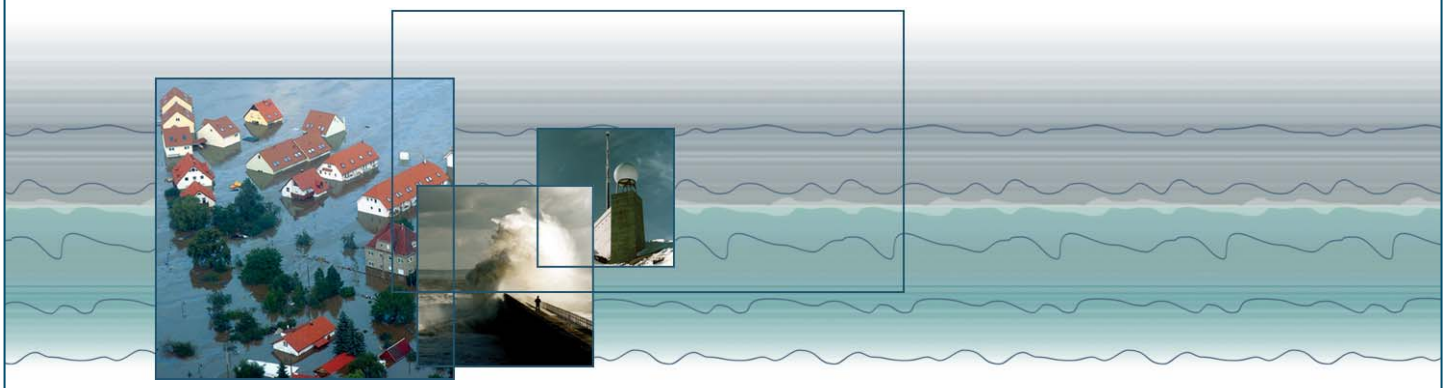
Integrated Flood Risk Analysis
and Management Methodologies



River capacity improvement and partial floodplain reactivation along the Middle-Tisza

SCENARIO ANALYSIS OF INTERVENTION OPTIONS

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Lead Author	**Sándor Tóth (HEURAqua)**
Contributors	**Dr. Sándor Kovács (Middle-Tisza DEWD, Szolnok, HU)**
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SUMMARY

The experience and consequence of the repeated extreme floods of the past 8 years along the Tisza River as well as the broad knowledge accumulated on its flood problems as a result of vast research programmes implemented through many decades may serve as a firm basis to develop precautionary and sustainable flood risk management solutions.

FLOOD*site* Task 22 envisaged the followings:

– development of river basin based, precautionary and sustainable flood management strategies based on the investigation and analysis of previous floods,

– fostering international co-operation.

– pilot study application of general vulnerability analysis techniques developed in FLOOD*site* sub-theme 1.3, in one of the flood cells to identify the effectiveness of flood management strategies.

The research output at hand is going to describe the work and results of items listed under Activity 1 Action 2, 4 and 5 of the research implementation plan, namely

– analysis of factors of river capacity problems along the Middle-Tisza section,

– scenario analysis of intervention options to raise the flood conveyance capacity of the flood bed,

– scenario analysis of partial floodplain reactivation with controlled inundation.

The report gives brief overview of the major floods of the recent past, serving evidences on the deterioration of flood conveyance capacity along the Middle-Tisza and triggering effective solutions to reduce flood crests including river capacity improvement, partial floodplain reactivation and flood detention.

Research work started with a preliminary collation of relevant information and identification of the potential data sources and subsequent data collection related to maps and other documents of different ages to gain insight into the morphological changes of the rivers, the changes of prevailing land use types, information on the raising of the natural sandbars on the riverbank, artificial structures in the floodway.

Analysis of the collected data specified the scale of reduction of wetted cross section along characteristic reaches of the river, also the development of natural sandbars and the summer dikes erected on those, finally the drastic changes in the land use and cultivation branches of the floodway, leading to very disadvantageous forest conditions characterised by dense undergrowth and adventive and invasive species deteriorating smoothness-roughness conditions.

Using HEC-RAS 1D hydrodynamic model, building the collected data into the model, after successful calibration and verification, scenario analysis of intervention options was accomplished focusing on

– improvement of flood conveyance capacity of the river by creating a ‘hydraulic corridor’ in the floodplain, within which man made obstacles of flow including summer dikes, stub depots will be demolished, sand bars will be opened and the prevailing land use of forests with dense undergrowth will be turned into pastures and meadows with mosaic-type woodland;

– relocation of the primary flood embankments to cease bottlenecks of the designated hydraulic corridor;

– impacts of selected flood detention solutions.

Individual and combined effects of river capacity improvement, selected detention basins as well as combined effect of river capacity improvement and flood detention was investigated.

Results of modelling are summarised and form important input of the design and implementation of the flood hazard reduction programme of the region called Update of the Vásárhelyi Plan.

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1. Introduction

After a relatively long dry period unprecedented series of extreme floods hit the *Upper-* and *Middle Tisza River* between November 1998 and March 2001. During the 28 month period four extreme floods occurred, as a consequence of which the total duration of flood alerts reached 24 month. Within this, extraordinary alerts lasted 9 month. The November flood in 1998 as well as the March flood in 2001 brought new records in flood peaks along the *Upper-Tisza*, the latter caused even dike breach there. However, these floods due to the attenuation of the single flood waves resulted in a high, but not extreme flood on the *Middle-Tisza* section which is subject of our investigation, being the selected pilot site downstream *Szolnok*. The location of the *Tisza River Basin* in Europe is illustrated in *Fig. 1*., also evidencing the above mentioned frequent extreme flood events, while orientation on the *Middle-Tisza* region and the pilot site itself is given in *Fig. 2. and 3.*

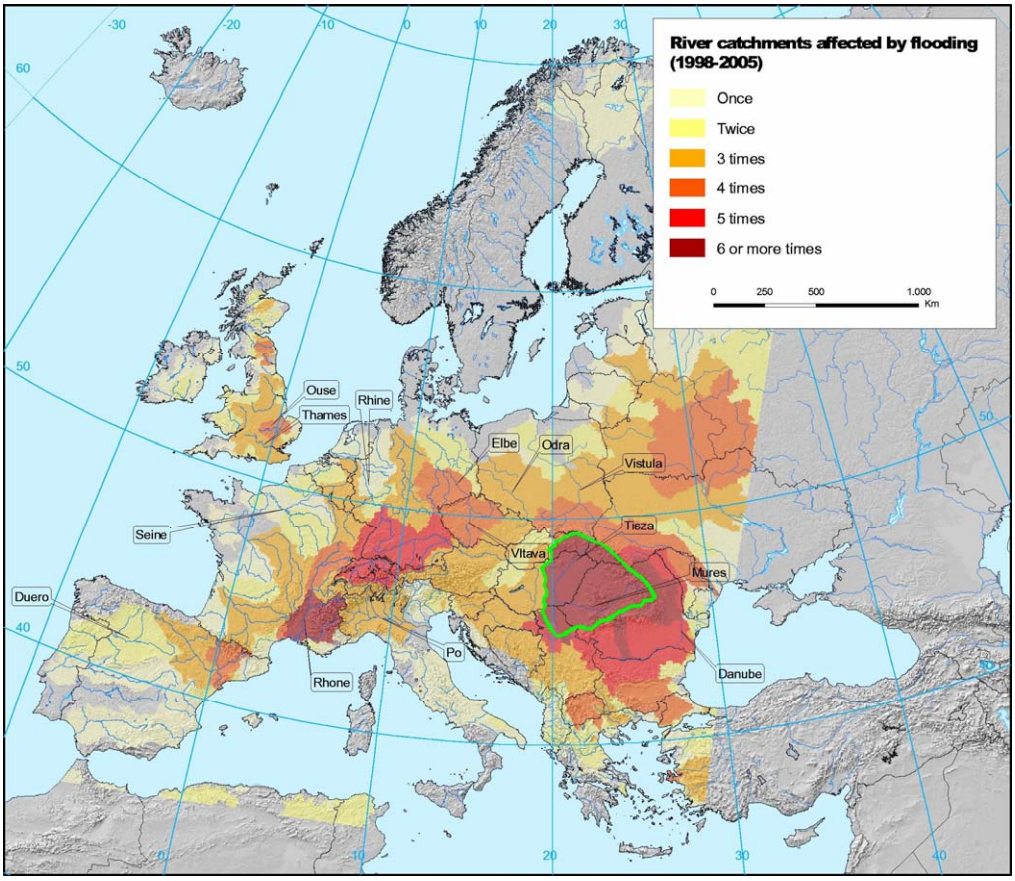


Fig. 1. The Tisza River Basin in Europe

The spring floods of 1999 and 2000 were results of multipeak floods arriving from the *Upper-Tisza* and *Bodrog* rivers, also supplied by some of the other upstream tributaries and created extreme floods both in the terms of flood crests and flood duration along the *Middle-Tisza (OVF[1] 2000)*.

