HOW THE FLOODPLAIN VEGETATION RAISES THE FLOODRISK ON THE RIVER TISZA

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ABSTRACT. How the floodplain vegetation raises the floodrisk on the river Tisza. With the following article more attention should be drawn to the fact that the impact of the floodplain roughness on the water level is decisive. Some Hungarian studies dealing with this issue are summarised and the most significant statements are lined out. Beside the channel-geometry the hydraulic aproximations play also an important role when modeling a compound channel. With a 2D numerical model a sensitivity analysis was made to study how the floodplain vegetation raises the flood risk. Some general statements were made on how the water level can be decreased with e.g. interventions along the river banks or developing a 'hydraulic corridor', a cutoff through the meander.

Key-words: floodplain, risk, Tisza, vegetation, impact

1. Literature review

Lately several articles are dealing with the determination of the flood conveyance capacity of the Tisza floodplain and with improvement opportunities. We are giving a **short overview** in this article **of some available expertise and Hungarian article** of this issue and **summarize the significant statements**. It became clear, which are the main research areas that haven't been dealt with yet. For example it hasn't been analyzed, how the different interventions (such as cutting the vegetation or changing the type of cultivation) influence the flood conveyance capacity on a meandering river section with a lengthwise and crosswise differently covered floodplain. In the second part of this study **some general conclusion are drawn** from results of a **two-dimensional** (2D) numerical model. For example how a "hydraulic corridor", a cutoff with a good flood conveyance or cleaning a band along the riverbank decreases the water level.

Of course there are many other "important aspects" that are closely related to this field. Mentioning only one crucial question the correlation between the art, density, spacial distribution of the vegetation and the flood conveyance capacity.

In the following we would like to introduce a study dealing with the question "**The Effect of The Vegetation on The Floodplain Conveyance"**

(*Rátky-Farkas 2003*) handling the theoretical basis and also some laboratory and in local measurements. Some important aspects from the summary:

– The resistance of a grassy, bushy vegetation should be calculated differently than that for a wooded area.

– The roughness of a flexible (bending under flow) vegetation has to be accounted differently than of a rigid vegetation.

– At rarely wooded areas (average tree distance / average trunk diameter > 10) the bed and undergrowth roughness shouldn't be ignored.

– It is essential to know for the roughness and so for the resulting water level if the water fully or only partially covers the plants (scrubs, trees).

– There hasn't been in practice an accepTable method developed to determine the density of a grassy, bushy (soft-stemmed) vegetation.

– **We should reconsider the roughness coefficients we use** – that are based mostly on text descriptions and on our technical sense.

Here are some extreme data from the literature: on the river Tisza from the water surface gradient a roughness coefficient of 2,5 $m^{1/3}/s$ was calculated, and a 4,5 $m^{1/3}/s$ roughness coefficient was measured. We have to get used to these unbelievable values at areas with very dense vegetation.

– Unfortunately the problem of defining the roughness can't be solved by considering the flow hydraulically (mathematically) more precise (using 1D, 2D, 3D or turbulent models).

On the river Tisza between *Kisköre* and *Tiszaug* (268-403 river km) *Dr. Peter Bakonyi* has made research on **how the floodplain roughness and the dike height influence the waterlevel**. (*Bakonyi 2003*). By developing the classical 1D model, the connection between the main channel and the floodplain – which is periodically separated by dikes or bars – was modeled with weirs (this method is also called 1,5D model). The non-permanent calculations were made for the floods of the Years 1970 and 2000. The following conclusions were made:

– The roughness coefficients of the main channel (which are actually calibration parameters of the numerical model) are in the range of 29-39 $m^{1/3}/s$ whereas these for the floodplain are in the range of 2-5 $m^{1/3}/s$.

– Analizing only the maximum discharge of the floods of 1970. and 2000. there should have been only 96 cm water level increase. Unfortunately the flood of 2000 caused 132 cm higher water level than in 1970. The **40 cm increase was probably caused because of the reduction of the water conveyance capacity**.

