Ecological Engineering 92 (2016) 181–189

Contents lists available at ScienceDirect

Ecological Engineering

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

Assessing floodplain porosity for accurate quantification of water retention capacity of near-natural riparian ecosystems—A case study of the Lower Biebrza Basin, Poland

Dorota Mirosław-Świątek[a,*], Sylwia Szporak-Wasilewska[b], Mateusz Grygoruk[a]

[a] Warsaw University of Life Sciences—SGGW, Faculty of Civil and Environmental Engineering, Department of Hydraulic Engineering, Nowoursynowska 159, 02-776 Warsaw, Poland
[b] Warsaw University of Life Sciences—SGGW, Faculty of Civil and Environmental Engineering, Water Centre Laboratory, Ciszewskiego 6, 02-776 Warsaw, Poland

ARTICLE INFO

Article history:
Received 15 March 2015
Received in revised form 17 February 2016
Accepted 21 March 2016
Available online 12 April 2016

Keywords:
Floodplain
Wetlands
Vegetation
Volume
Porosity
Modelling
Retention
Water storage
Biebrza

ABSTRACT

Near-natural lowland floodplains, which nearly disappeared in temperate climates due to the vast anthropopression, play a critically important role in shaping biodiversity in regional scales. The other important aspects of floodplains such as their role in flood mitigation for downstream reaches of rivers, catchment-scale ecosystem services, and agriculture emphasize the need for research of these ecosystems, with special focus on the flood-vegetation interactions. In our study we performed an experiment oriented at the accurate quantification of water retention capacity of the densely vegetated floodplain located in NE Poland, referring to the floodplain porosity (ε). We conducted measurements of the geometry of selected types of the floodplain vegetation, with a special focus on the communities dominated by the common reed (*Phragmites australis* (Cav.) Trin. ex Steud.), the reed-manna grass (*Glyceria maxima* (Hartm.) Holumb.) and dominant representatives of loosely structured sedges (*Carex acuta* L.) and of tussock sedges (*Carex appropinquata* Schumach.)., which allowed us to derive the volume of these species and eventually the floodplain porosity coefficients in a function of various flood depths. Estimated values of ε equalled from 0.882 to 0.993. Average value of ε for all vegetation communities analysed for all flood depths considered equalled 0.968. Consideration of the derived ε values in the case study on the floodplain water retention capacity estimation in hypothetical conditions of a standard flood (2-year recurrence interval) resulted in the reduction of the total water storage volume of the floodplain by 0.75 mn m^3 of water. Results of our research indicated that the studies oriented at quantification of water storage within the floodplain as an asset for ecosystem services should consider floodplain porosity due to its significance in the accurate estimation of floodplain capacity.

1. Introduction and state-of-the-art

Structure of the floodplain, especially its topography, land use, and vegetation, influences the overland flow and dynamics of floods (Aberle and Järvelä, 2013; Coulthard et al., 2013; Neal et al., 2012; Forzieri et al., 2011; Kadlec and Knight, 1996; Miroslaw-Swiatek, 2007). Variable hydraulic characteristics of vegetation patches formed by diverse species of the vegetation, remain of critical importance for both modelling and management of these environments by influencing flow patterns and determining extents of flood (Baptist et al., 2004). From the perspective of floodplains in agricultural landscapes, considerable attention was paid to the assessment of friction and stiffness of low and medium vegetation (grasses, sedges, reeds), which interacts with the conditions of water flow (Aberle and Järvelä, 2013; Darby, 1999; Forzieri et al., 2011; Nicholas and Mclelland, 2004; Nikora, 2010; Stoesser et al., 2003; Yang and Choi, 2009). However, little is known in terms of the actual fraction of volume occupied by water in floodplains, herein defined as floodplain porosity. Floodplain porosity (ε) determines the fraction of the volume which can be filled with water over the total volume of the floodplain. The volume of the floodplain during the flood depends on water level and consists of water and all the elements of the wetland's environment, in which the crucial role is played by the vegetative parts of vascular plants (e.g., leaves, stems,

* Corresponding author.
E-mail addresses: d.swiatek@levis.sggw.pl (D. Mirosław-Świątek), s-szporak@levis.sggw.pl (S. Szporak-Wasilewska), m.grygoruk@levis.sggw.pl (M. Grygoruk).

