

## Development of a MIKE11 Model of the Danube, Tisa and Sava Rivers in Serbia

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### **Keywords**

MIKE11, flood risk management, Serbia.

### **Abstract**

The Tisa and Sava rivers, which are major tributaries of the Danube River by basin area and flow, join the Danube within the territory of Serbia. Peak flows of these rivers usually occur in early spring due to snowmelt.

After more than a two-decade-long dry period, extremely high water levels of the Danube River were recorded in 2002, 2005 and 2006. In the spring of 2006, peak flows of the Danube and its tributaries occurred at nearly the same time, resulting in an extreme situation in the lower Danube. These events drew the attention of the general public, water management companies and professionals to flood risk mitigation strategies, keeping in mind ongoing socio-economic development of the flood-prone areas and the predicted climate change and variability. It was concluded that an indispensable step toward the improvement of a flood risk mitigation strategy would be the development of an up-to-date flood routing model for major rivers in Serbia. This model would later be used to estimate the efficiency of possible flood retention and other flood defense measures.

MIKE11 software was used to develop an unsteady model of the Danube, Tisa and Sava river stretches in Serbia (the Danube from the Hungarian border at km 1434 to Smederevo at km 1116, the Tisa River from the Hungarian border at km 157 to its mouth, and the Sava River from the Croatian border at km 210 to its confluence with the Danube). The model covers the complex channel network of these alluvial rivers, including main river channels, channel bifurcations around river islands and branches along large floodplains. Main river channels are well defined in the model, with 700 cross sections surveyed in 2004 at approximately 1 km distance. Due to a lack of DTM, the geometry of floodplains was defined by using available, somewhat inaccurate topographical maps. The estimate of the Manning roughness coefficient for floodplains was based on satellite imagery. Daily water levels recorded by the gauging station at Smederevo are the downstream boundary, while daily inflows at border cross-sections of the Danube, the Tisa and the Sava are the upstream boundaries of this complex flow model. The model also takes into account the inflow from second-order tributaries (such as the Drava and Tamiš rivers discharging into the Danube, and the Drina and Kolubara rivers discharging into the Sava River).

Model calibration was based on a 2006 hydrological dataset. The Manning roughness coefficient of the main river channel was adjusted during the calibration process. The model was verified against a 2005 hydrological dataset.

This paper presents a detailed description of the model development process and of the experience gained thereby. It also outlines possible future uses of the developed model.

## INTRODUCTION

The northern part of Serbia is situated in a lowland area where the Danube River meets its two largest tributaries (both by discharge and catchment area) – the Tisa and the Sava (Figure 1), which significantly increase the Danube's discharge.

