DOI: 10.2428/ecea.2012.19(03)030 ECOL CHEM ENG A. 2012;19(3):287-294

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INFLUENCE OF LAND USE ON FLOOD WAVE PROPAGATION IN THE LOWER BIEBRZA BASIN

WPŁYW SPOSOBU UŻYTKOWANIA DOLINY NA PRZEPŁYW FALI WEZBRANIOWEJ W BASENIE DOLNYM BIEBRZY

Abstract: The status of riparian wetlands depends on water conditions, especially the main role is played by flooding which occurs almost every year on wetland areas. The aim of this work is the evaluation of the influence of land use on flood wave propagation in the Biebrza River floodplain. An 1D numerical model of river flow was applied to the Biebrza River floodplains covered with reeds, sedges, grasses, bushes, and trees. Various scenarios of land use with such activities as extensive agriculture, willow scrubs and birch trees cutting or no activity (natural succession) were analyzed to evaluate the influence of changes in vegetation structure on the flood wave propagation in the river valley. Simulations were performed for the maximum flood event in 1979 in the Biebrza Basin. The results were presented for selected river cross-sections.

The obtained results show the influence of floodplain vegetation type on the water stage hydrographs and flood duration in the Lower Biebrza Basin.

Keywords: 1D hydrodynamic model, The Lower Biebrza River Basin, Numerical Terrain Model, flood wave

The status of riparian wetlands is mostly connected with flooding and the appearing structure of valuable ecosystems here depends on annual floods of defined duration and frequency. The most important flood characteristics of plant communities development are: flooding area, flooding frequency, and average depth of flooding [1–3]. It indicates that there is a very strong relationship between a vegetation structure and water conditions [2]. On the other hand, floodplain vegetation significantly affects flood extent in the valley. This question was a main task of this paper. The influence of the different floodplain land use, described by changes in vegetation structure, on flood wave propagation in the *Lower Biebrza River Basin* (LBRB) was analyzed. The Biebrza River valley is an extremely valuable wetland site of a global significance protected by Ramsar Convention and annual flooding influence formation of a unique character of

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the study site. A zonal system of various plants reflects water conditions of the LBRB [4–6] and causes spatial division of the resistance to water flow.

Materials and methods

Study site

The Biebrza River valley is situated in the Northeast of Poland and designated as a wetland site of a global significance, which is under protection of Ramsar Convention. The analysed area is located in the Lower Biebrza River Basin (LBRB) is an ice-marginal valley where the floodplain (21 000 ha) is a predominant morphologic structure covered by mosaic vegetation starting from sedge, sedge-moss and reed communities to willow shrubs, black alder forest, swampy birch and peat coniferous forest (Fig. 1). In the LBRB the river valley is 30 km long and 12–15 km wide. The Biebrza River is the main channel of the hydrodynamic network of the Lower Basin and it is about 50 km long [7]. The river course winds and forms meanders, side streams, and old riverbeds which area activates only during periods of high water flows. The width of the river channel varies from 20 to 35 m.

