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Evolution of hanging dams in the Mitis River, Quebec (Canada)

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INTRODUCTION

Large-scale variations of bed morphology, channel slope, bed material size and flow depth along a sedimentary link were related to river ice dynamics and ice distribution (Bergeron et al., 2011). It was suggested that upstream variations of river ice processes affect downstream river ice dynamics. Similar large-scale variations of fluvial environments affecting river ice processes are observed along fluvial style successions for which frazil slush inputs and transport along open reaches upstream affect large-scale frazil ice distribution (Bergeron et al., 2011) and downstream hanging dams evolution (Sui et al., 2000; 2002) throughout winter.

Hanging dams are made of accumulated frazil ice and are observed in deep river pools (Sun and Shen, 1988; Sun et al., 1992; Sui et al., 2002; 2006; 2008). Once hanging dam fixation is initiated, it begins to grow and evolve throughout winter depending on frazil ice regime, hydraulics and heat exchanges. Hanging dam evolution is a key element in the complexity of interactions between river ice and fluvial dynamics (Allard et al., 2011). Understanding large-scale variations of hanging dam dynamics in space and time as well as its interaction with fluvial dynamics would lead to a better understanding of cold-region fluvial systems. The main objective of this paper is to examine and describe hanging dam evolution along a fluvial transition of the Mitis River, a semi-alluvial river in Eastern Québec.

METHODS

Frazil ice regime surveys were accomplished in the Mitis River over the winter season to associate upstream frazil ice regime to downstream hanging dam evolution. Five automatic digital cameras were installed in both upstream and downstream reaches. Combination of both field surveys and photos from in situ cameras provided a space-time series of frazil ice regime properties along the fluvial transition.

Hanging dam surveys were carried out at two locations once the ice cover thickness allowed safe work. Two hanging dam surveys (S1:JD 29-38 and S2:JD 57-59) were realized in two steps: (i) A ground-penetrating radar (GPR) survey was performed, using a NOGGIN 500 GPR system (Sensor & Software GPR©) with a 500 mHz antenna, to acquire information on underneath ice layers. Four to seven GPR cross-sections were positioned along the pool from the upstream limit to the downstream end. (ii) Holes were manually cored to obtain data on the cover stratigraphy, frazil ice layer thicknesses and riverbed depth. In situ data were used to validate GPR data interpretations and calibrate the signal velocity through multiple ice layers.

RESULTS

Figure 1 shows time series of the accumulated freezing degree-day (AFDD), the river discharge, the daily temperatures, and the frazil ice regime properties at various locations along the river corridor. Frazil ice regime results show that upstream frazil slush inputs were roughly constant from JD 329 to JD 25. Camera survey and field observations also suggest that anchor ice production and frazil ice transport gradually stopped as the river ice cover grew and scarce frazil ice transport events occurred between S1 and S2. Ice cover complete formation was first noticed downstream at PK18.1. Ice cover gradually began to form from downstream to upstream study sites, following longitudinal gradient. Ice cover finally started to form upstream between JD 359 (PK 31.2) and 7 (PK 36.9).

