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Flow structure at an ice-covered river confluence

Nancy Martel[1], Thomas Buffin-Bélanger[1], and Pascale Biron[2]

[1] *Département de biologie, de chimie et de géographie, Université du Québec à Rimouski, 300 allée des Ursulines, Rimouski, Québec, G5L 2A1. Nancy.martel @uqar.ca*

[2]*Department of Geography, Planning and Environment, Concordia University, 1455 de Maisonneuve Ouest, Montréal, Québec, H3G 1M8*

INTRODUCTION

Studies on river confluences have highlighted the complex relationships between flow structure, sediment transport and bedforms development (Rice et al.., 2008). Best (1987) proposed a conceptual model in which the flow structure at a river confluence encompasses six flow regions, namely the stagnation zone, flow deflection, flow separation, maximum velocity, the recovery flow and the shear layer (Figure 1).

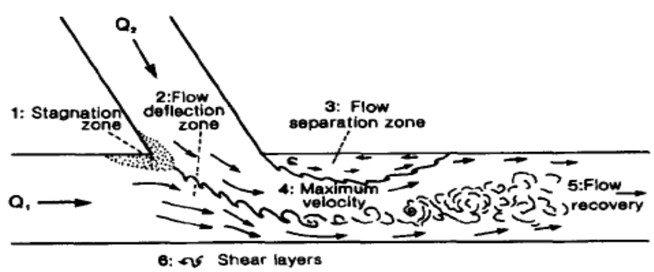

FIG. 1. Flow Dynamics at Open Channel Confluences [Modified from Best (1987)]

Figure 1. Flow regions at a river confluence (Biron and al, 1996)

It has been shown that the flow structure at river confluences is influenced by parameters such as the junction angle, the discharge ratio (Qr) and the bed morphology (Best, 1988; Riley et al., 2015). In cold regions, where ice cover occurs for most of the winter period, the flow structure is also likely to be affected by the roughness effect of the ice cover. The ice cover causes flow resistance that produces a second boundary layer changing the structure and turbulence of river flows. The expected velocity profile under an ice cover is characterized by a parabolic shape in which the maximum velocity is moved toward the center of the water column with increasing roughness (Crance and Frothingham, 2008). It has been documented that this shift in the location of the maximum velocity modifies the three-dimensional flow field in meander loops with an ice cover. Studies have highlighted the presence of superimposed helical cells with a reverse rotation direction (Urroz and Ettema 1994; Demers et al., 2011)

Although the flow structure at river confluence is relatively well documented and the general effect of an ice cover on the flow is known, the relationship between the flow structure and ice cover at confluences have yet to be explored. The aim of this study is to characterize and compare the flow structure at a medium sized confluence with and without an ice cover. Here, methodological issues and preliminary results are presented.

STUDY SITE AND METHODS

The confluence of the Mitis-Neigette River is located in Sainte-Angèle-de-Mérici in Eastern Québec. The discharge ratio (Qr) and the width ratio (Wr) between the tributary (Neigette River) and main channel (Mitis River) are 0.28 and 0.71, respectively. The Mitis River is a gravel-bed river fed by glacio-fluvial deposits while the Neigette River flow in large part in marine sediment of the Goldwaith sea. The difference in turbidity between the two rivers allows the position of the shear layer and turbulent structures to be observed when the flow is without ice (Fig 2a). The confluence was selected because a thick ice cover is present for most of the winter allowing for safe field work.

