ANALYSIS OF IMPACT OF NATURAL STREAM BED VARIABILITY REPRESENTATION ON COMPUTED WATER SURFACE.

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Abstract: The present paper deals with the impact of parameters such as representation of natural stream bed geometry on computed water surface calculated for the steady state conditions. For computations we used the commercial HEC-RAS [2] package module of steady analysis. The term representation is understood as the number of cross-sections through the river-bed, taken account of in the computation, and the value of the roughness coefficient *n*, determined from the Manning equation for different estimations of the hydraulic slope. Simulation computations were made for a selected segment of the upper Biebrza between water gauges Jastrzębna and Sztabin. Input data into the model consisted of hydrometric measurements made at selected measurement cross-sections and of a longitudinal profile of the water surface in the study area, obtained using the GPS Topcon Legacy GNSS receiver. The obtained results were analysed for the impact of hydraulic parameter variability on the computed longitudinal profile of the water surface.

INTRODUCTION

Determining the water surface along a stream is one of primary hydrological parameters which, when known, makes possible the analysis of numerous factors conditioning the function of river valleys, whether natural or under considerable anthropopressure. The generally applied tool – hydraulic model - is suitable for calculating water surface profiles for the steady gradually varied state. The basic computational procedure involves solving the one-dimensional energy equation. Water surface profiles are computed from one cross-section to the next by solving the energy equation with an iterative procedure, known as the standard step

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method. The formula and the method of its solution as such are relatively straightforward and widely discussed in literature of the subject eg. [1] [3]. An important point to establish is the sensitivity of the obtained solution in view of its constituent hydraulic parameters obtained from hydrometric measurements. Obviously it would be best to have at hand the greatest amount of data possible but in this we are constrained by budget available for the measurement campaign, the potential offered by the equipment, and last but not least accessibility of the studied area, which in case of natural river bed may be pose a considerable challenge for geodesic survey in floodplain areas. This makes output from numerical simulations demonstrating the sensitivity of the hydraulic model to parameters for natural river bed of great value and potentially important for arriving at the best possible methodology for obtaining data for numerical models. The purpose of the present study was to analyse, using a selected 16 km long segment of the upper Biebrza, model sensitivity to bed geometry representation and to the value of the Manning coefficient. The choice of the analysed segment was dictated by data availability and the natural features (e.g. active meandring process, micromorphology of the river bed, lack of hydraulic structures, etc) of the Biebrza River.