Table 1 Record flood crests in 1998-2001

River	Gauging station,	fkm	Record flood crest prior to 1998		New record in the year				Total increase
			cm	year	1998	1999	2000	2001	cm
Tisza	Tiszabecs	744,7	680	1970	708			719	+ 39
	Tivadar	705,7	865	1970	958			1014	**+149**
	Vásárosnamény	684,5	912	1970	923			941	+29
Bodrog	Sárospatak	37,1	688	1888		740			+52

[1] National Directorate for Water Management

Tisza	Tokaj	543,1	880	1979		894	928		+48
	Szolnok	334,6	909	1970		974	1041		**+132**

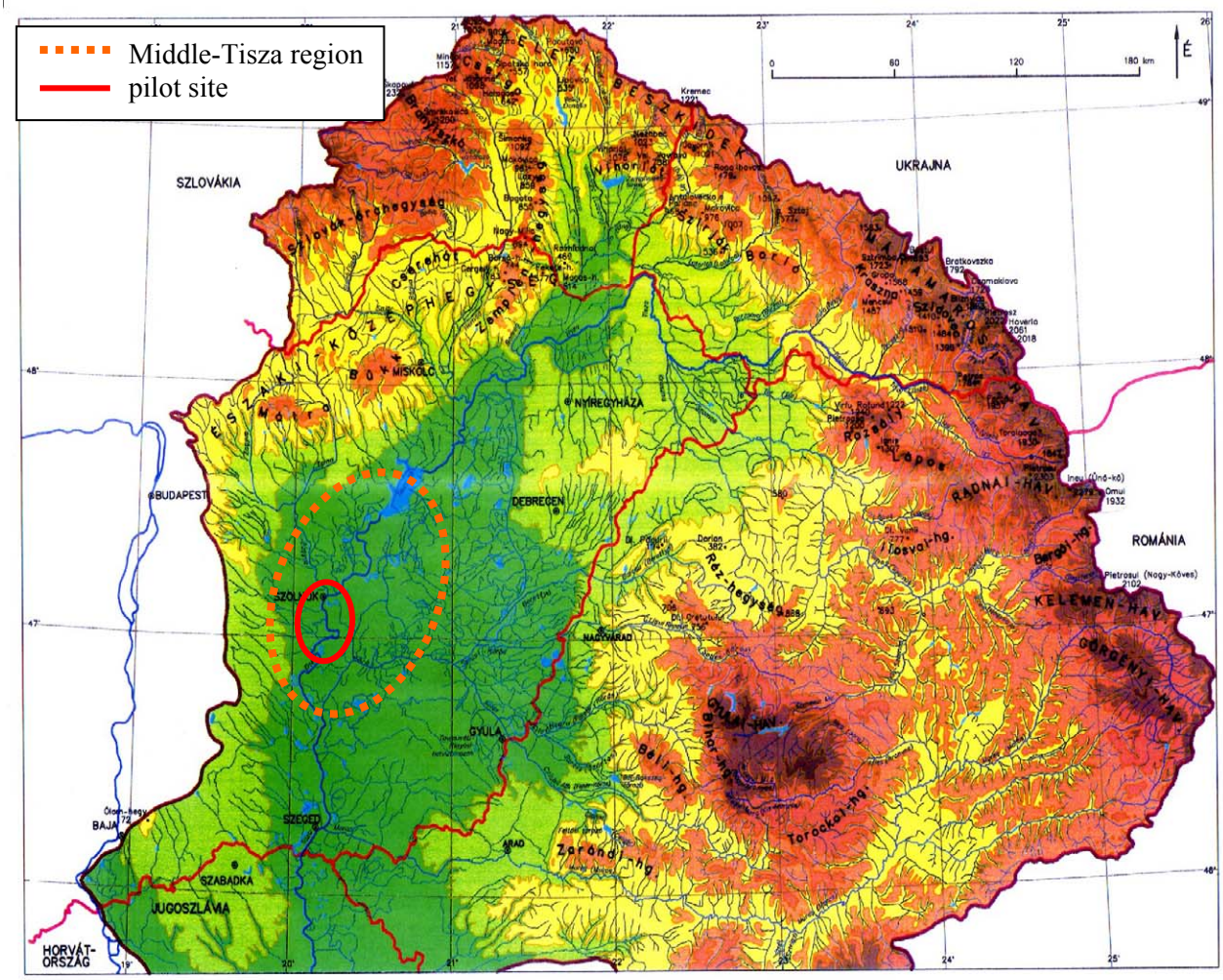


Fig. 2. The Tisza River Basin

1.1 Hydrometeorological conditions of the 2000 spring flood

The precipitation between November, 1999 and March, 2000 was 140-160 % of the average of the years on record. This implied that the excess rain varied from 40 to 190 mm on the various sub-catchments. Precipitation was especially abundant on the Upstream Tisza catchment.

Snow started accumulating in the mountains in early November. Alternating mild and cold spells, repeated snowfalls have consolidated and fed the snow cover continuously. By mid-March the thickness of the snow cover in the mountains above 1000 m altitude was greater than 60 cm in average, but data up to 200 cm have also been registered. The water volume accumulated in the snow cover on the catchment pertaining to the *Szeged* station has grown to 7 km^3, and was thus considerably larger than normal (*Middle-Tisza DEWD, 2000*), however, it might not be considered as extraordinary (there were similar snow covers in the years 1970, 1985 and 1987, too).

January has passed in relative calm, but things took an adverse turn in February. Flood waves of medium proportion had travelled down virtually all rivers in the *Tisza Basin*, coinciding with inundation in the Plains by undrained runoff larger than in the abnormal year of 1999. The disastrous cyanide plume has also passed down the *Tisza* in February.

In the first half of March rains varying from 20 to 35 mm fell on the whole catchment and started flood waves approximating the 2nd degree warning level on the *Tisza* and her major tributaries. The

first flood wave ($H_{max,\ Vásárosnamény}$ = 769 cm, at 684.4 rkm on 12 March – see *Fig. 4*.) filled up considerably the flood way of the *Middle-Tisza* section.