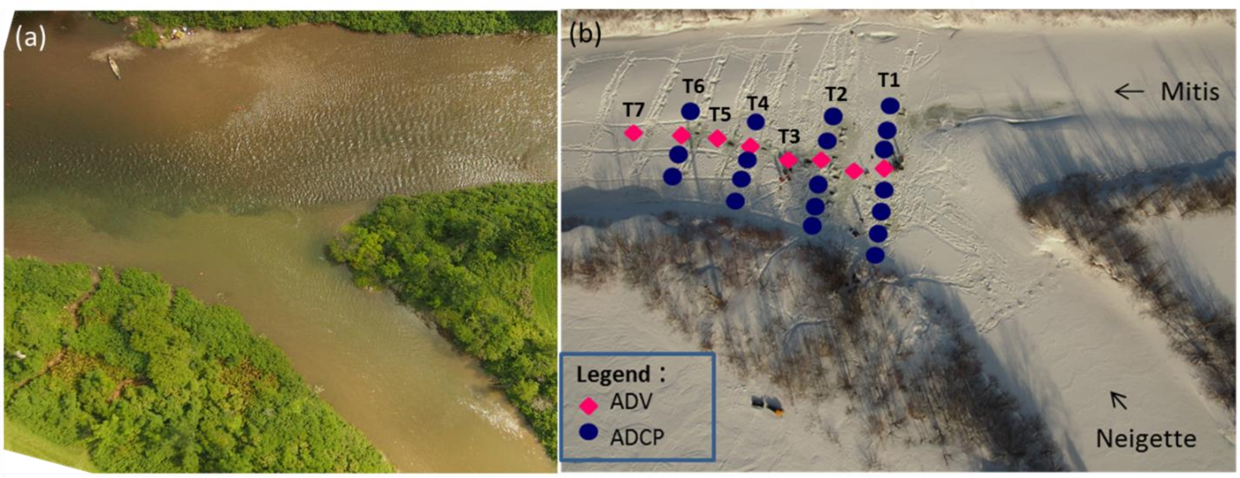

Figure 2. Aerial photos of the Miti-Neigette confluence in (a) summer and (b) winter. Locations of the ADV and ADCP velocity profiles are shown.

The project relies on two field campaigns. A winter field campaign where ice-cover measurements were taken in addition to hydraulic and morphological measurements and a summer campaign to acquire similar measurements in the absence of an ice cover. For both campaigns, velocity profiles are collected with an acoustic Doppler current profiler (ADCP) to reconstruct the three-dimensional flow structure with 15 min-long velocity profiles collected at a sampling frequency of 1Hz. Vertical profiles are also measured using an acoustic Doppler velocimeter (ADV) to characterize the size and frequency of turbulent flow structures within the shear layer. Velocity profiles comprised between 20 and 30 velocity measurements collected for 3 minutes at a sampling frequency of 25 Hz. Figure 2b shows the location of the velocity profiles sampled with the ADV and ADCP.

PRELIMINARY RESULTS

Figure 3 shows the UW velocity vectors (where U and W represent downstream and lateral velocity, respectively) and the turbulent kinetic energy (represent the sum of normal stresses for the three velocity components) for 7 velocity profiles (T1 to T7, where T1 is closest to the apex, Fig. 2b) sampled with the ADV. There are clear spatial patterns emerging for both variables as we move away from the confluence. First, the UW velocity profiles at T1 and T2 are complex and very different from the expected double boundary layer under an ice cover. However, UW velocity profiles adopt a more classical parabolic form with increasing distance from the confluence. Second, the maximum turbulent kinetic energy is higher in the midflow section for T1 to T3 while for the downstream profiles, the maximum values occur near the ice cover and near the bed. This spatial pattern reveal that there is an intense mixing occurring at midflow in the confluence. Finally, there is a clear thickness increase with increasing distance from confluence.