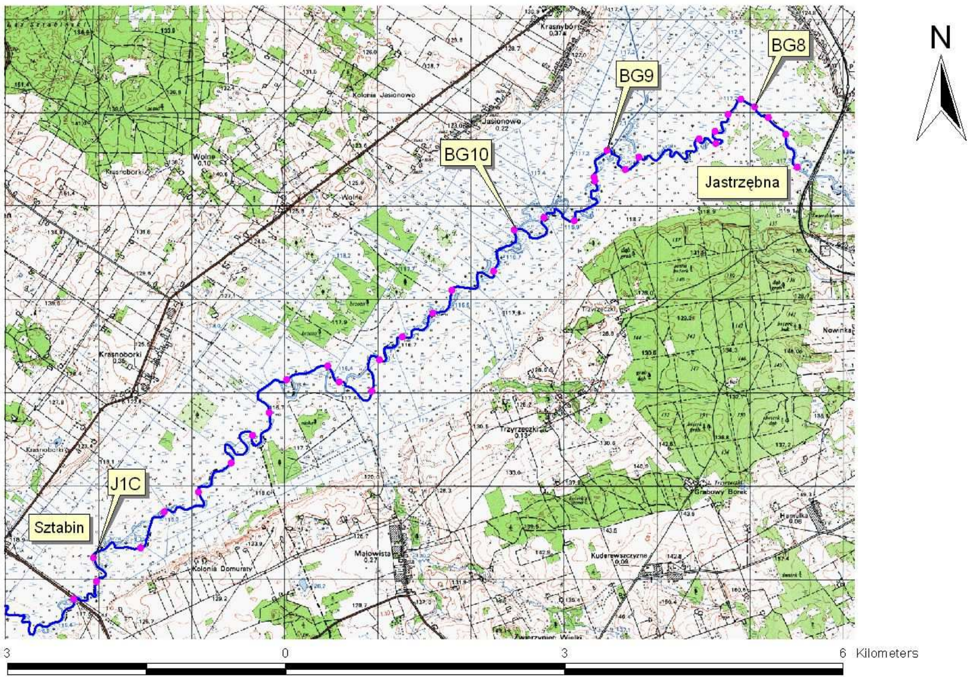

Figure.1. Points for measuring the water surface ordinate

ANALYSIS OF SIMULATION COMPUTATIONS

Measurements of water surface over the 15.83 km segment between water gauges Jastrzębna and Sztabin were made using the GPS Topcon Legacy GNSS receiver ensuring spatially accurate and real-in-time results. Water surface levels were recorded at 35 points (fig.1), lying, on the average, ca. 200m apart. The obtained longitudinal water surface profile is shown in fig.2.

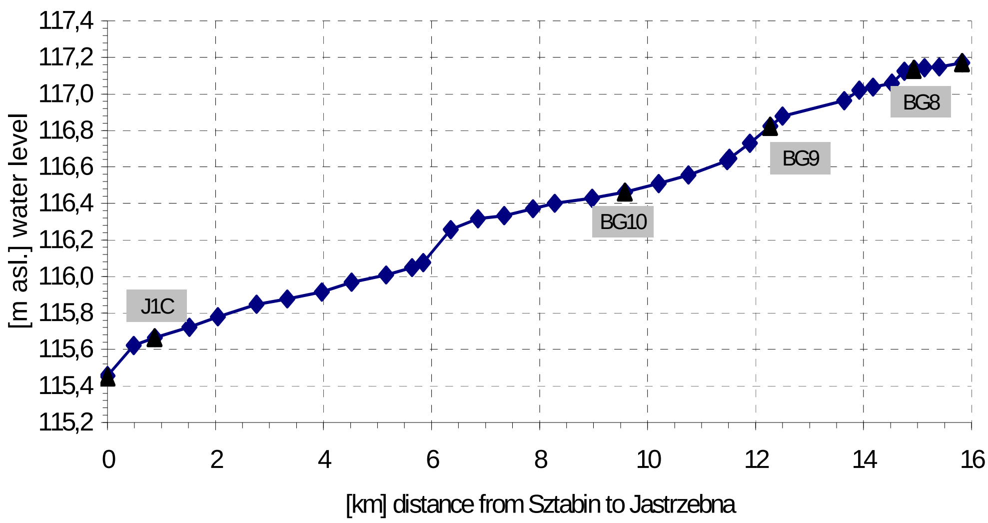

Fig.2. The measured longitudinal water surface profile (14.05.2003)

Hydrometric measurements were also made at six selected cross-sections (Tab.1), used subsequently in computing the basic hydraulic characteristics.

Tab.1. Hydraulic characteristics at measurement cross-sections

Cross section name	Localization along river [km]	A [m2]	R [m]	Q [m3/s]	S_f	n
Sztabin	0	28.83	0.98	3.04	0.000342	0.173
J1C	0.88	29.72	1.83	3.00	0.000087	0.138
BG10	9.58	33.11	1.74	2.63	0.000075	0.158
BG9	12.27	14.14	1.14	2.51	0.000241	0.095
BG8	14.93	31.92	1.69	2.40	0.000051	0.135
Jastrzebna	15.83	39.22	1.53	2.36	0.000054	0.162

Coefficient *n* was calculated from the Manning formula:

$$Q = \frac{1}{n} A R^{\frac{2}{3}} \sqrt{S_f} \qquad (1)$$

where the water surface slope, S_f, was calculated locally for each cross-section, using the measured longitudinal water surface profile.

$$S_f = \frac{H_{i+1} - H_{i-1}}{\Delta L} \qquad (2)$$

where:

H_{i+1} – water surface at the closest measurement point located upstream from the hydrometric cross-section,

H_{i-1} – water surface at the closest measurement point located downstream from the hydrometric cross-section,

ΔL – distance between measurement points *i+1* and *i-1.*

Cross-sections shown in Tab.1. were used in the identification of the hydraulic model of steady state flow in the Biebrza River in the reach between Jastrzębna and Sztabin, using HEC-RAS package. The upper boundary condition in the model was assumed as the flow measured at Jastrzębna, with the water surface at Sztabin defining the boundary condition at the most downstream profile. Flow from the differential catchment ($Q_{Sztabin}$-$Q_{Jastrzębna}$) was distributed uniformly as lateral inflow along the stream reach. The computed and measured water surface levels are shown in fig.3.

