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MONITORING OF PHYSICAL CHANGES ASSOCIATED WITH THE RESTORATION OF THE TIDAL PRISM TO THE PETITCODIAC RIVER AT MONCTON, NB

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Abstract: In 1968, a causeway was constructed on the Petitcodiac River between Moncton and Riverview, NB. The purpose of the causeway was to provide a highway crossing and protect up river farmlands from salt water flooding. The causeway cut-off 24 km ± of river subject to tidal flooding and reduced the tidal prism by 25 million m^3 ±. Following construction, siltation occurred in the 37.3 km of river below the causeway reaching a magnitude of 161 million m^3 in 2001. In April 2010, the gates on the causeway were opened and the tidal prism upstream was partially restored. This paper details the changes in physical properties of the river as a result of opening the gates. New tidal flats consisting of approximately 7 million m^3 have deposited upstream of the causeway and about 47 million m^3 of erosion has occurred downstream, about 40 million of which deposited in the upper reaches of the Bay of Fundy 37-50 km downstream by late fall of 2015.

1 INTRODUCTION

The 60 km long Petitcodiac Estuary between Hopewell Cape and Salisbury (Figure 1) is characterized by some of the highest tides and suspended sediment concentrations in the world. The estuary was significantly modified by the construction of a causeway between Moncton and Riverview during 1966-1968. The causeway and its gated control structure prevented tidal flooding of 24 km of upstream agricultural marshland, provided a new highway crossing, and a freshwater reservoir for industrial and limited recreational use. Negative impacts have included reduced fish passage, reduced tidal bore in the Moncton area, and extensive silting of the estuary downstream.

A major EIA (AMEC, 2005a) recommended that a portion of the causeway be removed. Following this report direction was given to open the gates and monitor the impacts of essentially free tidal exchange. A monitoring program was instituted to establish baseline physical conditions prior to opening the gates (2008 - April 14, 2010) and a follow-up program to evaluate physical changes after opening the gates on April 14, 2010. The gates have remained open to date. The latest complete surveys were in the fall of 2015.

This paper reports on the major physical changes that have been documented during the monitoring program. Some historical information documented in the 2005 EIA is also included. All elevations quoted refer to Geodetic Datum (CGVD28).

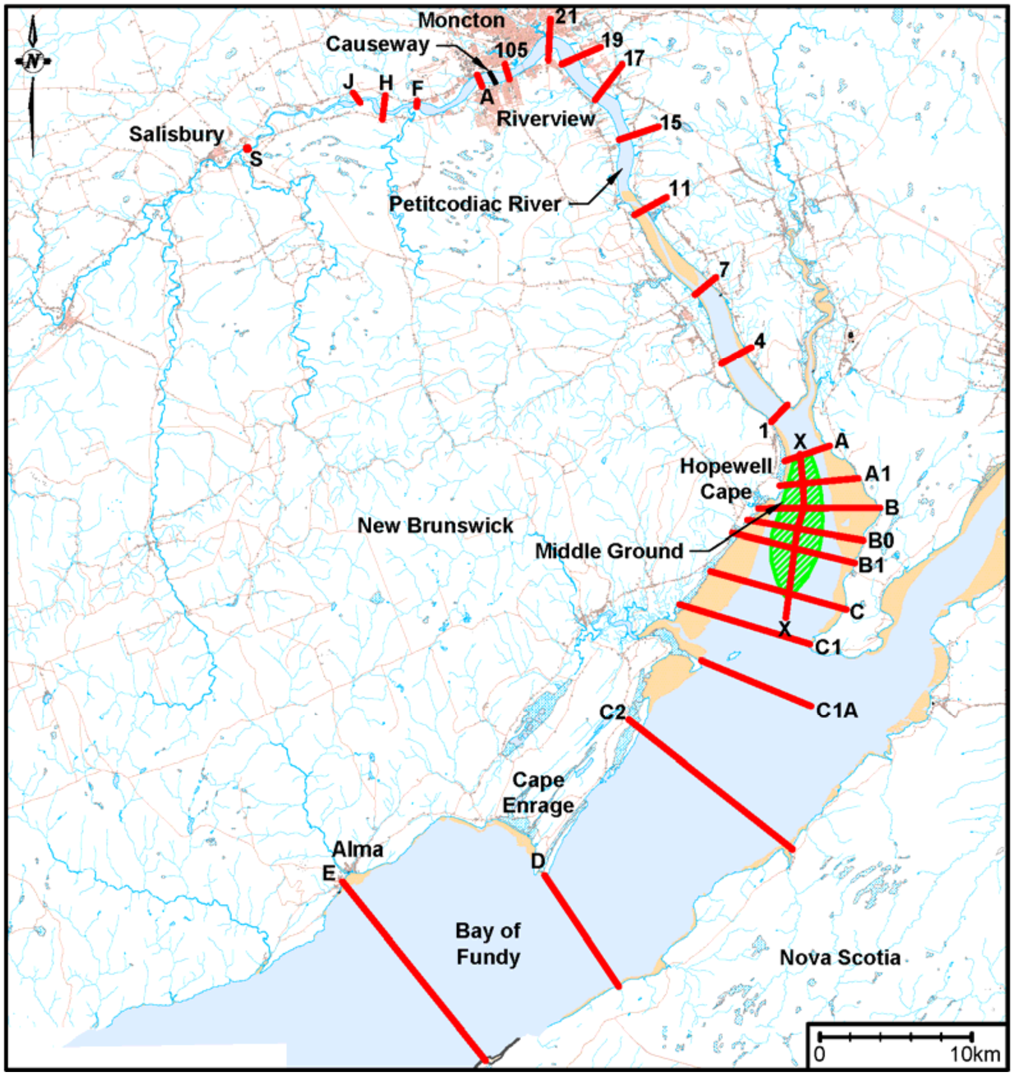


Figure 1: Map showing study area from Salisbury at head of tide to Alma in the Bay of Fundy with section lines.

