Modeling the Effect of Inlet Geomorphic Changes on the Circulation Dynamics in a Semi-enclosed Coastal Estuary

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Abstract

Eutrophication-induced hypoxia in a coastal estuarine system results in the deterioration of water quality, which is a growing issue worldwide. In early August 2016, an anoxic event caused the mortality of up to 75 percent of cultured oysters in aquaculture leases of northern Tracadie Bay, New Brunswick (TNB). Field observations revealed that, although the occurrence of summer hypoxia in north TNB is linked with anthropogenic stressors, changes in the geomorphology of one of the bay's inlet are likely to play a significant role in escalating the eutrophic conditions. However, adequate information on the circulation dynamics of TNB estuarine system was lacking. To address this knowledge gap, a high-resolution spatially-explicit hydrodynamic model was developed for TNB to evaluate the possible physical processes involved in generation of hypoxia leading to oyster mortality. The model showed high skill (0.93) in south TNB in simulating water level elevations and slightly lower skill (0.85) in north TNB. Findings from modeling scenarios based on past, present and future inlet geomorphology suggest that it has strong consequences on intricate circulation patterns, renewal of water and transport. Further, the model is coupled with a volume advection-dispersion tracer module to track the dissemination of effluent and identify areas at risk of hypoxia. Residual flow estimates revealed poorly-circulated stagnant areas, consistent with hot spots in sediment organic matter content. Outcomes from this study will be of relevance for the management of water quality and aquaculture practices.

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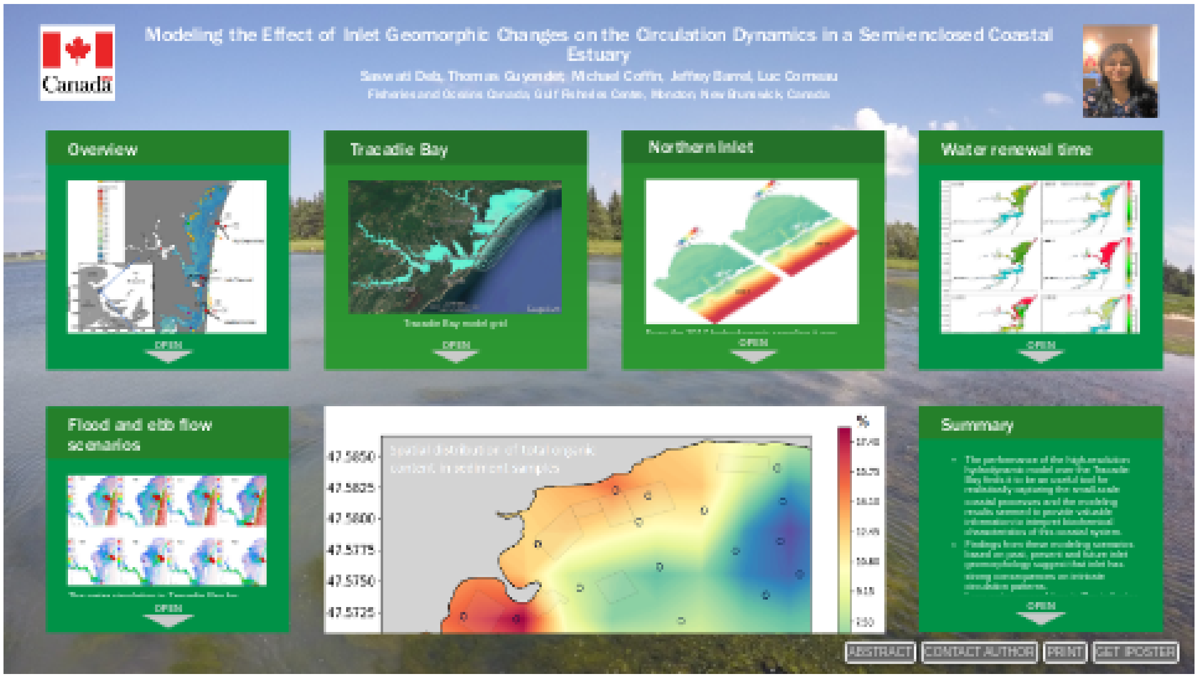

