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Environmental continuum of a watershed during the winter season

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1. Introduction

Continuing the research effort by Turcotte et al. (2012, 2014) about the watershed continuum, this work introduces another aspect of the dynamics of cold region watersheds by presenting the environmental continuum of a semi-agricultural catchment during the winter period. It presents continuous environmental parameter measurements along three channels of increasing order. The objectives of this study were (1) to describe the environmental behaviour of three channels affected by ice and (2) to evaluate the thermal, hydrological, cryologic, and environmental influences of tributary channels during winter. This extended abstract represents the first step of this study.

2. Background

The environmental behaviour of cold region channels in winter and the effect of an ice cover on environmental parameters has been documented in a few studies (e.g. Prowse, 2001). The most important environmental paramenter, water temperature, has been measured and succesfuly simulated a number of times (because it affects, and it is affected by, ice processes). Water turbidity, or sediment transport rates, has been measured in winter, especially during the breakup period when transport rates are known to be very high (e.g., Beltaos and Burrell, 2000), which can generate an important morphological impact (e.g., Turcotte et al., 2011). On the other hand, studies reporting other environmental parameters such as dissolved oxygen and conductivity in winter conditions are more scarce. Schreier et al. (1980) and Whitfield and McNaughton (1986) presented studies assessing the spatial variability of dissolved oxygen and conductivity along different rivers, but this parameter was not measured on a continuous basis. Hamilton and Moore (1996) are among the few to report continuous winter measurements of these parameters.

The present study is one of the first to present measured environmental parameters monitored on a continuous basis during the entire winter season, including the dynamic breakup period. It is also one the few studies to emphasize the cryologic and environmental behaviour of tributary channels of varying orders (sizes).

3. Instruments and sites

Research sites were located in the Etchemin River watersed, flowing northward on the South side of the St. Lawrence River at Québec City (Figure 1; Table 1). Measured parameters included: Air température (°C, ONSET U22-001), ice coverage (%, Canon 20D cameras), water temperature (YSI 6600 V2), channel discharge Q (ONSET U20-001-04, ISCO 2150, and one Provincial Government hydrometric station) as well as conductivity, dissolved oxygen (DO_2), and turbidity (YSI 6600 V2).

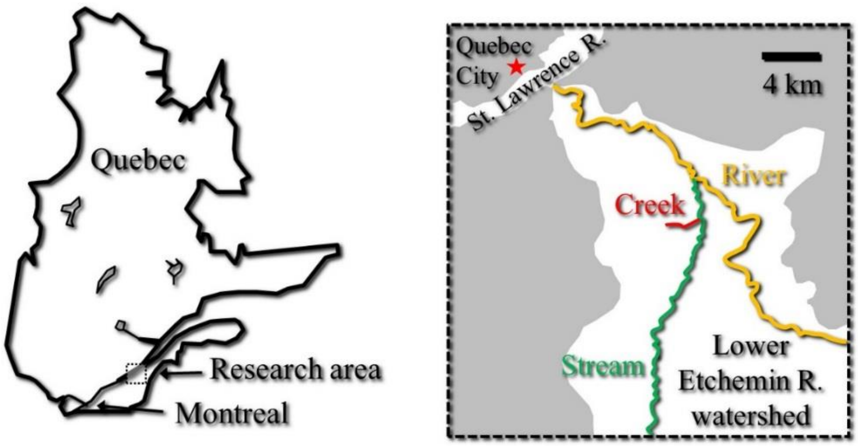

Figure 1. Location of the monitored channels in the Etchemin River watershed.

Table 1. Characterisitcs of the studied channels and watersheds.

Channels	Watershed area	Crops ratio	Channel width
Etchemin River	1100 km^2	30%	60 m
Le Bras Stream	200 km^2	70%	20 m
Bélair-Sud Creek	6 km^2	80%	3 m

4. Results

Figure 2 presents the graphical results of each measured parameters from Dec. 1st. 2011 to April 3rd, 2012 (after the spring breakup event).

Air temperatures: Winter temperatures (Mid-Dec. to early Mar.) varied between -30°C and 2°C with an average of -9.5°C. Winter thaws are indicated by vertical arrows in Figure 2.

