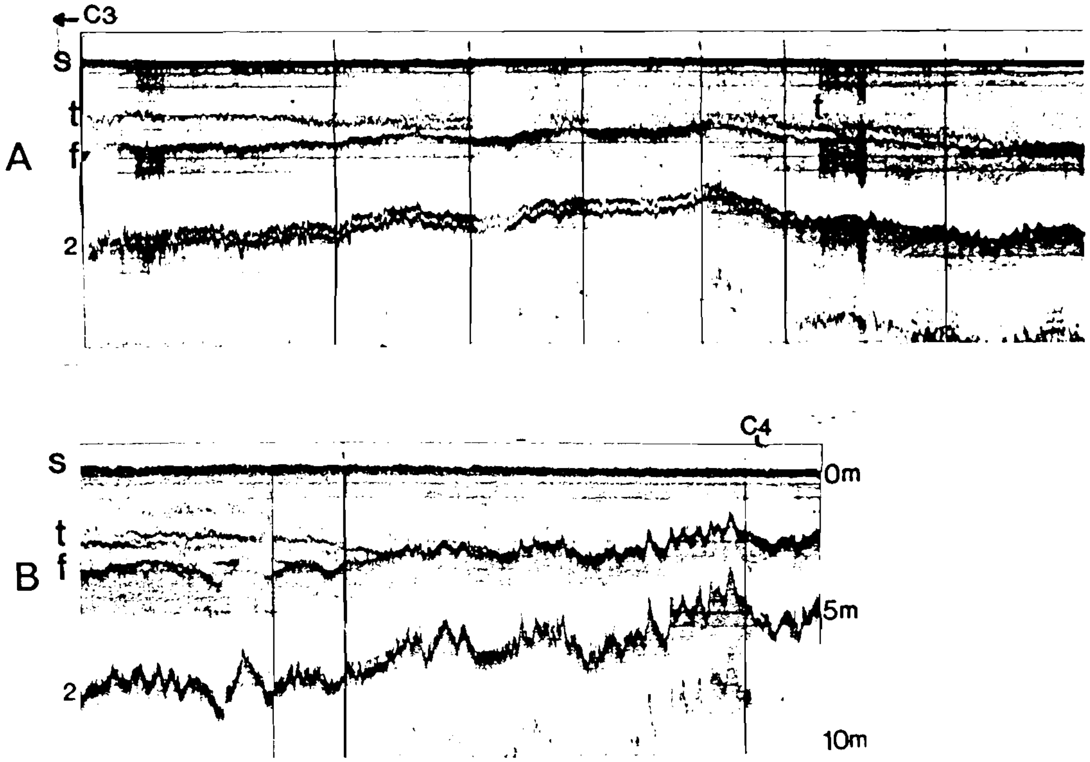

Figure 9. High frequency (220 kHz) echograms showing midwater interfaces (t) caused by turbid suspensions. (S = water surface; f = bottom; 2 = second reflection.) South channel, 1/7/82 (A), neap tide and 4/7/82 (B), intermediate tide.

reached vertically integrated mean values of around 150 mg $l^{-1}$ at discharge rates exceeding 1000 $m^3$ $s^{-1}$. These were maintained for 5 consecutive days. The total solid discharge from the upper into the lower estuary over this period is estimated at $6 \times 10^4$ metric tons, about 1/5 of the total mass of post-diversion muds deposited in the 27 km estuary below the rapids, and twice the present annual SPM transport rate outside the estuary, as estimated below (INGRAM *et al.*, 1986).

## OVERALL TURBIDITY INCREASE IN THE LOWER ESTUARY AFTER CUT-OFF

To determine if a significant increase in turbidity has taken place in the lower estuary since cut-off, data collected in 1981, 1982 and 1984 were examined statistically. A least-square regression of turbidity on salinity was done for each year's observations, surface and bottom values being pooled separately (N between 54 and 99). The inverse correlation was fair in all cases ($r \geq .7$), except for bottom values in 1982 ($r = .3$). Sediment resuspension possibly linked with the July 1982 rise in discharge may have weakened the relationship. The calculated regression lines are shown on Figure 10. At any given salinity, and more clearly so toward higher values, the turbidity increases in 1982 and 1984 with respect to 1981, an indication of SPM retention in the estuary. The lines were examined for difference in slope by mean of the Tukey multiple comparison test (ZAR, 1984). No significant differences were found between the lines for the surface data (81S, 82S, 84S). However, for data collected in the bottom layer, slopes for 1982 and 1984 are significantly lower (95% level) than for 1981, which suggests that the longitudinal turbidity gradient along the estuary diminishes with time as more SPM accumulates in the lower reaches of the channels. All lines converge toward high values of the turbidity for very low salinities. This is predictable since tidal and wind mixing maintain uniform vertical SPM concentrations in the water column in the shallow region of the maximum turbidity zone.

