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Erosion potential of dynamic ice breakup in Lower Athabasca River. Part II: Field data analysis and interpretation

Spyros Beltaos

Watershed Hydrology and Ecology Research Division, Canada Centre for Inland Waters, Environment and Climate Change Canada, Burlington, Ontario, Canada

A R T I C L E I N F O

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A B S T R A C T

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. Of special interest is the very steep reach above Fort McMurray, which is a potential natural source of polycyclic aromatic hydrocarbons. A two-year field program (2013–2014) has furnished unique data, reported in a companion paper, on the spatio-temporal water level variation during the breakup event. Herein, methodology is developed and applied for using the water level data sets to extract values of key hydrodynamic variables, which cannot be measured during breakup and ensuing ice runs. The results of the analysis indicated that flow velocity, discharge, and bed shear stress can exceed 4 m/s, 10,000 m^3/s, and 100 Pa during the passage of sharp waves caused by releases of ice jams. According to past reports, the 2013 and 2014 breakup events, though dynamic, were not extreme. Yet, their severity exceeded by far the highest open-water flow values in the same reach over the period of record (2.5 m/s, 4440 m^3/s and 35 Pa). Suspended sediment concentrations and loads during breakup were estimated via flow-based rating relationships developed from WSC sediment data. It was shown that concentrations could easily exceed 10 g/L, while a breakup event could supply a significant fraction of the total sediment load for the year and transport naturally occurring PAHs into the industrial oil sands reach.

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), 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 (LAR).

As described in the companion paper (Beltaos et al., 2018), the present study aims to document and assess the sediment transport potential of the LAR during dynamic ice breakup events and obtain essential data that could eventually be used to test suitable source-fate hydrodynamic models. Current modelling capability does not extend to the highly dynamic waves that are generated when ice jams release. Such waves have been termed “javes” for short and are known to amplify erosive forces and sediment transport capacity during their passage (Beltaos, 2013a).

The study reach (Fig. 1) contains several sets of rapids upstream of Fort McMurray (FMM for short). Its large width (~400 m) and water surface slope (~0.001) contribute to occurrence of major ice jams and extreme javes, resulting in flow velocities of 5 m/s or more. The field data sets generated by the present study are presented in the companion paper (Beltaos et al., 2018). They comprise spatio-temporal variations of the water level during the breakup events of 2013 and 2014 and are utilized herein to quantify erosional capacity.

The example of Fig. 2 illustrates the passage of a jave by two neighbouring water level measuring stations, along with the temporal variation of the water surface slope with time. The latter is a key variable that indexes the longitudinal component of the force of gravity, which “drives” the intensity and erosive power of hydrodynamic variables.

Background information on the physical characteristics of the study reach, bathymetry, climatic conditions, and ice cover is presented in Beltaos et al. (2018). Consequently, the objectives of this paper are to: (a) formulate appropriate methodology for data analysis and interpretation; (b) present the results of the analysis and summarize the magnitudes of key hydrodynamic variables, such as mean flow velocity

E-mail address: spyros.beltaos@canada.ca.

