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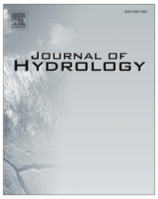

Investigating the respective impacts of groundwater exploitation and climate change on wetland extension over 150 years

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SUMMARY

Peatlands are complex ecosystems driven by many physical, chemical, and biological processes. Peat soils have a significant impact on water quality, ecosystem productivity and greenhouse gas emissions. However, the extent of peatlands is decreasing across the world, mainly because of anthropogenic activities such as drainage for agriculture or groundwater abstractions in underlying aquifers. Potential changes in precipitation and temperature in the future are likely to apply additional pressure to wetland. In this context, a methodology for assessing and comparing the respective impacts of groundwater abstraction and climate change on a groundwater-fed wetland (135 km^2) located in Northwest France, is presented. A groundwater model was developed, using flexible boundary conditions to represent surface–subsurface interactions which allowed examination of the extent of the wetland areas. This variable parameter is highly important for land management and is usually not considered in impact studies. The model was coupled with recharge estimation, groundwater abstraction scenarios, and climate change scenarios downscaled from 14 GCMs corresponding to the A1B greenhouse gas (GHG) scenario over the periods 1961–2000 and 2081–2100. Results show that climate change is expected to have an important impact and reduce the surface of wetlands by 5.3–13.6%. In comparison, the impact of groundwater abstraction (100% increase in the expected scenarios) would lead to a maximum decrease of 3.7%. Results also show that the impacts of climate change and groundwater abstraction could be partially mitigated by decreasing or stopping land drainage in specific parts of the area. Water management will require an appropriate compromise which encompasses ecosystem preservation, economic and public domain activities.

1. Introduction

Peatlands are complex and fragile ecosystems driven by many physical, chemical, and biological processes. Numerous studies have provided a comprehensive understanding of wetland hydrology, especially regarding the interactions between surrounding aquifers and surface water networks (Bradley, 2002; Frei et al., 2010; Grapes et al., 2006; Lischeid et al., 2010; Reeve et al., 2000; van Roosmalen et al., 2009; Wilsnack et al., 2001; Winter, 1999). Because peat soils can serve as sinks, sources, and transformers of nutrients and other chemical contaminants, they have a significant impact on water quality, ecosystem productivity and greenhouse gas emissions (Hemond and Benoit, 1988; Johnston, 1991; Kasimir-Klemedtsson et al., 1997; Roulet, 2000). The extent of peatlands is tending to decrease worldwide, (Estimated to 6% over the period 1993–2007 – Prigent et al. (2012)). However, peatlands are considered as important carbon reserves (15–30% according to Botch et al. (1995), Turunen et al. (2002)), and important potential sources of CO$_2$ even though they cover only 3–4% of emerged areas on the earth. As the oxygen concentration in peat increases due to water drawdown, surface decomposition is enhanced by bacterial aerobic processes (Holden et al., 2004). Oxygen enhances organic matter mineralization, leading to CO$_2$ release to the atmosphere and nutrients production, particularly carbon-bound nitrogen and sulfur. Decreasing groundwater levels can also cause land subsidence, due to the reorganization of the peat structure (Silins and Rothwell, 1998).

The hydrology of the peat layer and extent of this peat area are impacted by drainage for agriculture, groundwater abstractions in underlying aquifers and climate change. The general impact of climate change on hydrological systems has been studied, focusing on surface water (Christensen et al., 2004; Fowler et al., 2007a),

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and more recently on groundwater reserves (e.g. Goderniaux et al., 2009, 2011; Green et al., 2011; Herrera-Pantoja and Hiscock, 2008; Holman et al., 2011; Scibek et al., 2007; Woldeamlak et al., 2007). However, few studies have addressed the impact of climate on the evolution of peatlands, which are specific ecosystems located at the interface between surface water and groundwater. Moreover, the respective impacts of climate change and anthropic water abstraction on wetlands have not been investigated and compared.

Peatlands are commonly observed in lowland areas where shallow gradients, impermeable substrates or topographic convergence maintain saturation. Peatland classification is generally related to two fundamental factors: source of nutrients and source of water. Bogs or ombrotrophic peatlands are dependent on precipitation for water and nutrient supply, whereas minerotrophic peatlands or fens rely on groundwater (Johnson and Dunham, 1963). As a consequence, two different points of view have generally been adopted in studies of the impact of climate change. Thompson et al. (2009) performed an impact study on the Elmley marshes (8.7 km^2) in England using a coupled surface–subsurface model, where subsurface is represented by a single uniform layer. In their study, precipitation and evapotranspiration were the main hydrological processes, due to the impoundment of the marshes within embankments and their low hydraulic conductivity. Conversely, other studies emphasized the importance of the interactions with groundwater. Candela et al. (2009) developed a groundwater model (415 km^2) for a basin in the Island of Marjorca (Spain), to assess the impact of climate change on groundwater resources and on springs discharging into a smaller wetland area. Herrera-Pantoja et al. (2012) used a generalized groundwater model of eastern England wetlands to assess climate change impacts on water levels and their consequences on typical plant species. Barron et al. (2012) assessed the risks for wetlands and groundwater-dependent vegetation in the southern half of the Perth Basin (~20,000 km^2, Australia) under future climate change scenarios. Their study is based on a global approach using coefficients of groundwater sensitivity to climate change, and a regional-scale groundwater model.