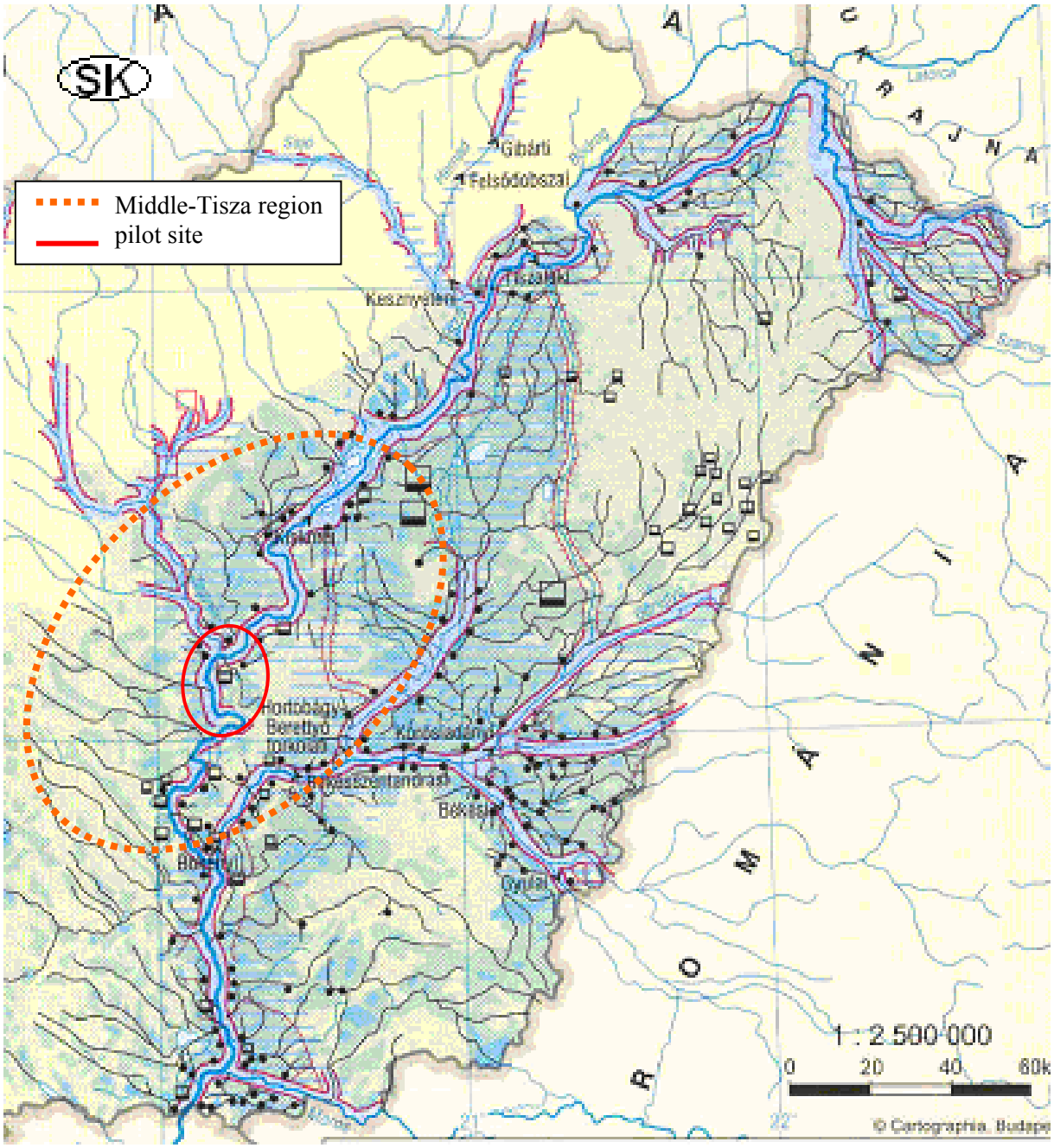


Fig. 3. River network and flood defences in the Tisza Valley in Hungary

Daytime temperatures grew steadily towards the end of March. In the Plains the daily highs reached +20 °C and even in the mountains temperatures as high as 5-10 °C were measured. The ensuing high-rate snowmelt was accelerated by rains totalling at 43.7 mm on the *Upstream Tisza*, 13.6 mm on the *Szamos-Kraszna* and 34.9 mm on the *Bodrog* catchments, respectively. The water levels were hardly about decreasing along the *Middle-Tisza* when the next flood wave ($H_{max,\ Vásárosnamény}$ = 806 cm) arrived on 2 April that would have resulted in a water level of 900 cm in the section at *Szolnok* (334,6 stream-km).

On the 5th of April another storm front has reached the *Carpathians* and caused abundant rainfall. Depths varied between 15 and 40 mm, but some stations recorded 60-90 mm. Rain and snowmelt runoff have triggered another flood wave on the *Tisza* with a height exceeding the previous two ($H_{max, Vásárosnamény}$ = 882 cm, 8 April). There was no example for such three flood waves yet, which developed in the *Vásárosnamény* section within one month! Simultaneously, there were some other flood waves started on the tributaries, too. The flood waves of the last group culminated at the border sections onf the tributaries almost on the very same day (6th and 7th April). Despite of the fact that the floods of the tributaries did not produce new maximums, except for the *Fehér-Körös*, they caused a very high bed fill up on the middle section of the *Tisza* because of their huge water volume and the extremely flat slope of the river (3-6 cm/km). It should be noted that the flood volume passed the *Szeged* station was estimated at 15 thousand million m^3, approximately twice as much as the total runoff in a normal year.

The third flood wave arrived onto this filled up bed resulting in extreme flood situation along the *Middle-Tisza* reach.

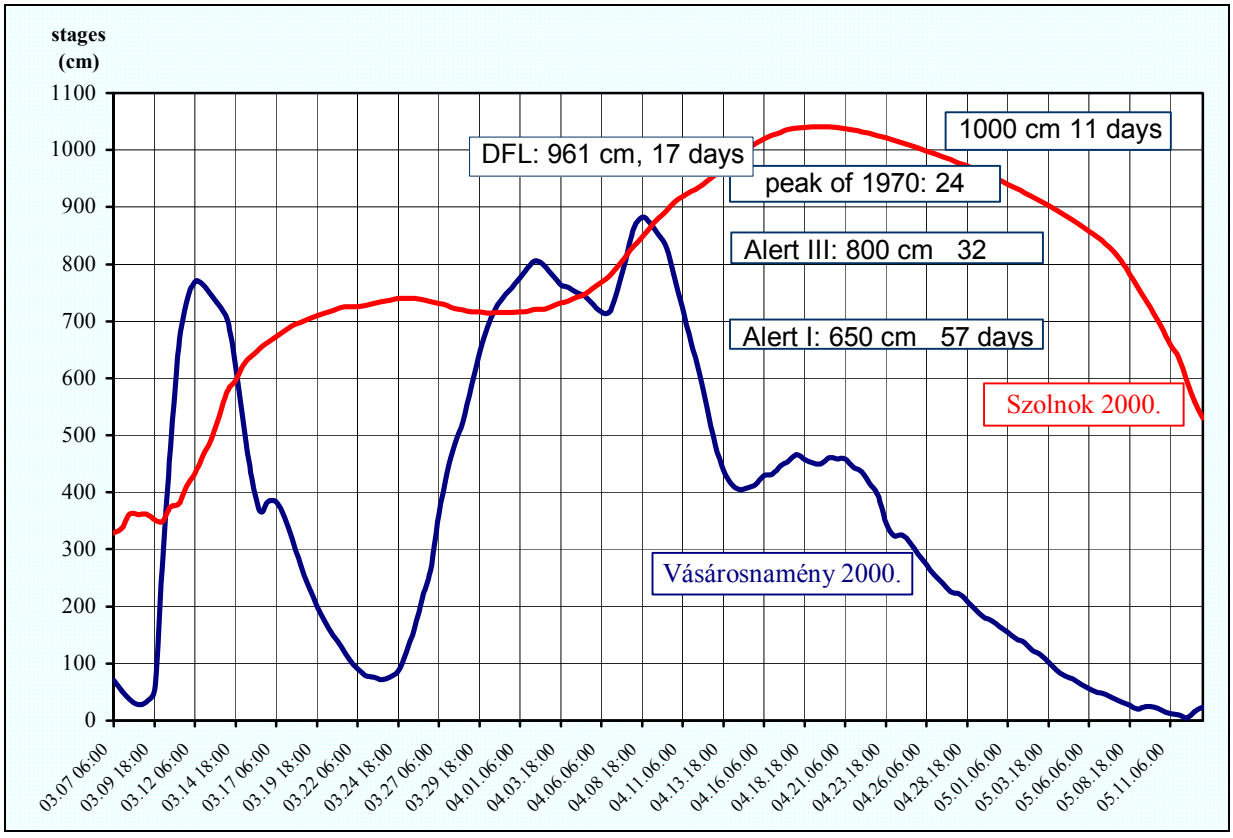


Fig. 4. Flood hydrographs at gauging stations Vásárosnamény (684,45 fkm) and Szolnok (334,6 fkm) during the 2000 spring flood

The new flood crest record at *Szolnok* (1041 cm) exceeded the record of the previous year by 67 cm and that of the flood of 1970 by 132 cm. Data regarding duration as indicated on the hydrograph show the extremity of the flood load to the defences: flood stages exceeding design flood level (DFL) lasted as long as 17 days, and water covered the wet side toe of the dikes (Alert I: 650 cm).

1.2 Signs of river capacity problems along the Middle-Tisza section

1.2.1 Trends in the change of water levels

Analysis of the time series of annual maximal, mean and minimal water stages of the past century at the *Szolnok* gauging station (*Fig. 5.)* shows a trend of increasing high water levels, slightly decreasing mean water levels and decreasing low water levels *(Kovács, S. – Váriné Szöllősi I. 2003)*. The

decrease in the mean and low water levels is the result of the deepening and narrowing of the mean river bed as it will be seen on the evaluation of the changes of the cross sections. The reason of the increasing maxima is also partly connectable to the above changes but is more complex and will be explained by the evaluation of the discharge measurements.