2 THE ESTUARY BEFORE THE CAUSEWAY

The earliest information on physical features of the estuary is an 1861 hydrographic survey. Some cross sections are available from work on a proposed tidal power development in the 1940's and for the design of the causeway in the 1960s. Hydrographic surveys from October 1965 are available for the Upper Bay of Fundy.

The diurnal spring tide elevation at Hopewell Cape at the mouth of the estuary is in the order of +7.0 m and at Moncton was in the order of +7.5 m. The tidal bore height at Moncton ranged from 0.5 to 1.5 m depending on the state of the tide and runoff from the land. During spring tide conditions, the tidal prism was about 424 million m^3 upstream of Hopewell Cape, and the mean tidal discharge at Hopewell Cape was in the order of 19,000 m^3/sec. The total drainage area above Hopewell Cape is 2,026 km^2 with a mean fresh water discharge of about 48 m^3/sec.

Suspended sediment concentrations, carried by the tides into the estuary, have historically been high, giving rise to the name Chocolate River. Suspended sediment loadings, in the Moncton area, before the construction of the causeway are estimated to be in the order of 20,000 mg/L. Seasonal build-up of sediment in the order of 3 m occurred about 10 km above Moncton during the summer months. It is estimated that seasonal movement of silt in and out of the estuary was on the order of 10 to15 million m^3 building up over the summer and eroding in late fall or the next spring.

The river bends were far from stable with changes of up to 30 m laterally as far as 15-16 km upstream, probably due to ice and 40-100 m laterally in the lower 5-12 km upstream probably related to tidal action.

3 RESPONSE OF THE ESTUARY TO THE CONSTRUCTION OF THE CAUSEWAY (1968)

Figure 2 is an aerial view showing partial completion of the causeway. The main effects of the causeway were to form a freshwater reservoir at elevation +6 m extending 24 km upstream and to cause significant sedimentation in the estuary downstream of the causeway. The rate of sedimentation was very rapid especially in the upper few kilometres of the estuary with its new head at the causeway. The tidal prism at spring tides was immediately reduced in the order of 25 million m^3. By 2002, 34 years after the causeway was constructed, a further reduction of 140 million m^3 of the prism and 21 million m^3 below low tide level occurred due to siltation downstream. The maximum seasonal silt build-up was relocated downstream to the Moncton area.

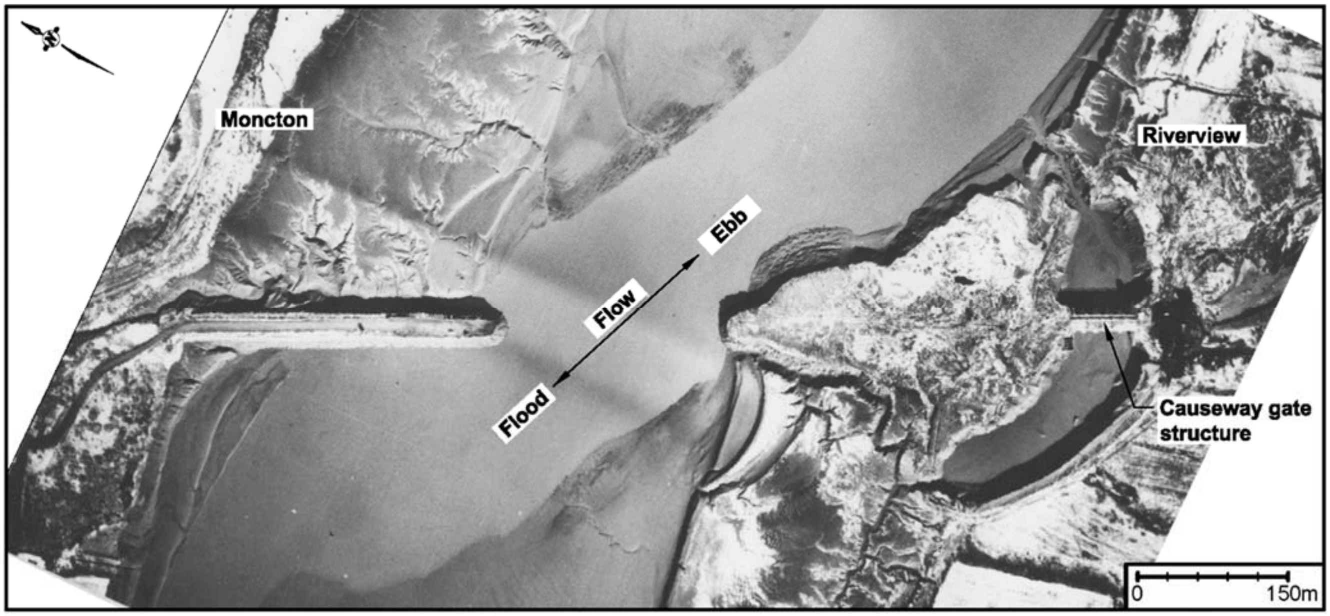


Figure 2: View of the Petitcodiac River causeway under construction in the fall of 1967

The origin of the silt which was depositing in the estuary below the causeway was a matter of some controversy. Various theories ranged from erosion of the cliffs surrounding the Upper Bay of Fundy to a deep scour hole found in a 1996 survey off Cape Enrage. When comparing a project survey in the upper bay in May 2010 (shortly after the gates were opened) with a hydrographic survey in 1965, it was revealed that about 100 million m^3 of erosion had occurred over this period in an area known as the Middle Ground, which in 1965 showed 2 m ± of dry land at low tide, and which gradually disappeared over the years since the causeway was built.

Wave action on the reservoir particularly in the 10 km above the causeway resulted in up to 20-30 m of bank erosion over an 18-29 year period, mostly on the adjacent marshlands. The tidal bore could not extend beyond the causeway and because of the increased channel bed elevation, the bore was greatly diminished in height at Moncton. A fishway constructed in the control structure was deemed to be ineffective for all species and for all stages of the life cycle of each species.