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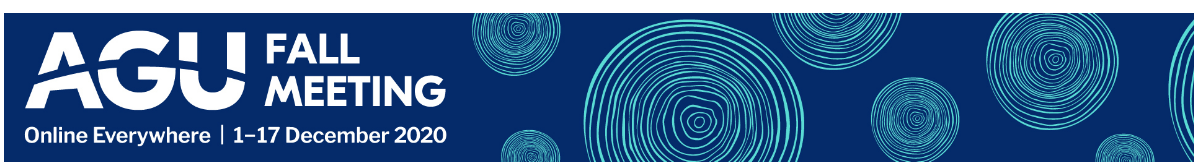
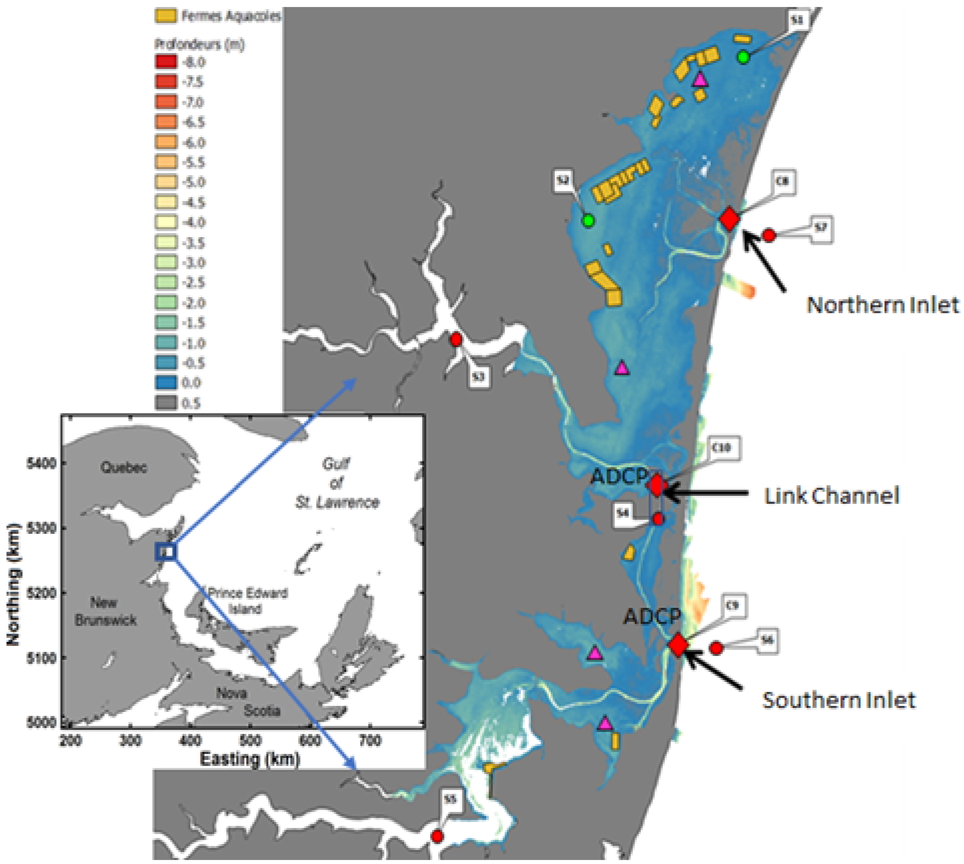


OVERVIEW



Tracadie Bay (LiDAR bathymetry in meters)

Oyster mortality in 2016

Causes

- Anoxia occurred due to absence of dissolved oxygen.
- Eutrophication due to increase in nutrient concentration.
- Adequate information on the circulation dynamics of Tracadie Bay estuarine system was lacking.
- Knowledge gap in understanding the consequences of inlet geomorphic transformation on overall hydrodynamic functioning of semi-enclosed estuary.

