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Original Research Article

What we can learn from a wetland water balance? Narew National Park case study

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ABSTRACT

Analyses carried out in this paper aimed to provide an integrated, dynamic, yet simple water balance model for riparian wetland areas with insufficient observation data. The proposed approach was based on a combination of a conceptual model of wetland water balance with an integrated river basin model SWAT (Soil and Water Assessment Tool). It allowed determining the water balance components of the protected part of the Upper Narew River valley. Scenario analyses were conducted with the aim of evaluating the effect of changes in external and internal factors on the water storage within the NNP wetlands, with a particular emphasis on the issue of soil desiccation. The model calibration was based on comparing simulated water storage within the wetland with the mean groundwater depths for the period 2000–2004. The reference conditions were defined by the "Baseline" scenario (water balance simulations for the period 1990–2009), whereas future conditions were represented by three scenarios: "Climate" (climatic changes according to two GCMs driven by SRES A2 emission scenarios), "Reservoir" (changes in operation of Siemianówka reservoir situated upstream of the study area) and "Succession" (changes in vegetation cover of the NNP). The results allowed identifying possible factors contributing to degradation of hydrogenic habitats. The conclusion from this study is that the largest impact on the water storage within the NNP wetland, and thus on water conditions for hydrogenic habitats can be expected under projected climate change, whereas scenarios of change in reservoir operation and vegetation succession have a rather moderate impact.

1. Introduction

Protected wetlands are often located in the areas barely known in terms of hydrology and geology and very little observational data resources are available. Protection activity planning should be based on analysis of hydrological processes determining both current and future wetland conditions. Many hydrological models and concepts have been applied to wetlands, starting from conceptual models, through lumped, semi-distributed to distributed models which differ in their physical basis, complexity and data requirements (Leauthaud et al., 2012). Water balance models can be used not only to explain past hydrologic conditions but also to predict future hydrologic behaviour under altered conditions. One of the simplest floodplain water balance model was

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developed by Whigham and Young (2001) for use in an environmental flows decision support system. Bauer et al. (2006) developed a large-scale (1 km grid) coupled 2D surface water-groundwater model to study the water balance of the entire Okavango Delta under a range of scenarios. There have also been extensive studies of a large floodplain of the Lower Havel River in northern Germany that have involved the development of the Integrated Modelling of Water Balance conducted by Krause and Bronstert (2005), Krause and Bronstert (2007) and Krause et al. (2007a, 2007b).

The upper part of the Narew River valley upstream of Rzędziany (NE Poland) is one of the last examples of extensive undrained, non-reclaimed fluviogenous mire wetlands in Central Europe (Gradziński et al., 2003; Banaszuk and Kamocki, 2008). Reduction in surface water inflow into the wetland, shorter duration and magnitude of flooding, decrease in summer precipitation and increase in evapotranspiration have led to the substantial fall of the groundwater table in the valley and a decrease in volume of water stored in organic sediments (Banaszuk and Kamocki, 2008; Mioduszewski et al., 2002; Mioduszewski, 2006; Dembek et al., 2004). These unfavourable changes in hydrological conditions affected wetland soil and vegetation communities in a number of ways, e.g. cessed peat accumulation, soil desiccation, disappearance of hygrophilous species and invasion of alien *Phragmites australis* communities (Szewczyk et al., 2003; Banaszuk and Kamocki, 2008). Furthermore, the study of Kiczko et al. (2011) has shown that Siemianówka reservoir situated more than 70 km upstream from the NNP border can be used to shape average water conditions in the park. Yet, the hydrological research in this unique area protected as the Narew National Park (NNP) is constrained by insufficient amount of continuous hydrological measurements. Already unobserved water gauge situated in the research area outlet, which is under backwater influence of the dyke was giving a significant error in the assessment of flow rate in the past (Mioduszewski et al., 2004). Groundwater depth data in wetland soils are available for a short time period only.

The objective of this paper is to project the impacts of several dominant factors, including climatic change, vegetation succession and change in upstream reservoir operation, on the sub-surface water storage in the NNP wetlands using a conceptual water balance model coupled with the catchment-scale SWAT model. The developed model operating in the 10-day time step has modest input data requirements and makes it possible to determine the direction and approximate magnitude of future changes of water balance components under the influence of aforementioned external factors. It has been built with consideration of possible water transfer mechanisms specific for the NNP as outlined in Acreman and Miller (2007). The approach of integrating a conceptual wetland water balance model with the existing SWAT model seems to be an appropriate solution for a comprehensive recognition of water conditions and for a risk assessment to hydrogenic habitats protected in the National Park.

The scenario perspective on projecting future wetland water balance conditions of the Narew National Park (NNP) presented in this paper was applied to this region for the first time. It allowed for determining the importance of particular water balance components for the dynamics of unsaturated zone. The previous water balance models (Tyszewski et al., 1998) for the Narew National Park focused on its functioning depending on water needs of water users in the Upper Narew River drainage basin, with the special attention on Siemianówka reservoir management. In the water balance model developed in this paper it was assumed that the water needs of the Park can be described using the minimum required (environmental) flow which protects the valley from over drying (Tyszewski et al., 1996; Okruszko et al., 1996a,b; Piniewski et al., 2014).

2. Study area

The Upper Narew River valley within the borders of National Park is located in the north-eastern Poland in the Podlaskie Voivodeship. The water balance model was developed for Natura 2000 Special Area of Conservation "Narew Marshes" which almost entirely overlaps with the area of the Narew National Park (Fig. 1). This area covers 71.7 km^2 and constitutes part of the Narew Valley, whose upstream end is situated about 500 m downstream of the Suraż water gauge of Institute of Meteorology and Water Management, while the downstream end is located at the Rzędziany–Pańki dyke, where no hydrological monitoring is carried out.

The Narew river on this stretch is an anastomosing river with its complicated, branched network of streams, oxbow lakes, swamps, periodical wetlands and river backwaters described in detail by Gradziński et al. (2003).

Long and natural floodings occurring most frequently between February and the first half of May are characteristic for this area. Due to the large width of the river valley, very low longitudinal slopes and high hydraulic roughness coefficients of riverbed and floodplains, water spreads a relatively thin (0.2–1.0 m) layer over the entire study area during flooding (Mioduszewski et al., 2004). For example spring flooding in the beginning of April 2005 (04.04.2005, flow measured at Suraż gauge equal to 38.6 m^3/s) estimated on the basis of Landsat 7 ETM+ images covered an area of 62.9 km^2. Along the NNP border four middle-sized ungauged tributaries inflow their waters to the system: Liza, Awissa, Turośnianka and Czaplinianka.

3. Materials and methods

3.1. Water balance model

The water balance of the NNP was calculated based on the approach that integrates a lumped, conceptual water balance model with previously developed SWAT model for the part of the Narew basin situated upstream of the Zambski Kościelne gauging station (Piniewski and Okruszko, 2011; Piniewski, 2012). The whole study area is treated as a uniform "soil" layer (i.e. as a shallow sub-surface storage) having homogenous properties and constant depth. The simulation period covers 20 hydrological years (in Poland beginning on 1 November), from 1990 to