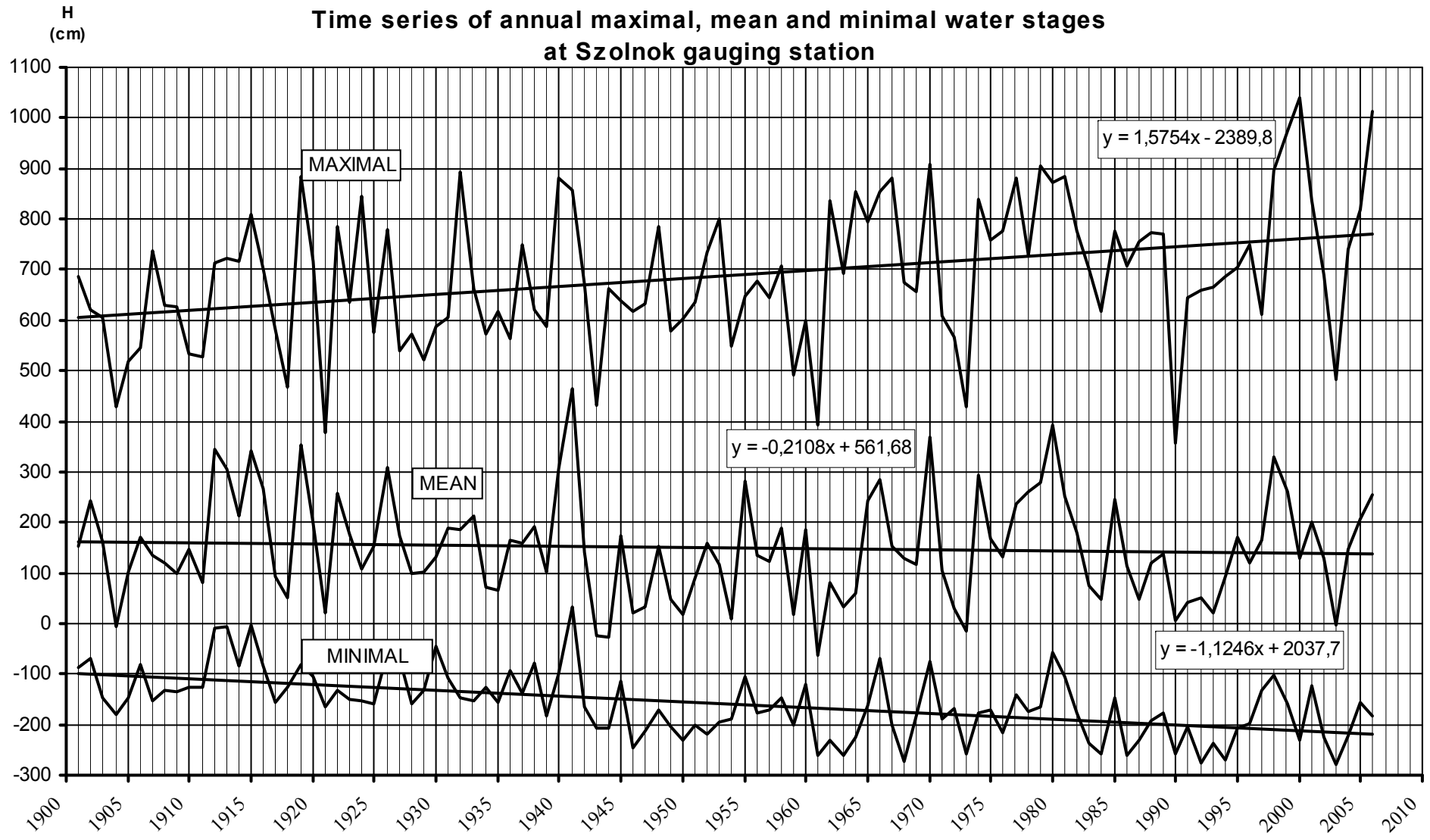


Fig. 5. Time series of annual maximal, mean and minimal water stages at Szolnok gauging station

1.2.2 Trends in the change of flood conveyance (river capacity)

Flood conveyance of the *Middle-Tisza* reach can be best and most accurate demonstrated by analysis of the flood discharge measurements of different floods. We may declare this despite the fact, that due to the slight bed and water surface slopes, the backwater effects of the *Hármas-Körös*, the *Maros* and, to a certain extent, also the *Danube* river have impact on the passing down of flood waves and on the shape of flood loop curves.

An important question of analyses of flood discharge measurements was whether to accept or involve into the survey the historical measurement results (from 1895 and 1932). We will see below, that these measurements must not be disregarded by all means. Only by the processing and analyses of these measurement results is possible to find an explanation and to understand the phenomena have been taking place in the regulated bed for 100 years.

Fig. 6. demonstrates the results of flood discharge measurements performed at the *Szolnok* section of the *Tisza* river during significant and extreme floods in the years 1895, 1932, 1970, 1979, 1999 and 2000. It has to be mentioned, that the measurements in 1895 and 1932 were performed not direct in the section at *Szolnok*, but in the bottlenecks of *Tiszapüspöki* and *Vezseny*, however, the water levels were related to the gauging station at *Szolnok* already at the time of measurements. Another, very important factor that gives explanation on the high conveyance capacities measured in those years, that no summer dikes existed yet in 1895 and only a few in 1932 with significantly lower dike crests than in the period of 1950-1980 *(Kovács, S. – Váriné Szöllősi I. 2003)*.

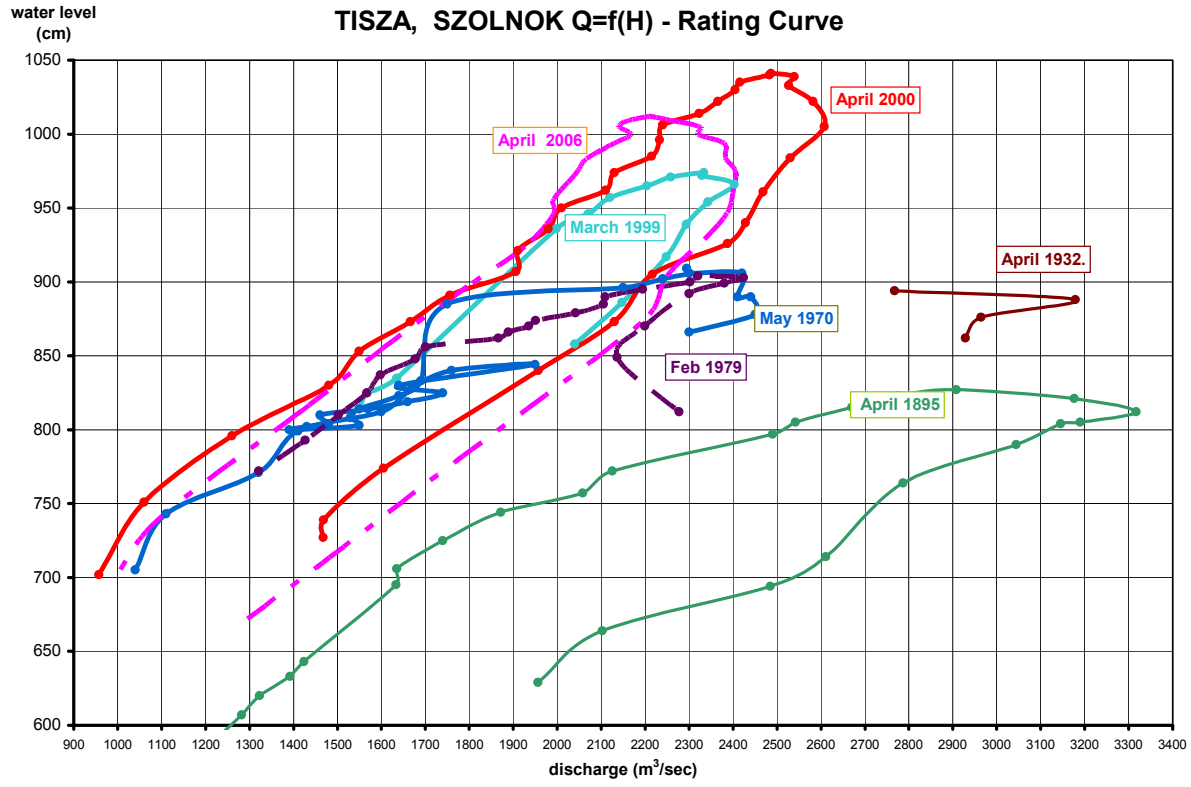


Fig. 6. Results of flood discharge measurements at Szolnok at different floods

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 discharges measured 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.) Although the maximum water level was less by 140 m^3/sec in 1932 than in 1895; the culmination of water level occurred higher by 67 centimetres. Between 1895 and 1932, there were 37 years elapsing. During this period of almost four decades, new, short embankments were built to regulate the floodway. The increase of water levels can be explained by the narrowed floodway that has changed the water discharge capacity of the flood bed.

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. Culminations belonging to flood discharges over 2.400 m^3/sec slightly exceeded the 900 cm value. 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 exceeded slightly the values of 1932 occurred at flood discharges 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 similar flood discharges 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.

It can clearly be seen that the steepness of the Q-H 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 an increase of 3,5 m^3/sec in discharge is enough in the river section at *Szolnok*.

Summarising: conveyance of similar discharge needs much higher water-level. River capacity is continuously decreasing because of changes (narrowing) in the cross sections, roughness ruining, origins of which is to be sought in the changes of the flood bed, mainly as a result of human interference, including also changes in land use.

2. Analysis of factors of river capacity problems along the Middle-Tisza section

HEURAqua first of all prepared a work plan for the preparation for and organisation of the conditions of data collection, including a preliminary collation of relevant information on and assessment of the potential data sources. In this period special attention was paid to the Museum and Archive of Water Affairs, the National Hydrological Archive, the National Technical Emergency Controlling Headquarters and, of course, the Middle-Tisza District Environmental and Water Directorate.

