ГОДИШНИК НА УНИВЕРСИТЕТА ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ – СОФИЯ

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TISZA RIVER MODELLING ON THE COMMON INTEREST SECTION OF HUNGARY AND SERBIA

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Keywords: *hydraulic calculation; Tisza river model*

Research area: *river systems modeling*

ABSTRACT

This work describes the methodologies used in performing the one- dimensional flow calculations within HEC-RAS. With HEC-RAS we perform one-dimensional water surface profile calculations for steady gradually varied flow in natural or constructed channels. Subcritical, supercritical, and mixed flow regime water surface profiles were calculated. We also used equations for basic profile calculations; cross section subdivision for conveyance calculations; composite Manning's n for the main channel; velocity weighting coefficient alpha; friction lossevaluation; contraction and expansion losses; computational procedure; critical depth determination. This produced a prognostic-simulation model that links the whole catchment area of the Tisza river from Ukranian borders to Tisa river inflow into the Danube in Serbia provides an integrated approach to the problems of water control. The model enables integrated management of river systems in both countries and the regulation of the impact of high water.

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1. Introduction

Because of its returning and gradually increasing, and sometimes extremely high floods as well as of recurring and lasting law water periods the River Tisza is considered to be the most variegated river in this part of Europe. Characteristics of the river decisively originate from the shape of the catchment system, from the relation between the water output of tributaries and that of the main stream, from the considerable amount of drift and stream deposit, from the slight slope on the long lowland section of the river, form the extreme climate and from the regulation of both low and high water bed.

The effects of human interventions can be demonstrated along each stream kilometre of the Tisza as well as on each square kilometre of its catchment system. The run-off conditions of flood waves have changed across the full water level range. The river, practically from its region of source down to the mouth flows between embankments. On the catchment area of the River Tisza there are a number of head works, both public and industrial or agricultural with different purposes. Total joint capacity of these head works exceeds the water output of the river in the Tisza Valley at the time when conditions of low water are prevailing. River Tisza, with its catchment area of 157.200 square km is considered to be the most important tributary of the water system of the River Danube. Approximately 30 percent of the total catchment area of the River Tisza lies on the territory of Hungary while the further 70 percent is to be found on the territory of Slovakia, Ukraine, Romania and the Serbia [7].

Most of the river basin area is covered by impermeable (magmatic, metamorphous) rocks, and by semi-permeable (tufacoeus, foliated, marly) layers as well as soils of different permeability over these formations [7].

Vegetation cover has an important role in the soil protection. Considerations on the role of forests on the catchment area are rather different. According to certain professionals the forests are not able to significantly reduce the run-off of waters deriving from rainfalls of extremely high intensity. Differences in some percentage of forest covered areas have no significant affect on to the run-off. However, the reduction of forest covered area up to more ten percents results in considerably increased collection of water and erosion [3]. At the beginning of 1900s 5 to 8 percent of the flood plain was covered by forest, while this proportion reaches up to 40 to 60 percent today. This difference, however, considerably decreases the water discharge ability of the river in case of high-waters [7].

2. Methodology

2.1. Climate conditions of the catchment system

In the formation of climate conditions on the catchment area of the River Tisza there are four air mass groups playing a decisive role. The arctic continental air having lower moisture content, but delivers air waves being cooler by 10 to 15 ^{o}C. Air waves arriving from the northern section of the moderate belt, i.e. from the Atlantic Ocean deliver milder air in winter and cooler in summertime as compared to that of the Carpathian Basin, however, with higher humidity in both cases. Air masses from inside the Eurasian continent deliver rather cold and dry air in winter period and that of slightly warming character in summertime. The fourth group of air masses is constituted by warm zone air, i.e. the one arriving through the Mediterranean Sea. Arrival of these air waves is accompanied by warming up and regularly by rainfalls.