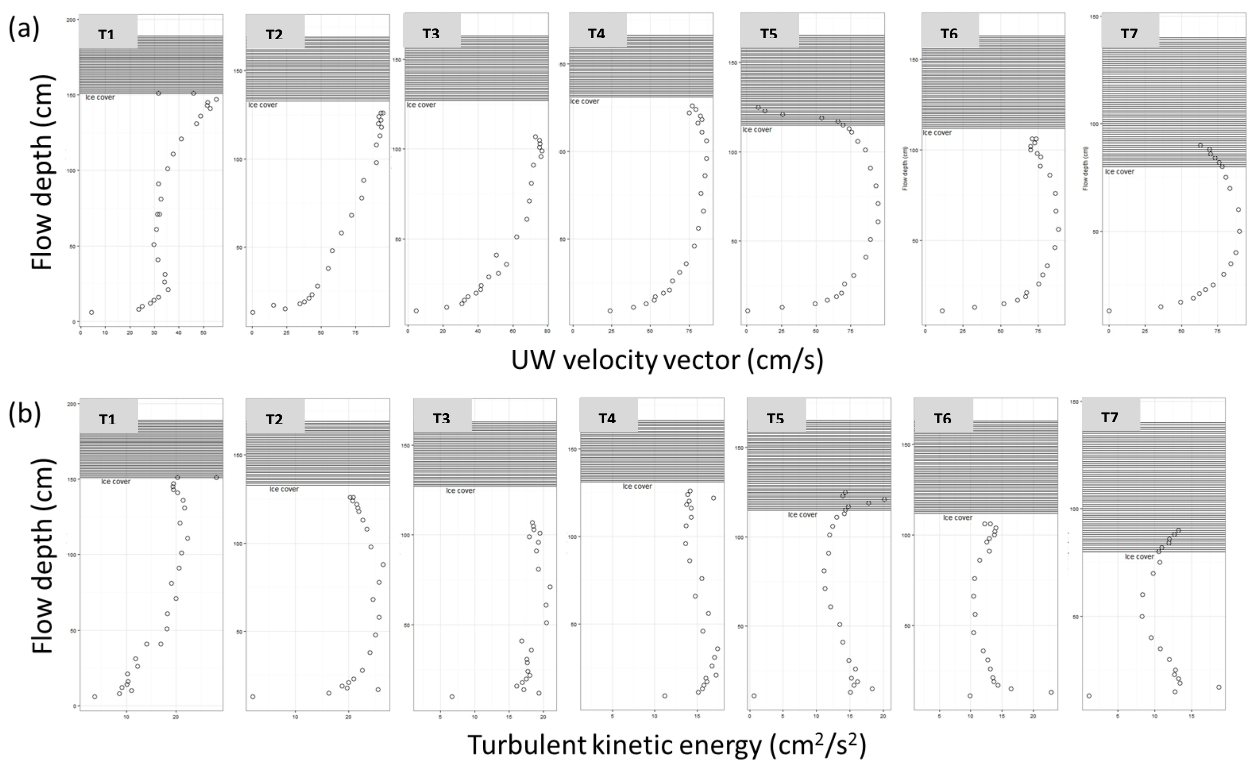

Figure 3 a) Horizontal (UW) velocity vectors and b) turbulent kinetic energy at increasing distances from the apex, from T1 to T7 (see location on Fig. 2b). The ice-cover thickness is represented in grey.

The project presents many challenges in both logistics and data analysis. In the winter, measuring velocity profiles in the field is complicated because of the cold affecting the instrumentation and field assistants. Also, the location of the shear layer was difficult to evaluate in winter conditions. In the summer, high flow velocities and the deep scour hole challenge the use of instrumentation attached along a pole because of problems of vibration. It is possible that not all the data collected in the winter will be reproduced in the summer. However, despite these challenges, we believe the results will promote the advancement of fundamental knowledge both on flow dynamics at a medium-sized confluence, since there is a paucity of field studies at that scale, and on the interactions between river ice and flow structure at these complex sites.

CONCLUDING COMMENTS

The study aims to quantify and compare the flow structure at a confluence with and without ice. The study relies on original and valuable field data on 3D flow dynamics. The preliminary results show for the first time the complex velocity and turbulent kinetic energy profiles in the confluence mixing layer region under an ice cover. The turbulent structure quantification will provide invaluable information to model the spatio-temporal evolution of these structures and to propose a figure similar to Figure 1, but that will take into consideration the presence of an ice cover at confluences.

Acknowledgments

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