Our aim was to collect and analyse maps and other documents of different ages to gain insight into the morphological changes of the rivers, the changes of prevailing land use types, information on the raising of the natural sandbars on the riverbank, artificial structures in the floodway. Taking into consideration that implementation of comprehensive flood alleviation schemes in the Tisza Valley started in the middle of the 19th century and was finished in the 1930-s, it could be expected that estimable information on the floodway (the high water bed outside the mean river bed) conditions would be available from the turn of the 19th-20th century.

2.1 Data collection on the reduction of the area of the flood bed (floodway) in the past 220 years

The first detailed topographic survey, also called **I. Ordnance Mapping** (or I. Military survey, „Josephinische Aufnahme") of the Austrian Empire, including the Hungarian Kingdom was done in 1763-1785. Mapping of the territory of the Hungarian Kingdom has been realized in 1782–1785, 965 colourful, handwritten cartographic segments were produced. Scale of the map: 1 inch of Vienna represents 400 fathom of Vienna, in metric system 1:28,800. Extension of a segment is 24x16 inch, corresponding to 63x42 cm, representing 18x12 km area.

Roads, settlements, vegetation conditions are represented. Elevation conditions are presented „a la vue", the "eye-lash" style gives a plastic view of terrain conditions. Rivers, water flows are presented prior to regulation.

Original documentation of the I. Ordnance Mapping can be found in the Kriegsarchiv in Vienna, colourful copies of original size of these maps are stored in Hungary in the Institute and Museum of Military History *(http://www2.arcanum.hu/index/map/MoKatFelmHun/Tanulmany.html)*.

Examples showing *Szolnok* region and the *Vezseny bend* are shown in *Figures 7* and *14*, respectively.

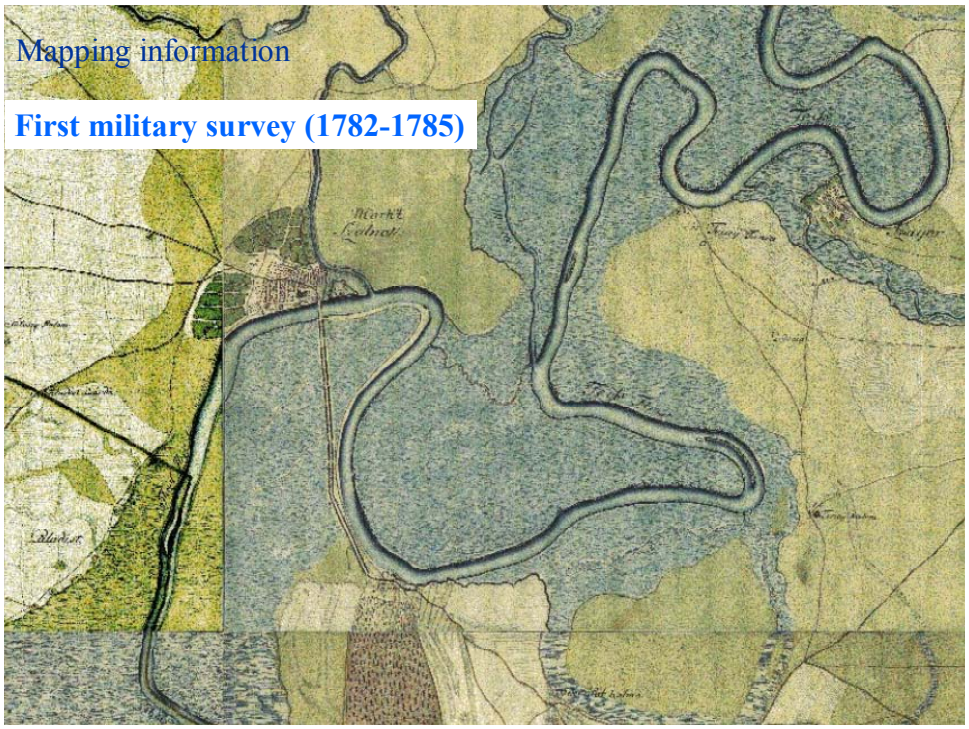


Fig. 7. Szolnok first military survey



Fig. 8. Szolnok, second military survey

The **Second Ordnance Mapping** (or 2nd Military Survey). Due to the developments in geodesy, the lack of projection system, the presentation of the terrain in "a la vue" style made the first ordnance mapping outdated. The Napoleonic wars triggered a new survey that was ordered by Emperor I. Franz in 1806. This survey was based on a geodetic network developed parallel to the survey and centred to the Stephansturm in Vienna. Projection system (not consistently) used was the *Cassini-type* cylindrical projection. The scale of the maps was the same as in case of the first one, 1:28,800. Content of these maps became more detailed, accuracy was also better, not only because of military requirements but

due to those of railway development and river training. Elevation conditions are presented by Lehmann-type geometric hachures (without contour lines), with rare elevation data.

Original documentation of the II. Ordnance Mapping can be found in the Kriegsarchiv in Vienna, colourful copies of original size of these maps are stored in Hungary in the Institute and Museum of Military History *(http://www2.arcanum.hu/index/map/MoKatFelmHun/Tanulmany.html)*.

Example showing *Szolnok* region is shown in *Figure 8*.

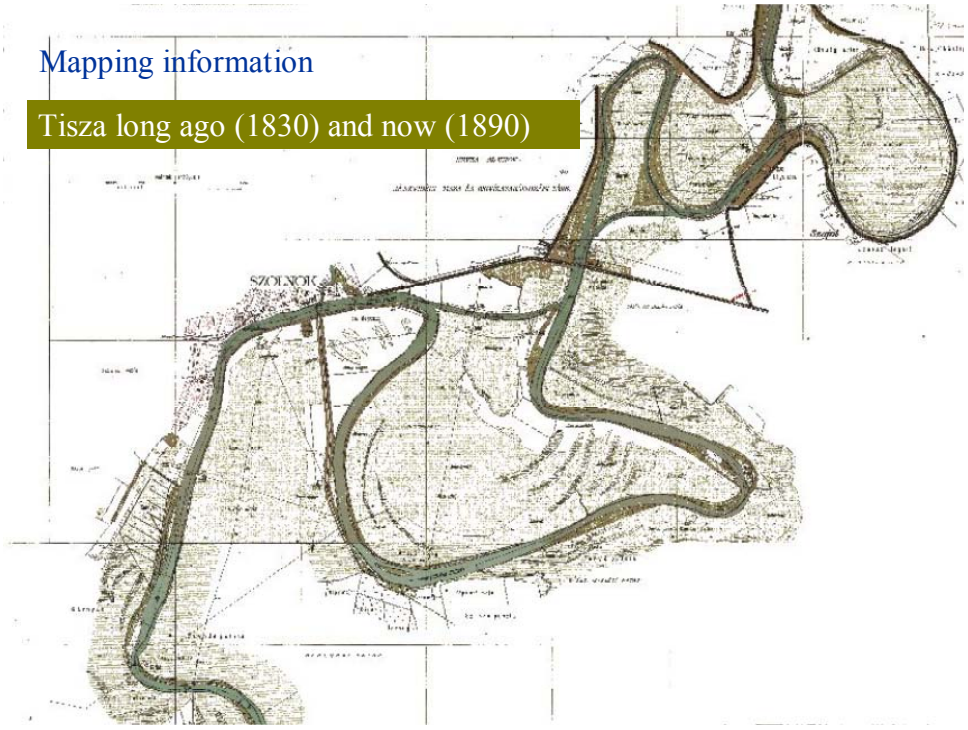


Fig. 9. Szolnok, 'Tisza long ago and now'

"Tisza long ago (1830-40) and now (1890)" – the first hydrographic mapping of the River Tisza was completed between 1834 and 1842 organized by Sámuel Lányi. The field sheets of 1:7,200 scale were merged eventually in 1845 at the *Central Tisza Survey Institute* into the map called the "Hydrographic State of the Tisza River and her flood plains". The atlas of 22 maps to 1:72,000 scale has displayed the full length of the Tisza and the wide flood plains accompanying her. This survey presented the conditions prior to regulation.

The second survey was completed by the Hydrographic Department of the National Hydrotechnical Directorate in 1890-91. The map scaled 1:2,880 was prepared by using the cadastral maps and covered the entire flood bed. The survey was transformed to the scale of 1:25,000 and was published in 1902 under the title "Tisza long ago (1830-40) and now (1890)" *(Lovas, A – Vajk, Ö. 2003)*.

Examples showing *Szolnok* region and the *Vezseny bend* are shown in *Figures 9* and *15*, respectively.

Tisza Atlas (1929-30) – aluminium plates of the "Tisza long ago (1830-40) and now (1890)" were utilised to the production of this map. The old version was presented in black while the changes in red thus the map provides an easily perspicuous picture from the changes of the riverbed after regulation.