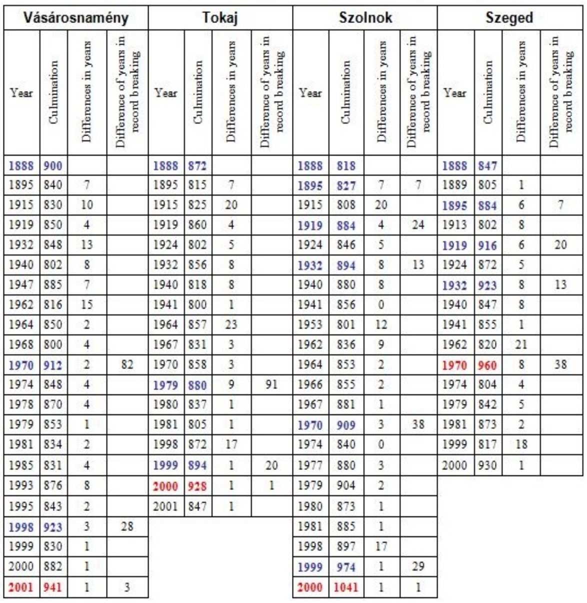
The average temperature on the catchment area of the River Tisza varies between 1 ^oC and 11 ^oC, depending on regional location and altitude. Extreme values of the temperature reached -36 ^oC and +41 ^oC. The extent of evaporation is in close relation with the temperature of the air. On the Great Hungarian Plain the maximum annual value of evaporation exceeds 700 mm. The value of aridity factor, i.e. the quotient of annual evaporation and precipitation, exceeds 2 in extremely droughty years [7].

2.2. Remarkable floods on the River Tisza

In the Table 1 we demonstrated the height of significant flood waves culminating over 800 cm that were measured at four water gauges on the River Tisza with the indication of the year, the number of years elapsing between them as well as the time differences of breaking the records [1].

At the section at Vásárosnamény, there was the longest period lasting for 15 years between 1947 and 1962, when there was no flood wave over 800 cm. This was characteristic between 1941 and 1964 (23 years) at Tokaj, between 1895 and 1915 (20 years) at Szolnok, while between 1941 and 1962 (21 years) at Szeged. During the past couple of years there were flood waves over 800 cm relatively frequently. However, at the section at Tokaj, Szolnok and Szeged, there were no such hydro-meteorological conditions between 1981 and 1998 (in case of Szeged between 1981 and 1999) which should have provided conditions for development of flood waves exceeding 800 cm. The flood wave in the year 1855 was an important station in the history of floods in the Tisza Valley as well as in that of flood prevention arrangements; its extraordinary dimensions have applied pressure on the government for taking measures considering the matter of regulations. This event may be considered as the last flood before the regulation works; and following this the flood levels have considerably increased as a result of raising embankments and decreasing the area of the flood plain.

Table 1. Significant floods in the Tisza Valley



Vásárosnamény				Tokaj				Szolnok				Szeged			
Year	Culmination	Differences in years	Difference of years in record breaking	Year	Culmination	Differences in years	Difference of years in record breaking	Year	Culmination	Differences in years	Difference of years in record breaking	Year	Culmination	Differences in years	Difference of years in record breaking
1888	**900**			**1888**	**872**			**1888**	**818**			**1888**	**847**		
1895	840	7		1895	815	7		**1895**	**827**	7	7	1889	805	1	
1915	830	10		1915	825	20		1915	808	20		**1895**	**884**	6	7
1919	850	4		1919	860	4		**1919**	**884**	4	24	1913	802	8	
1932	848	13		1924	802	5		1924	846	5		**1919**	**916**	6	20
1940	802	8		1932	856	8		**1932**	**894**	8	13	1924	872	5	
1947	885	7		1940	818	8		1940	880	8		**1932**	**923**	8	13
1962	816	15		1941	800	1		1941	856	0		1940	847	8	
1964	850	2		1964	857	23		1953	801	12		1941	855	1	
1968	800	4		1967	831	3		1962	836	9		1962	820	21	
1970	**912**	2	82	1970	858	3		1964	853	2		**1970**	**960**	8	38
1974	848	4		**1979**	**880**	9	91	1966	855	2		1974	804	4	
1978	870	4		1980	837	1		1967	881	1		1979	842	5	
1979	853	1		1981	805	1		**1970**	**909**	3	38	1981	873	2	
1981	834	2		1998	872	17		1974	840	0		1999	817	18	
1985	831	4		**1999**	**894**	1	20	1977	880	3		2000	930	1	
1993	876	8		**2000**	**928**	1	1	1979	904	2					
1995	843	2		2001	847	1		1980	873	1					
1998	**923**	3	28					1981	885	1					
1999	830	1						1998	897	17					
2000	882	1						**1999**	**974**	1	29				
2001	**941**	1	3					**2000**	**1041**	1	1				

