The flood extent in the lower Biebrza basin calculated by the 1D flow model for different land use scenarios

SYLWIA SZPORAK, DOROTA MIROSŁAW-ŚWIĄTEK,
JAROSŁAW CHORMAŃSKI
Department, of Hydraulic Engineering and Environmental Restoration, Warsaw University of Life Sciences

Abstract: *The flood extent in the lower Biebrza basin calculated by the 1D flow model for different land use scenarios.* An application of an steady 1D flow model for determination of a flood extent in the natural river valley is discussed in this paper. The Pasche method was used to calculate the total Darcy-Weisbach friction factor for each cross section according to the type of vegetation and flow interaction between the main channel and vegetated areas. In this approach friction caused by interaction between the main channel and vegetated areas are taken into account. The model was applied to the Biebrza Valley, fairly undisturbed river-marginal peatland, located in the north-east of Poland. Actual land use carried out in the National Park was analyzed to determine the influence of changes in the vegetation structure on the flood extent in the river valley. The obtained results show variation of a flooded area in relation to the vegetation of the floodplain.

Key words: 1D flow model, absolute roughness.

INTRODUCTION

The aim of this work was determining changes of water conditions on the floodplain as a result of a different vegetation management scenarios leading to different vegetation successions. These changes of water conditions were described by a flood extent on floodplains The steady river flow model, which takes into water level calculation spatial distributed friction factors according to type of floodplain vegetation and flow interaction between main channel and vegetated areas, was used with the GIS techniques as a tool for a flood extent evaluation. In this approach, roughness height coefficients and hydraulic characteristic of vegetation covering floodplains are very significant. Therefore methods determination of these hydraulic characteristics of low and high vegetation in Lower Biebrza Basin was particularly described.

MATERIALS AND METHODS

Hydraulic calculations of the riverbed capacity require methods which include natural vegetation structure of the river waterside zones and the floodplain. The values of the resistance coefficients of the floodplain vegetation still belong to rareness. Presently the most often used are roughness coefficients for Manning's equation, but the choice of the sufficient one among the tabular values is subjective. Another method is determination of plant characteristics elaborated by Rouvč (1987). The division on high, medium and low vegetation (proposed by Bretschneider and Schulz 1985) is used in such calculations.

High vegetation is considered here as higher than water flow depth (trees and shrubs) and in small degree go under hydrodynamic water pressure, medium vegetation as approximately equal to water depth (mostly shrubs) and low vegetation which refers mostly to sedge and grass communities (Fig. 1).

them in the direction of the water flow and transversal to it. Named parameters are determined on the basis of field measurements in the area of the water flow. The methodology of plant characteristics determination proposed by German engineers was applied in this study for high and medium vegetation in 13 cross
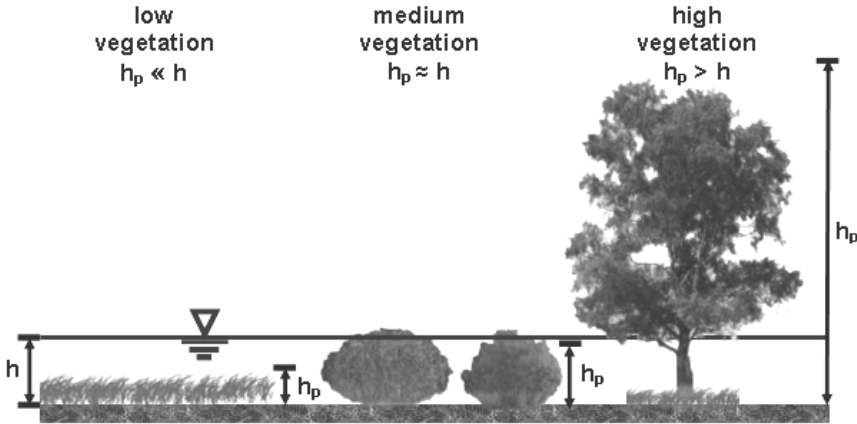
FIGURE 1. Vegetation classification proposed by Bretschneider and Schulz (1985)

Established criterion is ambiguous and in fact the same vegetation can be ranked into different types in view of the natural water levels variability.

