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Research article

Can isolated and riparian wetlands mitigate the impact of climate change on watershed hydrology? A case study approach

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ABSTRACT

The effects of wetlands on stream flows are well established, namely mitigating flow regimes through water storage and slow water release. However, their effectiveness in reducing flood peaks and sustaining low flows is mainly driven by climate conditions and wetland type with respect to their connectivity to the hydrographic network (*i.e.* isolated or riparian wetlands). While some studies have demonstrated these hydrological functions/services, few of them have focused on the benefits to the hydrological regimes and their evolution under climate change (CC) and, thus, some gaps persist. The objective of this study was to further advance our knowledge with that respect. The PHYSITEL/HYDROTEL modelling platform was used to assess current and future states of watershed hydrology of the Becancour and Yamaska watersheds, Quebec, Canada. Simulation results showed that CC will induce similar changes on mean seasonal flows, namely larger and earlier spring flows leading to decreases in summer and fall flows. These expected changes will have different effects on 20-year and 100-year peak flows with respect to the considered watershed. Nevertheless, conservation of current wetland states should: (i) for the Becancour watershed, mitigate the potential increase in 2-year, 20-year and 100-year peak flows; and (ii) for the Yamaska watershed, accentuate the potential decrease in the aforementioned indicators. However, any loss of existing wetlands would be detrimental for 7-day 2-year and 10-year as well as 30-day 5-year low flows.

1. Introduction

Wetlands have been recognized for their significant role on the hydrological cycle through water storage and slow release of water (Ogawa and Male, 1986; Padmanabhan and Bengtson, 2001; Liu et al., 2008; Wang et al., 2008; Wu and Johnston, 2008; Yang et al., 2010). Despite this general agreement, approximately half of their spatial extent has been lost worldwide (Zedler and Kercher, 2005). With the largest agricultural activity (Jobin et al., 2004) and the most populated region of Quebec (Li and Ducruc, 1999), Canada, the St. Lawrence Lowlands are characterized by several heavily affected ecosystems and among them, wetlands are no exception with almost 45% of affected areas (Joly et al., 2008). Their degradation or conversion in response to increase human activities (*e.g.*, agriculture, peat mining, and urbanization) is well known as one of the key disturbances of watershed hydrology and impairment to the global environment (Solomon et al., 2007). Thenceforward, their deterioration may have severe impacts on flow regimes (*i.e.*, watershed hydrology) inducing a positive feedback under climate change conditions.

Hydrological modelling has proven to be a useful framework to asses climate change impacts on wetlands (Fu et al., 2015; Fossey and Rousseau, 2016) or watershed hydrology (Quilbé et al., 2008; Boyer et al., 2010) and to illustrate the impacts of these landscape features on flow regimes (Wang et al., 2010; Martinez-Martinez et al., 2014; Golden et al., 2015; Evenson et al., 2015; Fossey et al., 2016). However, some gaps persist regarding the evolution of wetland impacts on watershed hydrology under changing climate conditions. Over the last decade, scientific knowledge on future climate impacts in Quebec, Canada, has advanced and expected changes are well identified (Ouranos, 2015). Indeed, in the St. Lawrence Lowlands, projected annual temperatures may increase by 2–4 °C for the period 2040–2070. While the total annual precipitation may be relatively constant, seasonal modifications are expected, particularly in winter. The decrease in snowfall and the increase in rainfall during this season will affect stream flows (Appendix A). Indeed, the increase in mean temperature and the

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associated decrease in the ratio of snow to liquid precipitation should lead to an increase in the amount of water available for winter flows and a decrease in snow water equivalent reducing spring, summer and fall flows (Boyer et al., 2010).

These expected changes and resulting impacts on water availability, and thus on the water balance at the watershed scale, may affect wetlands. Indeed, the quantity and periodicity of wetland inflows could be affected. In return, wetlands could be more vulnerable and their hydrological functions and/or physical integrity be threatened (Erwin, 2009; Hebb et al., 2013; Fossey and Rousseau, 2016). Nevertheless, some questions arise such as: (i) What is the contribution of wetlands to current flow regimes? (ii) How will the role of wetlands evolve under changing climate conditions? (iii) Will their impacts on watershed hydrology be modified in the future?; and (iv) If wetlands are vulnerable, what will be the impact on the hydrological regime?

Using a distributed hydrologic modelling platform, this study assesses: (i) the current contribution of wetlands to stream flow and (ii) the expected changes at the outlet of two key watersheds of the St. Lawrence lowlands, namely those of the Becancour and Yamaska Rivers. This assessment, through analysis of some commonly used hydrologic indicators (*i.e.*, Q_{max}, Q_7 and Q_{30}) provides a framework to distinguish climate change and wetland (*i.e.*, isolated and riparian) effects on watershed hydrology. It also highlights the potential benefits of wetlands under changing climate conditions.