In 2003 a detailed program of historical research and field surveys was carried out to assess both the present and past physical characteristics of the estuary. This information served to calibrate mathematical models and assess changes to the estuary since the causeway was completed in 1968 and to evaluate the response of the estuary to various options for future modifications. Detailed information on this program is summarized in the publication entitled “Environmental Impact Assessment Report for Modifications to the Petitcodiac River Causeway” and associated component reports (AMEC, 2005a and 2005b). No discussion is provided for the findings from the 2003 work; however, limited reference to the information is presented in the following sections and on some of the figures.

Figure 3 illustrates the magnitude of the seasonal changes that took place in 2003 at a section located 2.1 km downstream of the causeway. Because the penetration of the tide was stopped by the causeway, the sediment in the reach from below the causeway rapidly responded to the seasonal changes of the flows from the land. During high flows from the land, sediment was transported farther downstream and during periods of low flow from the land, sediment accumulated in the upper part of the estuary. The bed elevation ranged seasonally from about -4.0 m to about +4.0 m at this location.

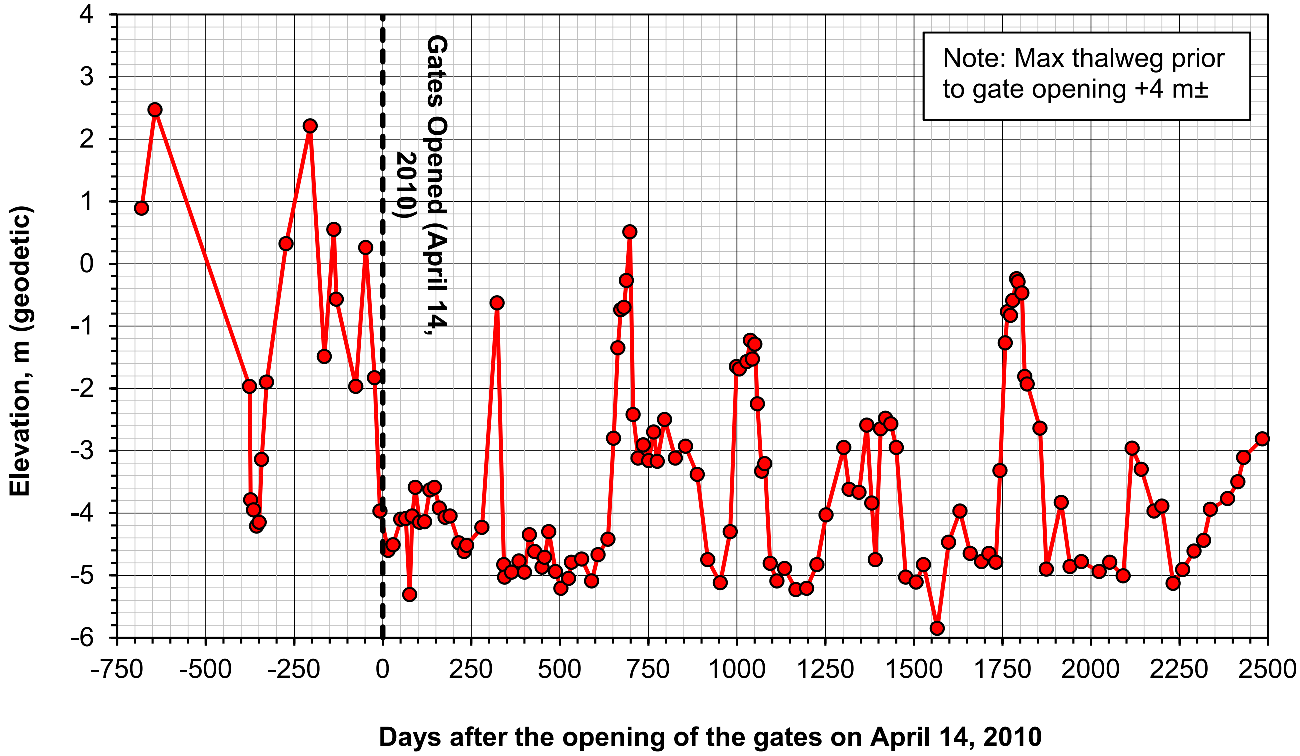


Figure 3: Thalweg elevation at section located 2km downstream of the causeway from 2008 to 2015

4 RESPONSE OF THE ESTUARY TO OPENING THE GATES AT THE CONTROL STRUCTURE

Direction was given to proceed with the opening of the gates at the control structure on April 14, 2010 to investigate the response of the estuary and to compare the observed changes to those predicted by the mathematical modelling performed by the Canadian Hydraulics Centre (CHC) for the 2005 report.

The physical measurements in the estuary extend from Salisbury to Hopewell Cape and in the Upper Bay of Fundy to Alma (Figure 1). The program was developed and adjusted to assess the major physical changes in space and over time.

Several key figures are presented to illustrate the magnitude of the changes associated with the opening of the gates. Some of these figures include information from periods before the construction of the causeway and over the period after the gates were closed in 1968 when a headpond elevation of approximately, +6 m was maintained. Hydraulic configuration of the causeway control structure is as follows:

- Number of gates = 5; total area of opening 169.0 m^2; electrically operated
- Elevation of the sill at the gate = -1.52 m; elevation top of gate opening baffle +4.6 m.

Immediately upon opening the gates the spring tidal prism was increased by approximately 20 million m^3.
The tidal prism cut off by the causeway was not completely restored due to the hydraulic capacity of the control structure and siltation in the headpond over the years, principally caused by various short-term gate opening trials.

4.1 Upstream of the Causeway to Salisbury

Nine sets of cross-sections at 24 locations were obtained in this portion of the estuary.

Figure 4 shows the channel width at elevation +4 m before and 5 years after the gates were opened in 2010. The rapid response in silt deposition is apparent in the narrowing of the channel, especially in the lower 10 km, where most of the narrowing took place in the first year.