High and medium vegetation

The basis of hydraulic calculations of riverbed capacity including its natural vegetation structure is assumption that water flow resistances are the same as resistances which occur when water overflow regularly distributed vegetation with averaged geometric parameters (DVWK 1991; Kubrak and Nachlik 2003).

Parameters which describe vegetation of the floodplain and are used in calculations are an average tree diameter or shrub branches and distances between

sections (Fig. 7) established in the Lower Biebrza Basin (DVWK 1991).

Low vegetation

Resistance coefficients λ of low vegetation are calculated from Colebrook--White'a equation on the basis of relative roughness value k_s determined for given type of vegetation (Indlekofer 1981):

$$\frac{1}{\sqrt{\lambda}} = -2.0 \log\left(\frac{2.51}{Re\sqrt{\lambda}} + \frac{k_s / R}{14.84} \right)$$

where, Re is a Reynold's number, R – hydraulic radius [m], λ – friction factor not overgrown part of a channel [–], k_s – roughness bed of a channel [m].

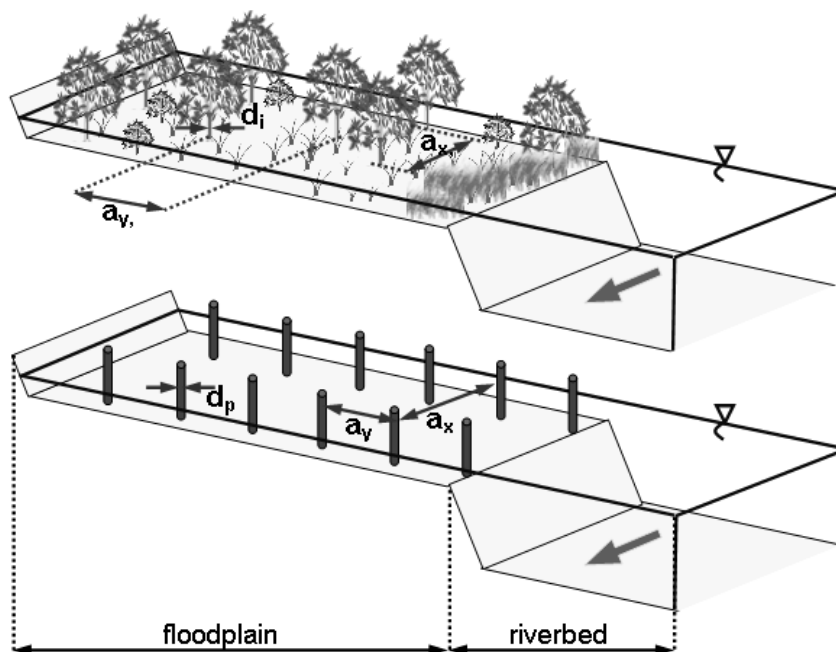The roughness height for vegetation in the Lower Biebrza Basin is determined

FIGURE 2. The high vegetation geometric characteristics

on the basis of values given by Ritterbach (1991) for the Wüpper River Valley in Germany and field measurements of particular vegetation type's height. On the basis of determined values (Tab. 1) different scenarios of land use were prepared.

In this paper the plant characteristics determination method is presented for the wetland vegetation in the Lower Biebrza Basin. Obtained results were used for 1D modelling in order to evaluate the influence of a different land use on the flood extent.

Plant characteristics were determined here for four different land use scenarios in order to designate their influence on a flood extent in the Lower Biebrza Basin. The land use changes in the model boil down to changes in absolute roughness coefficient values.

The first one (scenario 1) presents actual state with agricultural and protection activities carried out nowadays in the National Park (Fig. 3).

The second (scenario 2) takes under consideration situation when wet meadows (*Molinion* and *Calthion*), tall sedge plant communities (*Magnocaricion*) and pastures are embraced by extensive agriculture. In this situation the whole area covered by these plant communities is taken under account (Fig. 4).

