Journal of Hydrology 541 (2016) 1287–1302

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Assessing the long-term hydrological services provided by wetlands under changing climate conditions: A case study approach of a Canadian watershed

M. Fossey *, A.N. Rousseau

INRS-ETE/Institut National de la Recherche Scientifique – Eau Terre Environnement, 490 rue de la Couronne, G1K 9A9 Quebec City, Quebec, Canada

ARTICLE INFO

Article history:
Received 20 June 2016
Received in revised form 13 August 2016
Accepted 17 August 2016
Available online 18 August 2016
This manuscript was handled by Tim R. McVicar, Editor-in-Chief, with the assistance of David C. Le Maitre, Associate Editor

Keywords:
Wetlands
Hydrological dynamic modelling
Stable isotopes
HYDROTEL
Climate change impact

ABSTRACT

The water content of wetlands represents a key driver of their hydrological services and it is highly dependent on short- and long-term weather conditions, which will change, to some extent, under evolving climate conditions. The impact on stream flows of this critical dynamic component of wetlands remains poorly studied. While hydrodynamic modelling provide a framework to describe the functioning of individual wetland, hydrological modelling offers the opportunity to assess their services at the watershed scale with respect to their type (*i.e.*, isolated or riparian). This study uses a novel approach combining hydrological modelling and limited field monitoring, to explore the effectiveness of wetlands under changing climate conditions. To achieve this, two isolated wetlands and two riparian wetlands, located in the Becancour River watershed within the St Lawrence Lowlands (Quebec, Canada), were monitored using piezometers and stable water isotopes (δD – δ18O) between October 2013 and October 2014. For the watershed hydrology component of this study, reference (1986–2015) and future meteorological data (2041–2070) were used as inputs to the PHYSITEL/HYDROTEL modelling platform. Results obtained from in-situ data illustrate singular hydrological dynamics for each typology of wetlands (*i.e.*, isolated and riparian) and support the hydrological modelling approach used in this study. Meanwhile, simulation results indicate that climate change could affect differently the hydrological dynamics of wetlands and associated services (*e.g.*, storage and slow release of water), including their seasonal contribution (*i.e.*, flood mitigation and low flow support) according to each wetland typology. The methodological framework proposed in this paper meets the requirements of a functional tool capable of anticipating hydrological changes in wetlands at both the land management scale and the watershed management scale. Accordingly, this framework represents a starting point towards the design of effective wetland conservation and/or restoration programs.

1. Introduction

Extensive degradation and conversion in response to anthropogenic activities and needs have reduced the worldwide coverage of wetlands by about a half (Zedler and Kercher, 2005). Not surprisingly, protection of wetlands has become a major environmental issue spurred by the Ramsar Convention (Matthews, 1993), mainstreamed by the Millennium Ecosystem Assessment (MEA, 2003, 2005). Accordingly, we entered a "No Net Loss" era. Meanwhile, understanding wetland hydrology and assessing future hydrological conditions may be viewed as a logical path towards predicting their integrity, defined here as the ability to maintain current hydrological functions/services and structural conditions (*e.g.*, permanent flooding or drying conditions).

The long-term viability of wetlands requires maintaining the water supply in terms of quantity and periodicity. Indeed, this hydrological dynamic is responsible for: (i) directly maintaining the integrity of wetland structure, and (ii) indirectly maintaining the hydrological services which depend on the natural dynamics and the structural integrity. Moreover, viability and functionality are closely linked and highly dependent on climate and weather conditions. Therefore, the expected perturbations from climate change will play a critical role in the maintenance or loss of key hydrological dynamics (hydroperiod) and associated services, namely water storage and slow water-release. The combined effects of rising temperatures and rainfall changes, with a

* Corresponding author.
E-mail address: maxime.fossey@ete.inrs.ca (M. Fossey).

http://dx.doi.org/10.1016/j.jhydrol.2016.08.032
0022-1694/

decreasing proportion of snowfall, will in all likelihood affect the hydrological dynamics at the watershed scale.

These modifications could impact the wetland spill-fill dynamics at the seasonal scale and in all likelihood impacting biological integrity (*i.e.,* composition and structure) and hydrological services (*i.e.,* storage capacity and slow water-release ability). Knowledge of wetland hydrodynamic, as inferred by this hydrological modelling study, allows to: (i) further our understanding of the role of wetlands and associated key controlling factors, and (ii) to anticipate the impacts of climate change.

To date, wetlands have been studied on two different fronts: (i) description of wetland processes at the field scale; and (ii) assessment of wetland services at the regional/watershed scale. While the first is used to increase knowledge on various wetland processes such as water or solutes transfer (Hayashi et al., 1998a, 1998b; Mitsch et al., 2005; Peyrard et al., 2008) including the monitoring of restored/constructed wetlands (Petru et al., 2014; Song et al., 2014; Villa and Tobón, 2012; Zhang and Mitsch, 2005), the second has been used to assess the impacts on watershed hydrology (Daily et al., 1997; Evenson et al., 2015; Fossey et al., 2016; Golden et al., 2015; Martinez-Martinez et al., 2014; McLaughlin et al., 2014; Padmanabhan and Bengtson, 2001; Wang et al., 2010; Yang et al., 2008) including long-term studies integrating simulated climate changes (House et al., 2016; Walters and Babbar-Sebens, 2016).

