Seasonal erodibility of sediments in the Upper Bay of Fundy

Research Project #: 305-170.016

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2. Summary

Background

Concern over possible changes to sediment dynamics in the Upper Bay of Fundy as a result of tidal energy extraction from in-stream tidal power is warranted. The effects of energy extraction in the Bay of Fundy, in this case reduction of tidal flow by the construction of causeways in the late 1960's, was catastrophically demonstrated in the Petitcodiac, Avon and other estuaries (c.f. van Proosdij et al., 2009). The unexpected sediment infill downstream of these causeways severely impacted fish habitat, leading or contributing to the extirpation of species, including the Petitcodiac Salmon run.

Recent studies in the Petitcodiac suggest that when normal tidal flow is disturbed in areas where suspended sediment concentrations are high, dense layers of mud can form near the bed when flood current speed decreases. Once these layers form, they have the ability to significantly reduce resuspension of sediment by the ebb current, which in turn leads to greater deposition on the following tide. This non-linear interaction between fluid mud and the overlying water was not understood at the time of the causeway construction boom in the Bay of Fundy and is the probable cause of the rapid and extensive infill.

Law et al. (2008) have also shown that the erosion characteristics of bed sediments are strongly correlated to the amount of material < 4 μm present in the bed sediment and that a phase transition from non- cohesive to cohesive behaviour can occur when the concentration of this fraction exceeds 7.5% of the total mass. In simple terms, the accumulation of mud in sandy environments due to reduced flow can lead to a non-reversible shift in the equilibrium balance between erosion and deposition.

It is possible that conditions favourable to the accumulation of mud could be created by the alteration of tidal flow by Tidal In-Stream Energy Conversion (TISEC) devices. The areas with the greatest probability for such change would be tidal creeks and flats. Understanding the natural variation in sediment suspension and deposition in the Upper Bay of Fundy is essential for the development of sediment transport models to predict if sediment dynamics in the creeks and on the tidal flats would be adversely affected by TISEC.

Research Summary (Dec 31st, 2013 – Jan 2nd, 2015)

- The final scientific report was delivered to OERA on January 10th, 2014 and approved by OERA in April, 2014 as per J. Pinks.
- A no-cost extension to the project until December 31st, 2014 was requested by B. Law and approved by OERA on February 19th, 2014.

3. Scientific Objectives

- To measure the seasonal variation of erosion shear stress, sediment mobility and degree of flocculation for selected Upper Bay of Fundy tidal flats and creeks.
- To measure the seasonal variation in grain size for selected Upper Bay of Fundy tidal flats and creeks.
- To measure the temporal variability in suspended sediment concentration (winter vs. summer) in the outer Bay of Fundy, primarily at mooring site A5, to relate open water in-situ suspended concentration to that observed by the MERIS satellite.
- Provide the necessary erodibility and grain size parameters to sediment modelers to model sediment transport in the Upper Bay of Fundy.

4. Description of Progress

The description of progress is made based on the three key activities laid out in the original research proposal submitted to OERA in response to the scientific objectives listed above.

1. *Seasonal and spatial variability in erosion dynamics within the defined inshore areas (tidal flats, creeks)*

Abstract: JC Garwood, MSc. Thesis, 2013

The goal of this study was to investigate the effects of intertidal mudflat biofilms on sediment erosion in the Minas Basin of the Bay of Fundy, Canada. From April through November 2012, sediment cores were collected biweekly and eroded using a Gust microcosm. Half of the cores were eroded without undergoing prior treatment, while the other half were treated with bleach prior to erosion to destroy biofilms. Size-specific sediment retention by biofilms was evaluated by comparing the disaggregated inorganic grain size (DIGS) distributions of sediment resuspended from untreated and treated cores, while seasonal variation in natural sediment erodibility was assessed by focusing on the mass eroded from untreated cores only. Results show that biofilms preferentially retained clays and very fine silts (< 10 μm), and that overall sediment erodibility decreased from spring to fall. Results also indicate that abundance of the infaunal amphipod *Corophium volutator* and rainfall increased sediment erodibility.