In this study, we considered peatlands as components of a complex system where the different surface and subsurface compartments interact. Our general objective was to evaluate and compare the competing impacts of climate change and water abstraction activities on groundwater storage and the extents of wetland areas. We focused on a 135 km^2 peatland area in the Cotentin marshes (Northwest France). Our three main objectives were: (i) to understand surface–subsurface connectivity and associated wetland hydrological sensitivity, (ii) to quantify the impact of projected increases in groundwater abstraction, and (iii) to estimate the impact of climate change at the end of this century. These objectives have been attained by using a 3D groundwater model for the Cotentin wetland area.

2. Study area

2.1. The Cotentin marshes

The Cotentin marshes are located within a large watershed in Normandy (Northwest France, see Fig. 1). The study area is situated within a natural reserve, and extends over approximately 135 km^2. Topography ranges from 0 to 30 m above sea level. Mean annual precipitation and potential evapotranspiration for the period 1946–2010 (from two climatic stations, Fig. 1) were 910 mm/yr and 630 mm/yr, respectively. In the lowland areas, the vast wetlands and peatlands partly consist of peat soils and are located along 3 main rivers: the ‘Sèves’ in the North, the ‘Holerotte’ in the West, and the ‘Taute’ in the South (Fig. 1). As suggested by hydrologic fluxes and chemical features (Auterives et al., 2011), this wetland area is closely related to groundwater. It is connected with an underlying highly transmissive aquifer and surface-water bodies are integral parts of the groundwater flow systems. For several centuries, this large wetland has undergone numerous disturbances. In the 18th century the wetland was flooded 9 months per year (Bouillon-Launay, 1992). Since 1712, a human-controlled drainage system has gradually been set up. From 1950 until now, the flooding season has been reduced to only 3 months on average

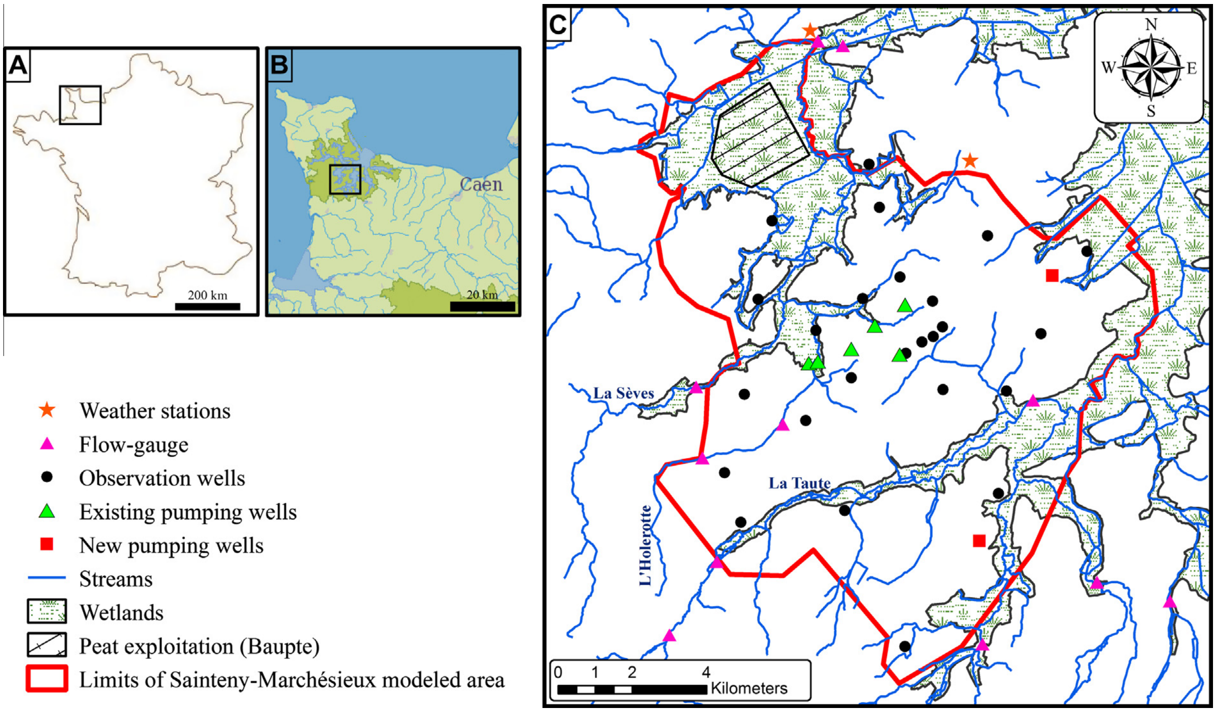

Fig. 1. Location of the Sainteny-Marchésieux basin. (A) Map of France. (B) Map of the Cotentin region. (C) View of the modeled area.