Given the above introduction, three major findings can be synthesised:

(i) At the field scale, where on-site instrumentation is possible; both in terms of cost and time, studies have led to the characterization of some wetland processes through measurements of key parameters useful for calibration of mechanistic models. That being said, the recent studies of Nilsson et al. (2013) and Park et al. (2014) highlighted the highly individualized dynamics of wetlands, raising the problem of on site-specific artefacts and transferability issue of the findings.
(ii) At the regional/watershed scale, hydrological models integrating wetlands are often present used to conduct studies related to current conditions (*i.e.,* without climate change considerations) focussing on the impacts of wetlands (*i.e.*, presence or absence) on stream flows. These studies, based on mathematical modelling have been carried out with respect to hydrological services. They reflect the overall impact of wetlands, but are unable to differentiate the hydrological contribution of a group of wetlands.
(iii) To our knowledge, there are few studies addressing wetlands within a climate change context with an emphasis on either the hydrological impacts (*i.e.*, on stream flows) at the watershed scale or the ecological impacts at the field scale.

Considering that the water content of wetlands is a key driver of the associated services (Ishida et al., 2006; Passoni et al., 2009; Woodward et al., 2014; Zhang and Mitsch, 2005), understanding the evolution of the impacts of wetlands on stream flows under changing climate conditions represents the first step towards the implementation of effective adaptation plans. Moreover, since the surrounding landscape contributes to the hydrological services provided by wetlands (Devito et al., 2005; Euliss and Mushet, 1996; Mitsch and Gosselink, 2000), it becomes necessary to account for the interactions between wetlands and their local environment.

To fill this gap, we propose a combined approach based on minimal field-scale data and regional/watershed scale data. Field data, including piezometric measurements and stable isotopic composition ($\delta^{18}O$ and δD) of water, were used to account for the current hydrological dynamics of studied wetlands, while projected climate data, used as inputs to a hydrological model, were used to assess the short- and long-term effectiveness of wetlands.

Our previous studies focused on the development of the PHYSITEL/HYDROTEL modelling platform to assess the role of isolated and riparian wetlands at the watershed scale (Fossey et al., 2015, 2016). In this study, we examine how climate change would affect this role in terms of hydrological dynamics and sustainable services through two main objectives; that is:

(i) development of a schematic depicting the hydrological dynamics of isolated and riparian wetlands; and
(ii) using a distributed model, assessment of the hydrological response of isolated and riparian wetlands under climate change.

In this paper, we evaluated the hydrologic conditions governing wetland services under current and anticipated range of climates. Our hypothesis is that the sustainability of wetlands and their services are governed by hydroperiods characterized by the frequency, duration, intensity and seasonality of water level changes within a given system. Also, as introduced by Erwin (2009), climate change may affect wetlands through alterations of the hydroperiods, raising general questions such as: (i) how will climate change disrupt the hydrological conditions of wetlands? (ii) will water inflows compromise their hydrological integrity? and (iii) will the temporal variability of their hydroperiods be consistent with their hydrological functions? To answer these questions and ultimately assess, conservation/restoration programs, or more generally wetland integrity, there is a need to implement a hydroclimate modelling framework.

2. Study site and theoretical background

2.1. Study area and wetland identification

The Becancour River watershed (2597 km^2) in southern Quebec, Canada, (Fig. 1) is one of the selected sites of a research project under Quebec's Climate Change Action Plan (*Plan d'action sur les changements climatiques du gouvernement du Québec*) (PACC-action 26), and is located within the St Lawrence Lowlands (29 000 km^2) (Mackey et al., 1996; McKenney, 1998). For this study, the focus is on four sites located in the aforementioned watershed, namely, two isolated wetlands and two riparian wetlands (note that these wetlands are identified as swamps): (i) one riparian wetland (RW1 46°29′N–71°37′W) within the Palmer River sub-watershed (252 km^2), and (ii) one riparian wetland (RW2 46°29′N–71°78′W) and two isolated wetlands (IW1 46°27′N–71°77′W and IW2 46°30′N–71°79′W) located in the regional Grande Coulées Park (*Parc Régional des Grandes Coulées*), within the Noire River sub-watershed (206 km^2) as shown in Fig. 1. Isolated wetlands cover 3 km^2 of the Palmer River sub-watershed (1%) and drain 29 km^2 (12%), while for the Noire River sub-watershed, they cover 26 km^2 (13%) and drain about 58 km^2 (28%). Riparian wetlands cover about 3 km^2 (1%) of the Palmer River sub-watershed and 18 km^2 (9%) of the Noire River sub-watershed. Meanwhile, their drainage areas within their sub-watershed are 25 km^2 (11%) and 39 km^2 (19%), respectively (Fig. 3).

The region, mainly characterized by sedimentary rock formation (Li and Ducruc, 1999) and located within the mid-sub-humid ecoclimatic region (Litynski, 1988), is prone to the formation of fragile and shallow groundwater leading to the establishment of numerous isolated and riparian wetlands (76% of bogs/fens and 17% of swamps). Under seasonal climatic influence, normal conditions for 1981–2010 (MDDELCC, 2014) show annual