## DISCUSSION

With the drastic reduction of the freshwater discharge (by 90%), the invasion of the lower estuary by James Bay waters, the development of a two-way estuarine circulation, and the considerable drop in residual velocities (by 90% at C4), conditions have been met rapidly for the retention of the SPM inside the estuary. The situation, however, is unstable, as large relative fluctuations in discharge, caused by increased precipitation, as in 1982, or flow manipulation, as in 1984, may temporarily flush out the salt and the SPM outside the estuary. Sediment deposition within the estuary is to some extent expected to be dependent on the spacing between these events, because consolidation of muds deposited from suspension is known to be rapid, and these muds soon acquire enough shear strength to resist erosion (OWEN, 1977).

The evidence for distinct lutite suspension layers moving along the bottom is not definitive as these layers could not be confirmed by profiles of light attenuance in the water column. Observed maximum turbidity and SPM values near the sediment interface were not high (less than 200 mg $l^{-1}$ SPM), but seem enough for coherent low density turbid layers to develop. Low density lutite layers have been reported both in lakes (LAMBERT *et al.*, 1976) and along the continental slope (STOW and BOWEN, 1980). It seems likely that surges of deposition in some traps during July 1982 are caused by episodic inputs of sediments from near-bottom suspensions, moving down channel by gravity, such as those appearing on the echo sounder records. The uniformity in particle size distribution of the suspended matter, the sediments collecting in the traps and the settled deposits suggests that these three materials consist of the same type of large loosely bound SPM flocs. The broad range in particle sizes, the poor sorting and the lack in modal sizes in these three related materials are consistent with the view that the bottom muds develop by the settling out of flocs in suspension, with little to no size fractionation on the bottom by winnowing. Near the bottom, the flocs make up mobile suspensions which settle as a stable mud layer in conditions of minimum tidal current velocity. The process appears analogous t that described in muddy estuaries (KIRBY anc PARKER, 1983).

A major factor that promotes sedimentation in the estuary is the asymmetry in tidal currents, with flood higher than ebb velocities and periods of slack water longer at high than at low tides. This causes lags in erosion and settling known to be responsible for mud deposition (POSTMA, 1967). The tidal current data for semi-diurnal spring tides and neap tides, in days with no winds during July 1982 were examined. Average duration of the high tide and low tide slack waters (tidal velocities less than 10 cm $s^{-1}$ were 58 minutes and 28 minutes respectively

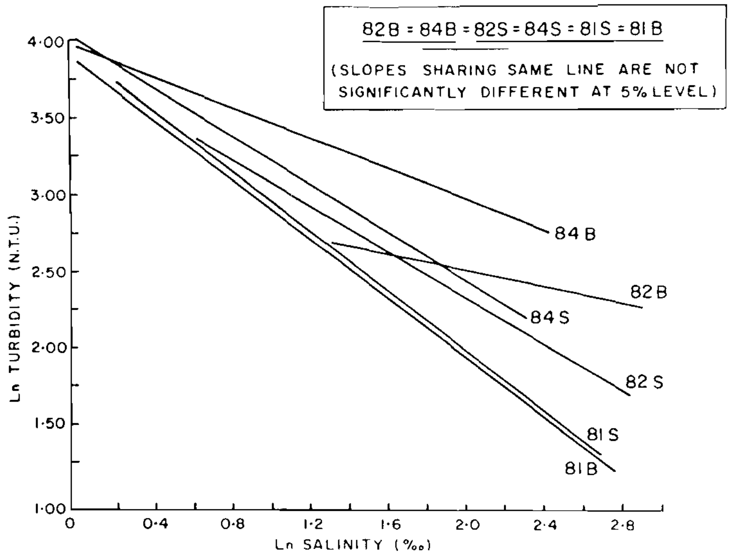

Figure 10. Regression lines of turbidity on salinity based on data collected in 1981, 1982 and 1984; surface (S) and bottom (B) values treated separately. (r = .7 or better for all lines except 1982b.)

(n = 11). It is estimated that on the average, estuarine SPM settles down for velocities less than 25 cm $s^{-1}$ (MIGNIOT, 1968). Based on the field determination values of particle settling velocities obtained during high water slack in a northern tidal estuary ($V_s = 2.4 \times 10^{-4}$ m $s^{-1}$; AMOS and MOSHER, 1984), considerable settling may occur during one hour from the bottom one meter of the water column, leading to significant mud accumulation during this phase of the tide. The effect of the tidal asymmetry resulting from increased bottom friction during shoaling should be reinforced by the reduction of about 0.5 m in mean water level (1/4 the average depth) after the diversion. The dominance of onshore westerly winds also tend to considerably increase the length of the high water slack. On the other hand, relaxation of the wind set-up also leads to an increase in the ebb velocities (LOGIMER, 1984) which favors resuspension.