Between the years 1998 and 2010, there were six disastrous flood waves following each other that stand without reference in the history of floods on the River Tisza and, have unavoidably arisen the reconsideration of flood prevention measures both in domestic and international relation.

2.3. Hydrological, hydraulic and statistical surveys

Because of its returning and gradually increasing, and sometimes extremely high floods as well as recurring and lasting law waters the River Tisza is considered to be the most variegated river of our country. Characteristics of the river decisively originate from the shape of the drainage system, from the relation of water output of tributaries to the main stream, from the considerable amount of drift, from the small slope on the long lowland section and from the regulation of both low and high water bed. Current length of the River Tisza is 945.8 km; its catchment area covers 157.200 square km. According to the measurements of past decades the maximum water discharge of the river at the Tivadar section (705,7 stream-km) exceeds the value of 4.000 m^3/sec, in the middle section, between Kisköre and Szolnok it is between 2.600 and 2.900 m^3/sec, while in the lower section, i.e. at Szeged (173,6 stream-km) it is over 4.000 m^3/sec. Before the regulation works the River Tisza was a strongly meandering stream with a small slope [1].

In the course of years between 1998 and 2001 such flood waves subsided on the River Tisza which have never been experienced before. The values of culminations have exceeded the previous maximum values by 130 to 140 cm. These new flood waves of critical height resulted in the reconsideration of flood prevention alongside the River Tisza.

2.4. Hydro-meteorological factors

The coincidence in time of flood waves of the River Tisza and those of tributaries basically determine the values of culminating water levels.

In 1999 and 2000, there were long lasting flood waves exceeding the authoritative level on the Middle-Tisza section. However, in 1998 and 2001, there were extremely high flood waves on the Upper-Tisza. The autumn flood wave in 1998 was exclusively generated by the heavy rainfalls. In the periods between 25th and 31st October and 1st and 5th November, 1998 there was a rainfall with 136.9 mm on the entire catchment area of the Upper-Tisza. In the development of the flood wave in March, 2001, the snow cover of 2 cubic km on the catchment area played a important role, however, the flood wave was the result of heavy rainfalls. In 2001, similar to the autumn flood wave in 1998, the heavy rainfall (124.5 mm between 3rd and 5th March) was the generator of the fierce flooding. These two flood waves resulted in a high, but not authoritative water level increase on the middle section of the River Tisza.

2.5. Water discharge ability of the bed

We can best and most accurate demonstrate the water discharge ability of the bed by analysing of water outputs. Figure 1 demonstrates the water output measurements on the occasions of floods with outstanding dimensions in the years 1895, 1932, 1970, 1979, 1999 and 2000.