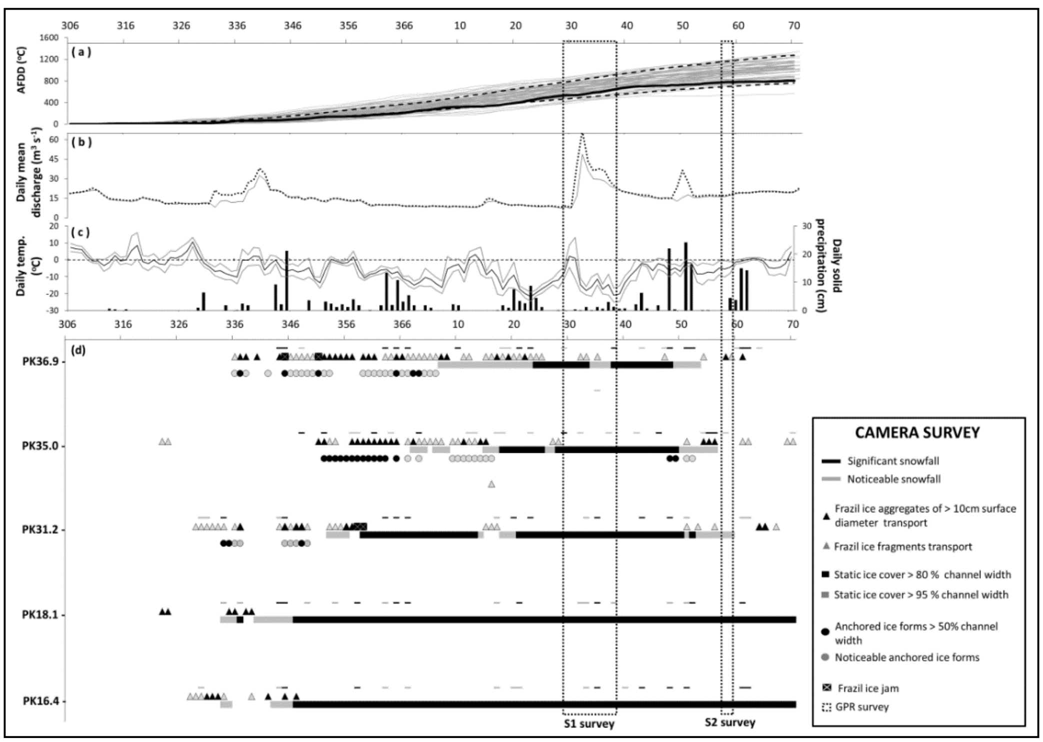

Figure 1. Daily hydrometeorologic conditions coupled to frazil ice regime informations for the period Julian day 306 (November 1st) to 120 (April 30th): (a) Accumulated freezing degree day (AFDD) from 1954 to 2012 (grey lines), for 2013 (black plain line) and the 95% interval estimate (black dashed line); (b) River discharge; (c) daily mean air temperature (black plain line), maximum and minimum daily temperatures (grey lines) and daily solid precipitations; (d) frazil ice regime properties from in situ camera.

Figures 2 and 3 (a-c) show frazil ice thicknesses distribution along three cross-sections during S1 and S2 surveys, respectively. At PK 18.1, frazil ice first deposited towards the convex bank of the meander (T3). The hanging dam then spread along T2 cross-section. At the end of the meander (T1), frazil ice accumulated towards the convex bank. Only a small amount of frazil ice was present at PK18.1 At PK16.4, frazil accumulated along the mid-pool cross-section (T5), but thickened toward the concave bank. Further downstream (T4), the hanging dam spread transversely. During the S2 survey, hanging dams was still present in the convex bank (T5). Downstream (T4-T3), the hanging dam spread transversely. At PK14.8, frazil ice formed a small hanging dam towards left bank at the upstream cross-section (T3). Further downstream (T2), the frazil ice also accumulated towards left bank. At the downstream end of the studied reach (T1), the hanging dam spread transversely. At S2, only a small amount of frazil ice was observed towards right bank at the downstream limit of the reach (T1).

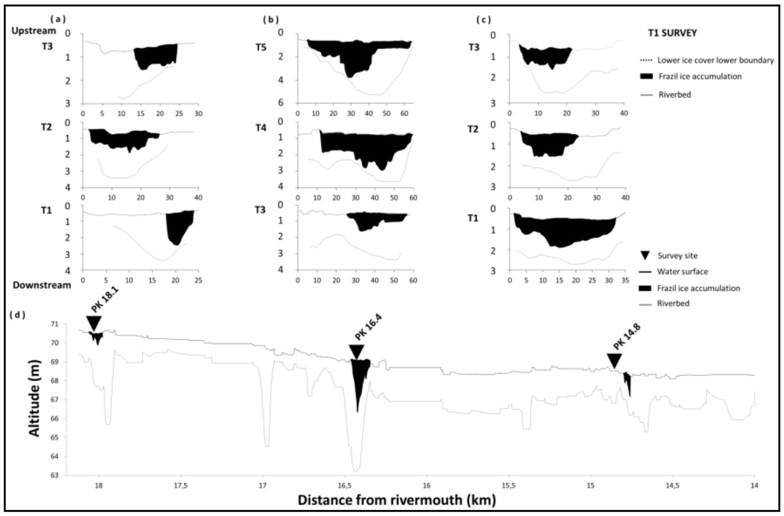

Figure 2 (a-c) Cross-sections showing the ice cover lower boundary, hanging dam and riverbed depths (m) with cross-section distance from left bank (m) during S1 survey. Looking downstream. (d) Longitudinal profile showing hanging dams of PK18.1, 16.4 and 14.8 frazil pools during S1.