In the Biebrza river valley, *Magnocaricion* covers areas which are reinforced mostly by rich surface water from the river, but also places with shallow stagnant water. In this scenario meadows are mainly mowed for cattle bedding and rarely used for hay, but play significant role in wetland ecosystems as natural filters for surface water and

TABLE 1. The roughness height values adopted for different vegetation types under different land use in the Lower Biebrza Basin

| Vegetation type	Absolute roughness k_s [m]		
	during vegetation period		beyond vegetation period
	no activity	active protectionn	no activity
Grasses	0.5	0.1	0.3
Grasses and loose tussock sedges mosaic	0.6	0.1	0.4
Loose tussock sedges	0.6	0.15	0.4
Loose and compact tussock sedges mosaic	0.6–1.2	0.2	0.5
Compact tussock sedges	1.2	1.2	0.5
Reed	1.2	0.2	1.2
Glycerietum maximae	0.6–1.2	0.2	0.4
Willow shrubs	0.4	0.4	0.4
Swampy birch forest	0.8–1.6	–	0.8
Black alder forest	0.8–1.6	–	0.8
Deciduous or coniferous tall forest	0.4	–	0.3
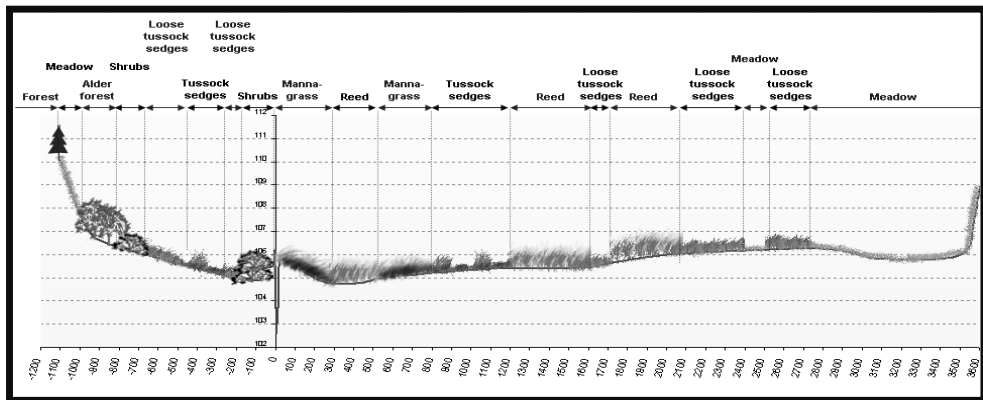
FIGURE 3. Example: Scenario 1 – actual state (bd3 cross section)

water retention zones. The natural value of wet meadows depends on frequency, terms and mowing methods. Single mowed meadows (*Molinion)* belong to one of the most valuable phitocenosis associated with river valleys (Kotowski and Piórkowski 2006) as they are rich in species (often very rare), and every year, late mowing determine their existence. *Calthion* meadows which are double or three time mowed help to protect the surface soil layer from excessive dryness and prevent or slow down the time of organic soil mineralization processes. Pastures in Biebrza valley are situated mostly in zones near the river. The best
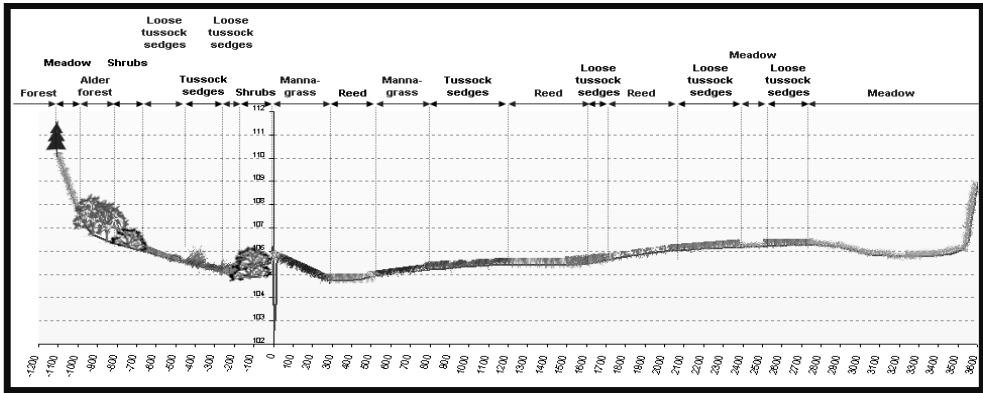
FIGURE 4. Example: Scenario 2 – reed, meadow, manna grass and sedge mowing (bd3 cross section)

extensive agriculture method here is grazing with the small cattle mount. This scenario includes also *Phragmition* and *Filipendulion* plant communities in agricultural use. The overgrowing process in many cases seem to be the natural succession, but taking under consideration the protection of the National Park the overgrowing processes are an unprofitable occurrence which decreases biodiversity, that's why the third scenario (scenario 3) takes also into account willow shrubs and birch trees cutting (Fig. 5).