Approach

- Assessment of key physical processes/factors affecting the occurrence or escalation of eutrophication thereby leading to oyster mortality in Tracadie Bay.
- Possible ways (in terms of inlet geomorphic transformation) to curb the eutrophic conditions.

ACRDP abiotic goals

To address our scientific approach, we developed the first high-resolution 3-D hydrodynamic model for the Tracadie Bay using FVCOM v4.1 (Chen et al., 2003).

The validated model was used as a tool to investigate

- the residual circulation,
- the water renewal time

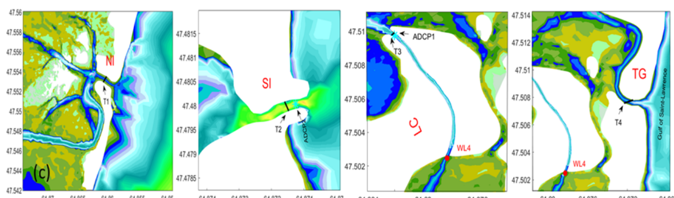
to identify the areas that are at risk of hypoxia.

Then, we developed simulation scenarios based on past, present and potential future inlet geomorphic transformations to determine

- the consequences on overall hydrodynamics and
- specific processes related to eutrophication vulnerability.

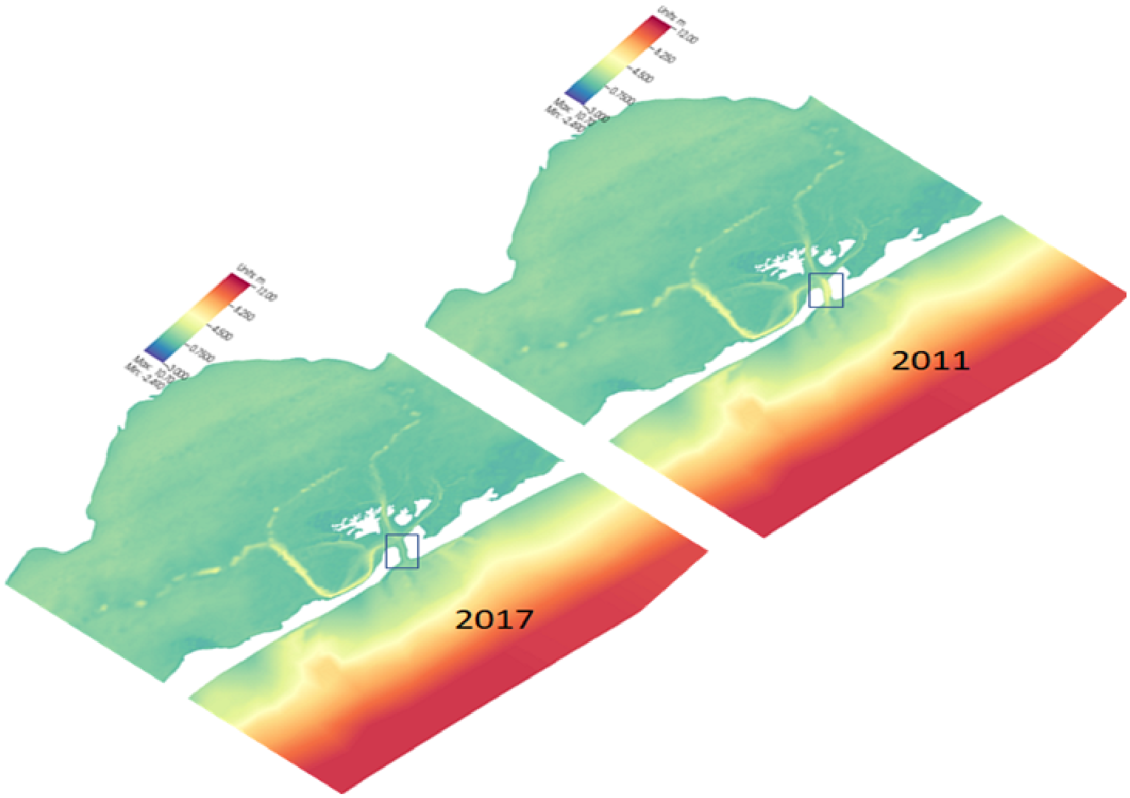
TRACADIE BAY

Tracadie Bay model grid



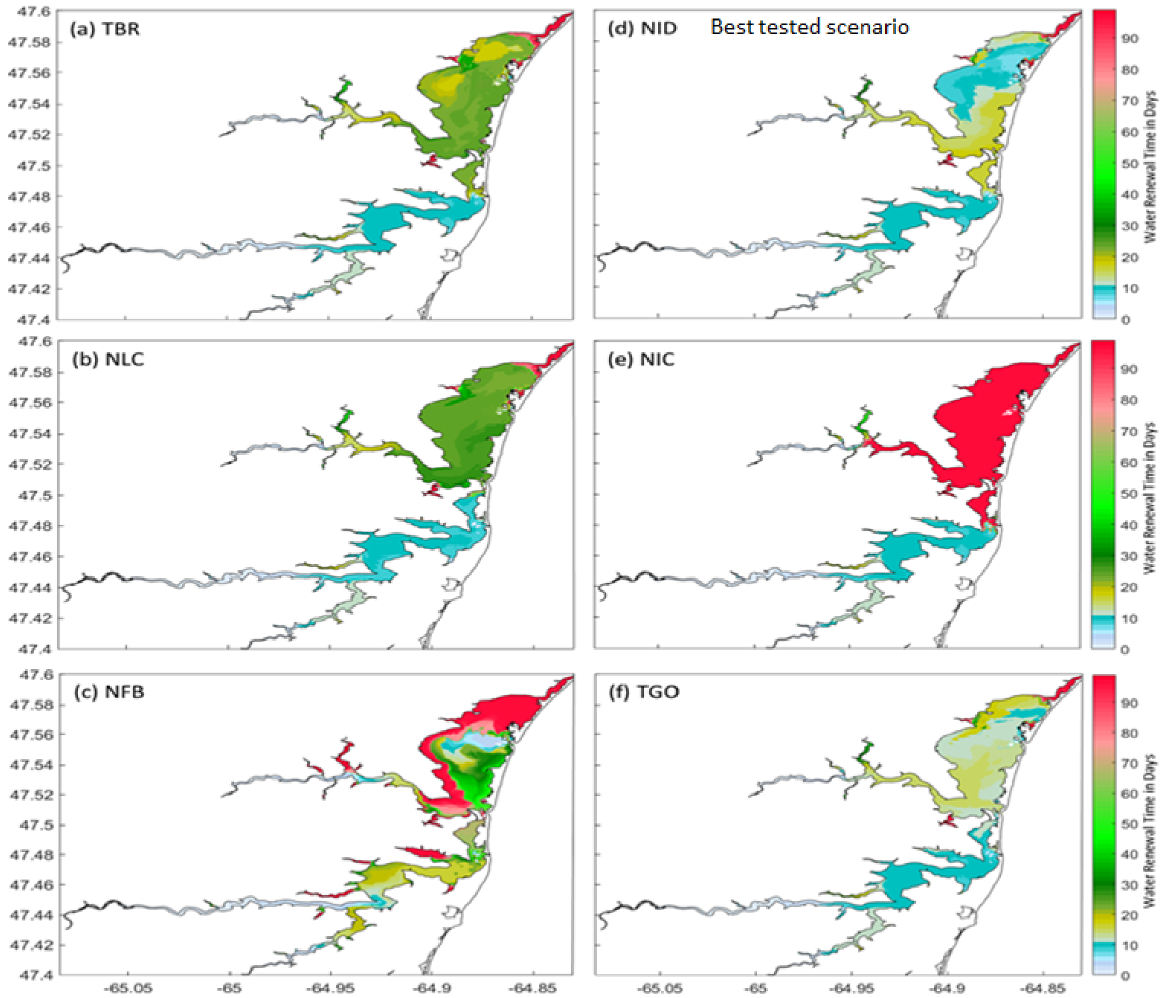
Inlet and channel morphology

NORTHERN INLET



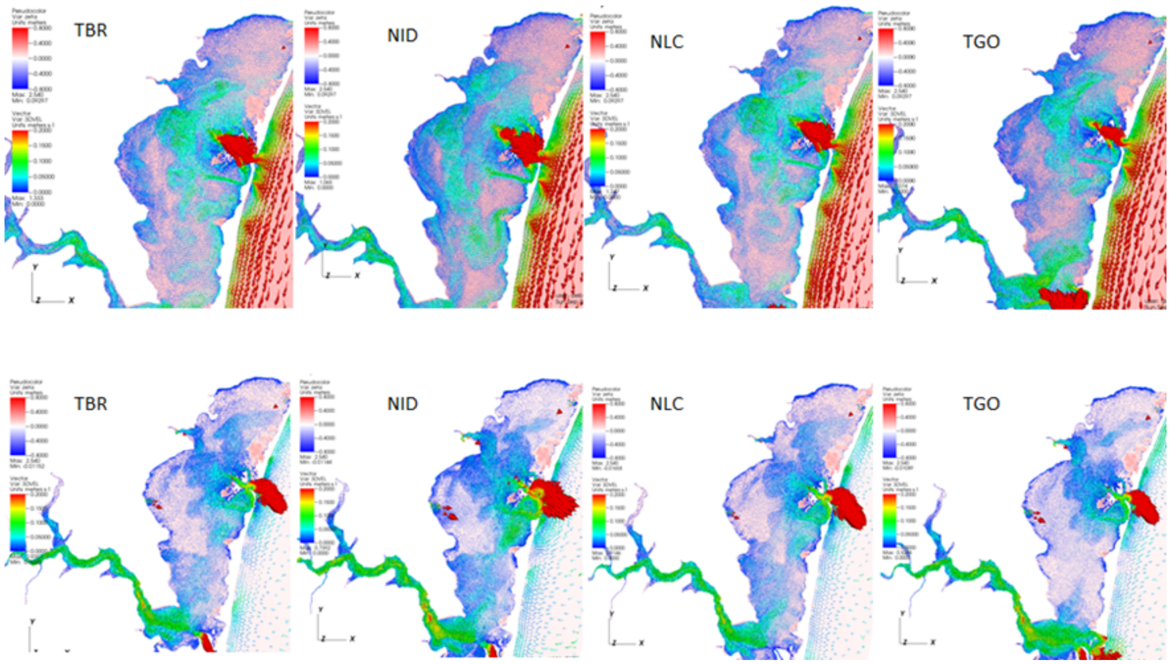
From the 2017 hydrodynamic sampling it was assumed that Northern Inlet to be constricted by more than 4 times from 2011 to 2017.