The computed mean square error of the model (MSE) (fig.4) was at 0.07m, the determination coefficient (R^2) - 0.999. As a next step, analysis was made of the impact of different methods of estimating water surface slope on the value of the Manning coefficient and as such on water surface ordinates computed in the model. In a variant referred to subsequently as ver-I, water surface slope (S_f) was computed as the difference in water surface levels between two successive cross-sections divided by the distance between them. Because frequently only the water surface levels at the water gauge cross-sections are available, in another variant (ver-II), S_f was determined on the basis of water surface ordinates for water gauges at Jastrzębna and Sztabin. In both variants the value of the roughness coefficient *n,* at hydrometric cross-sections was calculated from formula 1, the results obtained are shown in fig.5.

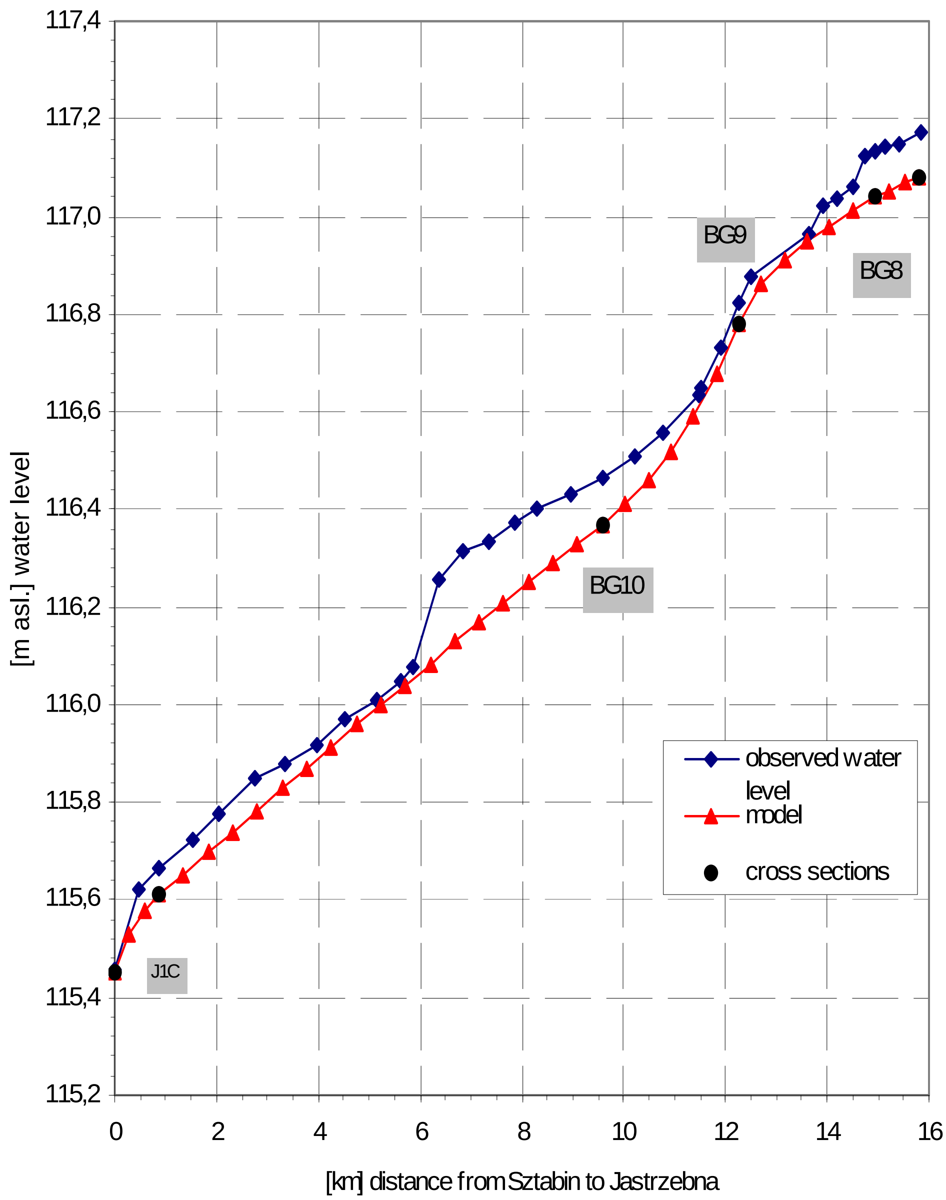

Fig.3. The measured and computed water surface levels

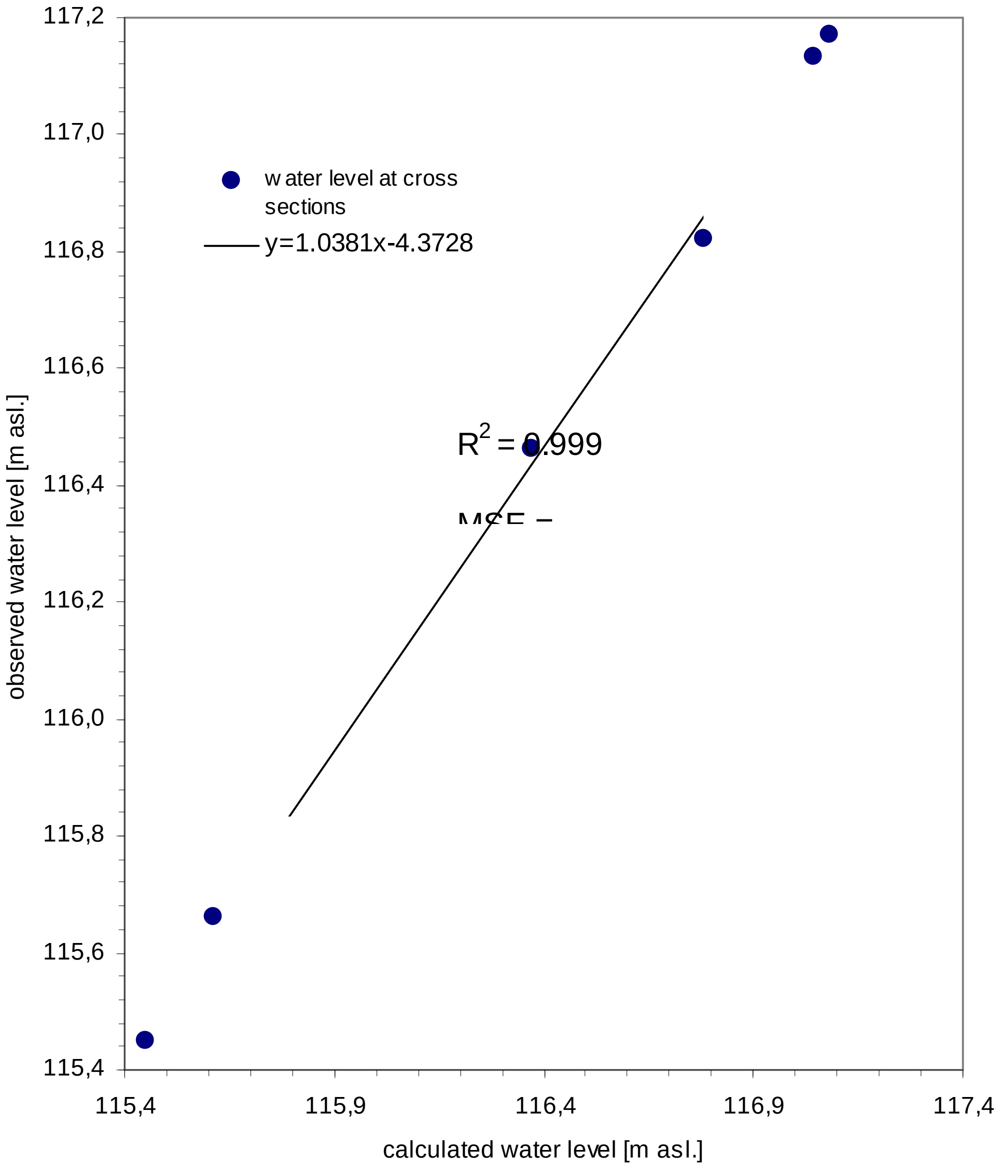

Fig.4. Model verification.