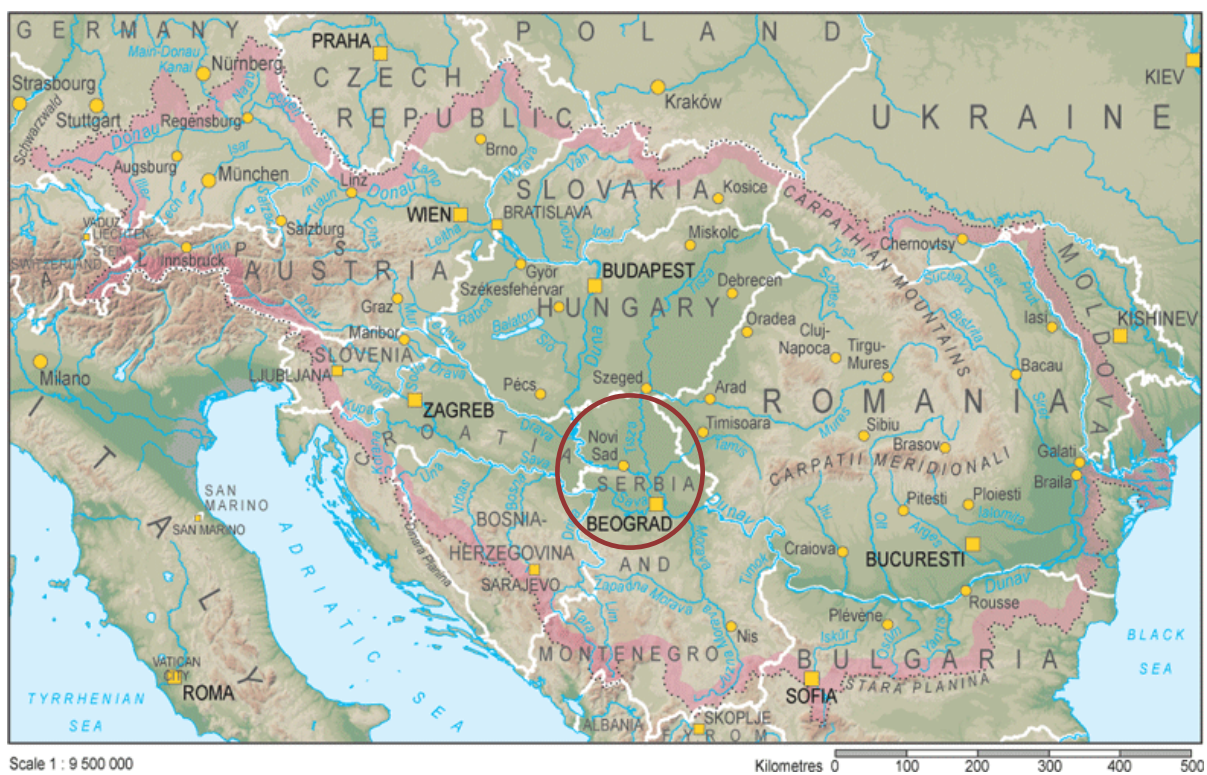


Figure 1: Location of the study area within the Danube River Basin (Source: UNEP, 2008)

The flow regimes of the Danube, Tisa and Sava in Serbia depend on snowmelt and rainfall; high water levels along these alluvial rivers usually occur in the spring. The most extreme situations are seen when snowmelt coincides with heavy rainfalls within the catchment area. Settlements in the former floodplains of these rivers are protected from flooding by levees, which can accommodate 100-year floods. However, due to increased development of human settlements and economic assets, and predicted but uncertain climate change, there is a need to accept a certain risk and adjust the present flood defense scheme to a “living with floods” concept. This concept would consider, among other measures, the use of the former floodplains for temporary storage of flood water, to reduce peak flood levels downstream.

So far, none of the institutions in Serbia responsible for flood defense has a hydrodynamic flow model which could be used for flood level forecasting along the levees or for the planning of a new flood management scheme. Therefore, a MIKE11 model of the Danube, Tisa and Sava river stretches in Serbia was developed to enable the assessment of flood management measures.

## MODEL DESCRIPTION

The model (Figure 2) covers the Danube River (from the Hungarian border at km 1434 to the town of Smederevo at km 1116), the Tisa River (from the Hungarian border at km 157 to its mouth), and the Sava River (from the Croatian border at km 210 to its confluence with the Danube). The flow is considered negative (from higher to lower river chainages).