WATER RENEWAL TIME



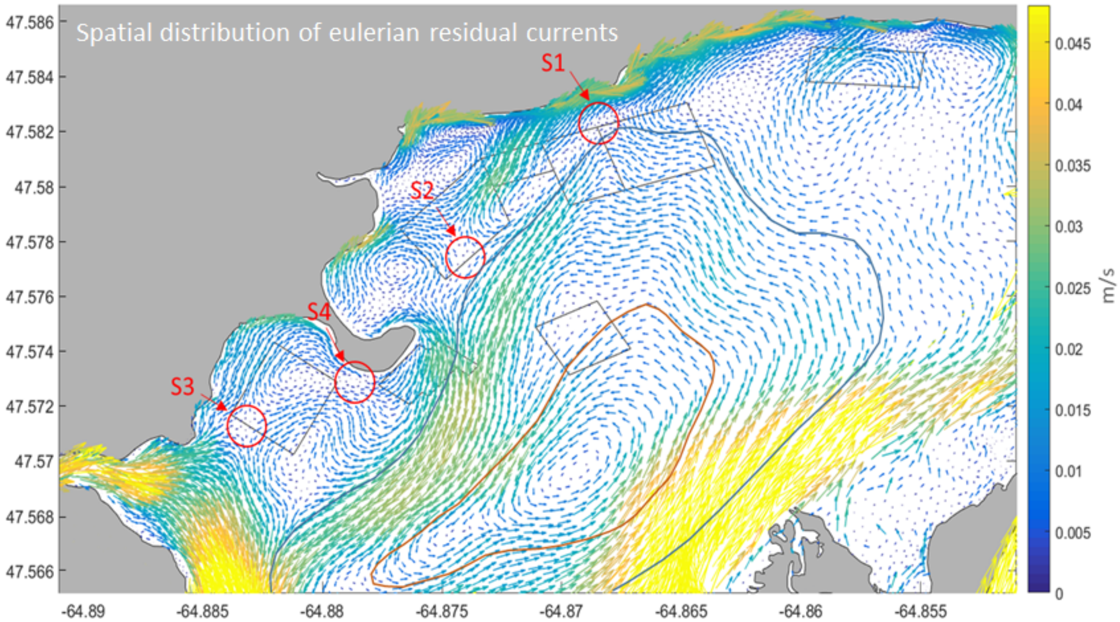
The domain's renewal efficiency by tides and atmospheric forcing determined that water renewal time can be used as an indicator of exchange between the Bay and the Gulf in assessing the vulnerability of a coastal system to water quality issues such as eutrophication.