Abstract: JC Garwood, PS Hill, HL MacIntyre, BA Law. "Grain sizes retained by diatom biofilms during erosion on tidal flats linked to bed sediment texture"
(Submitted to Continental Shelf Research, in review)

Size-specific sediment retention by diatom biofilms was measured by eroding intertidal muds at increasing shear stresses (0.01-0.60 Pa) using a Gust microcosm. The grain sizes

eroded from biofilm-covered sediment were compared to those from control cores from which the biofilms were destroyed using bleach. Biofilms were quantified using carbohydrate measurements. Cores from an intertidal mud flat in the Minas Basin of the Bay of Fundy (Canada) showed biofilms preferentially retained clays and very fine silts relative to fine and medium silts. In contrast, prior field observations on an intertidal sand flat indicated that fine and medium silts were preferentially retained by biofilms relative to clays and very fine silts. These contrasting results suggest a link between size-specific sediment retention and sediment texture, where sand biofilms retain coarser, non-cohesive sediment, while mud biofilms retain finer, cohesive sediment. This relationship implies that biofilms contribute to a positive feedback that maintains sediment texture in a stable state.

2. ***Seasonal and spatial variability in grain size within the defined inshore areas (tidal flats, creeks)***

Abstract: BA Law, TG Milligan, PS Hill, V Zions, JC Garwood. "Temporal and spatial changes in grain size on a macro-tidal channel-flat complex: Results from Kingsport, Nova Scotia, Bay of Fundy"
(Internal Review DFO, to be submitted to Continental Shelf Research after review)

In April 2012, a study was initiated to examine the seasonal change in grain size on a muddy macro-tidal flat and channel complex in Kingsport, N.S. Surficial sediment samples were collected for disaggregated inorganic grain size (DIGS) analysis every month for 1 year from a tidal flat and from a tidal channel and its banks. The monthly sampling was completed in March 2013. Sediment grain size on the tidal flat correlates with distance to the nearest channel, and flocculation plays a major role in sediment deposition. These results differ from those from Willapa Bay, Washington, USA, which a meso-tidal channel-flat complex that showed no relationship between sediment grain size, floc fraction and distance to the nearest channel. Findings from this study are discussed in terms of the ability of ecosystems to maintain a stable state and with regards to the development of tidal power in the Minas Passage.

3. ***Temporal variability in in-situ suspended sediment concentration (offshore, eg. Minas Basin)***

1) Abstract: L Ashall, RP Mulligan, BA Law. "Variability in Suspended Sediment Concentrations in the Minas Basin, Bay of Fundy, and Implications of change due to Tidal Power Extraction"
(In Review for submission to Coastal Engineering)

The Bay of Fundy in eastern Canada exhibits the world's largest tidal range and exchanges approximately 110 billion tonnes of water twice a day with tidal currents up to

$5ms^{-1}$ making it an ideal place for tidal power extraction using Tidal In-Stream Energy Conversion (TISEC) devices in the Minas Channel. Field observations collected from ship-based and bottom-moored sensors over an 8-day period in 2013 are used to validate a 3D hydrodynamic and sediment transport model with measurements of water levels, current profiles, waves and suspended sediment concentration profiles. The sediment conditions are initialized using a bi-modal sediment distribution map and the model simulates both cohesive and non-cohesive sediments in the Minas Basin. Modelled suspended sediment concentrations are compared horizontally, vertically, and temporally to observations and the results indicate strong data-model agreement for suspended sediment concentrations (SSC) over a range of 5 to 287 mgL^{-1}. The implications of constructing a large-scale turbine farm within the Minas Channel and the impacts on suspended sediment within the Minas Basin are investigated. The turbine farm is simulated by adding semi-permeable structures in the model that use an energy loss term in the fluid momentum equations in the hydrodynamic model. The results emphasize the sensitivity of the system to changes in flow and suggest that a large scale tidal energy farm could reduce SSC by 37% on average across the basin which would disrupt physical and biological processes particularly on the fine-grained intertidal areas around the macrotidal basin.