– By increasing the roughness coefficient on the floodplain to 10 m1/3/s in average – according to the numerical model – the flood of 2000. would have reached a 70 cm lower highest water level (HWL).

– The most effective solution to increase the water conveyance capacity of the high-water-bed is to clean, smoothen the floodplain.

– Further research has to be made – with 2D numerical models and/or physical modells – on how to increase the water conveyance capacity on reaches with high water surface gradient.

Idealizing the characteristical channel geometry of the Middle-Tisza with a regular and complex channel *Rátky (2003)* has made some calculations with a 2D hydraulic model to analyze **how the crosswise modification of the floodplain roughness influences the water level**. In case of **straight, prismatic channel** the crosswise changing of the floodplain roughness coefficient has a great influence on the water level if the river section is long enough so that the effect of the intervention can fully develope (a permanent, steady flow has formed). Under these idealised conditions:

– Establishing a 300 m band with good water conveyance by cutting the vegetation on the floodplain could result up to 50 - 60 cm water level sinking.

– Establishing a 30 m wide band – between the middlewater bed and the floodplain – with a good flood conveyance would result a 5 – 15 cm lower water level,

Based on the available data in 2003, and on approximations and most importantly based on practical experience it is confirmed that the emerging water level – and its increasing trend in the last Years – is mostly influenced by the floodplain conveyance capacity, therefore by the floodplain vegetation (art, status, density, spreading).

For **some (shorter) sections of the Tisza, 2D** permanent numerical **calculations** were made. For example: for *Szolnok* area (*Józsa-Krámer 2004, Rátky 2004*), for the spillway of *Vezseny* (*Rátky 2004*) for *Tiszasüly-Tiszaroff* area (*Józsa-Krámer 2004*), and for the ambiance of *Alpár* dike (*Rátky 2004*).

So far the 1D or 1,5D numerical water level calculations, were assuming along a long river section same roughness coefficient (k) or same rate of change of *k*. It is well known that an intervention on the river Tisza that result the same *k* on a long section (for example thinning the vegetation at the same rate) is not possible. Only interventions can be realized that take the characteristics of the river into account such as meandering, variable width or the mosaic art of coverage. The study "*Opportunities to improve the flood conveyance capacity on the river Tisza"* (*Rátky-Rátky 2009*) is **analizing the impact of interventions considering also the existing (calibrated) flood conveyance.** Based on calculations of the 2006 flood on the river Tisza with 1D unsteady numerical model, the following conclusions were drawn:

– The mean values of the roughness coefficients (calibrating parameter) $k_{mch,m}$ = 28,4 $m^{1/3}/s$ (main channel) and $k_{fpl,m}$ = 7,4 $m^{1/3}/s$ (floodplain) for the river Tisza between *Kisköre* and *southern bourde*r (~160-400 river km).

Comparing these results with the 1,5D calculations of Bakonyi (*2003*) the calibration parameter of the main channel is practically equivalent with the one mentioned above. On the other hand the calibration parameter of the floodplain – that is modeling the flow more accurately – was 2-5 $m^{1/3}/s$ which is also close to the above mentioned value. Since there were different models used and the calibrations were also made for different flood events (for Years 2000. and 2006.) such difference is feasible.

− The roughness coefficient depends mostly on the vegetation (location, condition, density etc.) So by thinning (or relocating) the vegetation a significant flood conveyance improvement can be achieved.

− The 1000 – 1500 m wide floodplain – 5 - 8 times wider than the main channel – delivers only 20-30% of the whole highwater discharge, calculating with the floodplain roughness coefficient of 22. April 2006. flood.