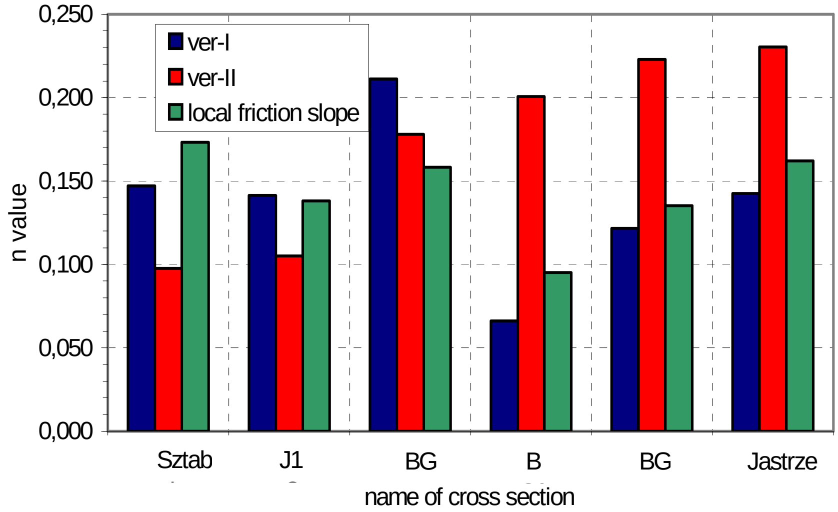

Fig.5. Manning coefficient values calculated for different variants.

In Variant ver-I differences in the value of *n* related to computations (local friction slope), where the local water surface slope was calculated from formula (2), maximum differences did not exceed 33%. Estimation of water surface slope for a segment of a natural river on the basis of readouts from water gauges separated by several to a dozen odd kilometres leads to substantial differences in the value of the Manning coefficient, which in this case may even reach 111% (ver-II fig.5). Different values of *n* also essentially influence the computed water surface levels. Maximum differences in ordinates were as high as 0.5m (fig.6).
The next important question related to modelling water flow in rivers is the impact of representation in the hydraulic model of river bed shape variability. In numerical computations this is reduced to the Δx (distance between the cross-sections) and hydraulic parameters (active surface, hydraulic radius) of cross-sections of the bed, included in computations. In the analysed example stream geometry is represented by 6 cross-sections (fig.3, Tab.1). In successive simulations we studied the impact on water surface levels of reduced representation of stream bed geometry. This was done by removing one of four cross-sections between Jastrzębna and Sztabin. Manning coefficients for the remaining cross-sections were the same as in the local “friction slope” variant. Highest differences in the computed water surface were noted after removal of cross-sections showing a relevant difference in the Manning coefficient values related to the *n* for the preceding or succeeding cross-section (fig.7). This was particularly noticeable after cross-sections J1C or BG9 were removed.