There is a considerable difference to be observed among the loop curves drawn up on the base of measurement results, but there can also be similarities explored sometimes. The maximums of water discharge measures in 1895 (H_{max} = 827 cm) and in 1932 (H_{max} = 894 cm) were similar and exceeded the value of 3.100 m^3/sec. (In 1932, it was possible to measure only close to the maximum water level.) The maximum water level was less by 140 m^3/sec in 1932 than in 1895; despite of it the culmination of water level occurred higher by 67 centimetres. Between 1895 and 1932, there were 37 years elapsing. During this period of close to four decades new, short embankments were built to regulate the overbank. The increase of water levels can be explained by the change of water discharge ability of the bed. In the course of the flood wave in 1919, unfortunately, there was no opportunity to accomplish water output measurements.

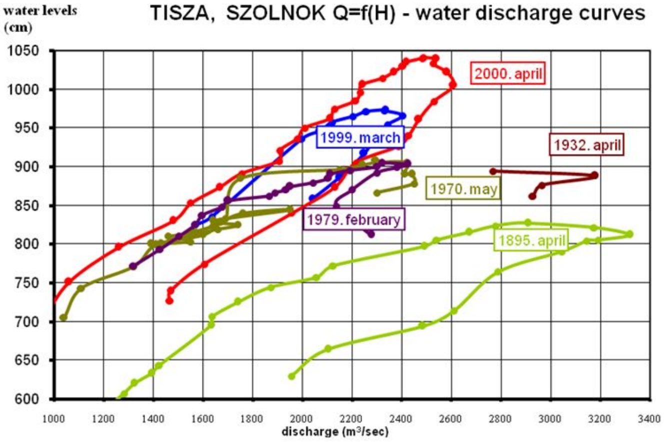


Figure 1. Water discharge curves on the River Tisza at the Szolnok section (334,6 stream-km)

The measurement results obtained in 1970 (H_{max} = 909 cm) and in 1979 (H_{max} = 904 cm) were very resembling to each other considering both water levels and water output. To the culminations that slightly exceeded the 900 cm there were water outputs belonging over 2.400 m^3/sec. Between 1932 and 1970, there were 38 years elapsing. (Almost exactly as many years as between 1895 and 1932.) However, the culminating water levels in 1970 and 1979 that slightly exceeded the values of 1932 occurred at water outputs that were less by 400 to 500 m^3/sec.

In the course of flood waves of the past years considerably higher maximum water levels developed. In 1999 (H_{max} = 974 cm) there were resemble water outputs measured to those of 1970 and 1979, however, at a water level being higher by 65 cm. In the course of the flood wave in 2000 (H_{max} = 1041 cm) the maximum water output was 2.600 m^3/sec. The steepness of (water output) loop curves gradually increases with the progress of decades. It has to be mentioned that for 1 cm increase of water level in the range over 800 cm it is only a water output of 3,5 m^3/sec enough in the river section at Szolnok.

Effects of **flood reduction** and the **improvement of water discharge ability at high water** have been based by scientific surveys.

Within surveys the numerical hydraulic calculations constituted a part of overriding importance including also **1D** and **2D** hydrodynamic model running.

3. Results and discussion

In this paper we shortly summarize our 1D hydrodynamic modelling activities serving as a base for further planning. The modelling has been accomplished by applying the HEC-RAS software [4].

3.1. The stream network of the 1D model

In its current structure, the database of the model includes the 403 km long rives section between Kisköre and Titel, as well as the 7 tributaries mouthing into the main stream, reaches is 13. The total length of streams involved into calculations exceeds 762 km. We have approached the stream system of the River Tisza and its tributaries by more than 1.200 cross sections. We installed 62 bridges, inline structures 1, lateral structures 5 and 12 storage areas (flood reducing structures) into the model [1].

The HEC-RAS model applied for the detailed description of the entire river system provides an opportunity for taking into consideration the hydraulic engineering structures, as well like bridges, barrages, culverts, overflow weirs, floodgates, bottom stages, bottom sills, side overflows and gates, static reservoirs, pump head stations and water intakes [5].

