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Manitoba Hydro

ArcticNet – Manitoba Hydro
Cold Region Estuaries Workshop

Numerical modeling of estuaries

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Cold Region Estuaries – Specific Features

An estuary is defined as the area where freshwater from watershed runoff meets salt water from the sea

All large rivers have estuaries but large water masses where freshwater mixes with salt water can also be defined as estuaries:

- Chesapeake Bay
- Hudson Bay

Estuaries are dynamic ecosystems that show more or less complex physical processes due to tidal and river discharge variations: water surface variations with tides, variable current patterns, mixing of water masses

Cold region estuaries show an other feature that adds to the complexity of the natural processes: the presence of an ice cover

Numerical Modeling of Estuaries

Due to the complex physical processes occurring in an estuary, numerical models are often used to simulate the expected impacts of predicted changes from external factors

Depending on the type of estuary, several types of models can be used:

- Simple 1D models for water levels and salt intrusion in well-mixed estuaries of regular and symmetrical geometries
- 2DH for well-mixed estuaries with irregular geometries
- 2DV for stratified estuaries with symmetrical geometries
- 3D models for more complex geometries and physical processes

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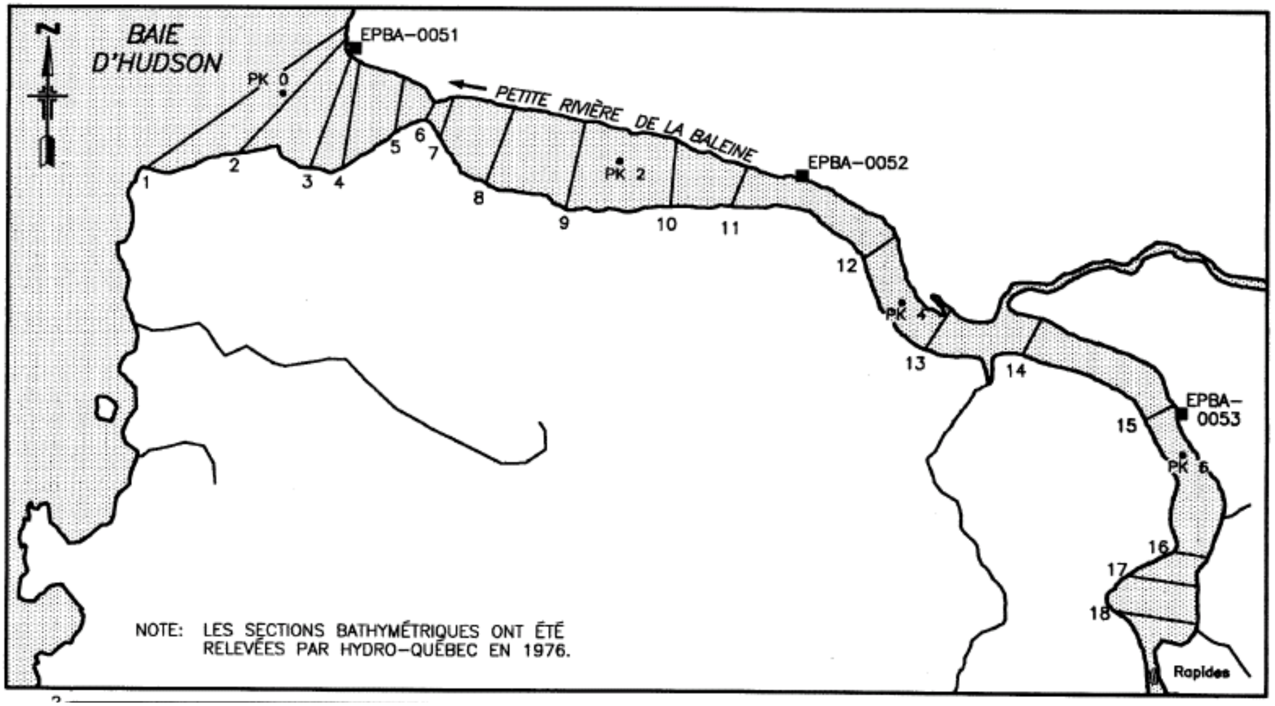
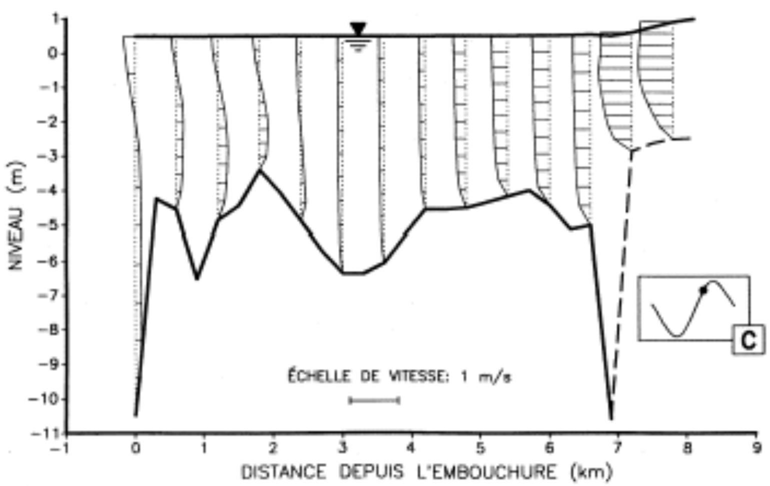
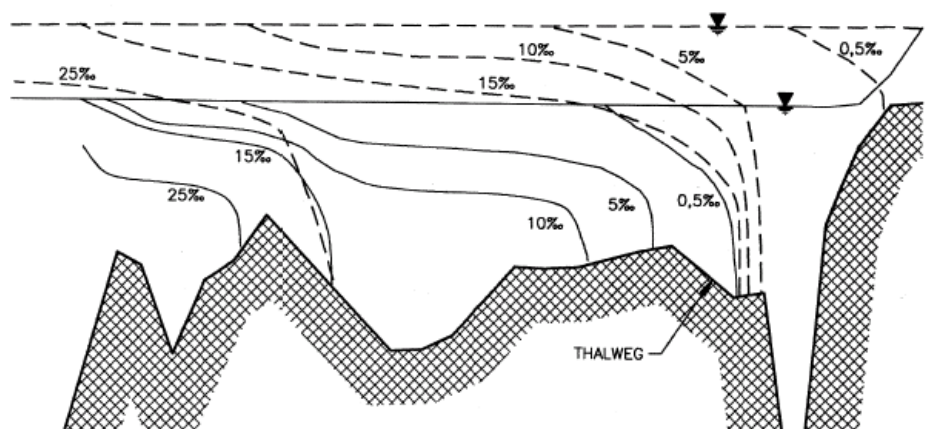
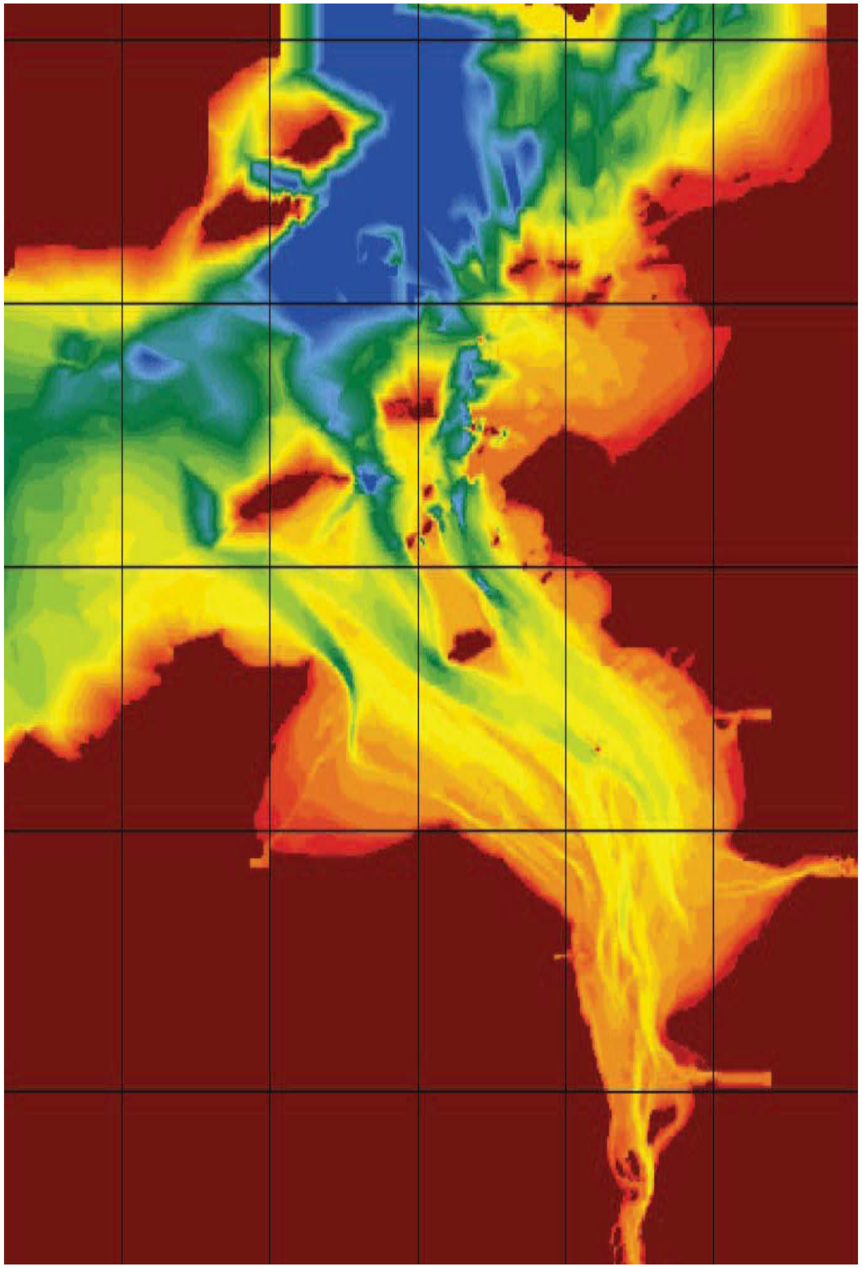
Great Whale River estuary – 2DV model (1994)