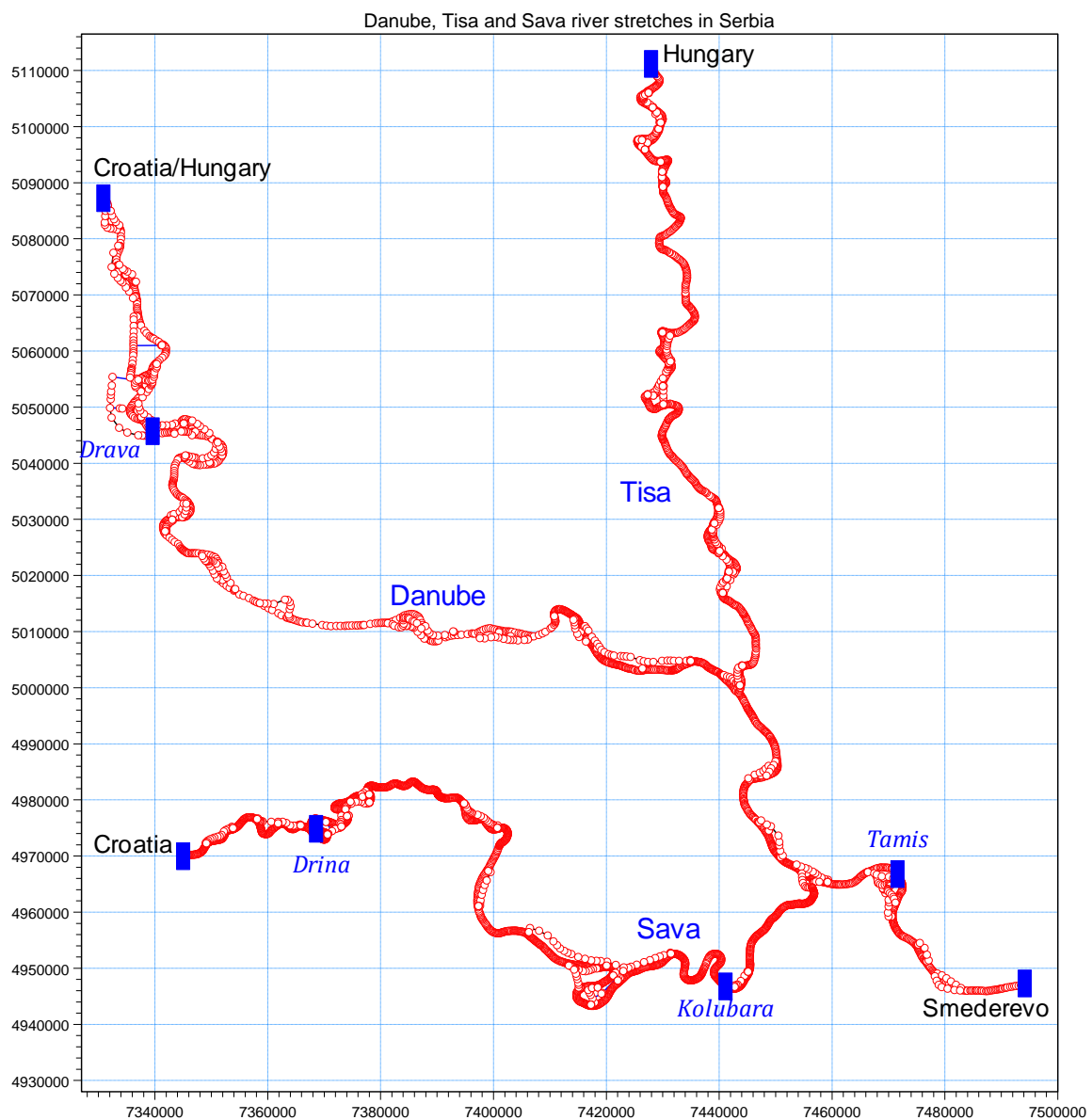


Figure 2: The model network with hydrodynamic boundaries

Three main branches represent the low-flow channels of the Danube, Tisa and Sava rivers (or the low-flow channels with floodplains along straight river stretches). There are also 16 branches around large islands which are directly connected to the main branches, and 53 branches along floodplains, mainly at river bends. The floodplains are connected to the main channel by link channels. Low-flow channels were defined with about 700 cross-sections in total, surveyed in 2004 at approximately 1 km intervals. Due to a lack of digital data, 10 to 40 year-old topographical maps were used to define floodplain width and topography. Low-flow channels and floodplains were defined with markers and coordinates of the left/right ends of cross-sections. The fitting of parallel branches cross-sections is shown in Figure 3.