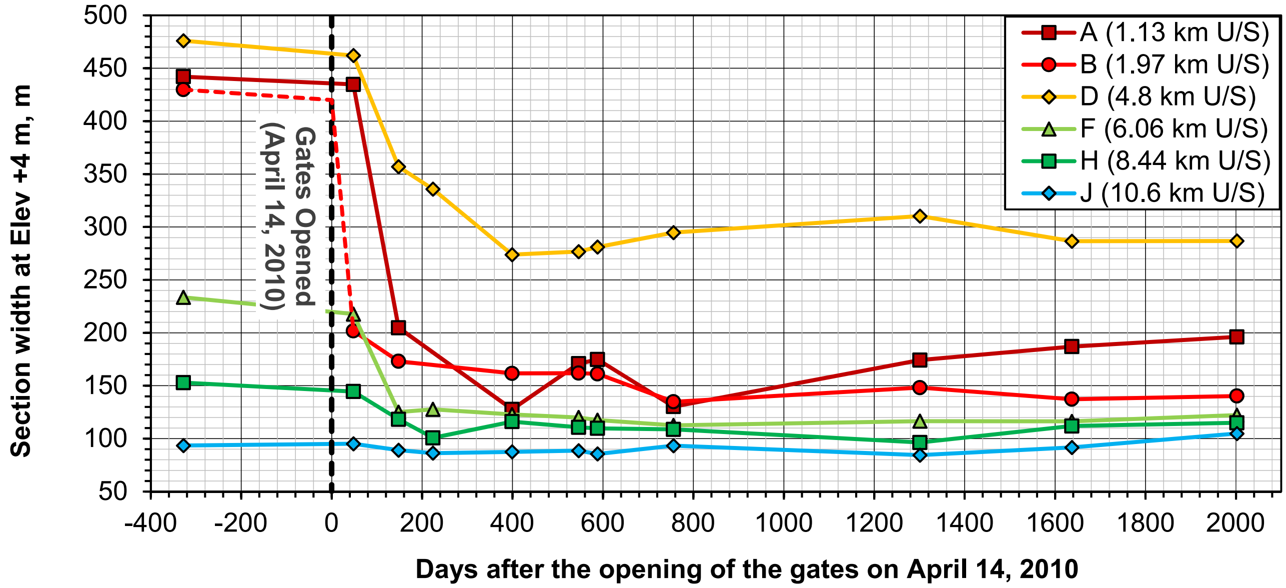


Figure 4: Channel width at elevation +4.0 m at sections upstream of the causeway from 2008 to 2016

Observations made shortly after the causeway was completed in 1968 indicated that deposition just downstream of the causeway was about 3 mm per tidal cycle. Therefore, it was assumed that the deposition upstream of the causeway when the gates were opened would be rapid and as much as 2 m per year from 720 tidal cycles, or until the level of deposition exceeded the mean tidal level.

Figure 5 shows the rate at which tidal mudflats built up. The rapid deposition has taken place on both sides of the channel. The depth of the deposit increased about 3 m over 5 years after the gates were opened. A single well-defined channel has also developed. These tidal flats started to develop vegetation in 2014.

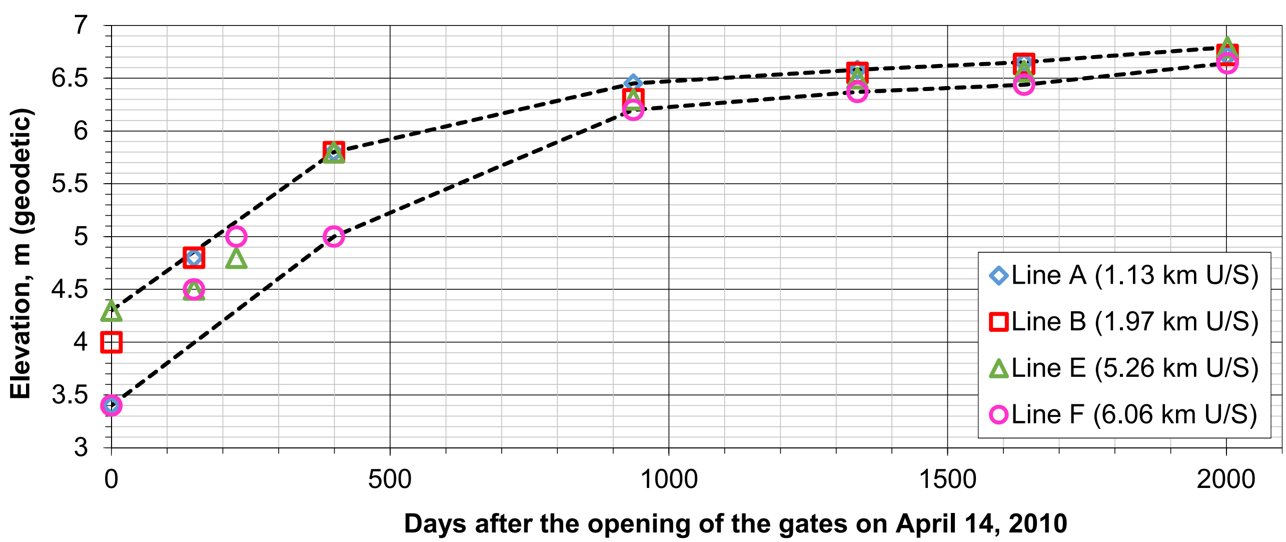


Figure 5: Typical elevation of the tidal flats from Line A to Line F upstream

4.2 Downstream of the Causeway to Hopewell Cape

Twelve sets of cross-sections at nine locations (Figure 1) were obtained along this 35 km of the estuary. The changes in the cross-sectional area provided a means of computing the changes in the volume of sediment deposited or eroded between surveys.

Figure 6 shows the relative width of the estuary along this reach. The channel has widened by 10 to 60 percent in the upper 20 km of the estuary in response to the opening of the gates. The maximum widening occurred about 8 to15 km downstream of the causeway.