Examples showing *Szolnok* region and the *Vezseny bend* are shown in *Figures 10* and *16*, respectively *(Lovas, A – Vajk, Ö. 2003)*.

Tisza Atlas (1967-76) – the segments present the flood bed of the river in a scale of 1:10,000. The map also contains river bed changes recorded by earlier hydrographic atlas. Survey of registered cross sections, data on bed load incl. grain size distribution are part of the information provided by this atlas.

Examples showing *Szolnok* region and the *Vezseny bend* are shown in *Figures 11* and *17*, respectively *(Lovas, A – Vajk, Ö. 2003)*.

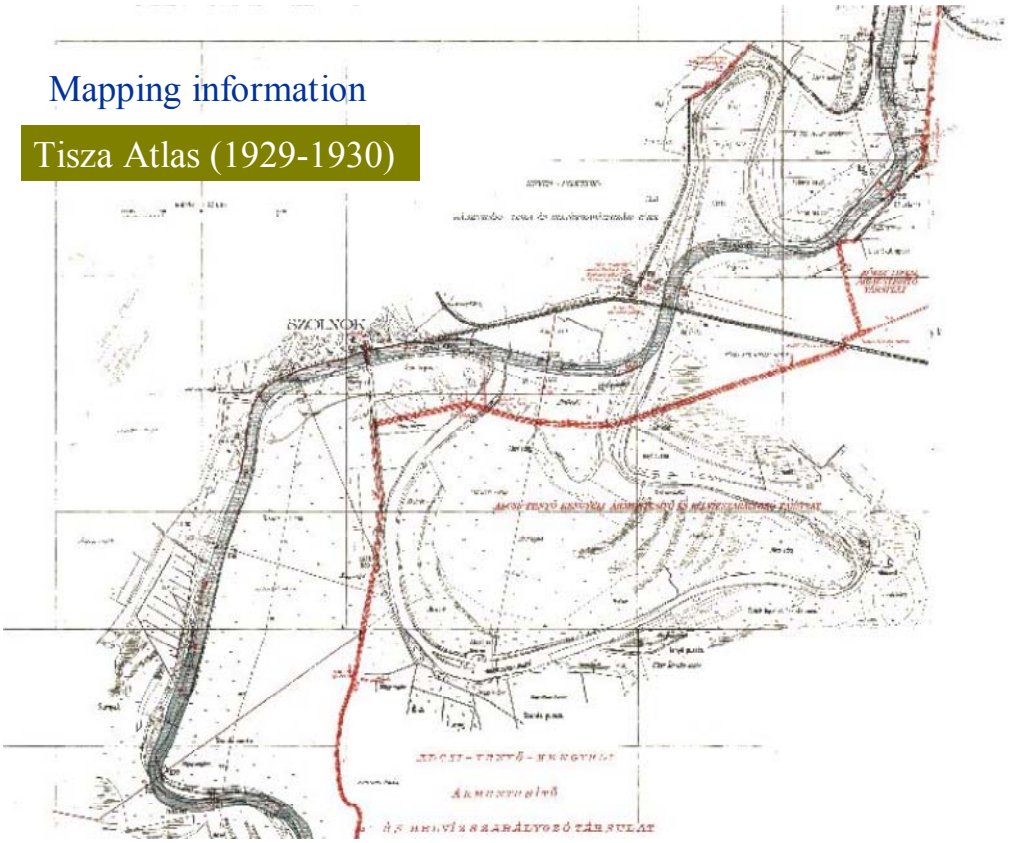


Fig. 10. Szolnok, Tisza Atlas 1929-30

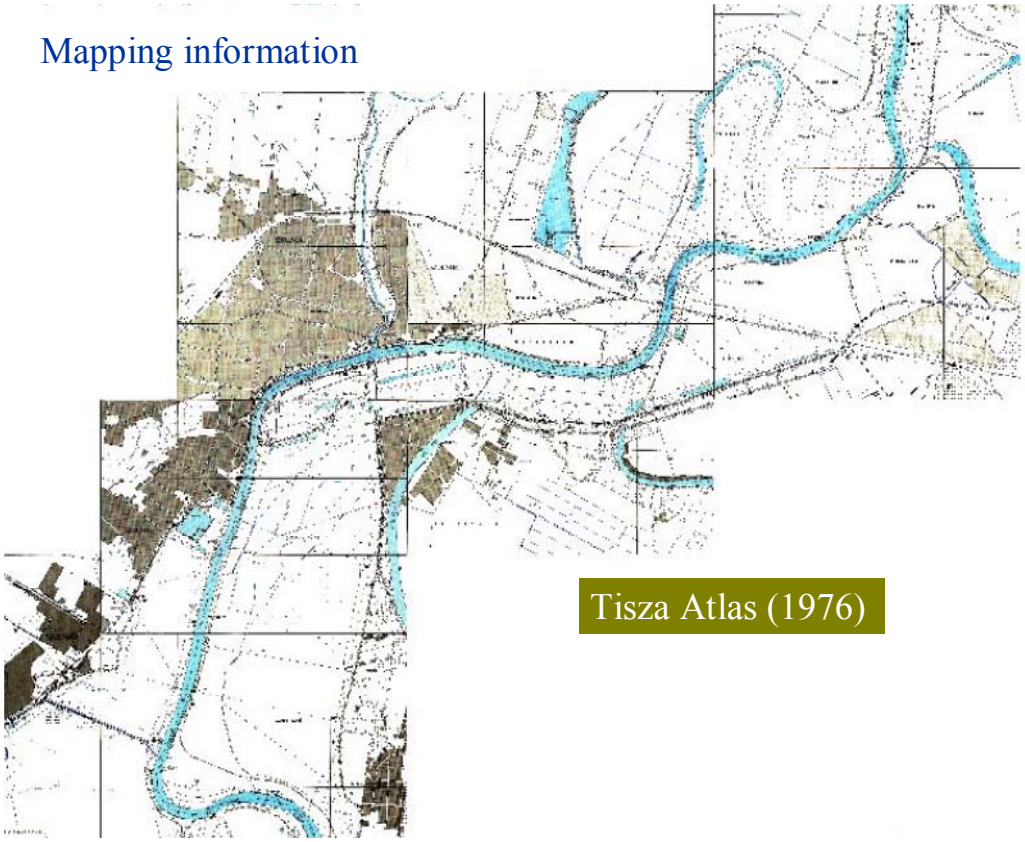


Fig. 11. Szolnok, Tisza Atlas 1976



Fig. 12. Szolnok, ortophoto 2001

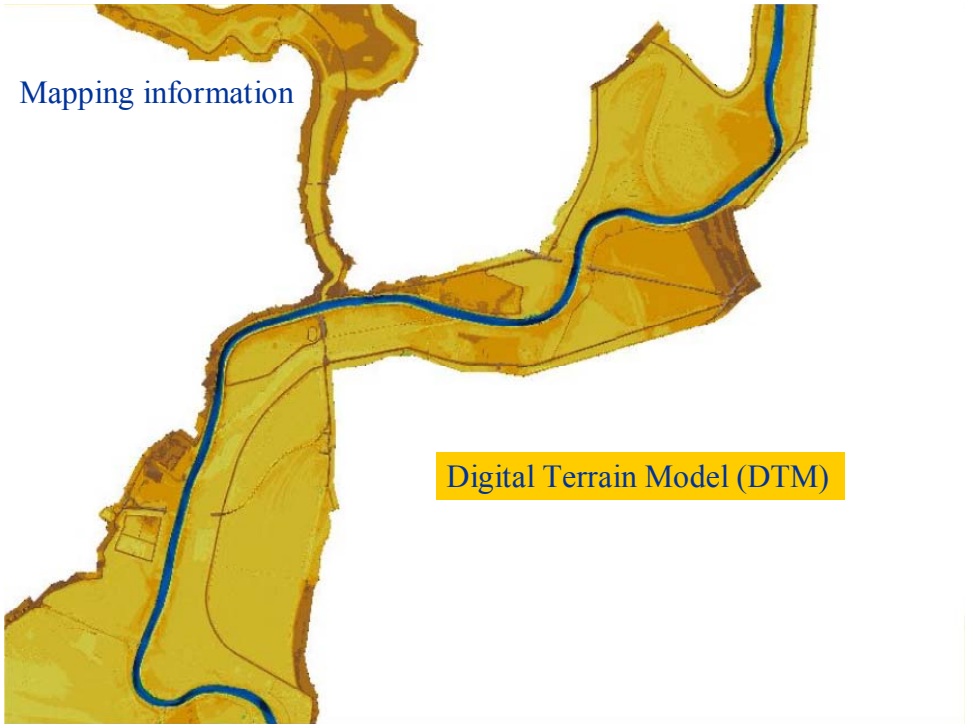


Fig. 13. Szolnok, DTM

Ortophoto 2001 – made by Eurosense Ltd. in 2001-2002 in the frame of the Update of the Vásárhelyi Plan project on the River Tisza flood bed along the river section 160-412 fkm. Area covered: 402 km^2, scale of aerial photos 1:8,000, camera: RC 30, recorded on Kodak MS positive. Number of photos: 1,048, number of ortophotos 403, size of ortophotos 1.4 * 1.4 km *(Gross, M. 2003)*.