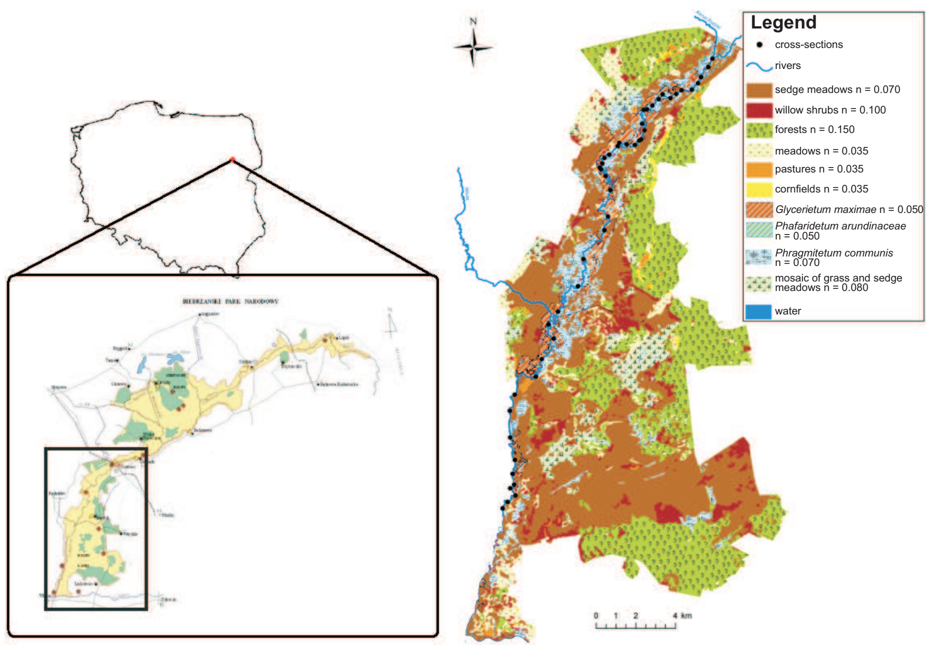

Fig. 1. Location of the Lower Biebrza River Basin (LBRB) and plant characteristic described by Manning's coefficient (n value) used in this study

The LBRB hydrological conditions, described by discharges calculated in upstream and downstream gauges Osowiec and Burzyn for maximum of annual discharges for a long term period from 1965 to 1996, are presented in Table 1.

Table 1

Discharges in Osowiec and Burzyn gauges calculated for a long term period from 1965 to 1996; *maximum of maximum* (WWQ), *mean of maximum* (SWQ) and *minimum of maximum* (NWQ) of annual discharges

Discharge	$Q_{Osowiec}$	Q_{Burzyn}
	$[m^3 \cdot s^{-1}]$	
WWQ	360.00	517.00
SWQ	82.06	131.89
NWQ	17.20	36.00

The most valuable ecosystems here are not only natural areas of peatlands but also large areas of open semi-meadows, which are the result of extensive agriculture use. The hydrogenic dependent habitats in the Biebrza marshes run on a stable ground water inundation or river flooding which occurs regularly and reinforce these representative water ecosystems every year. Changes of water conditions and discontinuance of extensive agriculture causes transformation of meadows and pastures into tall herb vegetation, reed and in the end the succession of shrubs and forest upon non-forest ecosystems of peatlands which can be observed in some places in the Biebrza River valley.

Scenarios determination

Various types of land use were determined for three scenarios and two of them present protective activities carried out nowadays in the National Park, which consist of preservation of open grasslands by mowing, elimination of biomass in selected areas, and mechanical scrubs cutting. In the first analyzed scenario (scenario I), wet meadows, sedge plant communities, and pastures are areas of an extensive agriculture. In this scenario, these areas are mowed for cattle bedding, used for hay production and as feeding areas. In the second scenario (scenario 2), there are willow scrubs and birch trees cutting, in addition to the former scenario. The overgrowing process in many cases seem to be a natural succession so the third scenario (scenario 3) allows the natural succession of willow shrubs and birch forest upon non-forest ecosystems in the valley.

Hydrodynamic model

In this work, a one-dimensional unsteady open-channel flow model UNET (One--Dimensional Unsteady Flow Through a Full Network of Open Channels) was applied to simulate flow in the LBRB. This program is a component of computer software HEC-RAS and it is a numerical solution of the mathematical model of river water flow based on the St. Venant equations [8]. In the topological discretization scheme of the flow, the LBRB and its floodplain are represented as a one-dimensional channel from Osowiec gauge (BD1) to Burzyn gauge (BD17). A geometry of the river channel and floodplain is described by 47 river cross-sections. The cross-sections were measured by manual sounding for the main channel part and the topography of the floodplain was calculated from the Digital Elevation Model [9]. A vegetation map was used to define spatial hydraulic roughness which was described by Manning's coefficient (n value) using Chow's tables [10], in the floodplain (Fig. 1) [11], and n values for the river channel were selected during the calibration process of the model. The LBRB model was calibrated and verified for the measured data and historical data of flood events in 1979, 1992, 1999. The upstream boundary condition is located at BD1 and formed by a flow hydrograph which is a sum of discharges at the Przechody and Osowiec gauges. The rating curve is used as a downstream boundary condition at the Burzyn gauge (BD17) [9]. The Wissa River is treated as a point lateral inflow and described by the flow hydrograph at the Czachy gauge.

