SALTWATER INTRUSION IN THE BAIE DE RUPERT, JAMES BAY, CANADA

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Background

As part of the Eastmain-1-A, Sarcelle and Rupert Diversion Project, a portion of the flow of the Rupert River was diverted to the Eastmain 1 Reservoir (Figure 1), through a series of diversion canals and tunnels. As a result, hydropower production at some of the powerhouses of the James Bay Complex has increased significantly. An environmental flow regime is provided at the diversion dam (Rupert dam) to preserve fish habitats and to mitigate the impacts on the environment. The discharge of the Rupert River at its mouth into Rupert Bay is thus reduced an average of 50% annually.

Rupert Bay receives the inflow of four major tributaries, the Nottaway, Broadback, Rupert and Pontax rivers. The decrease in the Rupert's discharge corresponds to an 18% decrease in the total freshwater inflow to the bay. The potential impacts of this change have been the subject of specific studies conducted as part of the Eastmain-1-A—Sarcelle—Rupert project's environmental impact assessment (EIA). Based on oceanographic data collected from 1975 to 2003 as well as numerical models, the impacts of the diversion on water levels and the intrusion of saltwater within the bay were assessed (Hydro-Québec, 2004). It was predicted that the upstream limit of the saltwater intrusion would shift 5 km upstream during ice-free periods, and slightly less in winter when ice cover is present.

In the project's conditions of authorization, monitoring the hydraulic conditions and the extent of saltwater intrusion in the Rupert Bay after the diversion of the river was required by Québec's *Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs* (MDDEFP) and by Fisheries and Oceans Canada. As part of the project's monitoring program, river discharge data, water levels in the bay as well as meteorological data must be collected during the 2008 to 2017 period. In addition, specific oceanographic data, including current and salinity measurements, are to be collected in 2010, 2013 and 2017. Here we present data collected in 2010 and 2013 and the interpretation of additional available data (Environnement illimité, 2011, Consorsium Waska-Genivar, 2014).

Objectives

The general objective of this study is to validate predictions made in the EIA in terms of modifications of oceanographic (salinity gradient) and hydraulic conditions (water levels) in the Rupert Bay and Estuary, as well as at the mouth of the Pontax River.

Specific objectives are:

- to determine the upstream saltwater intrusion limit in Rupert Bay in 2013, in ice-free and ice cover conditions;
- to compare the saltwater intrusion limit and water levels in the estuary and the bay to those prevailing before the diversion, to those predicted in the environmental impact assessment and to those observed during the first year following the diversion;
- to evaluate currents and saltwater intrusions in the Pontax River in 2013 and compare the results to those obtained before and after the diversion.

Cree Knowledge and Participation

As part of this study, Cree workers from the Waskaganish community provided technical assistance during the surveys at sea. The workers were experienced Cree land users of the area who had an interest in the saltwater intrusion issue, some of them are fishing in sites such as the mouth of the Pontax River and the islands bordering the entrance of James Bay. Their knowledge was collected using a combination of both passive and active methods.

Figure 1: Location of the study area

Methodology

The saltwater intrusion limit in Rupert Bay was assessed based on two field surveys in the bay in 2013. Hydraulic conditions were assessed based on the analysis of time series of hydrological, sea water level and meteorological data collected on an ongoing basis since 2008.

Oceanographic Surveys

The intrusion of saltwater was assessed in conditions favorable to a deeper incursion of the saltwater front within Rupert Bay, such as:

- the winter and summer baseflow periods, when freshwater discharge is minimal; and
- spring tides, which occur twice a month and when the inflow of saltwater to the bay is higher.

Both in winter and summer, four moorings, each comprising an ADCP[1] current meter and two CTD[2] probes, were installed for periods of 35 to 49 days, comprising two spring tides, during which saltwater intrusion is at its maximum. In addition to the data recorded at the moorings, discrete measurements were made simultaneously by two or three teams at specific stages of the tide cycle. These measurements aimed at precisely locating the maximum limit of the saltwater intrusion at high tide as well as its maximum recession at low tide. To chase the salinity front during the tide cycles, the teams used helicopters (Photos 1 and 2) and boats. The measurements included vertical profiles of salinity, temperature and current direction and velocity.

1 ADCP : Acoustic Doppler Current Profiler
2 CTD : Conductivity, Temperature, Depth

Photos 1 and 2: *Surface buoy marking a mooring station (left), Locating the saltwater front near the shore by helicopter (right)*

Data Analysis

In general, the salinity of natural waters ranges from practically 0 in freshwater to approximately 36 PSU[3] in oceans. In this study, the saltwater intrusion limit was defined using a salinity limit of 0.5 PSU.