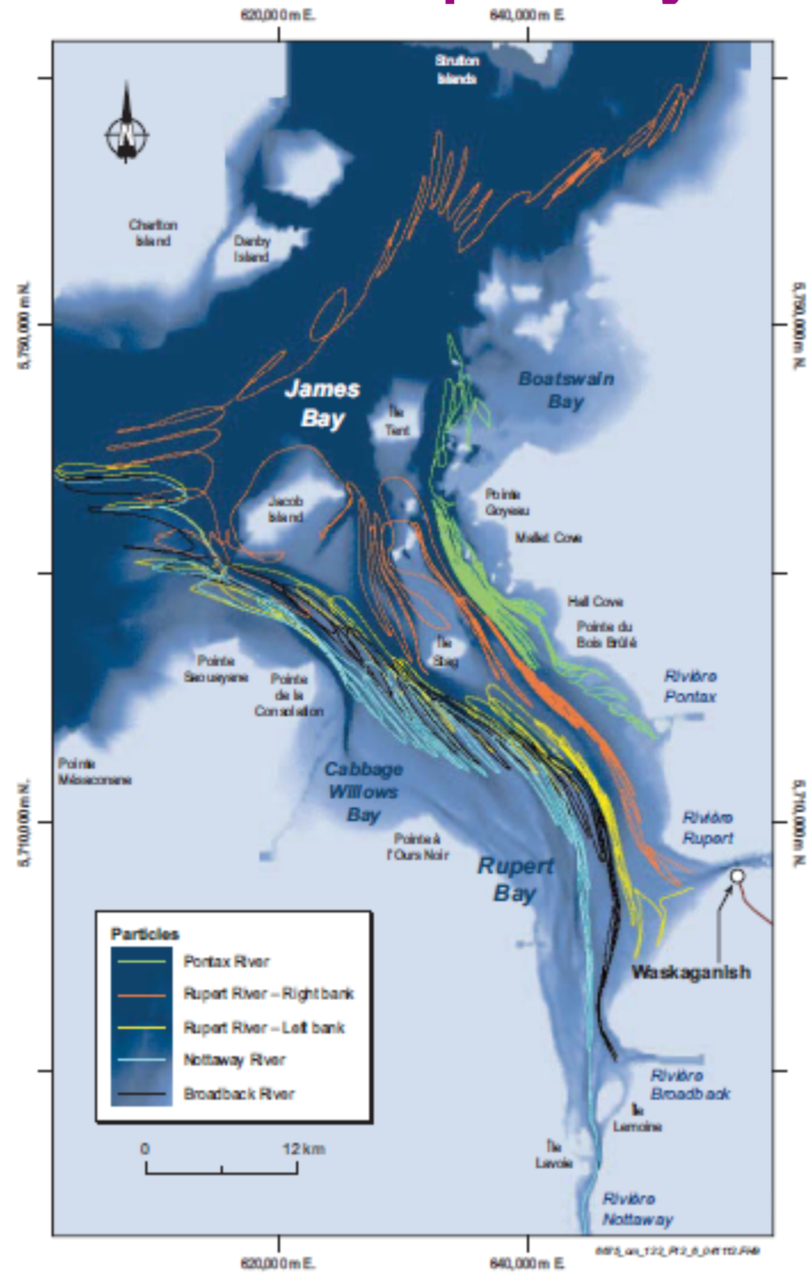






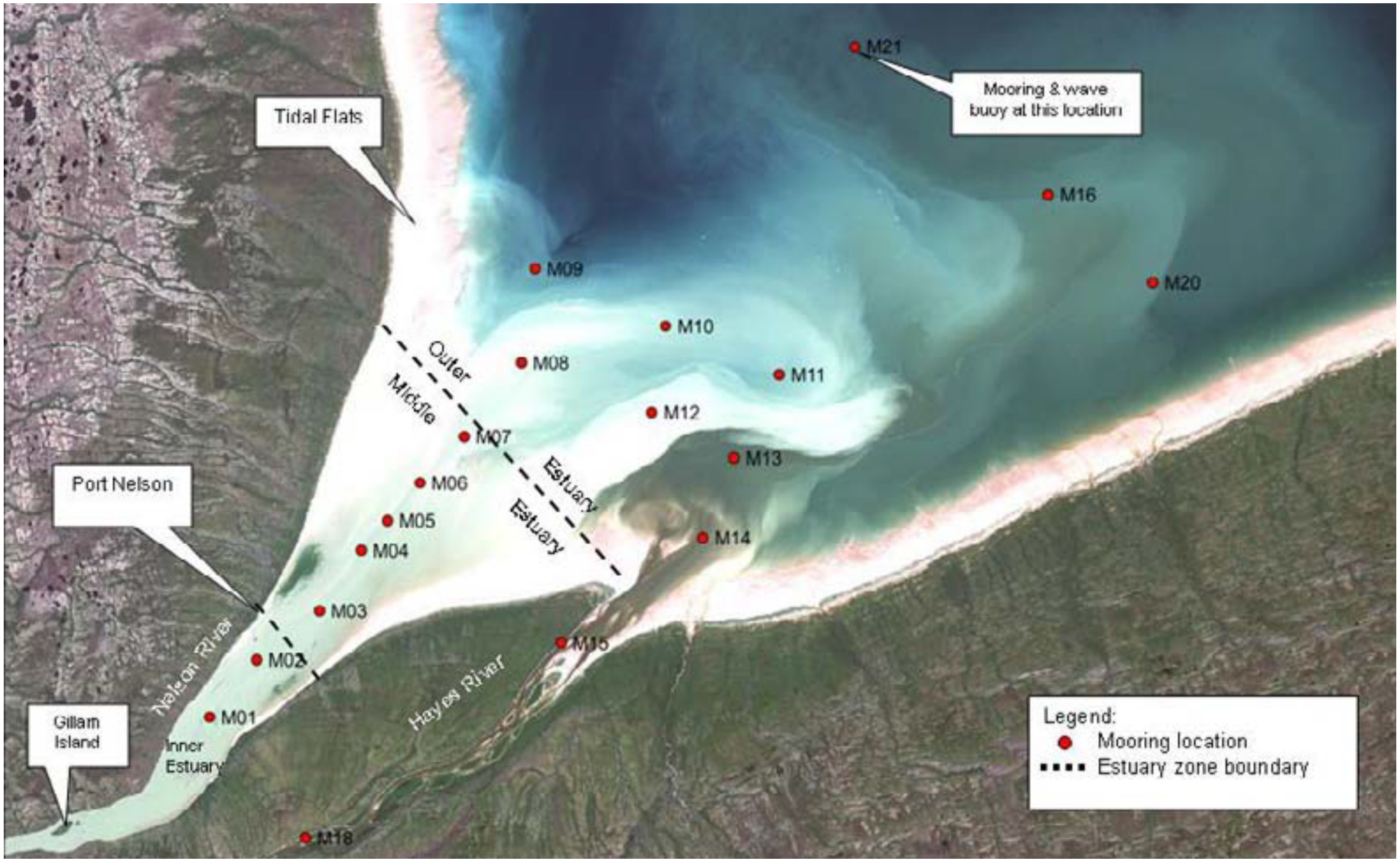
Rupert Diversion Project – 2DH model of Rupert Bay





Numerical Modeling of the Nelson River Estuary

A 3D numerical model was selected for the Nelson River Estuary due to the size