



# Erosion potential of dynamic ice breakup in Lower Athabasca River. Part I: Field measurements and initial quantification



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## ABSTRACT

As part of the Oil Sands Joint Monitoring Program, the present study aims to understand and quantify the erosional and sediment transport capacity of the Lower Athabasca River during the ice breakup period. It is motivated by past findings indicating that ice breakup processes can generate dominant contributions to the annual sediment load, which cannot be estimated by existing analytical methods and numerical models. Of special interest is the relatively steep reach above Fort McMurray, which potentially generates very large erosional forces during breakup and is a potential natural source of polycyclic aromatic hydrocarbons. A two-year field program has furnished unique data on the spatiotemporal water level variation during the breakup event. This information can serve to quantify key hydrodynamic variables and provide the requisite validation data for future model development to predict sediment transport under highly dynamic ice-influenced flow conditions. Bed shear directly indexes the erosional and sediment transport capacity of the flow; initial estimates based on the field measurements suggest that it exceeds all previously known values during breakup in other rivers. The power of the breakup is also manifested in the suddenness and height of various javes, in exceptionally high speeds of accompanying ice runs, as well as in bulk erosion of the river banks and bed in shallow areas.

## 1. Introduction

In 2011, the Governments of Canada and Alberta established a monitoring program for surface water quality and quantity, air quality and biodiversity of the Lower Athabasca River between Fort McMurray and its confluence with Lake Athabasca. This program, known as the Joint Oil Sands Monitoring Program (JOSMP; see [Appendix A](#) for a list of abbreviations), identified a need for systematic and comprehensive quantification and modelling of the source, transport and fate of materials and chemical substances entering the lower Athabasca watershed. To address this need, an integrated modelling framework was established and implemented from April 2012 to March 2015. The broad objective of this aspect of JOSMP was to provide critical knowledge about, and improved predictive modelling capability for, water availability and sediment/contaminant transport in the Lower Athabasca River. Erosion of river boundaries and transport of large amounts of sediment occur episodically as a result of high flows under open-water conditions, and of highly dynamic processes that take place during ice breakup. Previous investigations have shown that suspended sediment concentrations (SSCs) can attain very large values during the

brief ice breakup period, relative to those encountered under open-water and stable ice-cover conditions in the same river ([Beltaos, 2016](#)).

There exists considerable modelling capability for open-water flow and sediment transport processes, of which the physics are largely understood and quantified for modelling purposes. As demonstrated by [Shakibaeinia et al. \(2016\)](#), sediment transport modelling can also be carried out for rivers that are covered by a stable winter ice cover. The same does not apply to the period of ice breakup. Relatively moderate flows can result in major ice jams that generate much higher water levels than the rarest of open-water floods. When these jams release, highly dynamic waves propagate downstream, causing rapid and large increases in local water levels. Such waves have been termed “javes” for short and are known to amplify erosive forces and sediment transport capacity during their passage ([Beltaos, 2013](#)).

Consequently, a study was conducted to document and assess this mechanism in the Lower Athabasca River and obtain essential data that could eventually be used to test updated source-fate hydrodynamic models. Information has also been collected on the locations and characteristics of ice jams, which are known to cause extensive over-bank flooding and related sediment deposition into adjacent riparian

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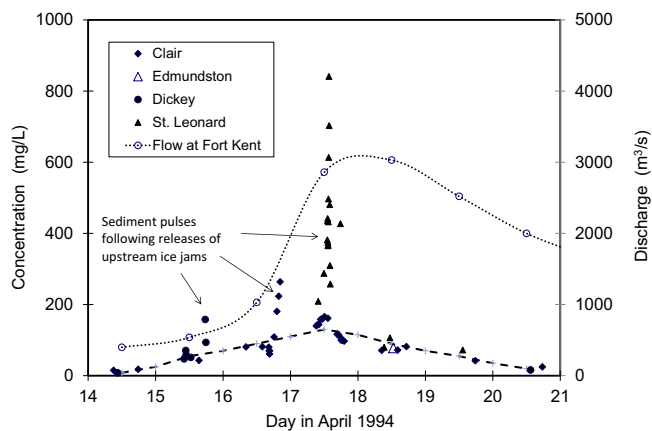


Fig. 1. Suspended sediment concentrations and mean daily flows during the 1994 ice breakup event in upper Saint John River, NB. Clair, Edmundston, Dickey and St. Leonard are locations of bridges from which samples were taken. Fort Kent is located across from Clair and is the site of a US hydrometric gauge. The dashed line approximates the runoff-generated variation of concentration with time.

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ecosystems. Modelling capability of ice-jam flood elevations would enable identification of additional out-of-channel depositional areas, where related effects studies could be conducted in the future.