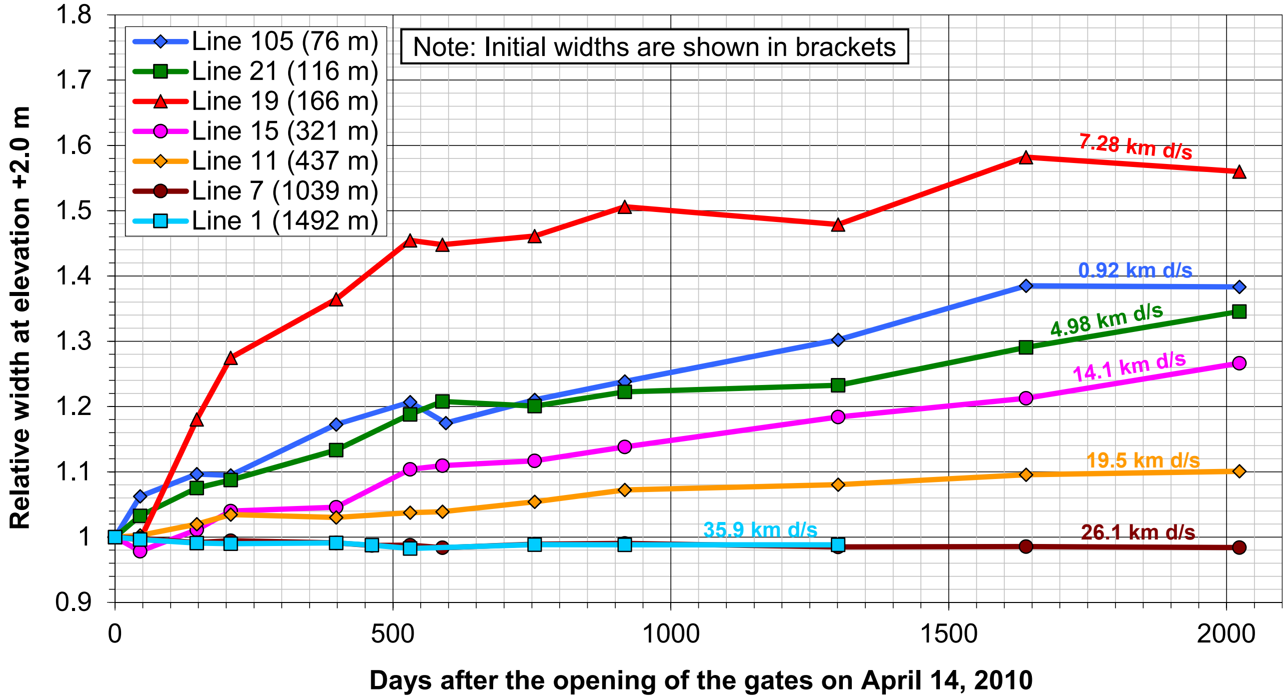


Figure 6: Relative width between the causeway and Hopewell Cape at elevation +2.0 m after opening the gates

The channel in the 20 km reach below the causeway is still widening at an average rate of about 6 m per year. Only about half of the seasonal change is occurring compared to the situation shown in Figure 3 before the gates were opened. The location of significant seasonal change has shifted 21 to 24 km upstream of the causeway toward the new effective head of tide.

A typical plot showing the variation of water level, salinity and total suspended sediment (TSS) concentrations during a tidal cycle at a site 2.0 km downstream is shown in Figure 7a before the gate opening and in Figure 7b after the gates were opened. Other measurements have shown that the tidal velocities at this site were increased and the suspended sediment concentrations were decreased after the gates were opened. These observations confirm a significant change in the hydrodynamic and sediment transport characteristics after the gates were opened.

In particular the river bed is lower by about 3 m after the gates were opened. The TSS peak on the flood tide is similar but the duration has been reduced. The TSS peak on the ebb tide has been greatly reduced probably due to the decreased amount of silt in the river bed after the gates were opened and deposition upstream. The salinity increased at the site during the ebb tide after the gates were opened because of the greater penetration of the tidal waters into the upper portion of the estuary.

4.3 Upper Bay of Fundy from Hopewell Cape to Alma

In 2003, no cross-sections were obtained below Hopewell Cape. When developing the monitoring program it was considered that sediment, which was expected to be eroded from the Petitcodiac estuary when the gates were opened, could be deposited in the Upper Bay of Fundy. During the monitoring programs a major effort was made to identify potential physical changes in the Upper Bay of Fundy and the program was adjusted several times. Figure 1 shows the locations of the cross-sections taken from Hopewell Cape to Alma.

Figure 8 shows a typical section, B1, in the Upper Bay of Fundy. There has been substantial erosion between 1965 and 2010, up to approximately 5 m. Since the gates were opened, there has been substantial deposition of about 1-2 m of material over a width of about 3 km.

5 CHANGES TO THE TIDES, TIDAL BORE, AND FISH PASSAGE

The monitoring program has shown that the highest tide levels were lowered by about 0.6 m, in the Moncton area, when the gates were opened, although this appears to be decreasing with time.