− At areas where the flood conveyance capacity is less than 80% of the mean conveyance, it was assumed that with – **in practice realistic – thinning of the vegetation** on the whole floodplain so that k_{fpl} = 15 $m^{1/3}/s$

~on a 30 km long band the top highwater level (Z_{max}) can be reduced with 20-30 cm,

~on a 50 km long band with 10-20 cm and

~on a 70 km long band with less than 10 cm.

The 1D or 1,5D numerical calculations – that are calculating the impact of interventions based on the existing (calibrated) water conveyance – do not provide general guidelines for the detailed planning on the meandering, non prismatic river Tisza. These calculations won't give any suggestions for example: where would the thinning of the vegetation or the changing of the plant cultivation increase the floodplain conveyance capactiy since the roughness is changing in place (laterally) and time.

The above mentioned 2D calculations on smaller sections of the river Tisza were providing some very useful information, but only the impacts of the interventions on the given river section – and as already mentioned – **no general conclusions could be made**.

2. Assessing the impact of the crosswise changing of the roughness on the floodplain

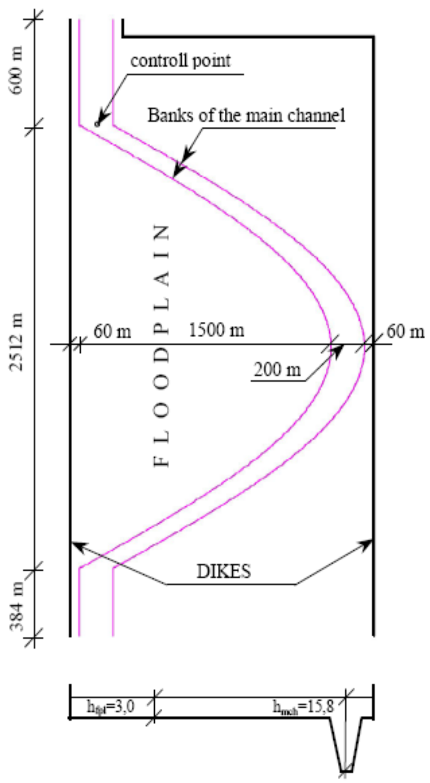
In this section we would like to present calculations with a 2D numerical hydraulic modell. Which water levels evolve **along a meander while assuming a crosswise changing of the water conveyance capacity** (roughness coefficient) **on the floodplain**. In fact a **sesitivity analysis was made to study how the floodplain vegetation raises the floodrisk**.

It should be emphasised that in the following only the hydraulic aspects will be taken into account. The necessary interventions for the improvement of the Tisza floodplain water conveyance capacity are very deverse, and a lot of other factors should be considered.

Twodimensional hydrodynamic model

A 2D verticaly homogeneous plain flow can only be used to describe the waterflow if the vertical acceleration is negligable compared to the gravitational acceleration, and if the vertical variation of other hydraulic parameters are insignificant. In most of the practical cases we can't negligate the vertical variation of the velocity. In order to study the phenomen with a twodimensional model, the vertical changes have to be taken into account. In waterways with small depth and great velocity the vertical variation of the velocity is mostly balanced because of the turbulence. In this case with using the mean value of the velocity and the momentum we get better aproximation than with assuming a vertically homogenous flow. The resulting equations are the so-called vertically integrated twodimensional equations due to the averaging 'technique'.

The *Reynolds-equations* which are the principal equations of 2D vertically averaged, numerical hydrodynamic model are derived from the *Navier-Stokes-equations*. They can be found already in university notes. (*Németh 1963, Ligget 1975, Abott-Basco 1987*). The used calculation method was already roughly introduced in some earlyer articles (*Rátky 1986, 2004/a, 2004/b*). Here we would only like to mention that the chosen numerical solution was an implicit, four step finate differences method. We won't further get into any details.