Maximum estimates of the mass transport of SPM out of the estuary are between 130 and 160 metric tons per day, or $0.2 \times 10^5$ metric tons to $0.4 \times 10^5$ metric tons per year, assuming 7 months of free flow with no ice. These estimates are based on average SPM concentrations noted in 1981 and 1982 (C81 = 18.7 mg $l^{-1}$; st. dev.: 12.4 for n = 27. C82 = 23.3 mg.$l^{-1}$; st. dev.: 12.4, for n = 95) and on a mean post-diversion annual discharge of 90 $m^3$ $s^{-1}$. Similar estimates ($0.3 \times 10^5$ metric tons per year) were obtained independently by LOGIMER (1984). The thickness of the semi-consolidated mud layerin 35 cores collected at various depths in 1982, weighed for variations with depth in the channels, suggests a total sediment mass of of about $1 \times 10^5$ metric tons deposited in the lower estuary during the two years following the diversion. The annual deposition is one half of this figures. The total annual solid discharge from the river into the estuary is therefore presently about $10^5$ metric tons per year. Data on SPM collected at river stations in 1976 indicate a pre-diversion solid discharge above $1 \times 10^6$ metric tons per year (D'ANGLEJAN, 1982). A reduction by a factor of 10 in river sediment supply to the estuary appears to have taken place, reflecting the considerable drop in discharge in spite of a considerable rise in the river turbidity.

## SUMMARY

As a result of a reduction in mean discharge by 90% (from 900 $m^3$ $s^{-1}$ to 90 $m^3$ $s^{-1}$), the following changes in the sedimentary regime of the Eastmain estuary have been noted during 4 years of observations:

1. A salinity intrusion reached 8 km inland of James Bay within a few weeks following the diversion and caused the trapping of fine suspended sediments in

the lower estuary and the development of a turbidity maximum zone within one year or less. The flow reduction produced a decrease in the residual tidal velocities by as much as 95%, as well as an increase in mean tidal velocities by 30% because of tide amplification and relatively larger set-up from the dominant westerlies.

2. In the present situation, the SPM distribution and particularly the position of the turbidity maximum zone are unstable. Natural or artificially induced pulses in river discharge, 100% or more above the mean flow, have the ability to periodically flush salts and suspended sediments toward the estuary entrance or out of it.

3. Semi-consolidated post-diversion sediments (80% $H_2O$) blanket the pre-diversion sand or hard clay surface. They form at net depositional rates of between 2 and 5 centimeters per year. These rates correspond to 1/8 or less of the mean vertical particulate flux of 25 mg $cm^2$ $day^{-1}$ (9 g $year^{-1}$, or 35 cm of wet sediments) as measured in traps at the head of the lower estuary during the open season.

4. Acoustic data and indirect evidence from rates of accumulation in sediment traps as well as from particle size distributions of the solid phases in suspension or on the bottom suggest that a large fraction of the settling sediments form relatively low concentration suspension layers (less than 500 mg/l) which may be redispersed by the tidal flows in the water column or may move under gravity toward the deeper channel depressions, where thicker post-diversion sediments are found.

5. An increase in near bottom turbidity after 1981 is supported by a statistical examination of the turbidity-salinity relationships for the 3 years of observation following flow diversion.

6. A ten-fold reduction in the annual rate of solid discharge to the estuary has taken place since cut-off. Rates of suspended sediment transport out of the estuary into James Bay are at least 25 times smaller than before.

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## ☐ ZUSAMMENFASSUNG ☐

Sedimentologische Änderungen, die die Folge einer 90% Flussreduktion nach der Umleitung der Eastmain Trichtermündung sind, wurden über 4 nacheinanderfolgenden Sömmer studiert. Nach der Flussabkürzung wurde die Trichtenmündung von Flusssedimente frei gehalten. Steigende Sedimentzurückhalten war die Folge der neuen Flussumstände. Nachdem Juli 1980 verursachte Salzfortziehung 8 km inländisch die Entwicklung einer maximalen Verwirrungszone in der Nähe des Eindringens. Diese Verwirrungszone ist unbeständig; grosse Schwankungen des Reststroms, die von örtliche Regen oder Kontrolausfluss des Damms, fluten hängende Sedimente stromabwärts. Bevor der Flussabkürzung häufen feine Sedimente sich über den Flussboden zum Verhältnis von 0.02 - 0.05 m/Jahr an. Nach Daten von Sedimentfallen und akustischen Berichten scheint die Sedimentbewegung durch verdünnte mobile lutite Hängungen in der Nähe des Sediment-Wasser-Berührungspunkts stattzufinden, besonders während Wogenperioden von Regenfluss.--*Stephen A. Murdock, CERF, Charlottesville, Virginia, USA*