3.2. Roughness (smoothness) coefficient

After having determined the value ranges of basic data and smoothness factors we agreed in the following calibration procedure, or convention, respectively [1]:

We determined the longitudinal variation of the smoothness factor in the main bed for such flood waves which advanced toward but did not exceed the first prevention grade (the river is still in the main bed). Through appropriate selection of the smoothness factor we were able to model the main bed water levels with sufficient accuracy in the region of the first prevention grade. At the same time, we accepted that this convention results in greater failure in the range of low waters.

Crosswise on the flood plain we determined zones of same smoothness and assigned the mean values of above smoothness categories to them. When determining these flood plain zones, based upon a good engineering estimation, we took into consideration also the roughness conditions of the sections between the two adjacent zones, i.e. the width of individual zones was taken as an average width related to the certain sections.

After this we completed the high water calibration of the model in a manner that we changed the smoothness factors assigned to the flood plain zones, related to a certain section of the Tisza, while paying attention for remaining within the smoothness ranges.

Figure 2. Bird's eye view on the bed of the River Tisza

In the course of flood waves the depth of the main bed reaches 24 to 26 m at many places, especially in river bends. In case of such water depths it is necessary to divide the water movement, i.e. to create also vertical layers. As soon as the water reaches the height of the bank edge, the branches of trees protruding into the water are decreasing the movement or flow rate of the water. In the case of meandering rivers with flood plain the flow conditions are modified vertically to a great extent by the coinciding waters passing along the main bed and on the flood plain (Figure 2).

The results of water discharge measurements in the course of flood waves have proven the need of vertical modification of the roughness factor. The results of measurements and calculations related to the main bed and the flood plain at the Szolnok section of the Tisza are demonstrated in Figure 3.

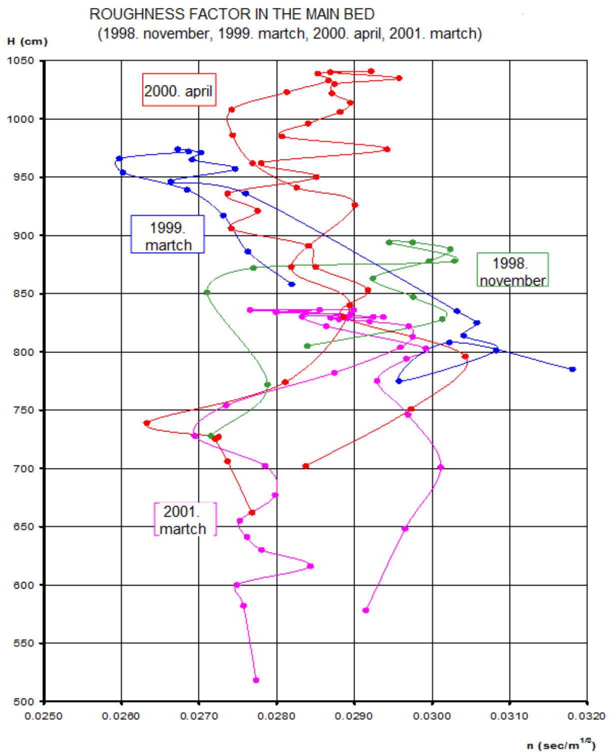


Figure 3. Development of the roughness factor in the main bed of the River Tisza

On the base of measurements accomplished in the course of 1998 and 2001 the roughness factors varied between 0,026 and 0,032 in the main bed. The shape of curves drawn up according to individual flood waves deviate from each other. In 1998, the value of the roughness coefficient increased with the increase of water level; however, it gradually decreased in the year 1999. In the course of the flood wave in 2000 we experienced an increase in the range between 350 and 750 cm, a decrease in that of 750 and 950 cm, then again an increase of the roughness factor in the range between 950 and 1040 cm [1].