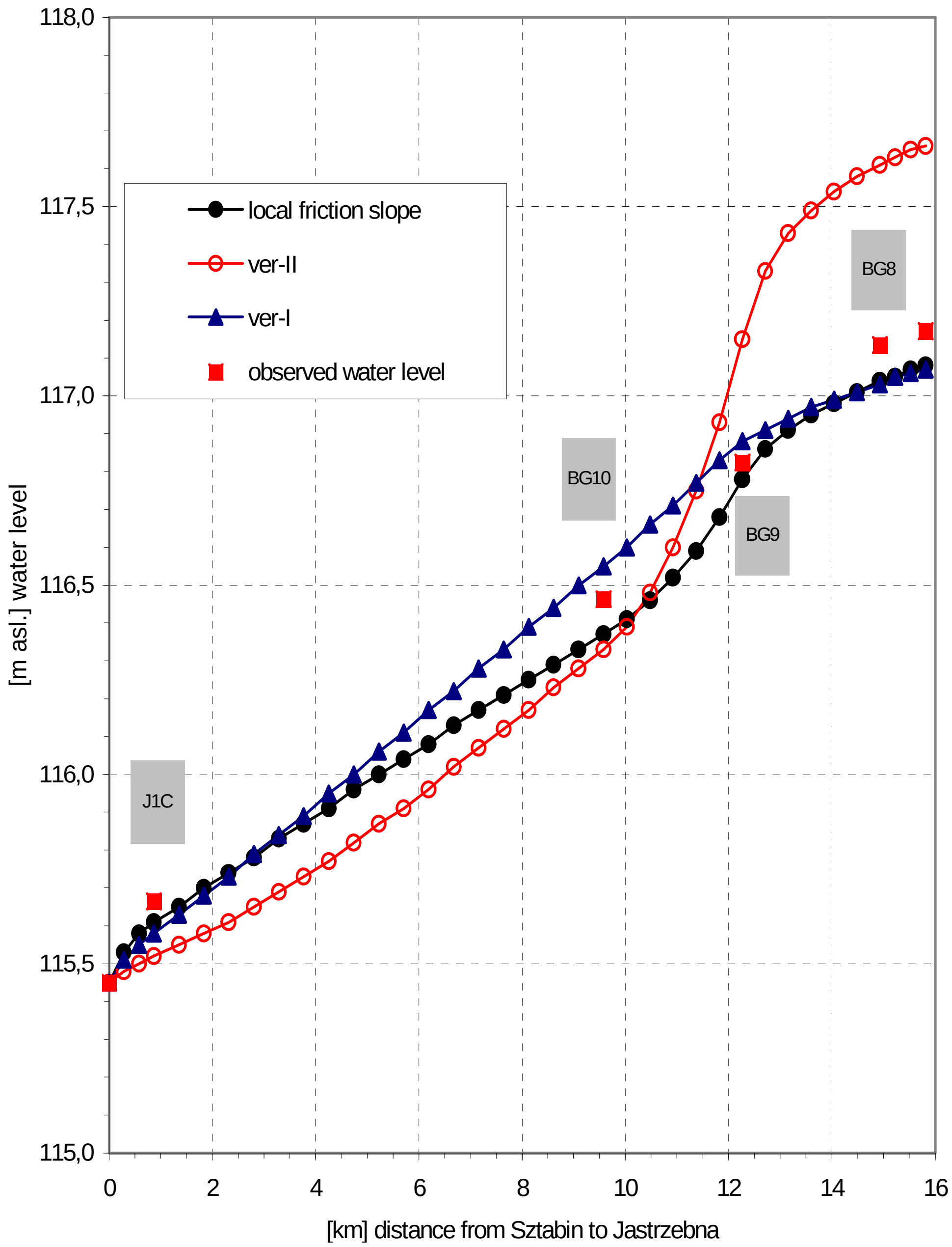

Fig.6. Computed water surface (Manning coefficient calculated for different S_f)