http://dx.doi.org/10.1016/j.ecoleng.2016.03.031
0925-8574/

tussocks, hummocks, branches), such that the $\varepsilon < 1$. Hypothetically, the floodplain porosity values reaching 0.0 indicate that a wetland storage volume is completely filled with vegetation and no space is left for water. The values near 1.0 suggest that plant mass takes up very little, or none, of the storage volume available for water and the total storage capacity of the floodplain can be effectively filled with water (Hunt, 2000). Kadlec and Knight (1996) reported that average wetland porosity values are usually greater than 0.95 and using value of 1.0 would be a good approximation. However, Kadlec and Wallace (2009) indicated a very important problem with wetland porosity (ε) nomenclature in the literature: some authors identify wetland volumetric efficiency (e_v or η) to be wetland porosity. They pointed out that the entire amount of water in a wetland may not be involved in active flow and the volumetric efficiency reflects this ineffective volume within a wetland compared to presumed nominal conditions. They found that normally the values of wetland porosity (ε) are in the range of 0.95–1.00 (Kadlec and Wallace, 2009; also presented earlier by Kadlec and Knight, 1996) and the value of wetland volumetric efficiency (e_v) for free water surface wetlands (FWS) with dense vegetation vary in the range of 0.78–0.96. The wetland porosity values with symbol η presented by Reed et al. (1995) and Crites and Tchobanoglous (1998) that vary from 0.65 for fully vegetated wetlands to 0.75 for dense to less-mature wetlands were suggested by Kadlec and Wallace (2009) to be considered rather as e_v (η), as these values refer to volume actively involved in water flow, without taking into account stagnant water in recesses resulting from microtopography of the area. The wetland porosity value of 0.75 was also presented by Gaerheart (1997) in unpublished data from Arcata Treatment Marshes but cited by Bendoricchio et al. (2000). Bendoricchio et al. (2000) also drew attention to wetland porosity literature values to be highly variable. Also, U.S. EPA (1999, 2000) assigned the range 0.70–0.90 to wetland porosity using ε to replace the e_v (Kadlec and Wallace, 2009). These ambiguities, as well as a large discrepancy of wetland porosity values declared by different authors, confirm the need for undertaking such a research as the one presented in this paper: having the flooded river valley in which total active surface water storage volume reaches some 10.4 mn m^3 (comparative to a medium-sized reservoir) and attempted to be considered as the ecosystem service of the floodplain (Grygoruk et al., 2013), it is compulsory to define the wetland porosity in order to account for the accurate values of water storage. As reported, the volume of the floodplain vegetation is difficult to assess in field experiments due to vast spatial (vertical and horizontal) heterogeneity of the floodplain's medium (Lagrace et al., 2000). However, several measurement methods are already known that allow for the estimation of vegetation characteristics, which can be used in determining floodplain porosity. Among them there are direct measurements of the vegetation-flow interactions in laboratory conditions (e.g., Nehal et al., 2012), in the field (e.g., Hutchoff et al., 2006), and also the indirect assessment methods based on the analysis of the Terrestrial (TLS) and Airborne (ALS) Laser Scanning (Jalonen et al., 2015, 2014; Tymkow and Borkowski, 2010; Mokwa et al., 2009; Straatsma and Middelkoop, 2006; Straatsma and Baptist, 2008; Straatsma et al., 2008; Mason et al., 2003). From the perspective of the applicability of the research on wetland vegetation volumes and its interrelation with the flow and floods, considerable attention was paid so far to constructed wetlands (Holland et al., 2004; Hubbard et al., 2004; Kadlec and Wallace, 2009; Schmid et al., 2004). However, not much was done in terms of the assessment of vegetation volumes (and by extension—floodplain porosity) within the near-natural, temperate climate, densely vegetated floodplains, which was claimed as compulsory in terms of the accurate assessment of water retention during floods (Grygoruk et al., 2013). Studies based on direct field research are also lacking (Bendoricchio et al., 2000), which makes as research on vegetation volumes vs. floods (water retention) in broad and densely vegetated floodplains has not been carried out much, but is needed from the perspective of wetland management, restoration, environmental conservation, and ecosystem services perspectives.

In this paper we attempted to estimate the porosity of the temperate-climate, densely vegetated floodplain of the lower Biebrza. Determination of the ε as a function of water depth in the stretch of the floodplain analysed was based on the *ex-situ* experimental measurements of the geometry of the wetland vegetation typical for a temperate European, near-natural floodplain, with a special focus on the communities dominated by the common reed (*Phragmites australis* (Cav.) Trin. ex Steud.), the Reed-manna grass (*Glyceria maxima* (Hartm.) Holumb.) and dominant representatives of loosely structured sedges (*Carex acuta* L.) and of tussock sedges (*Carex appropinquata* Schumach.). Even though selected plant communities comprise other-than-key species of plants, the high dominance of key-species in the biomass within their extent in the study area allows to assume that their physiognomic features (shape, height, stiffness, volume, structure of stews etc.) determine wetland porosity in sites analysed. The vegetation used for determination of the floodplain porosity coefficient was collected within the experimental plots distributed randomly within the Lower Biebrza Basin. We discussed the results of our calculations in terms of their applicability in management of valuable riparian ecosystems with a special focus on improving water storage capacity calculations.

2. Materials and methods

2.1. Study area

The study was carried out in the northern stretch of the Lower Biebrza Basin (Fig. 1), which is one of the core areas for wetland environmental conservation in the continental scale (Wassen et al., 2006) protected within the Biebrza National Park. Numerous research projects on floodplain ecohydrology (Keizer et al., 2014), ecology (Kotowski et al., 2013; Wieczorek et al., 2014), flood wave dynamics (Byczkowski and Kiciński, 1983; Ignar et al., 2011; Mirosław-Świątek et al., 2008), flood delineation (Chormański et al., 2011), and ecosystem services of the floodplains (Grygoruk et al., 2013) agreed that there is still a field to be explored in the matter of improvement of floodplain water dynamics in this unique and complex geoecosystem.

In this field, the research on the interactions between the vegetation and water level and discharge dynamics during floods appears to be critical for effective floodplain management by assuring the appropriate mowing regime (Grygoruk et al., 2014). The Lower Biebrza Basin is a fluvioglacial depression filled with outwash sands and covered by peat (up to some 3 m thick) that formed in the Holocene due to the constant inflow of groundwater and high water levels that remained in the valley (Oświt, 1991). The width of the valley in the stretch analysed ranges from 2 up to 6 km and the length of the stretch comprises 12 km. Due to the natural features of the Biebrza (numerous oxbows and meanders) which become the core of the valley, the length of the river in the stretch analysed is much longer and reaches 18.5 km. Average momentary discharge of Biebrza near its confluence to the river Narew reaches 39 m^3/s (max. 670 m^3/s; min 4.33 m^3/s) and the outflow volume from the catchment of Biebrza equals 1.24 bn m^3/year; Grygoruk et al., 2011). Unique morphology of the floodplain examined results in the fact that flooding is a regular and frequent phenomenon: the threshold of the overbank flow in the Lower Biebrza Basin is only approximately 20% higher than the average momentary river discharge (Byczkowski and Kiciński, 1983; Grygoruk et al., 2013, 2011).