2. Methods

2.1. Study areas

Based on criteria related to land cover representativeness and wetland diversity, two watersheds were selected: the Becancour and Yamaska River watersheds. They cover 2597 km^2 and 4788 km^2 in the St. Lawrence Lowlands ecoregion (Mackey et al., 1996; McKenney, 1998) in southern Quebec, Canada, respectively (Fig. 1). Tributaries of the St Lawrence River, the Becancour and Yamaska Rivers drain landscapes dominated by forest (54% and 35%. respectively), agriculture (23% and 41%), and wetlands (12% and 4%) (Beaulieu et al., 2012). As introduced in Table 1, in the Becancour watershed, wetlands cover a total area of 307 km^2 and drain 794 km^2 (31% of the watershed). Among them, isolated wetlands (IWs) occupy 210 km^2 (8%) and drain 464 km^2 (18%) while riparian wetlands (RWs) occupy 97 km^2 (4%) and drain 330 km^2 (13%). In the Yamaska watershed, wetlands cover a total area of 202 km^2 including 92 km^2 (2%) of IWs and 110 km^2 (2% of the watershed) of RWs. From another point of view, the Yamaska wetlands drain 646 km^2 (13%) including 305 km^2 (6%) drain by IWs and 341 km^2 (7%) by RWs.

Located in a humid continental climate (Köppen-Geiger classification:Dfb - Peel et al., 2007), the watersheds are characterized by warm summers and severe winters with strong seasonality. Normal conditions for the 1981–2010 period (MDDELCC, 2014) are associated with an annual mean temperature of 5.1 °C with an average maximum of 19.3 °C in July and an average minimum of −11.2 °C in January. The total mean annual precipitation is 1210 mm, including 953 mm of liquid precipitation and 257 mm of solid precipitation (Appendix A). For the Becancour and Yamaska watersheds, the specific average monthly values of climate statistics are reported in Appendix B.

2.2. Hydrologic modelling platform

2.2.1. Model description

The PHYSITEL/HYDROTEL distributed hydrological modelling platform was used to evaluate the expected changes due to climate change and to assess the effects of wetland types on watershed hydrology; quantifying their respective contribution to the flow regime (Fossey et al., 2015). More specifically, PHYSITEL is a specialized GIS and HYDROTEL is a continuous distributed hydrologic model (Turcotte et al., 2001, 2003, 2007; Fortin et al., 2001; Rousseau et al., 2011; Bouda et al., 2012, 2014; Noël et al., 2014). The model is currently used for inflow and hydrological forecasting at Hydro-Quebec, Quebec's primary power utility, and the Quebec Hydrological Expertise Centre (*Centre d'Expertise Hydrique du Québec, CEHQ).* This modelling platform can explicitly account for isolated (IWs) and riparian wetlands (RWs) (Fossey et al., 2015), using the Hydrologically Equivalent Wetland (HEW) concept (Liu et al., 2008; Wang et al., 2008). The basic computational units used by HYDROTEL and discretized using PHYSITEL correspond to Relatively Homogeneous Hydrological Units (RHHUs: subwatersheds or hillslopes) and interconnected river segments (Fig. 2).

For this study, the two watersheds were discretized as follows: the Becancour and Yamaska watersheds, into 1824 and 1299 hillslopes (mean surface areas of 2.6 km^2 and 7.3 km^2, respectively), and 736 and 513 river segments (mean length of 1179 m and 1623 m), respectively. Similarly, the watersheds were discretized into 859 and 498 isolated HEWs (mean surface areas of 0.24 km^2 and 0.22 km^2, respectively) and 444 and 296 riparian HEWs (mean surface areas of 0.22 km^2 and 0.31 km^2), respectively.

2.2.2. Model set up

HYDROTEL was run using a daily time step and basic meteorological data (*i.e.*, precipitation, minimum and maximum temperatures obtained from CEHQ for the 1961–2010 period). Meanwhile for this study, the simulated daily stream flows at the outlet corresponded to the output of interest. Model calibration and validation were done using a manual trial-and-error strategy (Turcotte et al., 2003) over different five-year intervals of the 1969–2010 period while using 1-year spin-up period to minimize initialization errors (for a complete overview, see Fossey et al., 2015). Both temporal and spatial validations were performed, allowing a quantitative and qualitative verification of simulated flows. Statistics for calibration and validation periods are reported in Table 2.

2.2.3. Theoretical background

The addition of wetlands module has improved the model's ability to accurately reproduce the basic components of hydrograph (*i.e.*, magnitude, frequency, timing and duration of water conditions) as reported in Fossey et al. (2015) for the Becancour watershed. These performance improvements increased the values of statistical indices from approximately 13% and 8% for the Becancour and the Yamaska (Rousseau et al., 2008, 2012) watersheds, respectively. Meanwhile, with respect to the hydrological modelling approach used for the Becancour watershed (Fossey et al., 2016), the impacts of wetlands depend on both their type (*i.e.*, isolated or riparian) and their geographic location within a watershed (*i.e.*, upstream/downstream gradient and stream order gradient). Moreover, for a given type and location, the results under similar hydro-climatic conditions illustrate the highly individualized and contrasting (i.e., positive or negative impacts) response that wetlands can exhibit as reported by Nilsson et al. (2013).

2.3. Climate scenarios

Daily climatic data for the 1961–2099 period were supplied by Ouranos, a Consortium on Regional Climatology and Adaptation to Climate Change. Ten simulations of the Canadian Regional Climate Model (CRCM 4 ×) (Caya and Laprise, 1999; Music and Caya, 2007;

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