Geometrical data

In order to make generalised statements the geometry has to be simplified. The main subject is how the changing of the roughness influence the water level. Those circumstances that has less influence or that make the generalisation difficult are not considered. Our calculations were done on a composite channel with sine curving. The shape of a cross section can be seen on the following graph. By the assumption of the geometrical data we were trying to orientate to the mean characteristics of the *Middle* and *Lower Tisza*. The used geometrical characteristics are the following: B_{mch} = 72 m bottom width of the main channel; $B_{fpl,min}$ = 60 m minimal floodplain width; $B_{fpl,max}$ = 1560 m maximal floodplain width,;h_{mch} = 15,8 m waterdepth in the main channel;h_{fpl} = 3,0 m waterdepth on the floodplain; ρ_{mch} = 5,0 m the left and right side slopes of the main channel; ρ_{fpl} = 0,0 m side slope of the floodplain by the dike (vertical wall); S_o = 3,0 cm/km relative fall of the bottom along the flood axis; L = 3496 m length of the studied river section along the flood axis. The bottom level of the last cross section was assumed Z_o = 0,00 m and of the first crosssection Z_o = 0,105 m.

Numerical data

Due to the chosen numerical solution method, implicit four step finite difference method with alternating direction, there were extra calculation points for the waterdepth (h) and for specific discharge in each direction ($p = h \cdot v_x$ és $q = h \cdot v_y$). There were altogether 97 380 + 97 817 + 97 608 = 292 805 nodes. The distance of the nodes were: dx = dy = 8,0 m, and the time step was dt = 0,8 s.

Initial condition

By each version the initial condition was so-called „cold start". That means that at each calculation node a waterlevel of Z = 15,80 m was assumed according to the outflow boundary condition, and the specific discharge in direction was zero ($p = 0{,}00\ m^2/s$, $q = 0{,}00\ m^2/s$).

Boundary conditions

Each version was run from a „cold start" until the phenomenon became steady in lengthwise and crosswise direction.

Outflow boundary condition: Z = 15,80 m constant water level.

Inflow boundary condition: In the first cross section the discharge was constantly increasing from 0,0 m^3/s to 2500 m^3/s in 2 hours and this value was remaining until the end of the calculation, (Generaly in 3,5 hours a steady state was achieved on the whole studied section)

Floodplain roughness coefficients of the studied versions

According to our goal in each version only the floodplain conveyance coefficient was varied. As we already realised (*Bakonyi 2003, Rátky-Rátky 2009*), the only realistic possibility to improve the flood conveyance capacity on the river Tisza is to increase the roughness coefficinet (k_{fpl}). By defining the roughness coefficinents we were trying to use all the available information and handle the question with greatest care. We were taking into account: some data from the literature (*MNOSZ 1952*, *MI 1985, Arcement-Schneider 1987, Rátky-Farkas 2003*), measurement results (*Zellei-Szibert 2003*) and results from calibrated models (*Bakonyi 2003, Rátky 2004/a, 2004/b, Rátky-Rátky 2009*).

The roughness coefficinet of the main channel was $\mathbf{k_{mch} = 35\ m^{1/3}/s}$ at all the versions.

By defining this value the measurements k_{mch} = 30-35 $m^{1/3}$/s at the flood of 2000. at *Szolnok, Vezseny* and *Csongrád* were taken into account (*Zellei-Sziebert 2003*), as well as the 1,5D modell which was also calibrated for the flood of 2000. with values of 29-39 $m^{1/3}$/s (*Bakonyi 2003*).

The floodplain roughness coefficients and the vegetation coverage: **20 $m^{1/3}$/s** floodplain with a good water conveyance: rare bushes and trees, or meadow with sparse bushes (short: *meadow*); **15 $m^{1/3}$/s** woodland covered areas, (short: *woodland*); **10 $m^{1/3}$/s**on average medium dense area with bushes covered, (short: *'average'*); **5 $m^{1/3}$/s** dense bushy band, (short: *bushy-band*); **3 $m^{1/3}$/s** very dense, rough band, (short: *dense-bushy-band*) („impenetrable" area with liana and climbing plants).