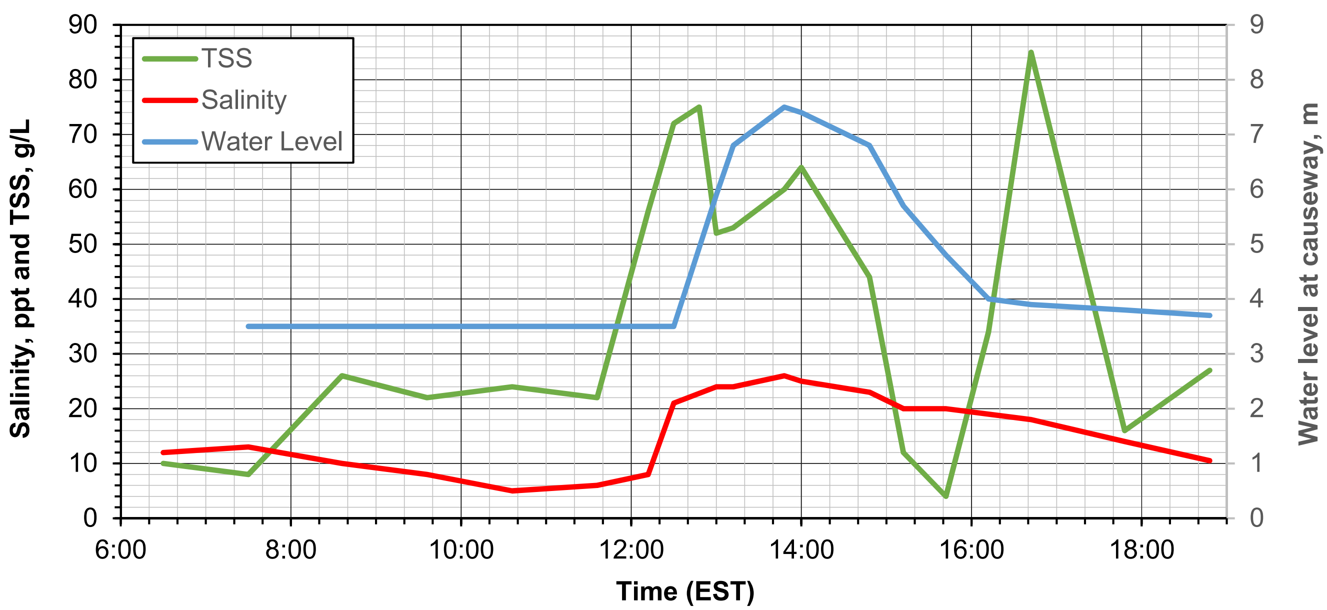
The tidal bore has increased significantly in the Moncton area. The height of the bore is now in the order of 1.0 m as opposed to less than 0.75 m. Seasonal silt build-up is significantly reduced in the Moncton area, having been relocated to its former position upstream of the causeway.

The passage of fish was greatly enhanced in terms of hydraulic considerations. There was no obstruction to the passage of fish when the water level was below the lower elevation of the gate baffles at elevation +4.6 m. When the water level was greater than, +4.6 m at the baffles, fish had to pass under them.

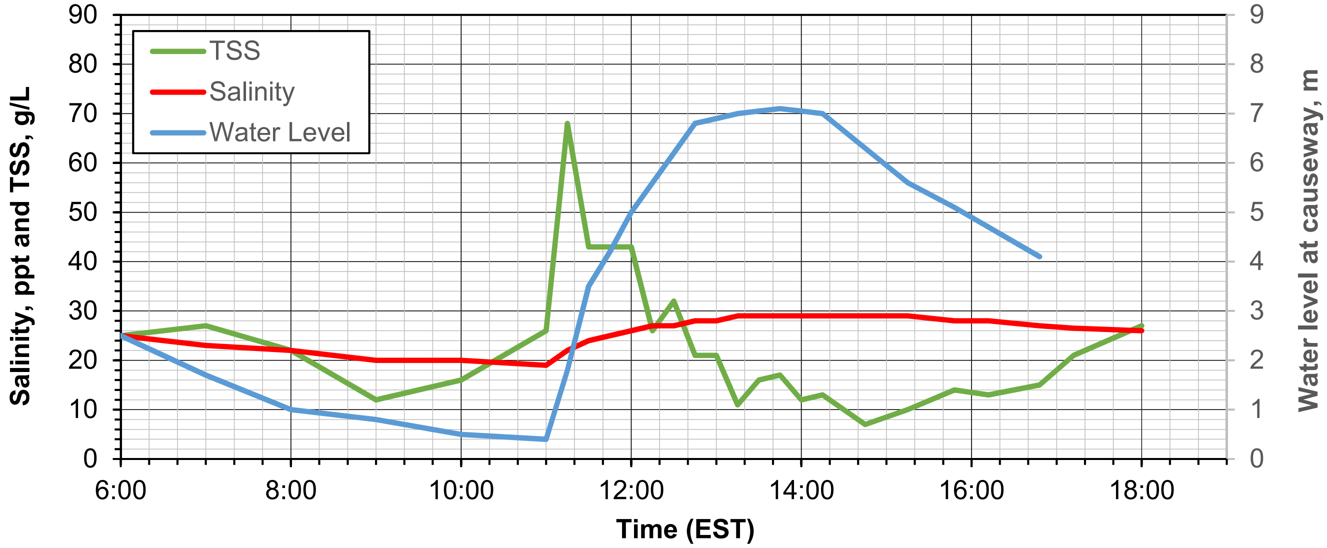
6 TOOLS USED TO MAKE PREDICTIONS OF CHANGE IN THE ESTUARY

A major mathematical modelling program was carried out by the Canadian Hydraulics Centre (CHC) as a component of the EIA (AMEC, 2005b). The calibrated and verified mathematical models were used to assess the hydrodynamics and sediment transport in the estuary between Hopewell Cape and the causeway and from the causeway to Salisbury for different scenarios. One of the scenarios was for the case with the gates, piers and baffles removed from the control structure. Although the discharge capacity for the computations was about 25 percent greater than that for the case with the gates opened, the model results could be compared with the observed changes along the estuary after the gates were opened.

In addition to the mathematical modelling, geomorphological methods were used to assess changes and rates of change in the estuary as a result of modifications made to the volume of the tidal prism. Based on the response of the estuary to the original barrier construction and the high suspended sediment loads, it was anticipated the changes would initially be very rapid.



a) September 12, 2009 pre-gate opening



b) September 10, 2010 post gate opening

Figure 7: Variation of water surface elevation, suspended solids concentration and salinity during a tidal cycle at the new Gunningsville Bridge located 2.0 km downstream of the causeway