The numerical calculations for the three scenarios [12, 13], which show changes in the land use, were made for the maximum flood event in the LBRB in 1979. In scenario I, Manning's coefficients for wet meadows, tall sedge plant communities, and pastures were given 0.035 n value. In the model scenario II, it was described by 0.035 coefficient for the floodplain area with willow scrubs. In the last simulation (scenario 3), Manning's coefficient for the study site was increased to 0.10 because of natural succession in this area.

Results and discussion

The results were analyzed in four river cross-sections which represent a variety of the hydromorphological shape of the main channel and floodplain in the Lower Biebrza River Basin. The distances from BD17, where the river course ends, to the selected cross-sections are 7.62 km, 29.62 km, 33.04 km and 39.96 km. Figures 2 and 3 show the calculated hydrographs of water stages and water stage profile of the maximum flood event of 3 April 1979 for the various land use scenarios.

The average depth in scenario I and scenario II was decreased by 0.25 m compared with the actual state (scenario 0). In scenario III, the average depth was increased by 0.20 m. Some differences in the water stage at the outlet (near BD17) are related to the downstream boundary condition which is formed by the rating curve. In computations, the influence of the vegetation structure on the rating curve was excluded which results in lack of influence of a land use type on a calculated water stage at BD17. Table 2 shows an average water depth in the floodplain, top flood width, and flood duration for the various land use scenarios.

The results for scenario I and scenario II are similar, because of willows scrubs covering a small area in the valley (Fig. 1). The highest changes of flooding time were calculated for P4 localized in the northern part of the Lower Basin, where the width of the river valley is lower than in the middle and southern parts of the research area. Time of flood in scenario I and II, when the resistance of flow is lower, was decreased by about 40 %. When the resistance of flow is higher because of growing vegetation (scenario III), flood duration was increased by 17 % compared with the actual state. An increasing valley width resulted in decreased flooding for scenarios I and II by 8 to 6 % along the river from P17 to BD14. In scenario III, flood duration was increased by 5, 7,