For practical specialist it might be suprising that such rough beds are also studied. In reference works such as the Technical Guidelines so small roughness values are not mentioned (*MI 1985*). It shouldn't be forgotten that these values from the literature were given an average roughness value for the so far common used computation with the *Chèzy-formula* for the whole crosssection (maybe for the floodplain alone). These mean values include values lot smaller or lot larger on parts of the given area. These *k* values – even though they are quantities with units in the water conveyance coefficient – are actually needful calibration parameter for the model.

A number of sources are supporting the possibility of the assumed values for the floodplain: at *Szolnok* and *Vezseny* based on some field measurements above clay pits and near point bars values of 5 $m^{1/3}$/s were also found (more precise these values were calculated from field measurements with the *Chèzy-formula*, *Zellei-Sziebert 2003*). Calculating with a 1,5D numerical model, after calibration " .... the floodplain roughness coefficinets were in the range of 2 - 5 $m^{1/3}$/s ." (*Bakonyi 2003*). Similarly by the calibration of a 1D numerical calculation for the Tisza between *Kisköre* and *southern border* of the country, for the whole section the mean value is $k_{fpl,m}$ = 7,4 $m^{1/3}$/s but values of 4 $m^{1/3}$/s are also usual. (*Rátky-Rátky 2009*). It has to be mentioned that the latter values are valid for the whole cross section and for 8 – 10 river km long sections, and that these are generaly values used for the calibration.

Based on these information it seems a realistic assumption that besides the generally used 'average' roughness value of 10 $m^{1/3}$/s we studied options near the river bank where there are very dense bushes with 5 $m^{1/3}$/s vagy 3 $m^{1/3}$/s.

Alltogether we were studying 25 versions with the above mentioned floodplain roughness coefficients under differencial spacial distribution and extention.

Results and evaluations

At each version the calculated water levels were analysed in the middleline of the main channel (at every ~50 m). At each version only the water levels at the beginning of the sin curve after top straight river section were compared (**see graph**). Hereafter this point will be called the *controll point*.

Those versions were considered as ***base cases*** in which the roughness coefficient on the whole studied area, on the whole width of the floodplain were equal. On **Table 1**. the calculated water levels are given at the controll point with $k_{fpl} = 10\ m^{1/3}/s$, $15\ m^{1/3}/s$ and $20\ m^{1/3}/s$. Apparently on a **~2900 m long river section**, if on the floodplain instead of an ‚average' roughness coefficient $10\ m^{1/3}/s$ the coverage is a ***woodland*** the water level is **11,6 cm lower** in case of a ***meadow*** the water level is **18,5 cm lower**. (Of course such a water level decrese can only be achieved in the first cross section of the sterch). Surprisingly (should be specially concerned), that a ~ 3 km neglected floodplain with poor water conveyance capacity can cause a sigificant 20 cm water level increment.

Table 1. Calculated water levels at the controll point by different values of k_{fpl}

version. N°.	floodplain description	k_{fpl}, $m^{1/3}/s$	Z, m	ΔZ, cm
9h	'*average*'	10	16,157	
9d	*woodland*	15	16,041	**-11,6**
9e	*meadow*	20	15,972	**-18,5**

Bushes on the river bank and the impact of the relocation

In **Table 2. and 3.** we would like to present the impact of the bushes on the river bank and their relocation. On the river *Tisza* between the middle water bed and the floodplain (at the river bank) with changing width, there is a band with much worse water conveyance capacity than the average. Our aim was to model this, with a narrow 24 m and a wide 64 m bushy band near the river bank with $k_{fpl} = 3\ m^{1/3}/s$ or $5\ m^{1/3}/s$ roughness coefficient.

The floodplain is mostly woodland covered (**k_{ht}** = $15\ m^{1/3}/s$):

– Along both of the river banks there is a 24 m wide ***dense-bushy-band*** ($3\ m^{1/3}/s$) which raises the water level with **7,4 cm** in the controll point (compared to a version where the river banks are with woods covered).