3.3. Hydrological basic data and limiting conditions

The hydrological database for the first part of calculations included the values of hourly water levels (Z), the water outputs (Q) of flood waves 2006 [10]. Over the above mentioned data, we developed also almost 50 time series of 1 hourly water levels having measured at standard measuring posts and at those of dam keepers for the calibration and verification of the model. It has been emphasized on more forums that the fundamental aim of regulations of flood plains consists in the possible restoration of water discharge ability of the River Tisza prior to the year 1970 [2,3]. On the river section between Kisköre and the southern confines of the country, within the framework of transformation of land use on flood plains we plan to clean out the high water run-off stripe, the so called hydraulic corridor, the demolition of summer dikes, the formation of hollow-chamfers that follow the track of drift line and improve the water discharge performance [6].

An important part of the analyses is the comparison between the authoritative flood levels with those developing as an effect of intended interventions.

4. Conclusions

The calculations performed with flood plain interventions demonstrate very well, that there will still be a river section (between the 278 and 302 stream-km) where the envelope of maximum water levels is above the authoritative flood levels even after the accomplishment of planned interventions [1].

The natural decrease of water discharge ability is considerable in the bed of the River Tisza as well as on the flood plain related with it. The interventions on short sections may mitigate the local problems only for a short time. Following the survey in connection with interventions on flood plains we accomplished the examinations related to reservoirs, or groups of reservoirs with and without flood plain interventions. Within framework of the first cycle of the “Update of the Vásárhelyi Plan” program there are 6 reservoirs designated. We performed the survey of reservoirs both for the authoritative historical flood waves and for the synthetic, so called generated flood waves, too. The number of model runs exceeded the 300 [1].

What has been done in the survey with and without flood plain interventions (related to the authoritative conditions of the past) of the 6 reservoirs designated for the first phase of the development is shown below [1, 6]:

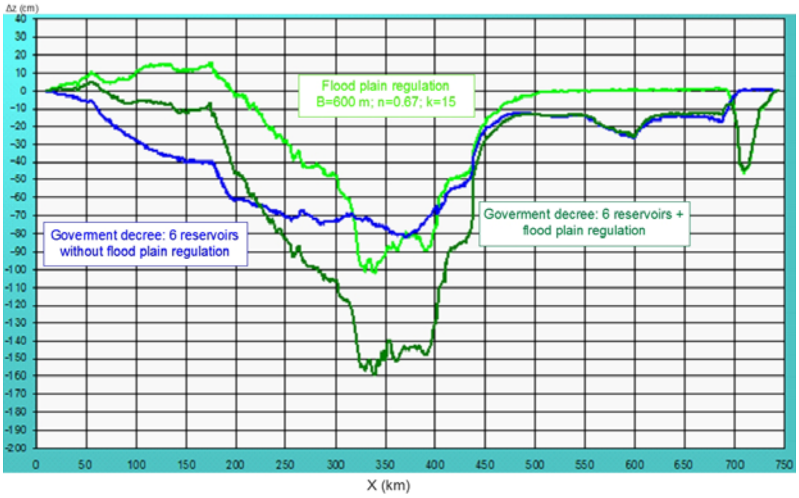


Figure 4. Effect of the 6 reservoirs, designated in the government decree, with and without flood plain regulation in case of the flood wave in the year 2000

We accomplished the survey related to the flood plain interventions and their possible effect on reservoirs with flood waves of different character. In this paper we introduce only those runs that were accomplished for the flood waves of the years 2000 and 2006. According to this, the flood plain interventions and the flood decreasing effect of reservoirs have demonstrated differences.

In the case of the flood wave of the year 2000 the maximum decrease of water level would be close to 160 cm as a result of flood plain interventions and the effect of opening the reservoirs. The results of the modelling have been shown in the Figures 4 and 5.

In the case of the flood wave of 2000 the degree of water level decrease would reach 160 cm as a result of joint effect of reservoirs and the flood plain regulations. With putting the flood time reservoirs into operation we can compensate the water level increasing effect of flood plain regulations on the lower section of the Tisza, below Algyő.