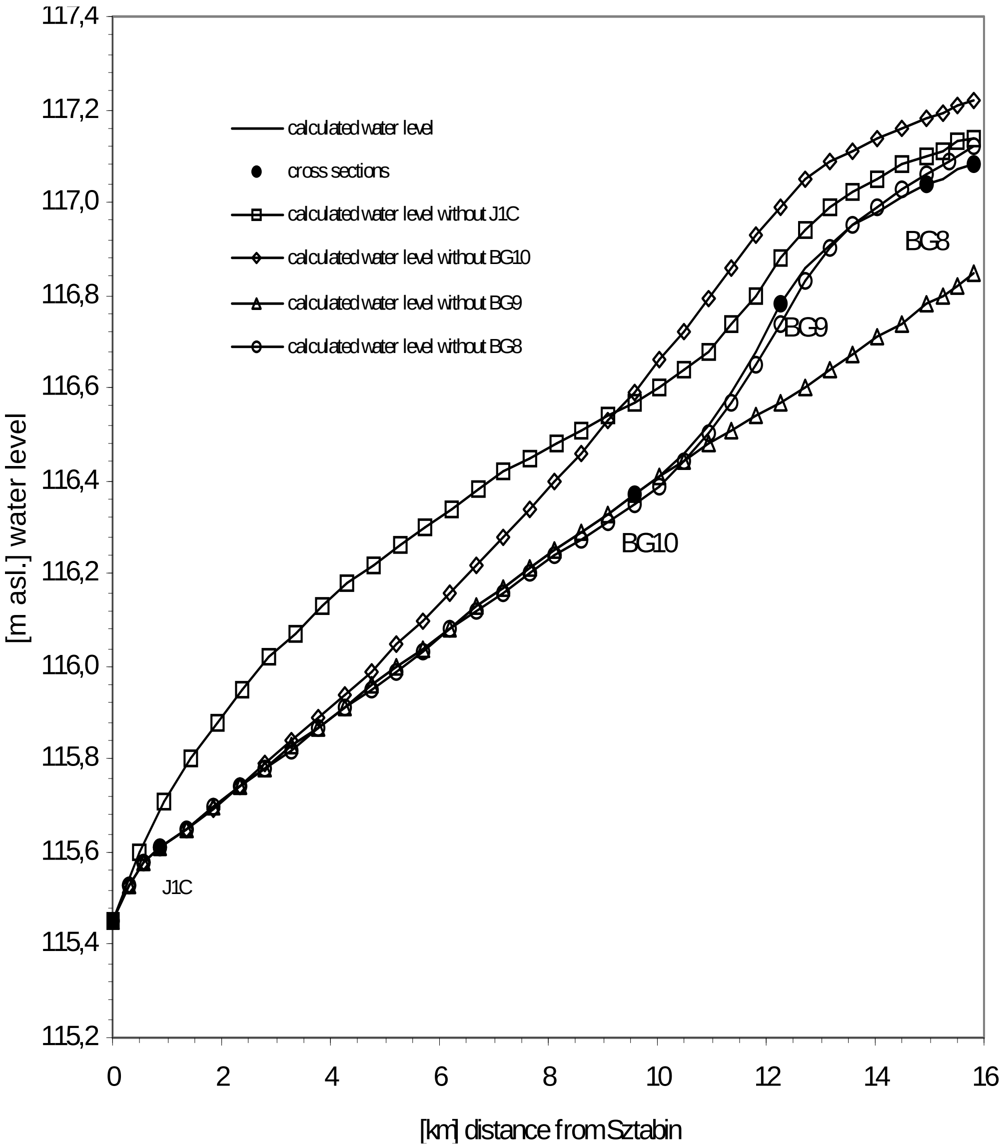

Fig.7. Computed water surface for different representations of river geometry in the Jastrzębna-Sztabin segment

CONCLUSIONS

Numerical simulations of the steady water surface in the upper Biebrza reach, between water gauges Jastrzębna and Sztabin indicate that in a case of natural river, in which due to the flow conditions water surface slopes are characterised by substantial variability, hydraulic parameters need to be determined from local measurements made for the analysed hydrometric cross-section. When the *n* coefficient is calculated from the Manning formula (1), where S_f is determined on the basis of water gauge readouts or measurements made for measurement points separated by several kilometres, this leads to considerable differences. Seeking to arrive at a correct representation of the river bed in the model it is necessary to make measurements of the longitudinal profile of the water surface and to measure the cross-section geometry at points, where slope is varying. In contrary, making measurements of the shape of cross-sections with a constant distance along a river , eg. every kilometre, does not guarantee correct mapping of hydraulic parameter variability of a river in a numeric model ([4], [5]). It means, that there is no question to have the appropriate number cross-sections but to have them adequate located with regard to the actual changes in bed morphology. Appropriate methodology of carrying of the measurement-taking campaign seeking to obtain input for the hydraulic model should base first of all on obtaining a longitudinal profile of the water surface and the river bottom as well as its width. In the next step locations of hydrometric cross-sections should be identified should be to identify, basing on the analysis of variability of longitude slopes and river bed morphology.

REFERENCES

Chanson H., 1999: *The Hydraulics of Open Channel Flows : An Introduction*., Butterworth-Heinemann, Oxford, UK.

HEC, 2000: HEC-RAS *River Analysis System - User's Manual*. US Army Corps of Engineers Institute for Water Resources Hydrologic Engineering Center.

Mahmmood, Yevjevich 1975: *Unsteady flow in open channels*. Water research publications. Fort Collins, Colorado.

Nuge, Holly, Verwey, 1980: *Practical aspects of computational river hydraulics*. Pitman Advanced Publishing Program, Boston, MA.

USACE, 1993: *River Hydraulics*. Engineer Manual 1110-2-1416, Headquarters, U.S. Army Corps of Engineers, Washington, DC, October 1993.