– If we are assuming along the river banks a ***bushy-band*** with a rougness coefficient of $5\ m^{1/3}/s$ the water level increment is ‚only'**3,5 cm.**

– If we establish instead of the *bushy-band*, a band with good water conveyance, a ***meadow*** with a roughness coefficient of $20\ m^{1/3}/s$ and the ***bushy-band*** **is replaced to the dike** the water level increment (again compared tot he version with woodland) is only **0,3 cm** which is practically negligible.

The area of the bushy-band along the dikes equals to the ones along the river banks. So the same area is provided for a bushy ecosytems. (The band along the dike is wider because it is shorter than the river bank).

– We also studied the emerging water level in **case of wider bands**. The water level increment by a 64 m wide *bushy-band* ($5\ m^{1/3}/s$) along the river bank is **6,4 cm.** At the same time assuming a *meadow* ($20\ m^{1/3}/s$) with a good water conveyance capacity and a *bushy-band* along the dikes (with the same area as the *meadow*) causes only a **1,1 cm** higher water level at the controll point.

Table 2. Calculated water levels with ’*woodland*’ floodplain roughness coefficient, 15 $m^{1/3}/s$

descr. of the floodplain vegetation, descr. of the floodplain band	**river banks**		**along the dikes**		**N°**	**controll point**	
	k_{fpl}, $m^{1/3}/s$	**width m**	**k_{fpl}, $m^{1/3}/s$**	**width m**		**Z, m**	**ΔZ, cm**
floodplain everywhere *woodland*					9d	**16,041**	
river banks ’narrow’ *dense-bushy-band*	**3**	24+24			10e	16,115	**7,4**
river banks ’narrow’ *bushy-band*	**5**	24+24			9m	16,076	**3,5**
river banks ’narrow ’ *meadow* Along the dikes *bushy-band*	**20**	24+24	**5**	40+40	9ü	16,044	**0,3**
river banks ’wide’ *bushy-band*	**5**	64+64			9n	16,105	**6,4**
river banks ’narrow’ *meadow* Along the dikes *bushy- band*	**20**	64+64	**5**	112+112	9q	16,052	**1,1**

On the floodplain an *’average’* roughness (k_{ht} = 10 $m^{1/3}/s$) can be assumed :

The calculated water levels and the differences correlated to the base case (ΔZ) are listed in **Table 3.**. These versions differe only from the previous with the base roughness; the rougness coefficient and the width of the bands on the river banks and along the dikes are the same. So in our oppinion a description of each version in text is not necessary.

Table 3. Calculated water levels with’*average*’ floodplain roughness coefficient, 10 $m^{1/3}/s$

Description of the floodplain vegetation, and the floodplain band	River banks		Along the dikes		N°	Controll point	
	k_{fpl}, $m^{1/3}/s$	Szélesség, m	k_{fpl}, $m^{1/3}/s$	Széles-ség, m		Z, m	**ΔZ, cm**
Floodplain everywhere ’*average*’					9h	**16,157**	
river banks ’narrow’ *dense-bushy-band*	**3**	24+24			10d	16,218	**6,1**
river banks ’narrow’ *bushy-band*	**5**	24+24			9ℓ	16,182	**2,5**
river banks ’narrow’ *meadow* along the dikes *bushy- band*	**20**	24+24	**5**	40+40	9v	16,142	**-1,5**
river banks ’wide’ *bushy-band*	**5**	64+64			9k	16,197	**4,0**
river banks ’narrow’ *meadow* along the dikes *bushy- band*	**20**	64+64	**5**	112+112	9r	16,137	**-2,0**

We would like to emphasize only three points about the results:

– Since the floodplain has already a poor water conveyance capacity ('*average*' k_{ht} = 10 $m^{1/3}/s$) – compared to the *woodland* – the *dense-bushy-band* and the *bushy-band* worthen the results less.