and geometry of the estuary, and to the presence of various water mixing processes



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Numerical Modeling of the Nelson River Estuary

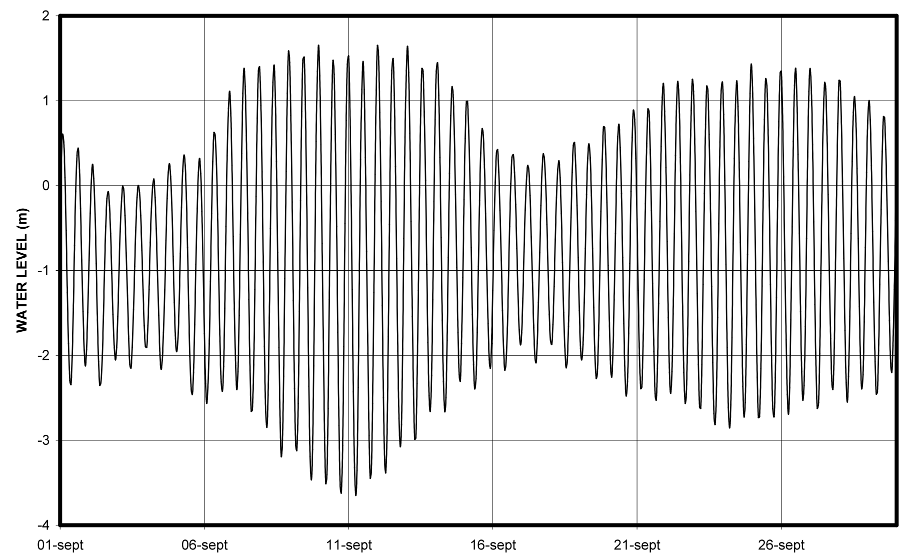
Rigorous numerical modeling approach:

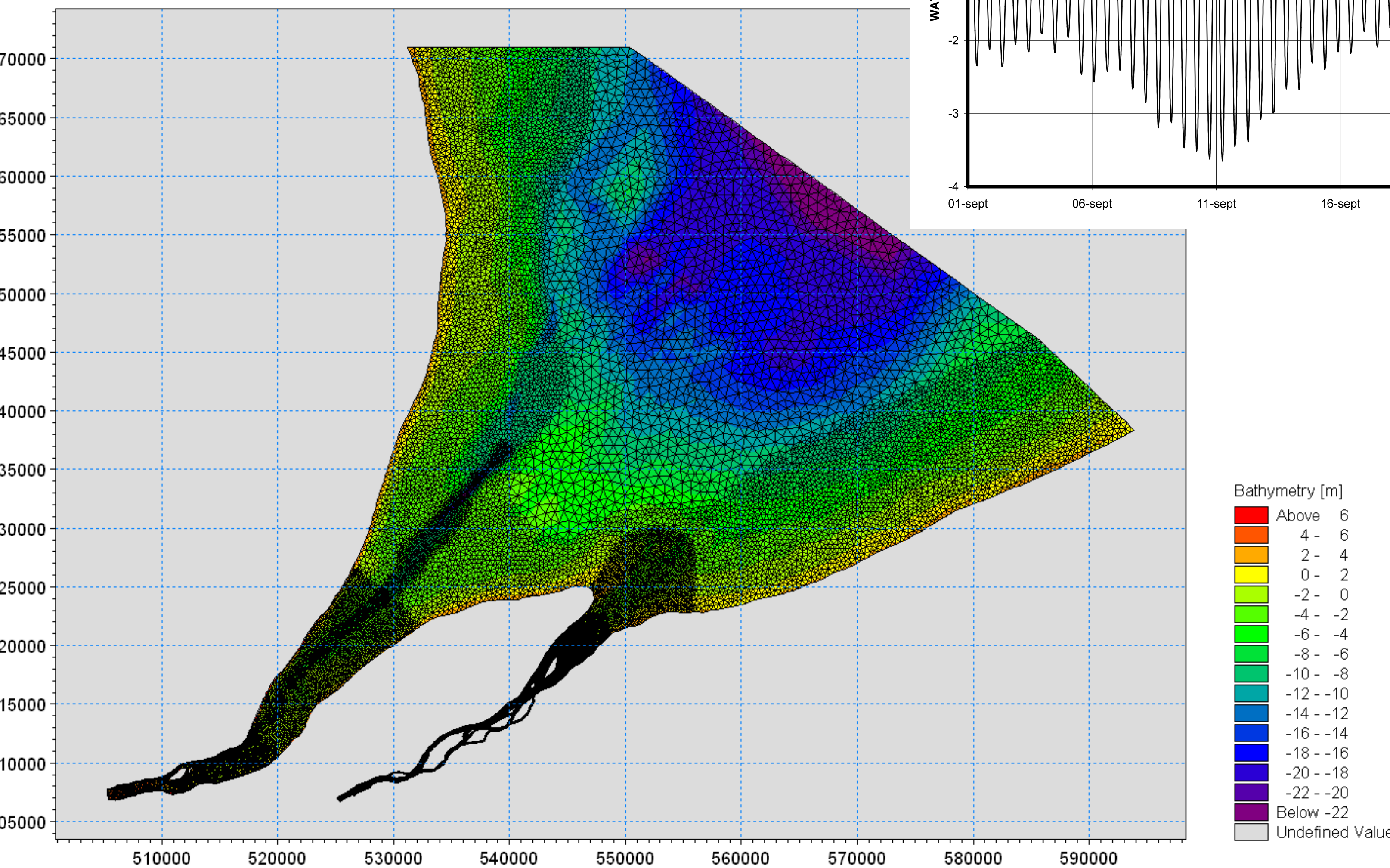
- Calibration based on selected series of observations from the 2005-2009 survey program
- Validation of model results with available data collected at different river flows
- Simulations of pre- and post-project conditions prepared to cover all expected tidal and river flow conditions
- Comparison of pre- and post-project results to show differences in average conditions as well as variability of each parameter