The analysis of the salinity data from the moorings consisted in identifying the periods when the salinity exceeded 0.5 PSU for a period of at least 6 hours (approximately half a tidal cycle). The data from the discrete measurements along the west and east channels and near the shores were mapped so as to locate the limits of saltwater intrusion and recession separately during the winter and the summer baseflow. The intrusion limit corresponds to the furthest upstream location where salinity exceeded 0.5 PSU. Conversely, the limit of recession corresponds to the furthest downstream location where a salinity lower than 0.5 PSU was recorded.

Meteorological and Water Level Data

Data collected since 2008 at the monitoring stations were also analysed to provide a statistical description of the meteorological conditions (air temperature, pressure and wind), water levels in the bay and discharge of the major tributaries. This data was validated and completed as required using statistical procedures. Water levels in the bay were the subject of a specific analysis aimed at understanding the importance of different components of the tide cycle (e.g. lunar and solar components) and the influence of meteorological perturbations on water levels in the bay. Finally, water levels in the estuary in post-diversion conditions were assessed.

Results

Saltwater Intrusion

During the summer survey, the upstream saltwater intrusion limit was located slightly to the south of Jolly Islands, on the east shore, and approximately 4 km to the south of the mouth of the Octave River on the west shore (Figure 2).

Near the centre of the bay, the intrusion limit was approximately 4 to 6 km further upstream compared to pre-diversion conditions. The position of the front was within the area predicted in the environmental impact assessment (EIA), which appears to be conservative. Compared to the low hydraulicity conditions observed in 2010, after the diversion, the limit in 2013 was approximately 2 km downstream. The location of the front in 2013 was thus intermediate between the position observed in 2003 and 2010. It is apparent that the incursion of saltwater in the channels decreases with the total discharge of freshwater into the bay. Lower discharges thus favour a deeper incursion of the saline front.

Near the shores, the pattern is somewhat different and more complex. The limit of the saline front near the shores does not appear to be driven solely by the freshwater discharge in the bay but is also influenced by meteorological

[3] PSU : practical salinity units

conditions such as atmospheric pressure and wind. There is thus considerable variability in the position of the front from year to year (Figure 2).

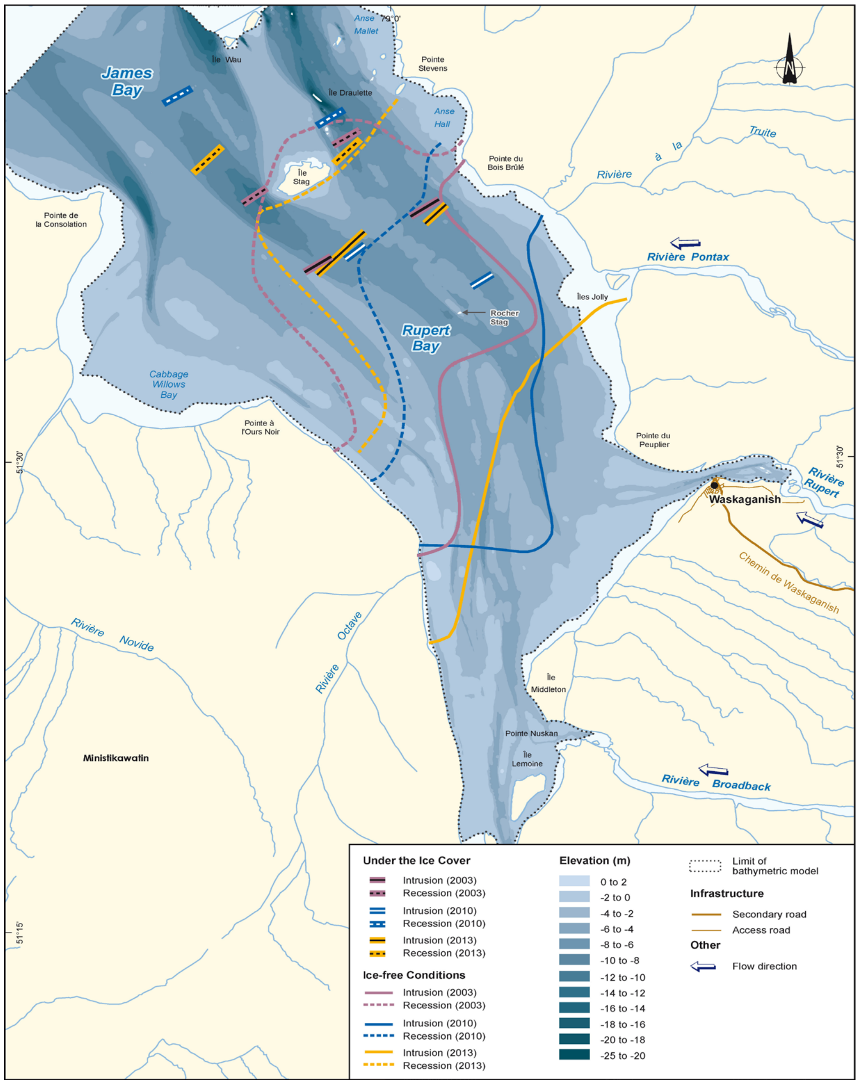

Figure 2: Measured limits of salt water intrusion in open water and ice cover conditions