The fourth scenario (scenario 4) allows the natural succession of willow shrubs and birch forest upon non-forest ecosystems of peatlands without any extensive agricultural practices (simulation of the future) (Fig. 6).

The flood extent calculation in the lower Biebrza Basin

The flood extent calculation was performed in this paper based on steady river flow. The water level profile in steady gradually-varied flow was calculated using the standard step method. This method is characterized by dividing the river with compound cross sections into short reaches and
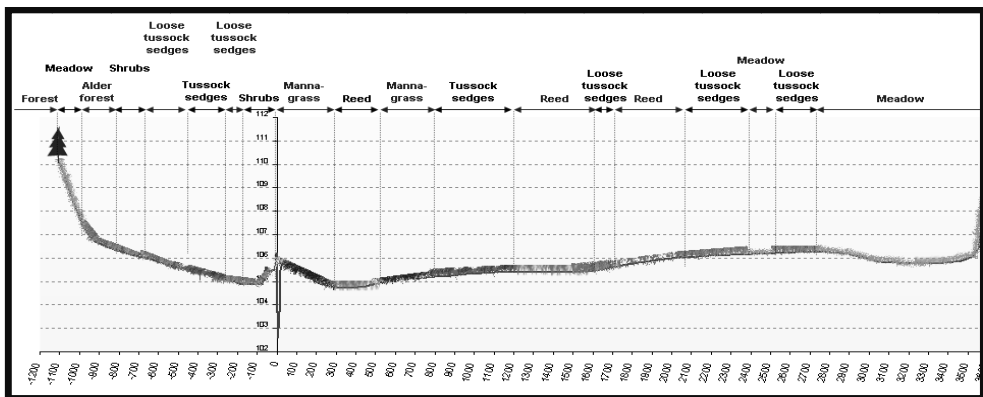

FIGURE 5. Example: Scenerio 3 – willow shrubs and trees cutting (bd3 cross section)
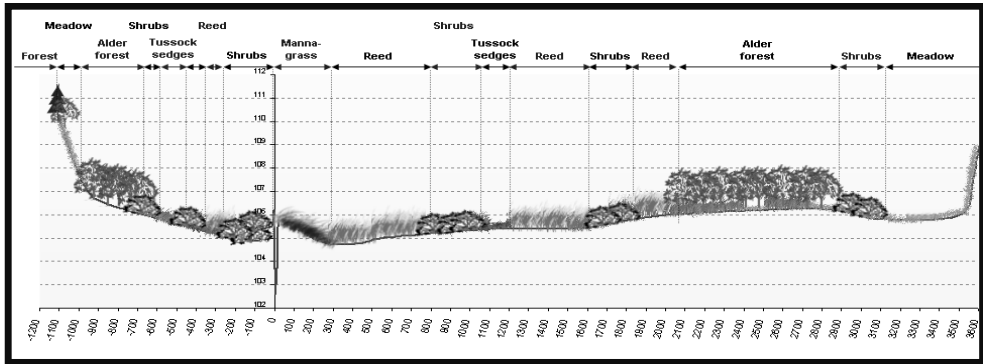
FIGURE 6. Example: Scenerio 4 – natural succession (bd3 cross section)

then carrying the computation gradually from one end of the reach to the other. Problem is formulated as follows:

For a given discharge, there is the river stage H_2 known at one section downstream and it is required to calculate the stage H_1 at the adjacent section upstream. A plan of the waterway is available at the both sections, from which values of cross section area, wetted perimeter, mean velocity, perimeter of vegetation, etc., can be determined for a given stage (Świątek et al. 2006). The discharge of the steady flow in the river was expressed as the product of the velocity and the water area. The mean velocity calculation was made using the Darcy-Weisbach formula. Velocities, friction factors and the components of discharge in the main channel and on the floodplains as well, were calculated according to the type of vegetation using momentum transfer between the main channel and the floodplains (Pasche 1984).