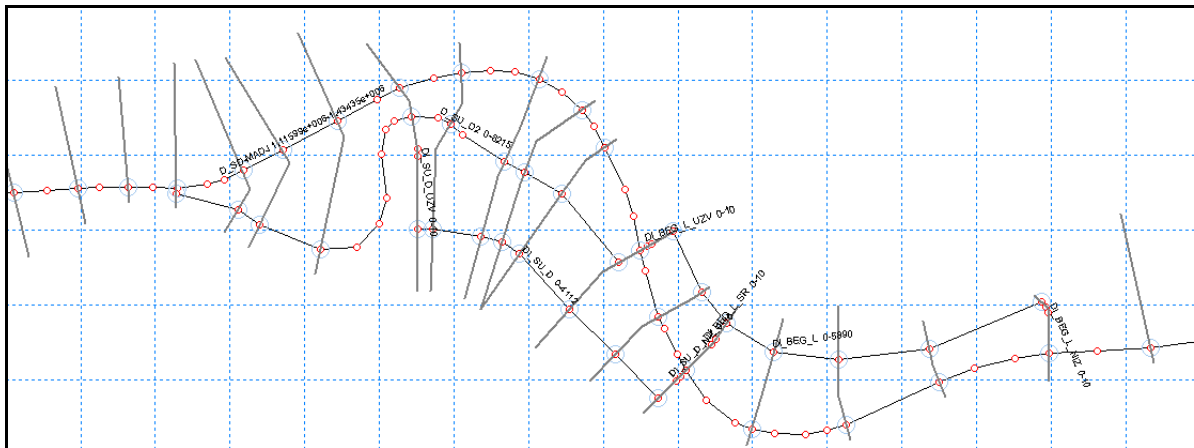


Figure 3: Complex river network with cross-sections

The resistance of the channel bottom and floodplains was described by the Manning roughness coefficient ( $n$ ). A 'uniform' transversal distribution was used for floodplains and 'high/low flow zone' distribution for composite cross-sections. Satellite images (Google Earth) were used to estimate type and density of vegetation on the floodplains, while Manning values were assigned according to Chow (1959) and Hjalmarson (1991), as modified by Phillips and Tadayon (2007). Daily water levels recorded at the Smederevo gauging station on the Danube are the downstream boundary, while daily inflows of the Danube (derived for the Bezdán monitoring station), the Tisa (at Senta) and the Sava (at Županja in Croatia) are the upstream boundaries. The model also takes into account the inflow from second-order tributaries such as the Drava and Tamiš rivers, which discharge into the Danube, and the Drina and Kolubara rivers which discharge into the Sava River (see Figure 2). Initial conditions were defined in the hydrodynamic parameters file on the basis of gauged water levels, while the initial water level in the floodplains was set at the bottom level of the cross-section. In order to speed up the model, cross-sections were divided into 60 levels for processed data computation. For the same reason, the 'Delta' value in the Computation Scheme of the Default Values in the HD Parameters file was increased from the initial 0.5 level to 0.7, which means that in the numerical scheme more weight is given to the previous time step result, leading to an improved stability of the model. As a result, this complex model can run with a fixed time step of 15 minutes, taking less than 9 minutes to complete a 1-year simulation.

## CALIBRATION AND VERIFICATION OF THE MODEL

The model was calibrated using the 2006 data set. Namely, an extreme hydrological event occurred in the spring of 2006, when peak flows of the Danube and its tributaries occurred at nearly the same time. As a result, very high water levels were recorded on the lower Danube (downstream of the mouth of the Sava River) – the return period of the peak was approximately 100 years. A smaller flood wave on all three rivers occurred in June.