River ice: A floating ice cover developed over 90% of the Stream in only 10 days (average T_{air} of -10°C) at the beginning of winter (Figure 2) It took 26 days (average T_{air} of -11°C) for the faster-flowing River to achieve the same ice coverage. The Creek only formed ephemeral surface ice sections and was mostly covered by free-spanning snow. This cover was particularly sensitive to melting events and often collapsed into the water. Both the River and Stream underwent a mechanical breakup with moderate to major ice jams from Mar. 18th to 21st.

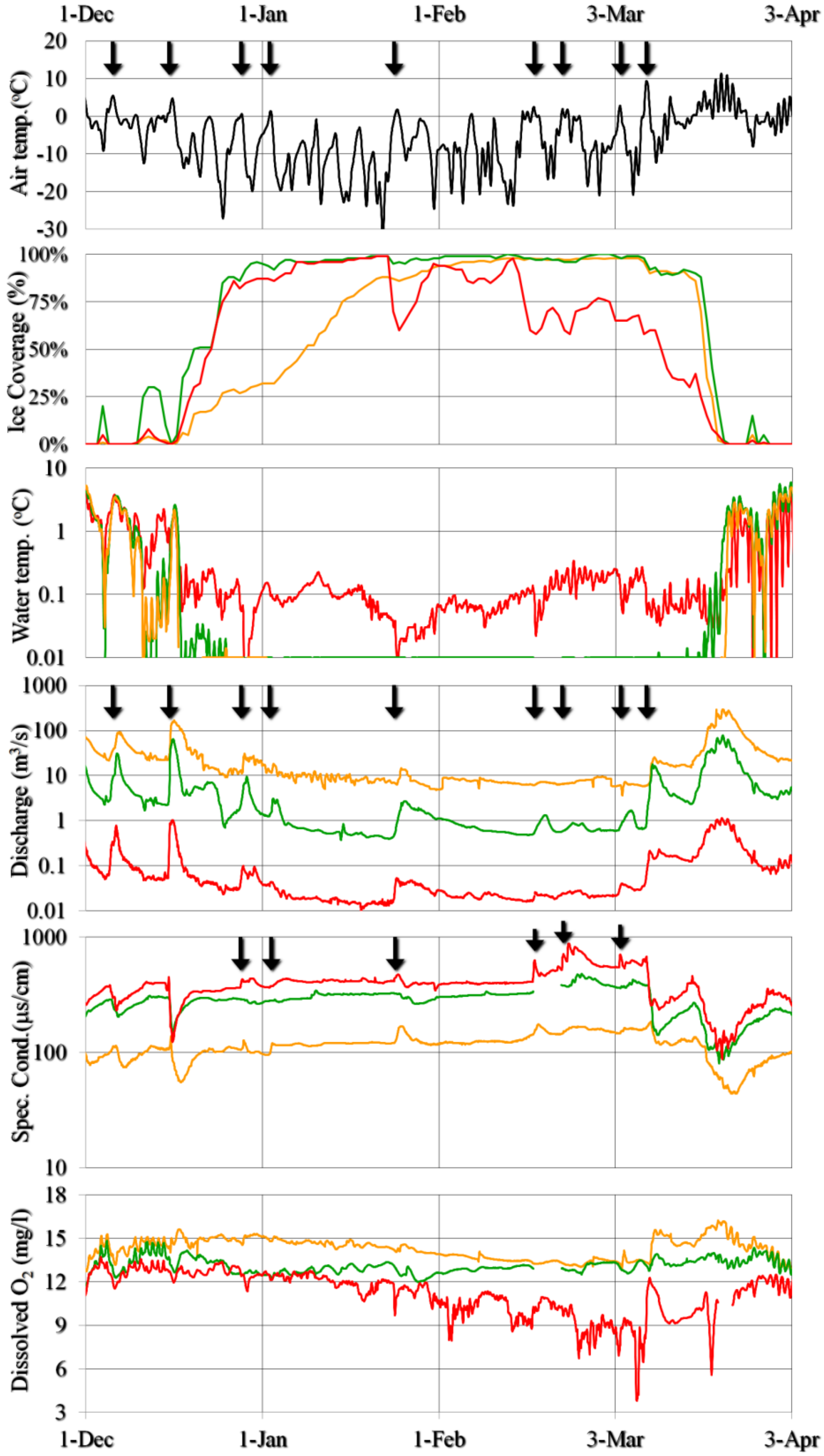

Figure 2. Measured environmental parameters during the 2011-2012 winter along the Etchemin River (orange), Le Bras Stream (green), and Belair Creek (red).