3D model simulations do not account for the presence of an ice cover and sediment transport

Numerical Modeling of the Nelson River Estuary

Water Levels recorded at Station M20 (2006)





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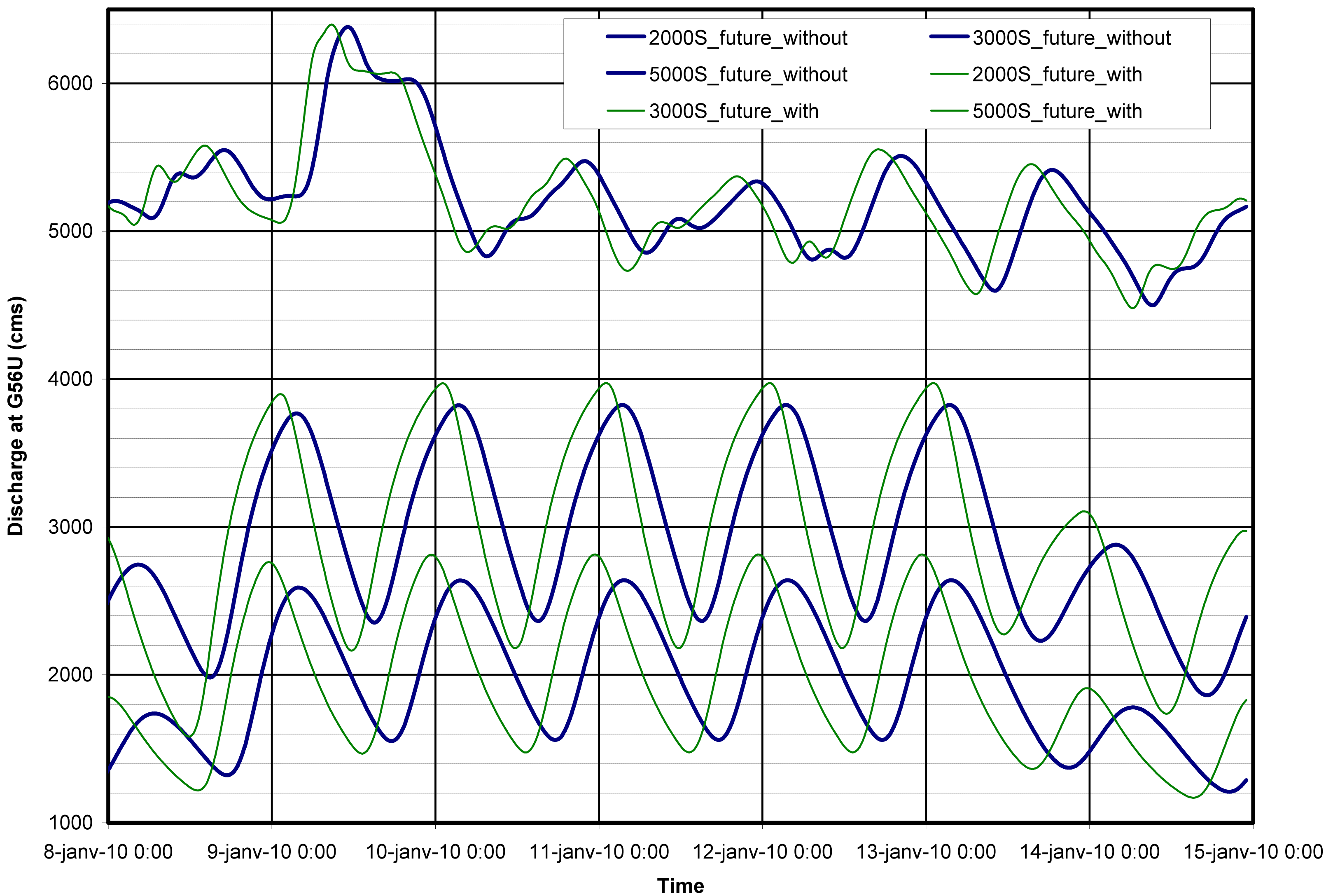
Numerical Modeling of the Nelson River Estuary



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Numerical Modeling of the Nelson River Estuary

Model results show that:

- Nelson River estuary shows a strong marine predominance: tide-generated volumes are an order of magnitude larger than river inputs
- Tidal forcing is largely predominant in the middle and outer Nelson estuary areas
- As expected, the Nelson River discharge has an effect mostly in the riverine portion of the estuary area (water levels, currents)
- Expected Post-project River flow changes will have no noticeable effect on the physical environment of the Nelson estuary
- Expected changes will not be measurable and will be well within the variability of existing conditions