The calibration procedure consisted of adjustments of the Manning roughness coefficient ( $n$ ) of the riverbed. Adopted values for the low flow channels of the Danube, Tisa and Sava are 0.027 to 0.035  $m^{-1/3}s$ . These values can be considered satisfactory as they fall within the Q-n curves previously developed for different river sections. The roughness of the floodplains was only slightly modified from initial values, without any adjustment of floodplain geometry. The model was less sensitive to changes of floodplain parameters than to bed roughness variation. Variation of link channel parameters has shown good results in the case of branches across large wetlands, such as Kopački Rit near the Danube and Obedska Bara near the Sava. Low water levels along the Tisa River are controlled by a barrage at km 63 from the mouth of the Tisa, which was not modeled due to its complexity. Therefore, the model was calibrated only for high flow conditions (above 1200  $m^3/s$ ), when gates at the barrage are fully open.

At the end of the calibration phase, the model gave satisfactory results for both low and high water flows (hydrograph shapes and peak values). A comparison of flood peaks observed in April 2006 at 7 gauging stations on the Danube, 5 on the Tisa and 5 on the Sava, and the model results, are shown in Table 1 (where  $\Delta T = T_{comp} - T_{obs}$  and  $\Delta H = Z_{comp} - Z_{obs}$ ). Observed and computed 2006 hydrographs for the gauging station at Novi Sad are presented in Figure 4.

*Table 1: CALIBRATION – Differences between peak observed and peak modelled values*

River	Monitoring station	$\Delta T$ (day)	$\Delta H$ (m)	Peak error (%)
Danube	Pančevo	0	0.03	0.04
	Zemun	0	0.01	0.01
	Slankamen	0	0.05	0.07
	Novi Sad	1	-0.06	-0.08
	Bačka Palanka	1	-0.20	-0.25
	Bogojevo	1	-0.17	-0.20
	Bezdan	1	0.11	0.13
Tisa	Titel	-2	0.01	0.01
	Novi Bečej	0	-0.28	-0.36
	Padej	1	-0.03	-0.03
	Senta	1	-0.04	-0.05
	Novi Kneževac	1	-0.20	-0.24
Sava	Beograd	0	-0.03	-0.04
	Beljin	1	-0.12	-0.15
	Šabac	1	0.03	0.04
	Sremska Mitrovica	-1	0.00	0.00
	Jamena	0	-0.20	-0.24