– If we establish instead of the *bushy-band*, a band with good water conveyance, a *meadow* and the *bushy-band* is replaced to the dike we get a lower water level than at the base case in the control point (ΔZ = -1,5 cm or -2,0 cm).

Impact study of a good water conveyance cutoff band on the floodplain

In **Table 4.** only the results of an '*average*' (k_{ht} = 10 $m^{1/3}/s$) floodplain are shown. The structure of the Table and the header is similar to the previous. The straight sections of the sin curve are connected/cut off with bands of meadow with different width and good water conveyance (k_{ht} = 20 $m^{1/3}/s$). At a *'narrow cutoff'* the width of the cutoff band equals to the meadow width at the river bank, but its area is half of that. On the other hand the '*wide cutoff*' area almost equals to the river bank band at both sides.

Table 4. Calculted water levels with cuttoff on an '*average*', 10 $m^{1/3}/s$ floodplain

Description of the floodplain vegetation , and of the floodplain band	River bank		Cutoff band		N°	Controll point	
	k_{fpl}, $m^{1/3}/s$	width, m	k_{fpl}, $m^{1/3}/s$	width, m		Z, m	**ΔZ, cm**
floodplain everywhere '*average*'					9h	**16,157**	
river banks 'wide' *meadow*	**20**	64+64			9i	16,119	**-3,8**
'narrow cutoff', *meadow*			**20**	128	9j	16,135	**-2,2**
'wide cutoff', *meadow*			**20**	256	9u	16,111	**-4,6**

Apparently, if the cutoff band is a **meadow the water level decrement at the control point is ~20% more** than in case of a meadow with the same area along the river bank.

Summary

This study was dealing with the water conveyance capacity of the river Tisza. It gave a summary of some earlier literature of this field. Based on the introduced 2D numerical simulation following statements can be emphasized:

1. If the impact of the roughness on the waterdepth (water level) – in a straight, prismatic channel assuming a **uniform steady flow** – is determined with the *Chézy formula* or with a 1D or 2D hydraulic numerical model, we get some good result in trend and order of magnitude, but the **impact is over-estimated** compared to reality.

2. **Previous studies** dealing with the interconnection of the water level on the river Tisza and the flood conveyance of the floodplain **drew attention to the fact** that it should be dealt with the impact of the floodplain roughness on the water level – as it was mentioned in the 1. point – **and some more accurate models should be tested**.

3. If rather than drawing attention to this problem, our aim is to get some more precise results that can be used for planning, especially **the real channel-geometry has to be better aproximeted**.

4. Beside the channel-geometry the hydraulic approximation plays also a decisive role. For an accepTable precision there is always – **for the specific phenomenon calibrated** – (1D, 1,5D or 2D) **model needed** when calculating a compound channel.

5. The following essential statements can be outlined based on the 2D numerical calculations (sensitivity analysis) on how the floodplain coverage influences the water level:

– Compared to the other parts of the floodplain **the area between the floodplain and the middle water bed is the most important area** which determines the floodplain conveyance capacity. The evolving water level depends mostly on the coverage (vegetation density) of this area.

– The rise of the water level can be stopped, or even **a decrease can be achived**, if instead of the rough band **along the river banks, a band is developed with good water conveyance capacity and the rough band is repleaced along the dikes**.

– An even lower water level can be achived if along the shortest way of the flow a cutoff is made through the meander and a band with good conveyance capacity is developed.

It should be pointed out that in our computation the cutoff length was half of the length along the meandering river bank (the cutoff was made on an oxbow).

– The positive effect of the cutoff on the water level depends significantly on the local chracteristics such as bottom level of the floodplain, the relation of the cutoff length to the length of the bending flow line, briefly how well developed the meander is.