2) **Abstract: RP Mulligan, PC Smith, PS Hill, J Tao, D van Proosdij, BA Law.** "Tidal current and wind-wave controls on suspended sediment concentrations in a macrotidal basin"
(In Review, submission to the Journal of Geophysical Research Oceans)

A hydrodynamic-wave-sediment model is used to simulate the tidal circulation, surface waves and suspended sediment concentrations (SSC) in Minas Basin, a 70 km long tidal estuary in the Bay of Fundy, for winter and summer periods in 2009. The model hydrodynamics are validated using acoustic-Doppler current profile observations, the surface SSC predictions are compared to satellite observations, and model results indicate that strong seasonal signals in SSC can be explained in part by seasonal changes in fetch-limited surface waves generated by local winds over the basin. Other processes that may seasonally influence sediment erodability (e.g., ice scour in winter; biofilm growth in summer) are not evaluated in this study in order to isolate the effects of surface waves in comparison with tidal currents. Model predictions in the intertidal areas indicate that surface waves can increase the bed shear stress from tidal currents alone by up to 1-5 Nm^{-2}, causing excess bed shear stresses to be higher and result in higher SSC by 100-200 gm^{-3} particularly during wind events that are stronger and more frequent in winter months. Resuspension of sediments on tidal flats is driven by the combination of shear stresses from near-bed wave orbital velocities and tidal currents, and transport of the suspended materials over deeper areas of the basin is driven by the strong tidal currents.

5. Dissemination and Technology Transfer

1) Results were presented at the NS Tidal Energy Forum at Acadia University, June 2013.

Title: **"Seasonal Change in Grain Size and Erodibility on a Tidal Channel-Flat Complex in Kingsport, NS"** (B.A. Law, P.S. Hill, T.G. Milligan, J.C. Garwood, V. Zions)

Title: "**Mudflat biofilms coarsen suspended sediment in the Minas Basin"**
(J.C. Garwood, P.S. Hill, B.A. Law)

2) Results were presented at the Coastal Estuarine Research Federation International meeting in San Diego, USA, November 2013.

Title: "**Temporal and spatial change in grain size and erodibility on a macro-tidal channel-flat complex in Kingsport, N.S., Canada, versus a meso-tidal channel-flat complex in Willapa Bay, Washington, USA**" (B.A. Law, T.G. Milligan, P.S. Hill, P.W. Wiberg, V. Zions)

Title: **"Seasonal and biofilm effects on sediment erosion and sorting in an intertidal mudflat in the Bay of Fundy, Canada**" (J.C. Garwood, P.S. Hill, B.A. Law)

3) Results were presented at the NS Energy Forum at world Trade and Convention Center, Halifax, N.S., May 2014.

Title: "**Seasonal change in grain size and erodibility on a channel-flat complex in Kingsport, N.S: Understanding natural variability and tidal power development**"
(B.A. Law, T.G. Milligan, P.S. Hill, J.C. Garwood, V. Zions, C. O'Laughlin)

4) MSc. Thesis of J.C. Garwood successfully defended Nov. 2013. Results of grain size, erodibility and suspended sediment concentration been broadcast to the community through FERN, MSc Thesis is available through Dalhousie University.

6. Publications

1) **J.C. Garwood**. MSc. Thesis, Dalhousie University, November 2013

2) BA Law, TG Milligan, PS Hill, V Zions, JC Garwood. Temporal and spatial changes in grain size on a macro-tidal channel-flat complex: Results from Kingsport, Nova Scotia, Bay of Fundy
(Internal Review DFO, to be submitted to Continental Shelf Research after review)

3) **JC Garwood, PS Hill, HL MacIntyre, BA Law.** Grain sizes retained by diatom biofilms during erosion on tidal flats linked to bed sediment texture"
(Submitted to Continental Shelf Research)

4) **Ashall, L., Mulligan, R.P., and Law, BA**. Variability in Suspended Sediment Concentrations in the Minas Basin, Bay of Fundy, and Implications of change due to Tidal Power Extraction.
(In Review for submission to Coastal Engineering)

5) **Mulligan, R.P., Smith, P.C., Hill, P.S., Tao, J., van Proosdij, D., and Law. BA**. Tidal current and wind-wave controls on suspended sediment concentrations in a macrotidal basin.
(In Review for submission to the Journal of Geophysical Research Oceans)