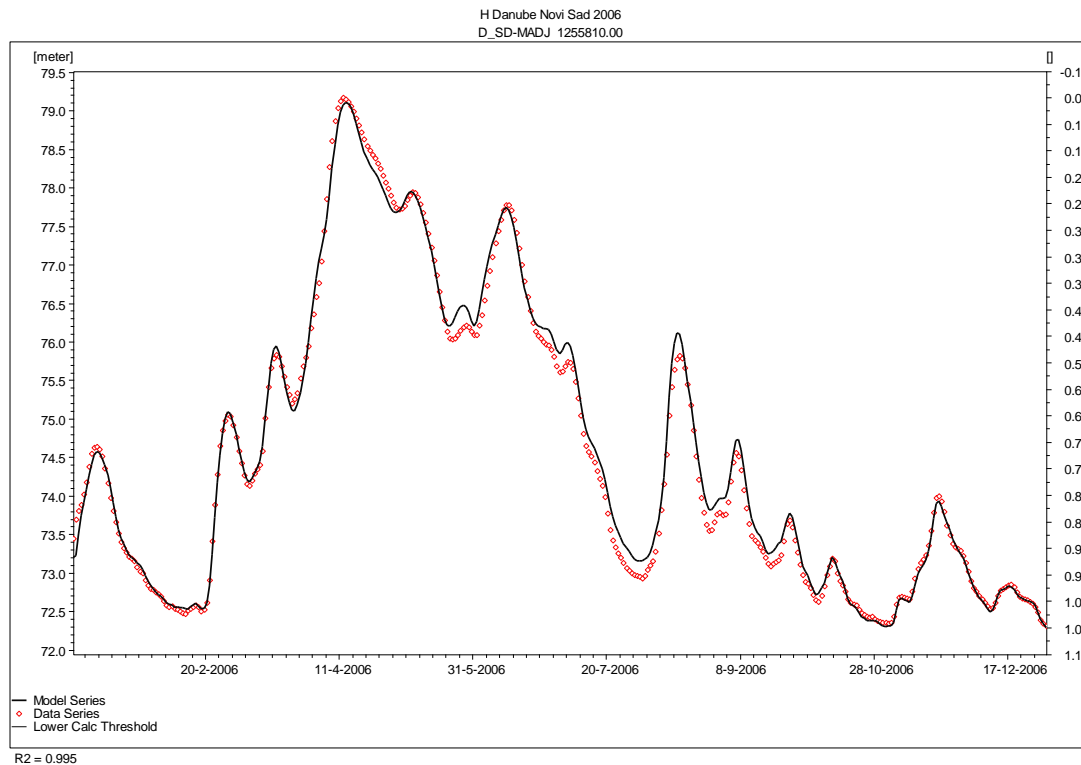


Figure 4: CALIBRATION – Observed and modelled hydrographs at the Danube by Novi Sad

Model verification was based on a 2005 hydrological data set, with a significant flood wave on the Sava River. Three small flood waves occurred in 2005 along the Danube and one long flood wave (2.5 months) on the Tisa. Peak deviations of the flood waves which occurred in period March – May 2005 are shown in Table 2, while a comparison of observed and computed hydrographs for the Novi Sad gauging station is presented in Figure 5.

Table 2: VERIFICATION – Differences between peak observed and peak modelled values

River	Monitoring station	$\Delta T$ (day)	$\Delta H$ (m)	Peak error (%)
Danube	Pančevo	-1	-0.14	-0.19
	Zemun	-1	-0.17	-0.23
	Slankamen	-1	-0.16	-0.21
	Novi Sad	-1	-0.18	-0.24
	Bačka Palanka	-1	-0.16	-0.21
	Bogojevo	-1	-0.26	-0.31
	Bezdan	0	-0.09	-0.11
Tisa	Titel	-1	-0.15	-0.20
	Novi Bečej	0	-0.17	-0.22
	Padej	0	-0.10	-0.13
	Senta	0	-0.08	-0.10
	Novi Kneževac	0	-0.08	-0.10
Sava	Beograd	0	-0.13	-0.18
	Beljin	-1	0.05	0.07
	Šabac	-1	0.23	0.29
	Sremska Mitrovica	-1	0.20	0.26
	Jamena	-2	-0.10	-0.12