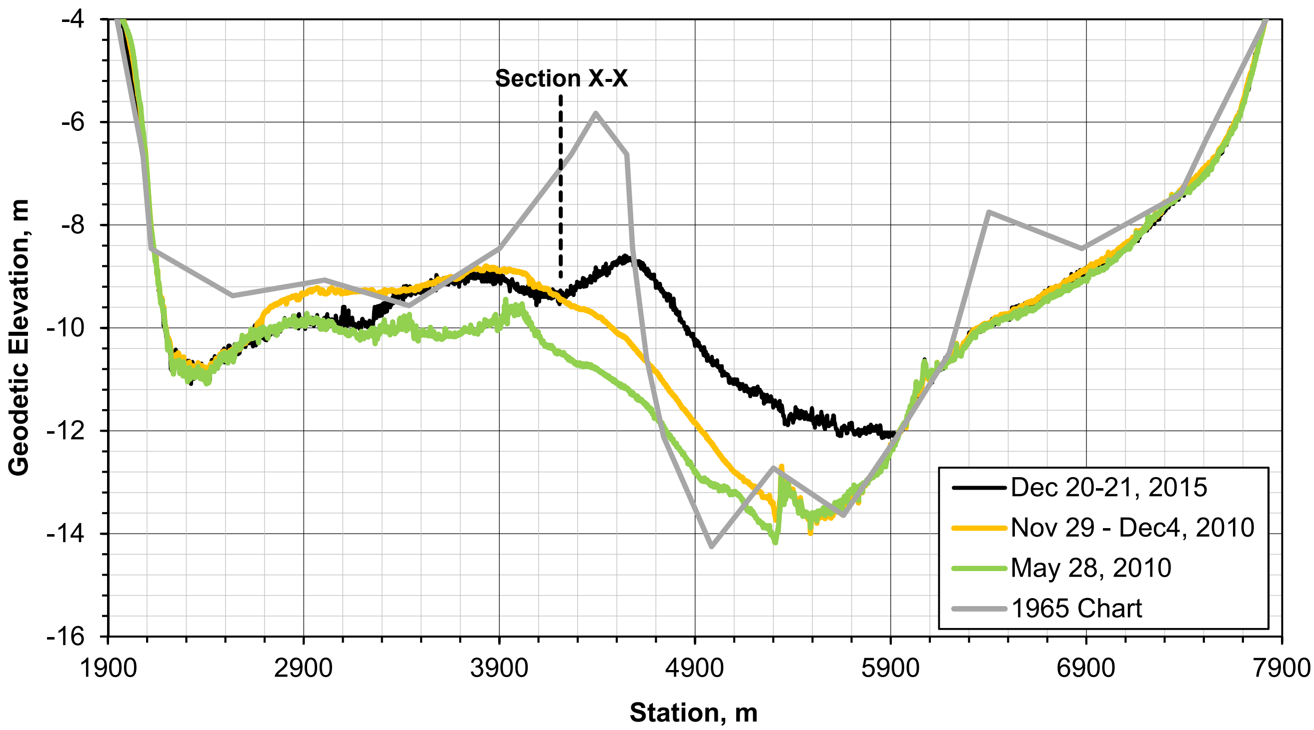


Figure 8: Cross section Line B1 located 45.8 km downstream

7 METHODS FOR ASSESSING CHANGES IN RESPONSE TO THE GATE OPENING

In order to compare the predicted changes for the gates opened scenario, it was necessary to carry out hydrographic surveys from Salisbury to Alma. The monitoring program had to be balanced in that adequate data had to be obtained to make reasonable assessments of changes in the Petitcodiac River estuary and the Upper Bay of Fundy but at the same time it was recognized that it would not be possible to obtain enough information for a fully developed scientific study.

The following information was obtained during the monitoring programs to augment the hydrographic surveys:

- Geo-referenced aerial photographs annually
- Real-time water level gauges at three sites
- Real-time web cameras at the control structure and near the head of tide.
- Monitoring of ice conditions
- Discharge measurements at the Gunningsville Bridge through five typical tidal cycles during a year
- Suspended sediment and water quality samples during hydrographic surveys and discharge measurements
- Bed material samples during hydrographic surveys
- Periodic ground level observations along the length of the estuary

Information from earlier work was also incorporated into the data sets to assess long-term changes. A computer based application was developed for rapid data storage and retrieval in graphical and tabular formats.

8 GENERAL COMPARISON OF ACTUAL AND PREDICTED CHANGES IN THE ESTUARY

The general behaviour of the estuary in terms of the response to the opening of the gates has been as predicted in the EIA (AMEC, 2005b); however, the rates of change measured were greater than estimated by the modelling. Rough assessments indicate that the rate of increase in volume of the tidal prism between the causeway and Hopewell Cape was in the order of seven times that predicted by the models for one year after the gate opening. However, the locations and magnitude of the major geometric changes after 5 years were quite closely predicted in the 2005 study by the mathematical modelling.

The data are shown in Figure 9 and the general downstream deposition in the Middle Ground area is shown in Figure 10. It appears that the deposition is occurring in the area that was eroded between 1965 and 2010.