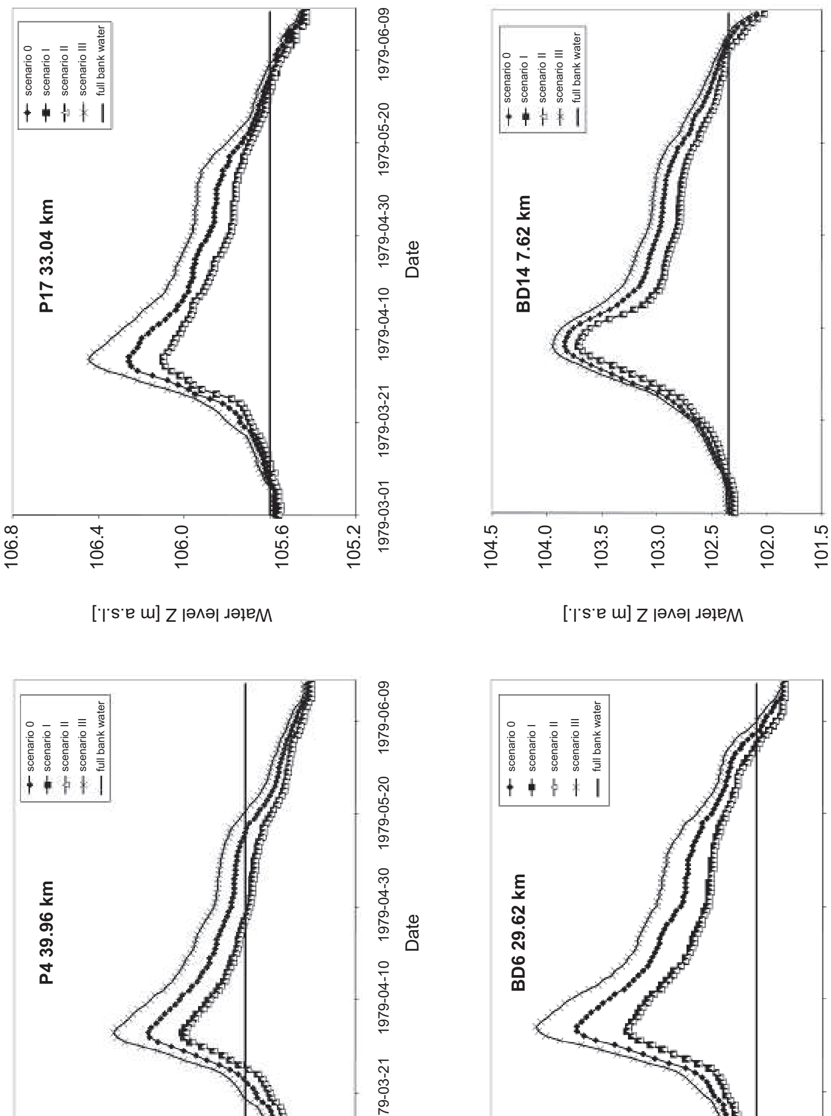

Fig. 2. Calculated stage hydrograph at select cross-sections for different land use scenarios

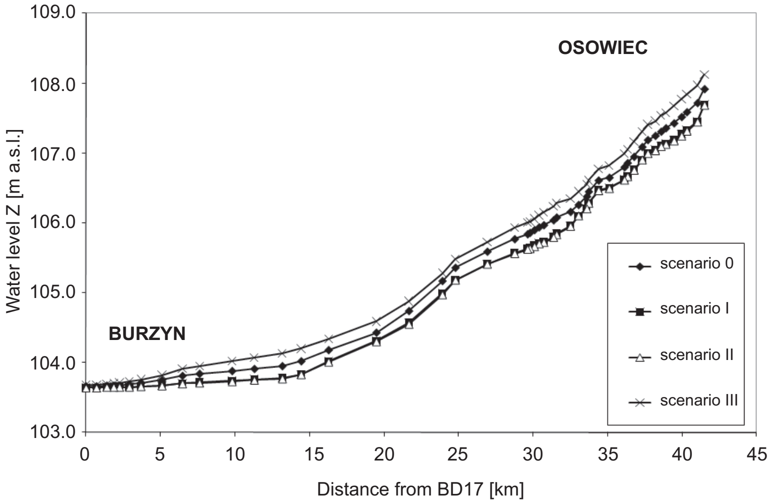

Fig. 3. Calculated water stage profile for different land use scenarios (3 April 2009)

Table 2

Variation of the average water depth on the floodplain, top flood width and flood duration for different land use scenarios

Number	Cross-section name	Distance along the river from BD17 [km]	Scenario	Average depth [m]	Top width [m]	Flood duration [days]
1	P4	39.96	0	0.58	2346	53
			I	0.51	1432	32
			II	0.51	1332	31
			III	0.64	2400	62
2	P17	33.04	0	0.24	3439	86
			I	0.19	3010	79
			II	0.19	3008	79
			III	0.29	3744	90
3	BD6	29.62	0	0.32	5103	92
			I	0.28	4685	86
			II	0.28	4666	85
			III	0.35	5367	100
4	BD14	7.62	0	0.49	6950	97
			I	0.44	5655	91
			II	0.44	5592	91
			III	0.53	7182	104

and 9 % for P17, BD6, and BD14 in comparison with the scenario 0. Changes in the average depth do not exceed 10 %. The variation of flood extent is connected with the cross-sections geometry. The highest decrease of width occurs at P4 for scenarios I and II and is about 40 %. In these scenarios it is about 10 % at P17 and BD6. The flood extent was increased by several percent in scenario III at the analyzed cross sections.