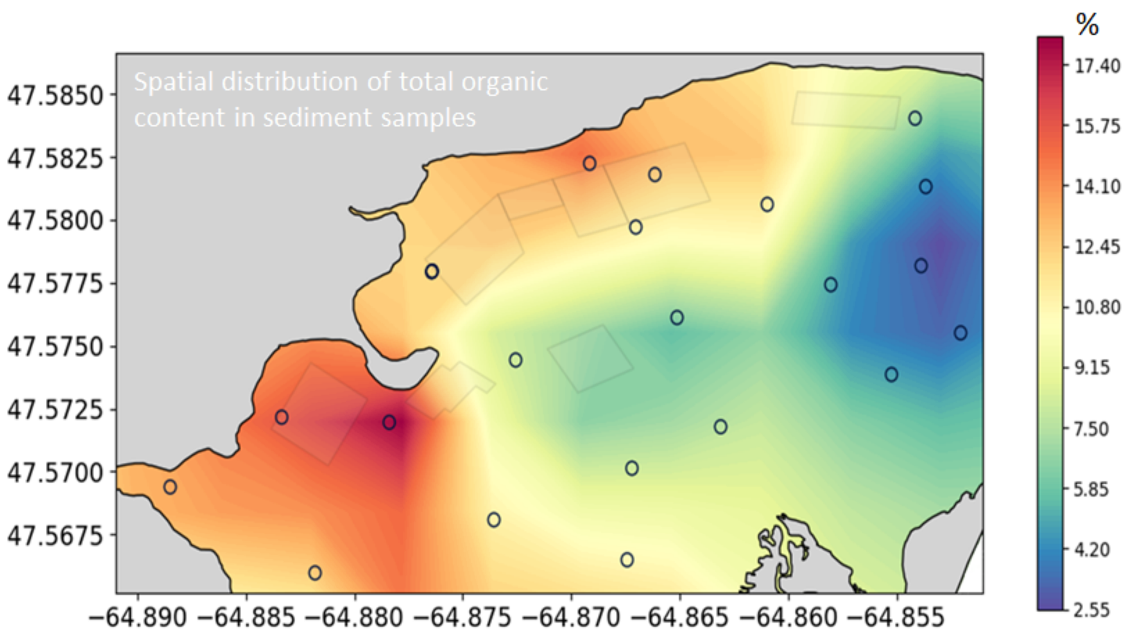
FLOOD AND EBB FLOW SCENARIOS



The water circulation in Tracadie Bay for different modeling scenarios is driven by same atmospheric forcing and boundary conditions. Among all the scenarios, dredging of northern inlet (NID) is the most efficient of the tested options with increased strength in flood and ebb currents. On the other hand, reopening of Tracadie Gully (TG) in TGO scenario, even though characterize the TGO model with three inlets resuming some more water exchanges between the Bay and the Gulf through TG but still shows weak circulation in northern areas of the Bay.

Modeling Scenarios	Description of the Scenarios
TBR	Tracadie Bay Base Run Model (TBR) is forced by observed hourly water level elevation, temperature, salinity at the open boundary, and driven by atmospheric forcing and river discharge.
NRD	River discharges are turned off from the TBR model.
NLC	The Link Channel connecting the northern and southern TNB is closed assuming earlier geomorphology of TNB.
NFB	All the atmospheric forcing is turned off in the TBR model and the model is set to barotropic condition.
NID	The constricted NI is dredged (dredged NI is based on 2011 LiDAR topographic data).
NIC	Extreme hypothetical scenario assuming the NI gets closed, suppressing any direct exchange between the Bay and GSL
TGO	Based on past geomorphic conditions of TNB, the Tracadie Gully was opened.


Spatial distribution of eulerian residual currents
S1
S2
S3
S4
m/s


Spatial distribution of total organic content in sediment samples
%

SUMMARY

- The performance of the high-resolution hydrodynamic model over the Tracadie Bay finds it to be an useful tool for realistically capturing the small-scale coastal processes and the modeling results seemed to provide valuable information to interpret biochemical characteristics of this coastal system.
- Findings from these modeling scenarios based on past, present and future inlet geomorphology suggest that inlet has strong consequences on intricate circulation patterns.
- Long water renewal time in Bay indicates poor flushing potential.
- Poorly-circulated stagnant residual flow distribution coincides with the hot-pots of sediment organic content, a proxy for degrading environmental conditions.
- However, our study revealed that dredging the NI (NID modeling scenario) seem to be the most efficient of the tested options to aid reduce the eutrophic conditions in the northern Bay.
- Overall, the generic modeling approach developed could help managing water quality and coastal activities such as sustainable aquaculture in similar eutrophic estuaries along the coast of southern GSL and beyond.

ABSTRACT

Eutrophication-induced hypoxia in a coastal estuarine system results in the deterioration of water quality, which is a growing issue worldwide. In early August 2016, an anoxic event caused the mortality of up to 75 percent of cultured oysters in aquaculture leases of northern Tracadie Bay, New Brunswick (TNB). Field observations revealed that, although the occurrence of summer hypoxia in north TNB is linked with anthropogenic stressors, changes in the geomorphology of one of the bay's inlet are likely to play a significant role in escalating the eutrophic conditions. However, adequate information on the circulation dynamics of TNB estuarine system was lacking. To address this knowledge gap, a high-resolution spatially-explicit hydrodynamic model was developed for TNB to evaluate the possible physical processes involved in generation of hypoxia leading to oyster mortality. The model showed high skill (0.93) in south TNB in simulating water level elevations and slightly lower skill (0.85) in north TNB. Findings from modeling scenarios based on past, present and future inlet geomorphology suggest that it has strong consequences on intricate circulation patterns, renewal of water and transport. Further, the model is coupled with a volume advection-dispersion tracer module to track the dissemination of effluent and identify areas at risk of hypoxia. Residual flow estimates revealed poorly-circulated stagnant areas, consistent with hot spots in sediment organic matter content. Outcomes from this study will be of relevance for the management of water quality and aquaculture practices.