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Climate and Freshwater Change Issues

Hydroelectric development in Manitoba, Ontario and Quebec has altered the hydrological regime of several rivers discharging into Hudson Bay

Climate change may also have a significant impact on the regional hydrological and ice regime in the future

To qualify these changes, the following activities were performed :

- Analysis of regional trends on observed series of temperatures, precipitations and river hydrology
- Review of regional climate change predictions and the impacts on the hydrological regime and ice volumes
- Review of scientific studies: impacts of hydroelectric development on the physical processes of Hudson Bay

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Historical Trends in Regional Temperatures

Long series of temperature data were analyzed using the Mann-Kendall test to determine statistical trends over time at 4 meteorological stations along the coast of Hudson Bay :

- Churchill A
- Moosonee UA
- Kuujjuarapik A
- Inukjuak A

Significant warming trends were found at all stations in the annual maximum, mean and minimum temperatures

Historical Trends in Precipitation

Conclusions - Precipitation:

- Statistically significant **decreasing** trends in snowfall and total annual precipitation at Moosonee, as well as in winter and spring
- Statistically significant **increasing** trends in snowfall and total annual precipitation at Inukjuak, as well as in winter and autumn
- Statistically significant **increasing** trend in total annual precipitation at Churchill, but no seasonal trends

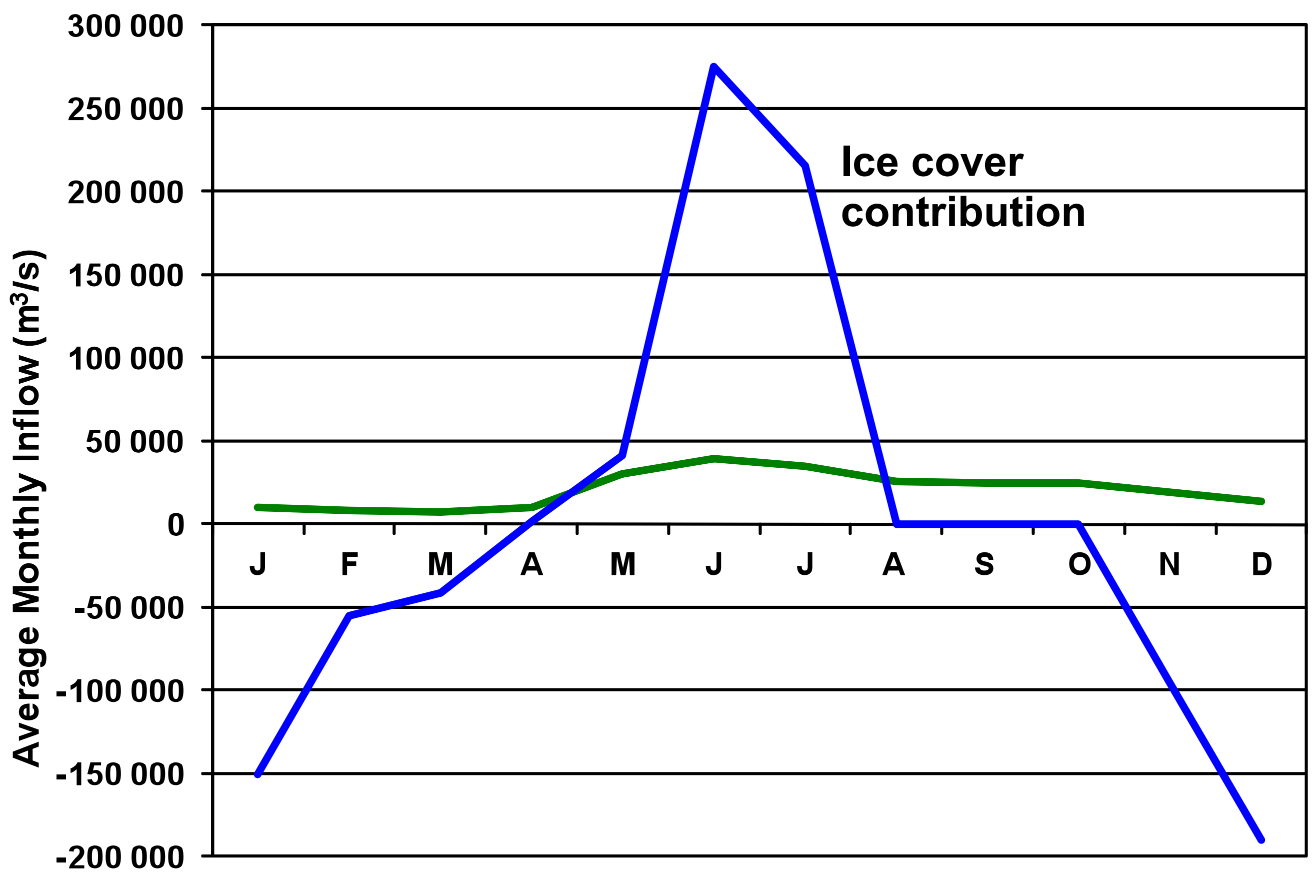
Historical Trends in River Hydrology

Conclusions - Hydrology

- The Nelson and La Grande Rivers are the two main freshwater contributors to Hudson Bay
- Déry et al (2005) studied the flow regime of 42 gauged rivers discharging into Hudson, James and Ungava Bays, and found a **statistically significant decreasing** trend of natural runoff in 36 of the 42 rivers studied

Climate and Freshwater Change Issues

Estimated mean monthly flows due to ice cover formation and melting in Hudson Bay more significant than the freshwater runoff contribution from all the rivers discharging into Hudson Bay (Loucks & Smith, 1989)



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Climate change predictions

Future climate forecasts were extracted from a database of climate model data from various international modeling groups for the Nelson River estuary

Database provided to Manitoba Hydro by the Ouranos Consortium on Regional Climatology and Adaptation to Climate Change

- A warming trend is predicted throughout the year by all GCMs
- The most significant increase in temperature is forecasted in winter, with predicted increases ranging from 1 to 4°C in the 2020s, 2 to 8°C in the 2050s, and 3 to 11°C in the 2080s
- Precipitation is also generally forecasted to increase in the future by most GCMs, with the largest gains in winter and directly related to increases in temperature

Climate change predictions

Delayed ice formation in the northern and northeastern portions of Hudson Bay (*Gagnon & Gough, 2005*)

Lower ice concentrations in the northern and northwestern portions of Hudson Bay (*Gagnon & Gough, 2005*)