The cross-sections, in the number of 13, were established at the distance of 2–6 km from each other along the river in order to describe the geometry of the river channel and the valley (Fig. 7).

The river bed elevations were measured using manual sounding. The floodplain morphology was represented by the Digital Elevation Model (DEM). The DEM of the Lower Basin was elaborated using ArcGIS by interpolation based upon the ANUDEM procedure (Hutchinson 1996) designed specifically for creation of the hydrologically correct DEM. The main data source was a set of the digital contour lines taken from topographic maps of 1:25 000. Additionally, the floodplain elevation was measured directly in the several cross-sections. The DEM was created with cell resolution of 25 meters and next, verified by surveying (RMS = 0.35 m) (Chormański 2003).

In the computation, the discharge at the upstream cross-section was used as the upper boundary condition, and the water level at the downstream as the lower boundary condition. Since the average distance between measured cross-sections was about 3.4 km the interpolated cross-sections were added with a space step of 0.5 km. The model was successfully verified with help of processed Landsat satellite image and field measurements (Świątek et al. 2006). The water level
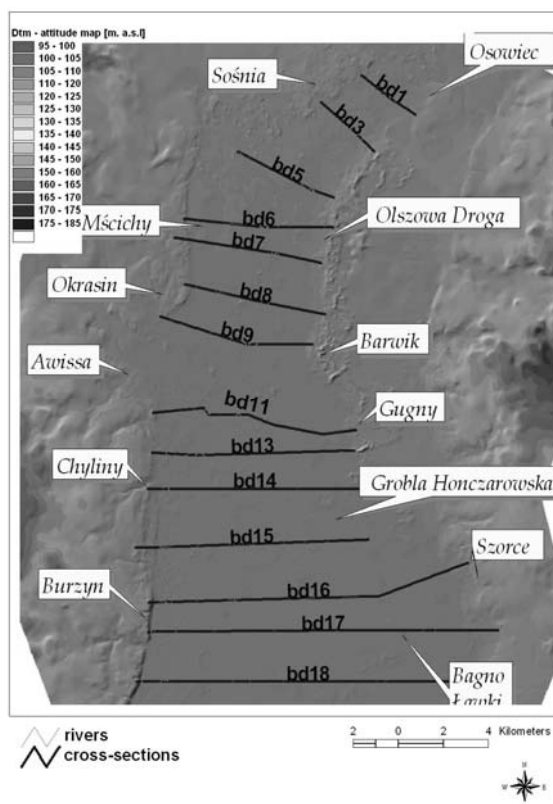
FIGURE 7. The cross sections established in the Lower Biebrza Basin

calculation was performed for the two following cases: absolute maximum (MAX Q = 229.20 m³/s) and mean of maximum flows (AVG Q = 70.51 m³/s) of annual discharges for historical records 1965 to 1996.

The Digital Elevation Model was coupled with the hydraulic model for mapping the extent of the flood in the valley. The water stages were calculated by hydraulic model in cross-sections, then, interpolated into the elevation model of the surface water, and next mapped for the whole floodplain. The flood extent and average flood depth were determined by GIS analysis. This calculation was performed per each grid cell of the valley for the particular management scenarios respectively.

RESULTS AND DISCCUSSION

Table 2 and Figure 8 show results of performed calculation compared to the actual state (scenario 1). Both management activities, grass mowing (scenario 2) and shrubs and trees cutting (scenario 3) decreased the flood extent by about 8% for average flood and 10%, for high flood. The average water depth decreased by 0.03 m and 0.05 m respectively. The difference between these two management scenarios is
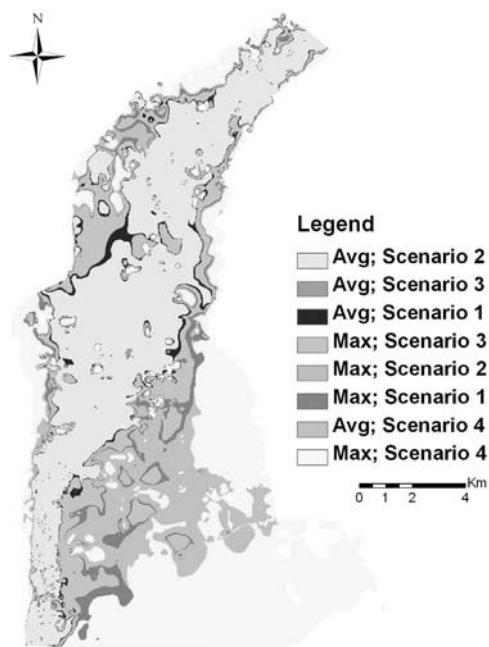
Legend
- Avg; Scenario 2
- Avg; Scenario 3
- Avg; Scenario 1
- Max; Scenario 3
- Max; Scenario 2
- Max; Scenario 1
- Avg; Scenario 4
- Max; Scenario 4