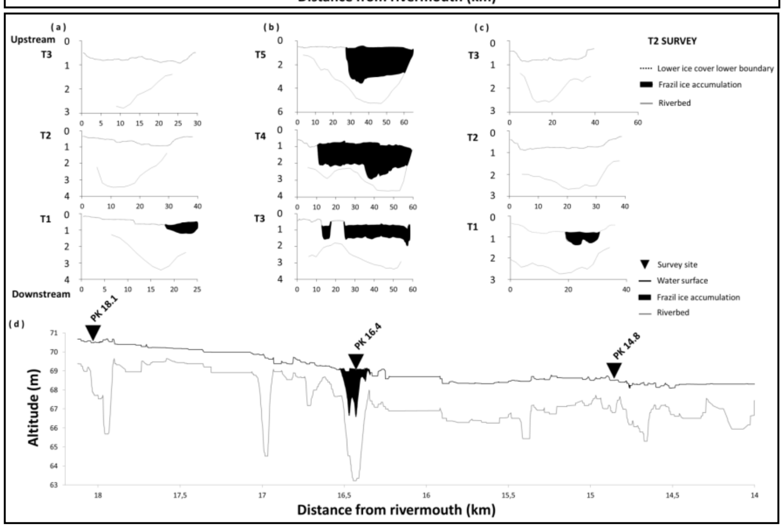

Figure 3 (a-c) Cross-sections showing the ice cover lower boundary, hanging dam and riverbed depths (cm) on cross-section distance from left bank (m) during S2 survey. Looking downstream. (d) Longitudinal profile showing hanging dams of of PK18.1, 16.4 and 14.8 frazil pools during S2.

The longitudinal profiles illustrated in figures 2d and 3d present a larger scale perspective on hanging dam dynamics. It also shows large-scale riverbed morphology and bed slopes variabilities. During the first survey, hanging dams along studied sites were mainly concentrated in the deeper part of the frazil pools. The accumulation pattern suggested that the hanging dam could have extended further downstream along the pool. At S2, different spatial patterns of hanging dams are present along the longitudinal profile as hanging dam thickness values significantly decreased, reducing the frazil ice volume and increasing flow areas within every pool.

CONCLUDING COMMENTS

This study highlights frazil ice regime in relation to riverbed morphology along a frazil rich river reach and documents the evolution of hanging dams at the downstream end of the meandering river reach. A longitudinal gradient of river ice dynamics and river ice distribution was observed along the fluvial transition. To some extent, the observed longitudinal gradient supports the conceptual model suggested by Bergeron et al. (2011). As suggested by the authors, frazil ice and anchor ice production occurred in upstream reaches and gradually reduced along the fluvial transition. Ice cover complete formation occurred earlier in the downstream reach whilst significant frazil ice production was still going on upstream. This asynchrony induced a rapid infill of downstream frazil pools. Large-scale frazil ice regime thus affected downstream hanging dam dynamics throughout winter. Hanging dam dynamics is reliant to frazil ice regime and hydraulics, which are affected by geomorphology. Spatial accumulation trends and general patterns observed within frazil pools can be explained by local hydraulics conditions that affect frazil ice underside transport. Initial hanging dams within meanders generally concentrated and thickened where higher flow depths were observed. The analysis of hanging dam evolution also suggests that hanging dams generally migrate downstream, get washed away or thermally decay during the winter. Interactions between hydrometeorological conditions, geomorphology, river hydraulics and frazil ice regime clearly affected hanging dam evolution along studied reaches. However, no clear relationships were found between hanging dam evolution and hydraulics due to a lack of data on hydraulics under the ice cover. Further advances on hydraulics conditions beneath the ice cover along meander reaches would be required for a better comprehension of the evolution of these hanging dams.

Acknowledgments

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