In the scenario III the flood extent, water depth and flood duration increased which means that the area of plant communities dependent from rich surface water from the river like *Phragmition* and *Magnocaricion* will increase at the cost of more valuable plant communities (like sedge-moss meadows). Long lasting inundation also does not support the development of woody vegetation except the alluvial forests. Using the hydrodynamic model it was impossible to predict how much changes in flooding characteristic will affect the vegetation, changing in the next turn its structure and location. One can only state here that secondary succession probably does not form a climax vegetation on the floodplain.

Conclusions

The obtained results show that vegetation structure on the floodplain influences the flood wave propagation in the LBRB. An intensive land use on the floodplain decreased the resistance of flow, which decreased flood duration, flood extent, and average flood water depth. These flood characteristics are strongly connected with the cross-sections geometry. The valley in the northern part is narrow, which causes the flood duration shortening; for an intensive land use on the floodplain the time was decreased by about 40 % compared with the actual state. In the other part of the Lower Basin the flood duration was shorter by less than 10 %. The influence of the natural succession on the flood wave is less significant than the influence of intensive agriculture. In this case, a flood duration changes by a few percent.

Achieved results were obtained with the use of a one dimensional hydrodynamic model which does not cover water flow across the river. It means that the used model represents simplified flow conditions in the Lower Biebrza River Basin, which is a wide area and for which this aspect is very important. The essential influence also has assigned ineffective flow areas that contain water which is not actively conveyed. Ineffective flow areas are used to described portions of a cross a section in which water ponds, but velocity of that water is close to or equal to zero. Moreover, the hydrodynamic model is an appropriate tool for assessment of various agricultural practices with regard to the effective management to protect the unique wetland site of the Biebrza National Park.

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WPŁYW SPOSOBU UŻYTKOWANIA DOLINY NA PRZEPŁYW FALI WEZBRANIOWEJ W BASENIE DOLNYM BIEBRZY

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Abstrakt: Stan ekosystemów mokradłowych jest uzależniony głównie od warunków zasilania ich wodami wezbraniowymi. W pracy przeanalizowano wpływ sposobu użytkowania doliny na propagację fali wezbraniowej na obszarze Biebrzańskiego Parku Narodowego (BPN) w Basenie Dolnym Biebrzy. W tym celu zastosowano jednowymiarowy model hydrodynamiczny przepływu wód rzecznych. Opracowany model wykorzystano do obliczeń symulacyjnych dla różnych typów użytkowania doliny. Występuje tu roślinność łąkowa, turzyce, szuwary, krzewy oraz olszyna bagienna i wysokopienny ols. Sposób użytkowania określono w trzech wariantach. W pierwszym scenariuszu przeanalizowano wpływ ekstensywnego użytkowania terenów łąk i pastwisk oraz intensyfikację użytkowania terenów zajmowanych przez szuwary i turzycowiska. W wariancie drugim zabiegi ochronne poszerzono o wycięcie w dolinie zakrzewień. Wariant trzeci opisywał stan, w którym nastąpiła naturalna sukcesja roślinności na terenach zalewowych. Obliczenia numeryczne wykonano dla maksymalnego wezbrania w dolinie rzeki Biebrzy z 1979 r. Wyniki symulacji opracowano w wybranych przekrojach obliczeniowych. Uzyskane rezultaty pokazały, że odpowiednie zagospodarowanie terenów zalewowych ma istotne znaczenie w Basenie Dolnym Biebrzy na przejście fali wezbraniowej.

Słowa kluczowe: model hydrodynamiczny, Basen Dolny Biebrzy, Numeryczny Model Terenu, wezbranie