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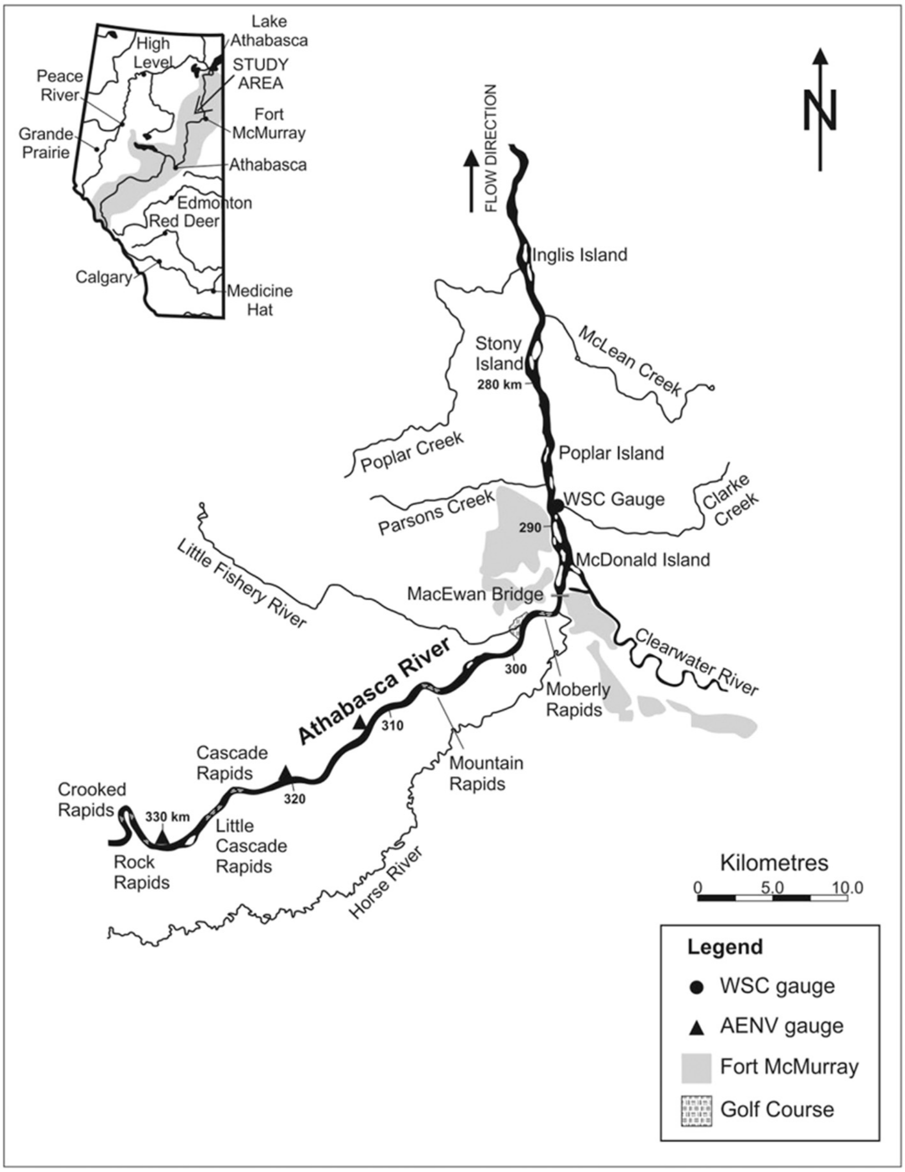

Fig. 1. Study reach of the Lower Athabasca River. From She et al. (2009) with changes. The km values mark distances above the mouth of, and measured along, the river.

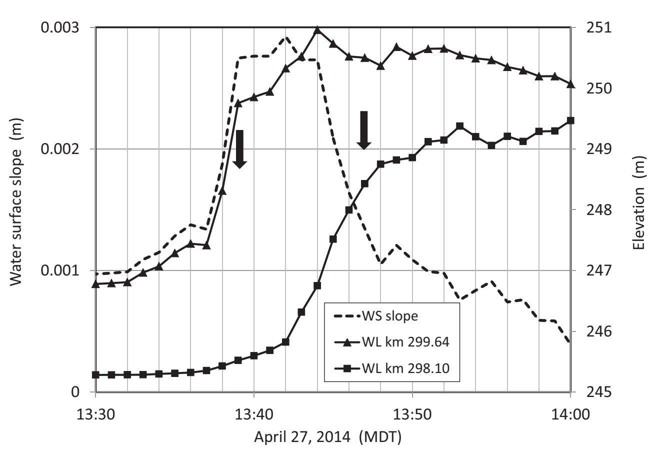

Fig. 2. Variation of water levels at, and surface slope between, neighbouring logger sites during the jave of April 27, 2014. WL = water level; WS = water surface. The arrows mark the times when the ice cover was mobilized at each logger site.

(U), discharge (Q), and bed shear stress (τ_b); and (c) apply these findings to assess the erosive power and sediment transport capacity of ice breakup in the LAR.

2. Methodology

2.1. Slope-area method

According to the one-dimensional formulation of the momentum equation, the average bed shear stress is given by:

$$\tau_b = \rho g \beta (Y + m\eta) S_f \tag{1}$$

in which S_f = friction slope; ρ = density of water = 1000 kg/m^3; g = gravitational acceleration = 9.81 m/s^2; Y = mean flow depth; and η = submerged portion of ice cover thickness. The coefficient m is set equal to 0 or 1, depending on whether the ice cover is stationary or moving. Moreover, the coefficient β is given by:

$$\beta = 1 \quad \text{(moving ice cover);}$$
$$\beta = \left\{1 + \left(\frac{n_i}{n_b}\right)^{3/2}\right\}^{-1} \quad \text{(stationary ice cover)} \tag{2}$$