In the estuary, near Waskaganish, no saline intrusion was observed in post-diversion conditions in 2010. This result is consistent with the prediction of the EIA.

At the mouth of the Pontax River, one episode of saline intrusion was observed in 2013, compared to 8 in 2010. These intrusions are correlated with strong winds from the west to north sectors and are more likely to occur when the discharge of the Pontax River is low, e.g., at the end of winter and summer. The effect of wind indicated by the statistical analysis is coherent with the knowledge of the Cree workers who participated in the study.

During the winter baseflow, when the bay is covered by ice, the incursion of saltwater is greatly limited compared to ice-free conditions. The limit of the front was located 10 km or more further downstream (Figure 2), near Stag Island. The smaller incursion was likely caused by the absorption of part of the tidal energy by friction with the ice cover. The saline front was relatively close to the position observed in pre-diversion conditions but a few kilometres downstream from the 2010 position.

Water Levels

In the bay, water levels appeared to be generally similar from year to year, with some fluctuations that most likely be explained by meteorological events such as storm surges, especially in summer and to a lesser degree in winter. No difference between pre- and post-diversion conditions could be related to the decrease in the discharge of the Rupert River (Figure 3).

In the estuary, the diversion was expected to cause a slight drop in water levels. A decrease was observed mostly at low tide, with no change observed at high tide. On average, the water level in the estuary was 10 to 15 cm lower than in pre-diversion conditions. This result is consistent with the EIA's prediction.

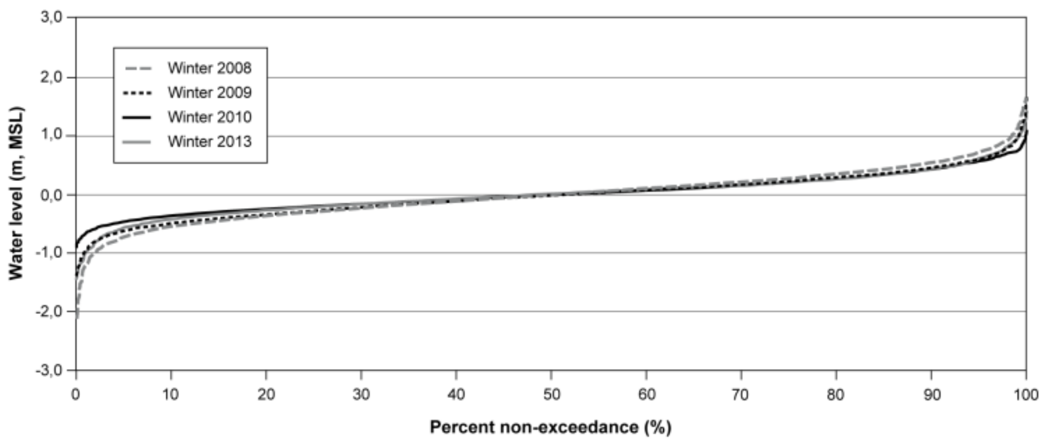

Figure 3 : Non-exceedance stage curves at Stag Rock Station for ice-cover conditions during 2008, 2009, 2010 and 2013

Conclusion

Rupert Bay is a singular site being a large estuary with very shallow depths that receives large volume of freshwater inflow from three major rivers on its eastern boundary and where tidal forcing and weather conditions play a major role in water level variations.

In order to improve knowledge of Rupert Bay hydrodynamics and to understand and measure the impacts of the diversion of one of its major tributaries on salt water intrusion and the limit of these zones, more than 15 studies, combining oceanographic and hydrological measurements to numerical modelling, were conducted since 1977.

Monitoring, undertaken in 2010 and 2013 relying exclusively on empirical data collected both in open water and ice-cover conditions, confirm predicted trends. Measured changes remain in the range anticipated by the EIA. This highlights the good overall performance of the impact assessment and validation process, where the impact of the diversion was first predicted with an acceptable level of precision and was confirmed and refined post-diversion only using empirical measurements during two years of operation of the project.

References

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