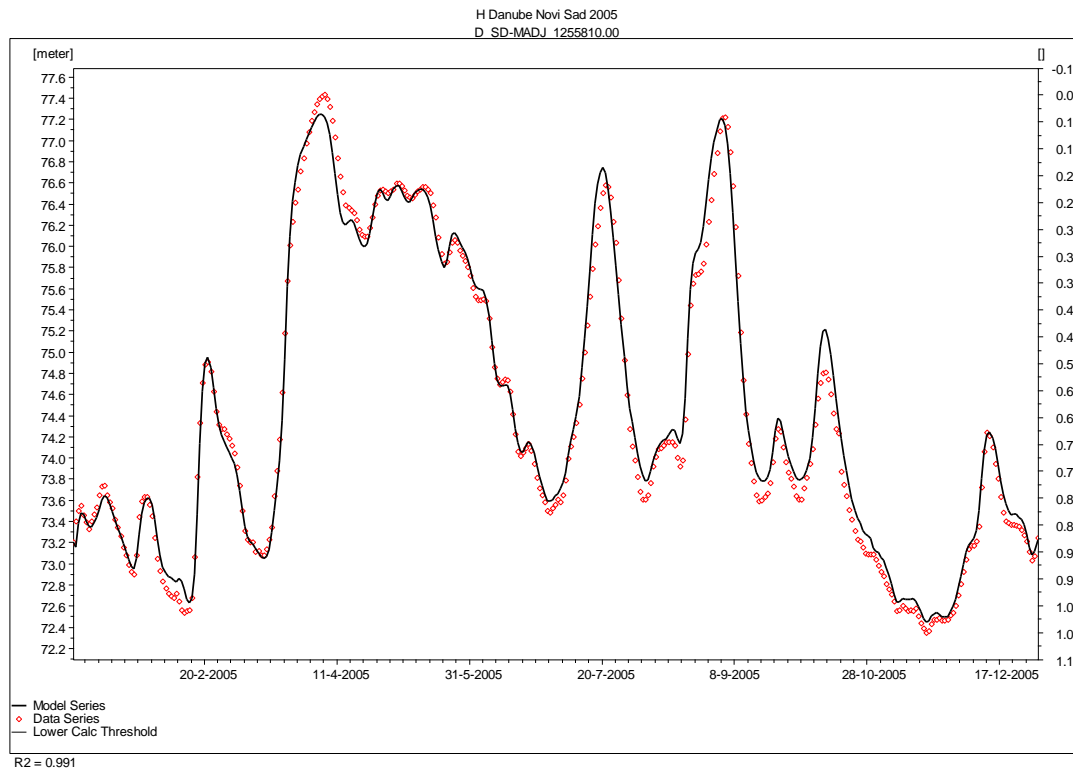


Figure 5: VERIFICATION – Observed and modelled hydrographs at the Danube by Novi Sad

## UNCERTAINTIES OF THE MODEL

The main uncertainties in model performance are related to hydrological and morphological input data. Water discharges of the Danube, Sava and Tisa rivers are derived from rating curves, which are not very accurate in the domain of flood water levels. In case of the Sava River and second-order tributaries, daily water discharges are determined at monitoring stations which are quite far upstream from the modeled area. An example is the Tamiš River, which empties into the Danube near Pančevo. The river discharge is determined 113 km upstream of the mouth, while the influence of downstream large flood plains and flow redirection through the Danube-Tisa-Danube channels is not monitored. Another source of error may be poor representation of the morphology of floodplains and bifurcations. As previously explained, their cross-sections were not represented by surveyed data but were derived on the basis of inaccurate topographical maps and assumptions.

## DISCUSSION

The resulting water level hydrographs have shown that the model can be used for simulations of both high and low water flows along the Danube and Sava rivers. With regard to the Tisa River, the model can be used only for high water flows, because the barrage which controls low water levels was not modelled.

The model is very sensitive to changes of the bed roughness coefficient and less sensitive to changes of floodplain parameters, which proves the fact that on these large rivers, majority of the flood water volume is carried through the main channel.

Inflows from five second-order tributaries, represented in the model as point sources, have different levels of importance. The inflow from the Drava River has a significant influence on the downstream discharges, both in cases of low and high flows of the Danube. Conversely, only extreme floods on the Tamiš River can influence the Danube's discharge in the downstream section. The two tributaries of the Sava River have completely different characteristics: while the discharge from the Drina River is very significant, inflow from the Kolubara River is negligible.

## **CONCLUSIONS**

The model of the Danube, Tisa and Sava river stretches in Serbia was calibrated using a 2006 data set and verified using 2005 flows. The resulting hydrographs have a good shape and acceptable deviations of peak water levels.

The model can be used for the assessment of flood mitigation measures (e.g., the use of lowland retentions) and flood defense measures (e.g., the erection of temporary flood defense structures on top of existing, low levees or quay walls), in cases of extreme hydrological situations. All the above mentioned measures are very delicate and costly, and must be organized in a timely and accurate manner. From that point of view, this model can be used to plan such measures because it computes the water levels and time of occurrence of flood peaks quite well.

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