FIGURE 8. The flooded area calculated for different management scenarios

TABLE 2. Variation of the flooded area and the water depth on the floodplain for different land use scenarios (MAX Q = 229.20 m^3/s, AVG Q = 70.51 m^3/s)

Scenario	Flooded area [km^2]	Average depth [m]	Flow condition
1MAX	93.29	0.65	MAX
2MAX	83.84	0.61	MAX
3MAX	83.21	0.60	MAX
4MAX	179.55	1.44	MAX
1AVG	61.35	0.49	AVG
2AVG	56.54	0.46	AVG
3AVG	56.27	0.45	AVG
4AVG	113.74	0.68	AVG

not significant. Scenario 4 (natural succession of the willow shrubs), in which model simulate theoretical situation when there are no changes in environment – no management works – generates very significant differences in both flood extents and water depth. The flood extent increased by more than 100% in both average and high flood, while simulated water depth increased by 0.2 m for average and 0.80 m for high flood.

CONCLUSIONS

The hydraulic model coupled with GIS enables to consider proposed agricultural practices of management scenarios for flood extent and flood water depth in the valley. Insignificant differences in roughness coefficients as well as not enough representation of the floodplain by the DEM, with lack of measurement data, could cause that the flood differences between two management scenarios (grass mowing and shrubs cutting) were slight.

The results obtained show that the variation of the flood extent is related to the vegetation structure of the floodplain. The most significant difference in flood extent was in the scenario in which human management was absent and natural succession of vegetation was taking place. In this scenario birch forest and willow shrubs occurred over large areas of wetland resulting in a significant increase of flood extend and water depth. The ecological consequences i.e. changes of vegetation structure due to the modified flood characteristics should be solve in future development.

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Streszczenie: *Zastosowanie jednowymiarowego modelu hydrodynamicznego do wyznaczania zasięgu zalewu w Basenie Dolnym Biebrzy przy różnym sposobie użytkowania.* W artykule przedstawiono jak różny sposób użytkowania doliny Basenu Dolnego Biebrzy wpływa na zasięg zalewów oraz ich średnią głębokość. Obliczenia przeprowadzono dla przepływu maksymalnego oraz średniej wartości zaobserwowanych przepływów maksymalnych z wielolecia, obejmującego okres 1965–1996. Obliczone jednowymiarowym modelem hydrodynamicznym rzędne zwierciadła wody wykorzystano za pomocą technik GIS i Numerycznego Modelu Terenu do określenia zasięgu oraz średniej głębokości zalewów. Zastosowany model hydrodynamiczny na podstawie ogólnego prawa przepływu Darcy-Weisbacha oraz procesy wymiany pędu i masy pomiędzy korytem głównym a terenami zalewowymi w ujęciu zaproponowanym przez Pasche, pozwala na uwzględnienie w obliczeniach wpływu porastają-cej tereny zalewowe roślinności. Cztery scenariusze użytkowania doliny realizowane są w modelu obliczeniowym poprzez przestrzenną zmienność chropowatości absolutnej roślinności porastają-cej dolinę rzeki. Scenariusze obejmują działania w zakresie ekstensywnego użytkowania terenów podmokłych, jak koszenie, karczowanie i wypasanie rozległych obszarów łąk. Przeanalizowano również scenariusz, w którym rozległe obszary torfowisk nie są objęte użytkowaniem, lecz są pozostawione do naturalnej sukcesji.

Author's address:
Katedra Inżynierii Wodnej i Rekultywacji Środowiska SGGW
ul. Nowoursynowska 166
02-787 Warszawa
Poland