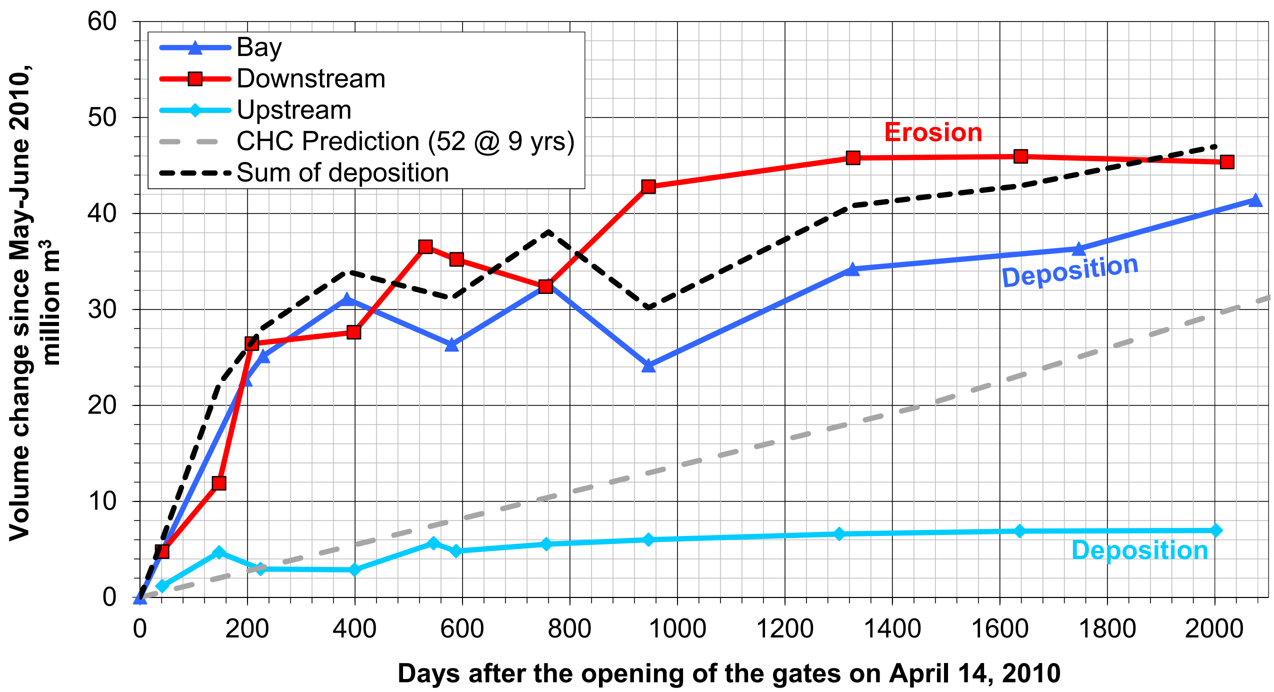


Figure 9: Deposition and erosion volumes (April 14, 2010 to January 2016)

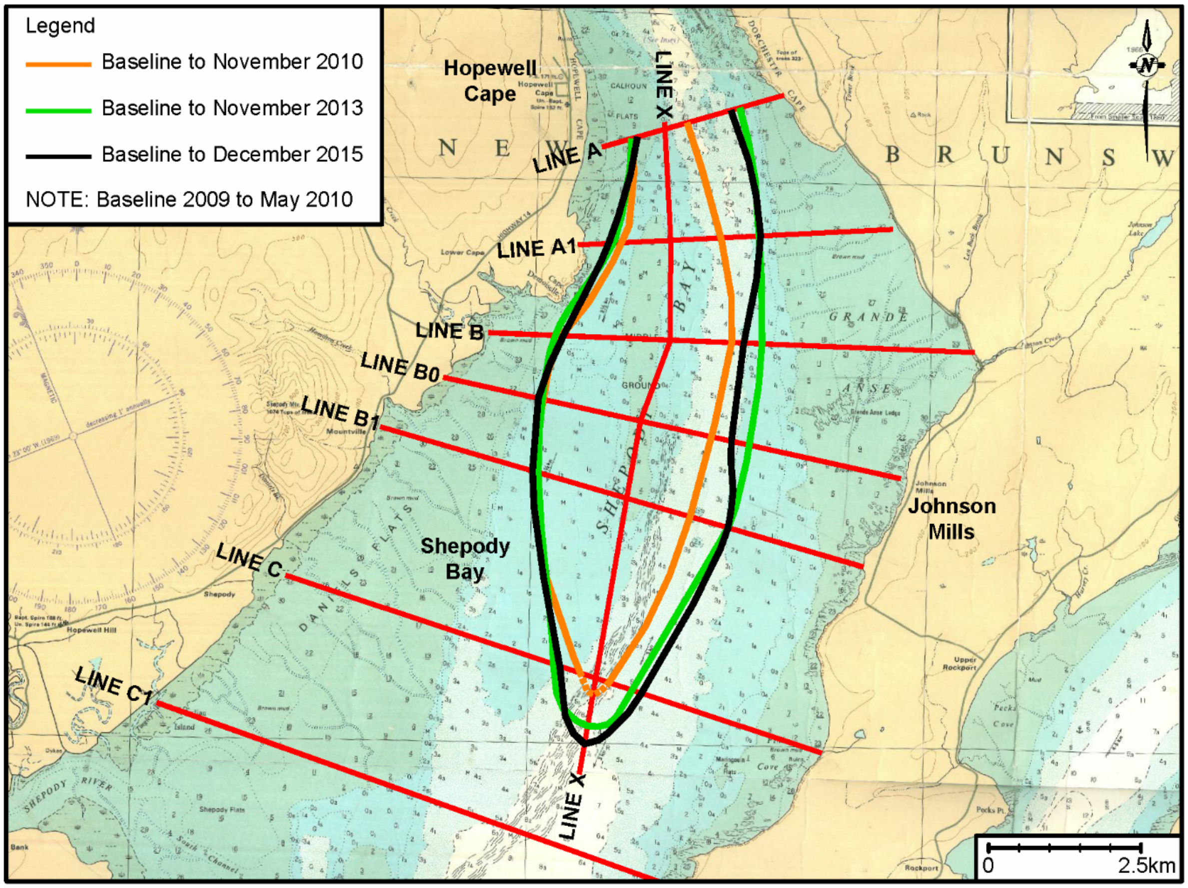


Figure 10: Location of major deposition in upper Bay of Fundy

9 SUMMARY

The monitoring programs provided a means of assessing the changes that took place in the Petitcodiac estuary and the Upper Bay of Fundy. The monitoring programs were a team effort and required the storage and manipulation of a wide range and a large amount of information. The monitoring program provided an essential means of assessing the major changes in erosion and deposition, and have shown that the 2005 predictions provided a reasonable representation of what actually happened. The program also allowed measures to be taken to protect infrastructure as required, and provided information to assess various claims made by adjacent land owners.

Acknowledgments

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References

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AMEC, 2005b. *Hydrodynamic and Sediment Transport Modelling Component Study for the Environmental Impact Assessment for Modifications to the Petitcodiac River Causeway*. Report YB299A. Submitted to the New Brunswick Department pf Supply and Services, Fredericton, NB, September 30, 2005, 133 p plus Appendices.