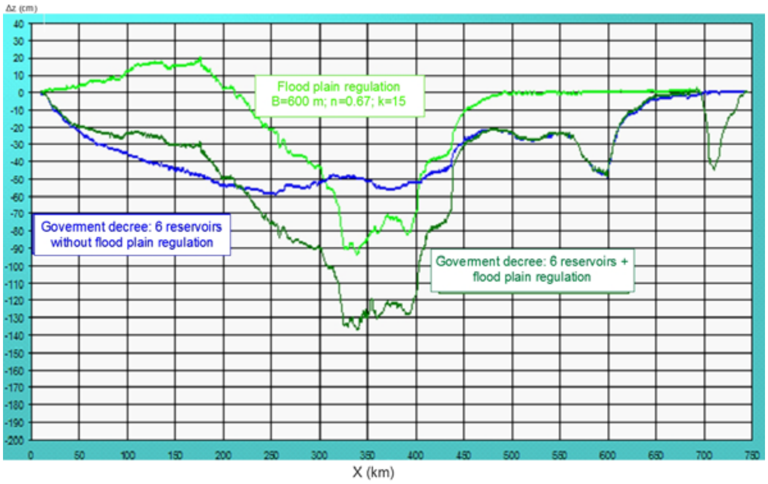


Figure 5. Effect of the 6 reservoirs, designated in the government decree, with and without flood plain regulation in case of the flood wave in the year 2006

Improvement of flood prevention safety along the Tisza Valley can unanimously be determined in the reduction of flood levels which can be performed by increase and opening of flood plains on areas where the geomorphologic, economic and socio-geographical conditions as well as the infrastructure make it possible. Also through the improvement of water discharge ability of the high water bed and through the realization of a flood level reduction reservoir system on the Hungarian flood plain in case the flood level reduction of disastrous floods should be accompanied with the reactivation of the inundation area by controlled water discharge. The relation between the water discharge ability of the high water bed and the flood level, especially the culmination, is rather complicated in the case of the River Tisza. Further on, it is of decisive importance that flow related conclusions and the calculations of water discharge lead to reliable results only in case of advancing from below to upwards and by taking the storage process into consideration. For this reason the interventions have been exposed to thorough hydraulic, fluid mechanical examinations constituting the fundamentals of selection of most pressing and effective interventions. The task of the program is to promote the society controlled restoration of the relation between the river and its inundation area. At the same time it makes a proposal for land use and infrastructural developments which are supporting the improvement of living conditions of residents in the sub-regions [2, 5].

Acknowledgements

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МОДЕЛИРАНЕ НА РЕКА ТИСА В ОБЩИЯ УЧАСТЪК НА УНГАРИЯ И СЪРБИЯ

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Ключови думи: *хидравлични изчисления, модел на р. Тиса;*

Научно област: *моделиране на речни системи*

РЕЗЮМЕ

Разработката представя методиката на изпълнение на еднодимесионални изчисления в модела HEC-RAS. В модела HEC-RAS проведохме еднодимесионални изчисления за пиезометричната линия при стационарен режим и плавноизменяемо течение в открити естествени и изкуствени легла. Бяха изчислени профилите на свободната водна повърхност при спокойно, бурно и комбинирано бурно и спокойно състояние. Използвани бяха уравнения за изчисление на базовите профили, подразделяне на напречното сечение с цел определяне на пропускната характеристика, съставни коефициенти на Манинг за основното легло, енергиен коефициент алфа, оценка на загубите на напор по дължина, загуби от стеснение и разширение, изчислителни процедури, критична дълбочина. В резултат бе получен прогнозно-симулационен модел, обхващащ цялата водосборна област на р. Тиса от Украинската граница до вливането на р. Тиса в р. Дунав в Сърбия, който предлага интегриран подход за решаване на проблемите, свързани с управлението на водите. Моделът позволява интегрирано управление на речните системи в двете страни и контрол на високите води.

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