Water temperatures: Water temperatures in the River and Stream remained mostly equal to 0°C when a floating ice cover was present. The Creek presented an insulating, free-spanning snow cover that contributed in maintaining the water temperature well above 0°C throughout winter (Figure 2). The coldest water temperatures in the Creek were achieved during runoff events.

Water discharge: Runoff events are indicated by vertical arrows in Figure 2. Minimum discharges were observed in late-Jan. to early-Feb. The breakup runoff event was driven by unusually high air temperatures in March.

Specific conductivity: Mid-winter runoff events were characterized by a conductivity rise (rather than the expected drop) in the River and Creek (Figure 2). This is probably due in part to the use of de-icing salt on roads. All channels presented high, anticipated late winter values (e.g., Hamilton and Moore, 1996; reaching 800 µs/cm in the Creek) and achieved an annual minimum at breakup because of the massive input of snowmelt water.

Dissolved oxygen: The presence of a floating ice cover did not affect DO levels in the Stream while the River DO trend presented a slight, expected winter depression (e.g., Chambers et al., 2000; Figure 2). In turn, the Creek DO winter trend presented a significant depression with marked instabilities despite the absence of a complete ice cover. This might be due to the observed presence of *Didymosphenia geminate* or to the dominance of poorly oxygenated groundwater inflow in this headwater channel (Schreier et al., 1980).

While DO levels increased just before breakup in the River and Stream, as was reported by Whitfield and McNaughton (1986), and as it would be expected from an oxygen transfer point of view, annual minimum values (4 mg/l) were reached in the Creek (Figure 2). This might be due to a sudden rise in biological DO consumption that dominated over photosynthetic oxygen production, or to the resuspension of organic material (Prowse, 2001) from the previous year's intense agricultural activities.

Turbidity: Water turbidity usually varies with the channel discharge (Q). Open water relationships between Turbidity and Q divided by the annually-averaged Q are presented in Figure 3. These are compared with winter relationships for all three channels. In winter, the Creek and Stream were affected by turbidity levels that were lower during (weak) runoff events but higher at low Q compared with their open water counterpart (turbidity levels were actually almost independent of Q). In contrast, turbidity levels were higher in the River at any winter Q, which is surprising from a sediment supply and from a sediment transport capacity perspectives (e.g., Ettema, 2006). Assuming a direct link between turbidity and sediment transport rates (yet to be determined), all three channels transported about 0.5% of their annual suspended load during winter (22% of the year, 6.5% of annual Q). At breakup and during the subsequent freshet (8% of the year, 18% of annual Q) about 25% of the annual load was transported. This was expected from a sediment supply (in-channel remobilisation and from the floodplain) and transport capacity perspectives.

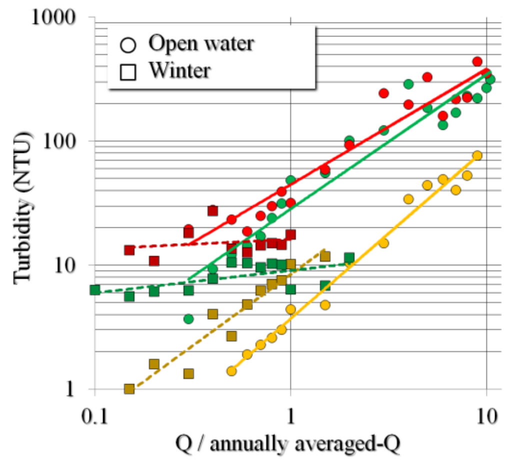

Figure 3. Turbidity expressed as a function of unit channel discharge for open water and winter conditions. The Etchemin River, Le Bras Stream, and Belair Creek are respectively shown in orange, green, and yellow.

5. Conclusions

As stated by Prowse (2001), "longitudinal gradients are rarely simple and reflect a complex mixture of climatic, hydrologic, hydraulic, geochemical, and anthropogenic chemical conditions". The watershed continuum approach presented in this work can contribute in quantifying interactions between multiple parameters over space (watershed scale: Creek, Stream, River) and time.

The present study was specifically directed to the winter season and the river ice breakup period. Winter monitoring techniques developed throughout this project and preliminary results presented here can contribute to a better understanding of (as well as to improving models that simulate) cold environments (1) water quality, (2) fluvial sediment transport, and (3) freshwater biology, especially in a warming climate perspective.

6. References

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