Higher ice concentrations in the southern part of Hudson Bay, particular to the north of Belcher Islands, due to increasing concentrations of small ice floes that are pushed to the south-east by prevailing winds and then accumulate and form ice ridges along the coast (*Wu et al., 2005*)

Earlier ice break-up in James Bay and along the south coast and the western portion of Hudson Bay (*Gagnon & Gough, 2005*)

Effect of Freshwater Changes

River regulation for hydroelectric energy generation reduces seasonal variations in flow, with significantly higher flows in winter compared to natural rivers

The following studies investigated the impacts of hydroelectric development on the physical environment of Hudson Bay:

> Prinsenberg (1983): 1D ocean mixed-layer model of post-development conditions showed that an increase in winter freshwater discharge into Hudson Bay would **decrease water temperatures and salinities** in the surface layer, resulting in **increased ice production** compared to pre-development conditions. However, these **changes would be within existing natural variations**.

Effect of Freshwater Changes

LeBlond et al (1996): Post-development regulated flows on rivers result in **larger under-ice freshwater plume areas** in winter, compared to pre-development, which would cause an **approximate 0.23% increase** in ice formation on Hudson Bay, negligible compared to the inter-annual variability in ice cover and thickness

Saucier & Dionne (1998): 3D coupled ice-ocean model used a 50% increase in total river inflows in winter between post- and pre-development scenarios, resulting in a 7 mm thicker uniform ice cover on Hudson Bay and a maximum ice thickness increase of 7 cm in the southeast corner of the bay. However these **increases are small compared to the existing natural variability**.

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Conclusions

Conawapa Project Impact on Nelson River Estuary

- No observable changes with the project compared to existing conditions. Changes are well within existing variability

Hydroelectric Projects impact on Hudson Bay

- River regulation results in less important seasonal variations in freshwater runoff
- Based on existing scientific literature, the changes in water mass characteristics (temperature and salinity) and in the ice regime induced by hydroelectric regulation are small compared to the natural variability of Hudson Bay's physical environment
- Changes are negligible when compared to the current and foreseen changes caused by global warming

Conclusions

Climate Change Impact

- Analysis of historical temperatures recorded in the Hudson Bay region shows statistically significant warming trends, resulting in earlier break-up and later freeze-up of ice in Hudson Bay
- Over the period 1971-2003, river discharges into Hudson Bay decreased by approximately 12% (Déry & Wood, 2005)
- Majority of GCMs predict temperature in the Hudson Bay region for all seasons, with the most pronounced increases occurring in winter. This increase in temperature, and the related changes in precipitation, due to global warming will have a profound impact on the ice regime and the hydrology of the rivers discharging into Hudson Bay.

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Thank you

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