Collection of water samples for sediment content analysis is not normally feasible or safe during the breakup period, but approximate data have been obtained using surface dip samples under exceptionally favourable conditions of safety and access (Beltaos and Burrell, 2016a, 2016b; Beltaos, 2016). An example is illustrated in Fig. 1, where high-concentration pulses are superimposed on a more gradual, but still large, increase in SSC. The latter is the result of spring runoff, while the pulses have been linked to javes. Together, these two processes can deliver large suspended sediment loads, comparable to, or even larger than, those delivered during open-water floods.

Jave intensity in the Athabasca River is likely to be particularly pronounced in the reach between Grand Rapids and Fort McMurray (FMM). Fig. 2 shows that this reach is the steepest within the last 800 km of the river and contains three sets of major rapids. Several lesser rapids (not shown) can be found between Boiler Rapids and FMM. The latter area also represents the southwestern end of the McMurray formation, a potential but unexplored natural source of

polycyclic aromatic hydrocarbons (Conly et al., 2002). The relatively large river slope ( $\sim 0.001$ ), coupled with the sizeable channel width ( $\sim 400$  m), can generate very high water levels when ice jams form and thence result in powerful javes.

Previous ice breakup studies in the Lower Athabasca River have been motivated by the need to develop adequate forecasting and warning for the city of FMM, known to be subject to severe flooding caused by ice jams (e.g. Andres and Doyle, 1984; Kowalczyk-Hutchison and Hicks, 2007). Visual evidence and measurements from these studies attest to the dynamic nature of breakup, especially above FMM.

The volume of field data and associated analysis is too large to permit presentation in a single paper. Herein, the objective is to provide the necessary background and discuss raw and processed data. These include: (a) hydrologic, hydraulic, and bed material characteristics of the study reach; and (b) data on various jams and javes that were documented during the breakup events of 2013 and 2014. The latter component comprised water levels that were measured throughout the study reach using closely spaced pressure sensors. The data obtained are uniquely detailed in spatial coverage and enable, for the first time, visualization of spatial waveforms as well as direct calculation of jave characteristics, such as water surface slope, flow velocity, discharge and shear stress. Comprehensive data analysis and interpretation are presented in a companion paper (Beltaos, 2018).

## 2. Study reach

The study reach (Fig. 3) extends from Crooked Rapids to Stony Island, for a total length of  $\sim 60$  km. On occasion, ice conditions were monitored well beyond the upstream and downstream ends of this reach, as might be needed for later interpretation and analysis. Upstream of FMM, the river is steep (average slope  $\sim 0.001$ ; She and Hicks, 2006) with high banks, frequent rapids, and relatively few islands. Below FMM, the river changes character, being relatively flat with low banks, many islands, and no rapids (average slope to Fort Mackay, located 56 km below FMM, is 0.00014; Kellerhals et al., 1972).

Water level and flow discharge are monitored by Water Survey of Canada (WSC) at the hydrometric gauge located on the right (facing downstream) river bank, a few km below FMM (Table 1). This gauge includes the flow of the Clearwater River, which is itself gauged at Draper, located about 18 km upstream of its confluence with the Athabasca River. Flow above FMM is estimated by subtracting the flow of the Clearwater River. The flows of minor tributaries, such as the Horse River, are negligible, at least during the spring freshet period.

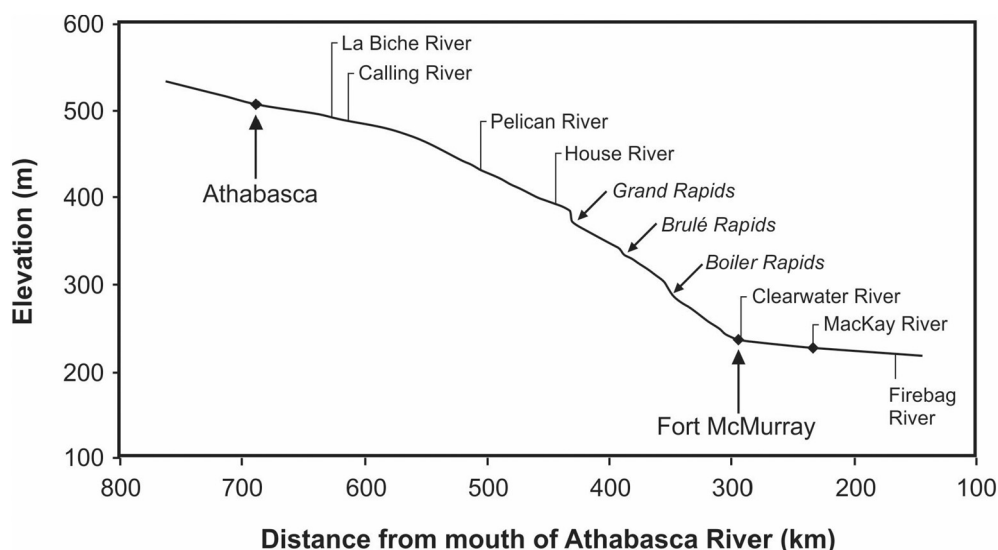


Fig. 2. Partial water surface profile of the Athabasca River.

From Kowalczyk (2005) with changes.

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