REFERENCES

1. Abbott, M.B.-Basco, D.R. (1989), *Computational Fluid Dynamics. An introduction for engineers.* London, New York.
2. Arcement G.J., Schneider V.R.(1987) *Roughness Coefficients for Densely Vegetated Flood Plains.* U.S. Geological Survey Water-Resources Investigations Report 83-427 Reston, Virginia.

3. Bakonyi P.(2003) *Onedimensional Modeling of the Middle and Lower Tisza*. (in Hungarian), Vízügyi Közlemények, évi Különszám, IV. kötet. 173-187. o, Budapest.
4. Józsa J.,Krámer T .(2004), *A területfejlesztés, a vidékfejlesztés, az árapasztást és a nagyvízi vízszállító képesség javítást szolgáló feladatok tudományos alapjainak és hátterének megteremtése a Vásárhelyi-Terv Továbbfejlesztésének I. Ütemére*. A Szolnok-Vezseny közötti hidraulikai környezetének permanens kétdimenziós modellezése. *BME,* Kutatási jelentés, Május 2004, Budapest.
5. Liggett, J.A.(1975), *Basic Equation of Unsteady Flow. In Unsteady Flow in Open Channels*, Vol. I. Edited by K. Mahmood–Yevjevich, For Collins, Colorado.
6. MI-10-291/2-85(1985), *Műszaki Irányelvek, Műszaki hidraulika*. Nyílt medrek vízszállító képessége. *Országos Vízügyi Hivatal*.
7. Németh E (1963), *Hidromechanika*, Tankönyvkiadó, Budapest.
8. Rátky, I.(1980), *A Kaszna folyó magyarországi szakaszának árvízi szabályozása*. VVI Vízépítési Tanszék. Szakvélemény, Budapest.
9. Rátky I. (1986), *Mélységmentén integrált kétdimenziós áramlás matematikai modellje*. Vízügyi Közlemények, évi 3. füzet. 315-330, Budapest..
10. Rátky I (2003), *Összetett szelvényű medrek vízszállítása, Szolnok térségében a hullámtér-rendezés hatása*, MHT XXI. Vándorgyűlés, Szolnok .
11. Rátky I .(2004), *A területfejlesztés, a vidékfejlesztés, az árapasztást és a nagyvízi vízszállító képesség javítást szolgáló feladatok tudományos alapjainak és hátterének megteremtése a Vásárhelyi-Terv Továbbfejlesztésének I. Ütemére. Permanens 2D modell Szolnok térségére*. *BME*, Kutatási zárójelent.és, 2004/a. május, Budapest.
12. Rátky I. (2004), *A vezsenyi árapasztó folyosóban lévő út koronaszint magasításának hatása az árapasztásra és a nagyvízi vízszállítóképességre, Permanens 2D modell-vizsgálat*. NEGENTRÓP Kft. Kutatási zárójelentés, 2004/b. augusztus, Budapest.
13. Rátky I .(2004), *A területfejlesztés, a vidékfejlesztés, az árapasztást és a nagyvízi vízszállító képesség javítást szolgáló feladatok tudományos alapjainak és hátterének megteremtése a Vásárhelyi-Terv Továbbfejlesztésének I. Ütemére. Permanens 2D modell az Alpári-nyárigát áthelyezésének vizsgálatára*, *BME* Kutatási zárójelentés, 2004/c. december, Budapest.
14. Rátky I., Farkas P.(2003), *The Effect of The Vegetation on The Floodplain Conveyance*,(in Hungarian) Vízügyi Közlemények, évi 2. füzet. 246-265.o, Budapest.
15. Rátky I.,Rátky É. (2009), *Lehetőségek a Tisza vízszállítóképességének javítására*, *Hidrológiai Közlöny*, , Közlésre elfogadva, Budapest.
16. Zellei L.,Sziebert J. (2003), *Árvízi áramlásmérések tapasztalatai a Tiszán*, Vízügyi Közlemények, Különszám, IV. kötet. 131-144. o, Budapest.