Digital terrain model – The DTM was composed from ortophotos made by Eurosense Ltd., low water cross sections surveyed by GPS controlled ultrasonic depth measurements and completing geodetic and GPS surveys to connect the measurements made on land surface and under water. On the

strongly overgrown flood plain areas, in the line of channel bars, the data of DTM were corrected by additional geodetic measurements.

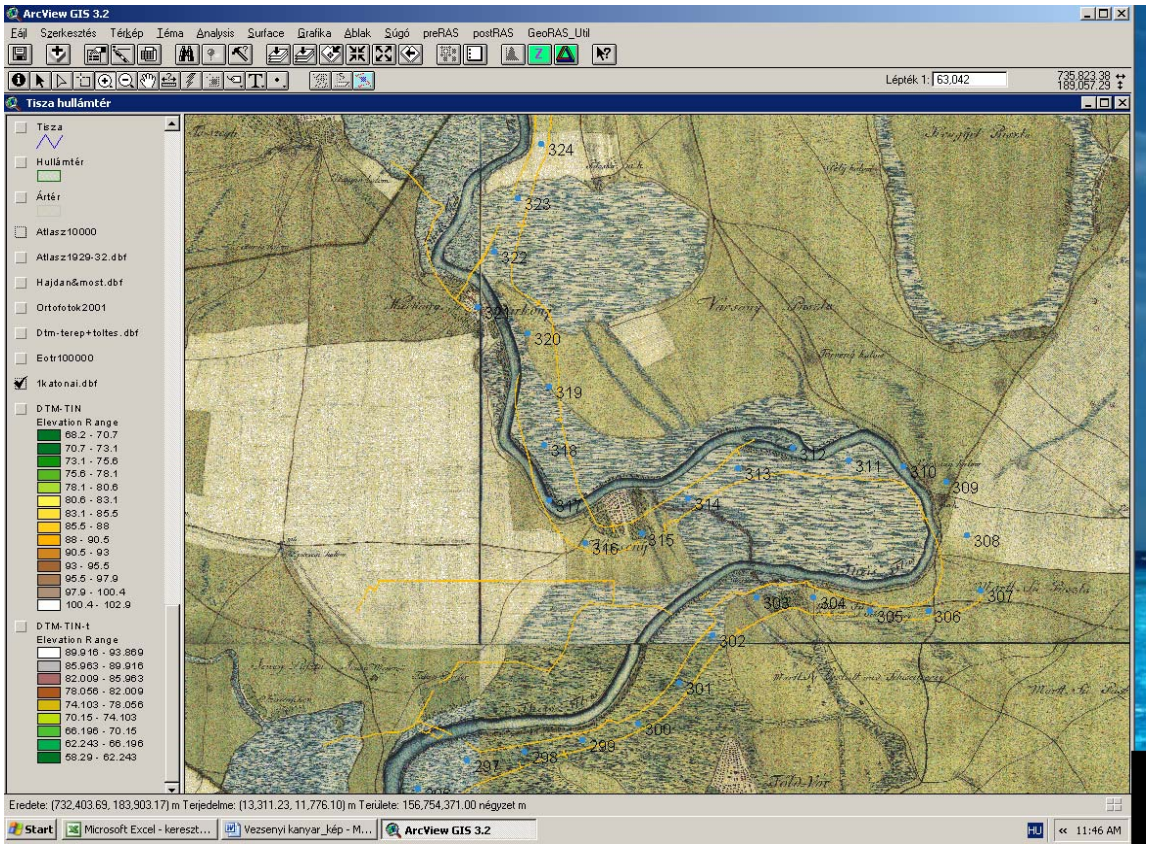


Fig. 14. First military survey, Vezseny bend

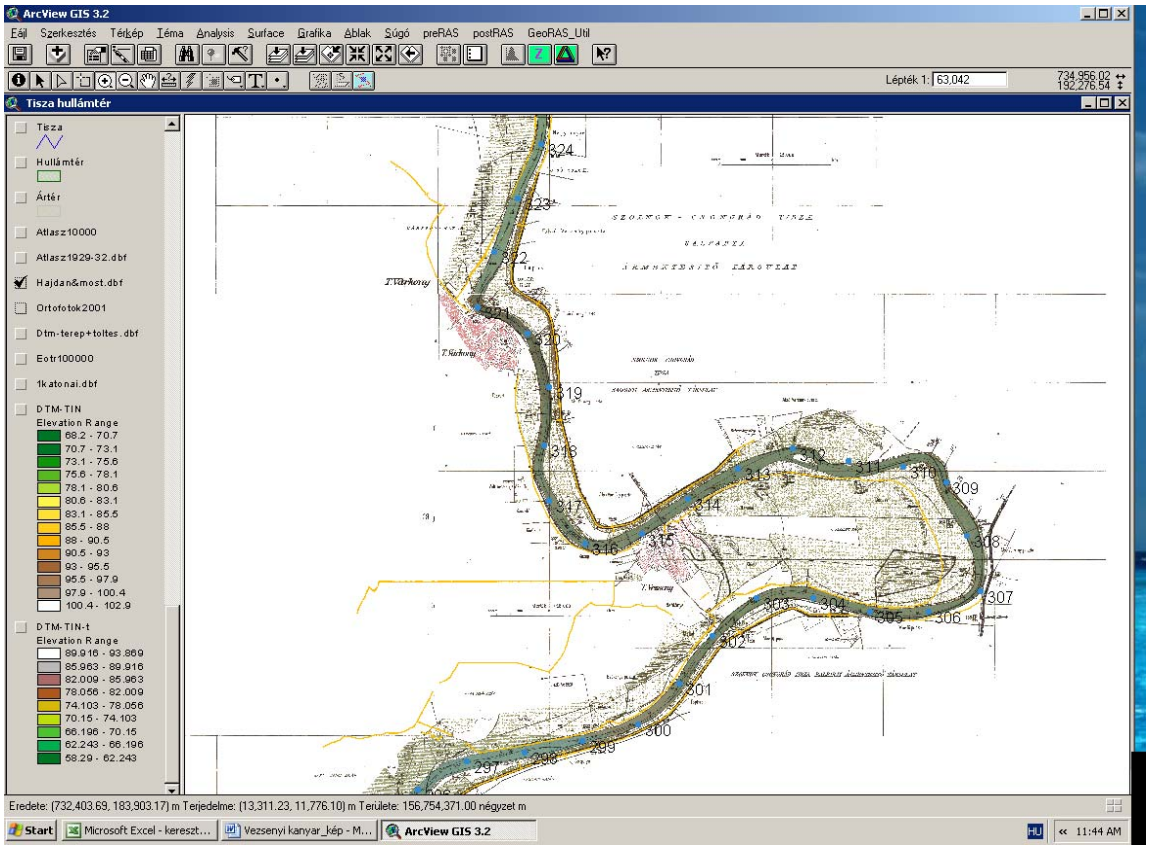


Fig. 15. 'Tisza long ago (1830) and now (1890)', Vezseny bend

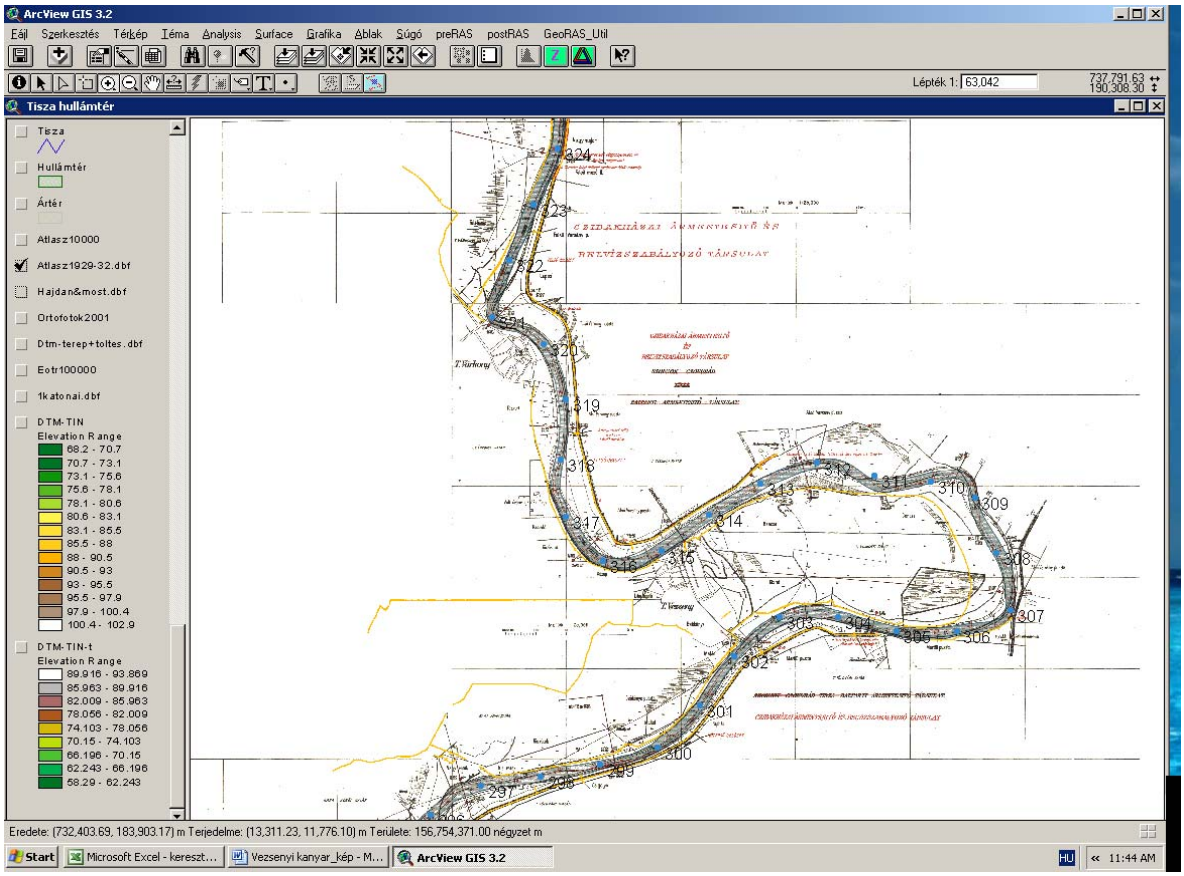


Fig. 16. Tisza Atlas 1929-1932, Vezseny bend

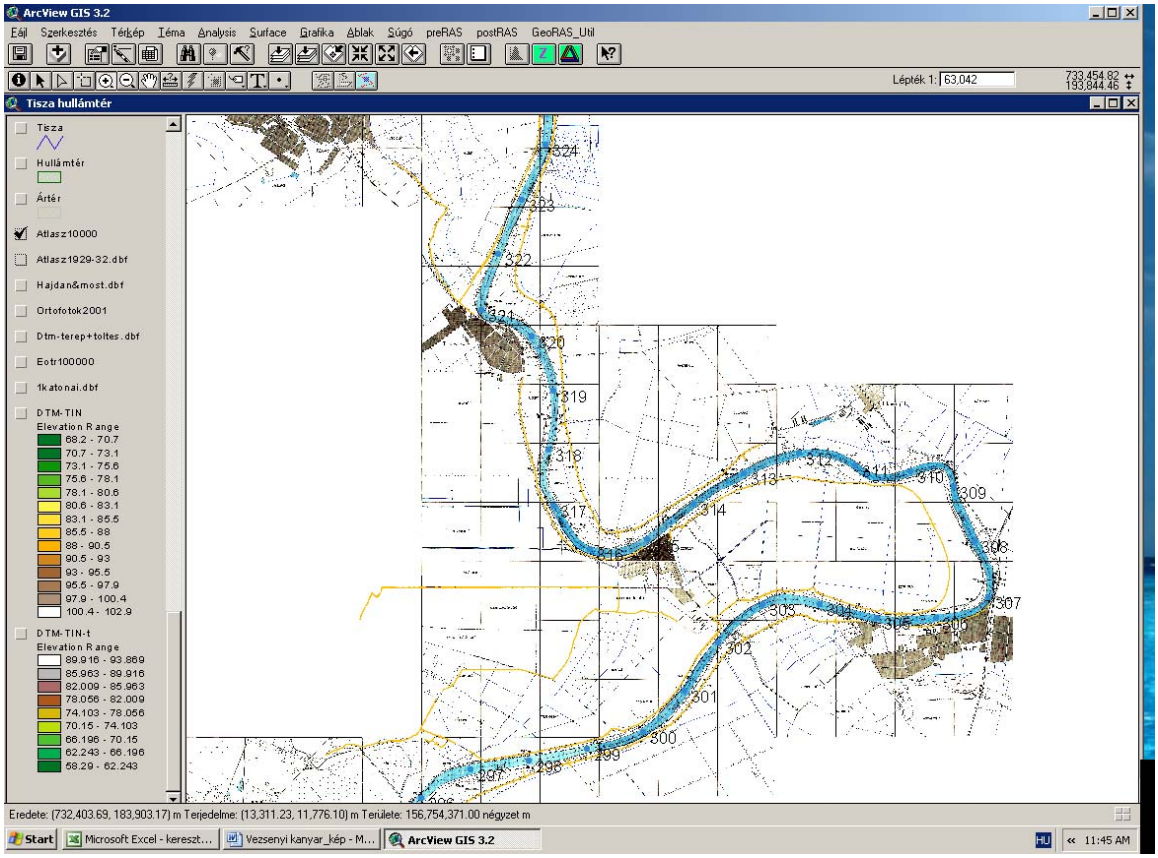


Fig. 17. Tisza Atlas 1976, Vezseny bend

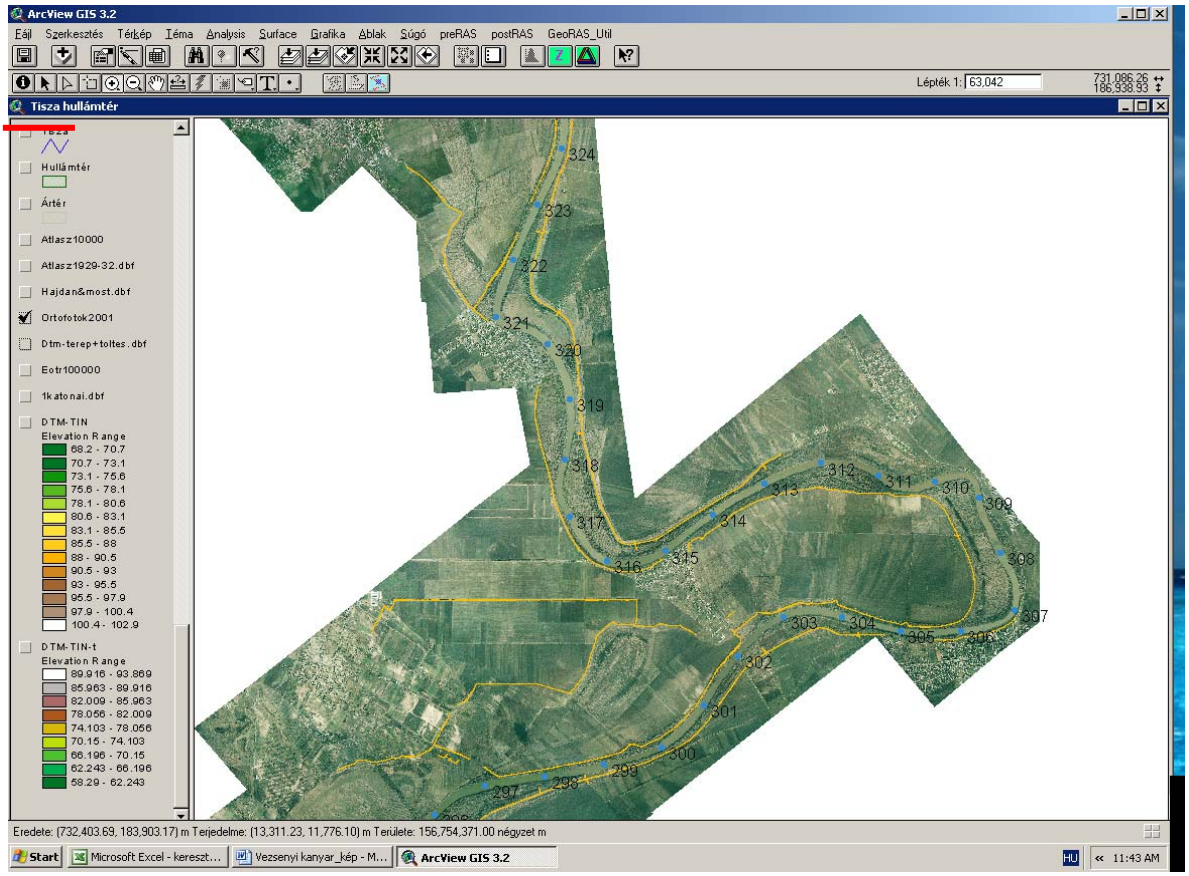


Fig. 18. Ortophoto made in 2001, Vezseny bend

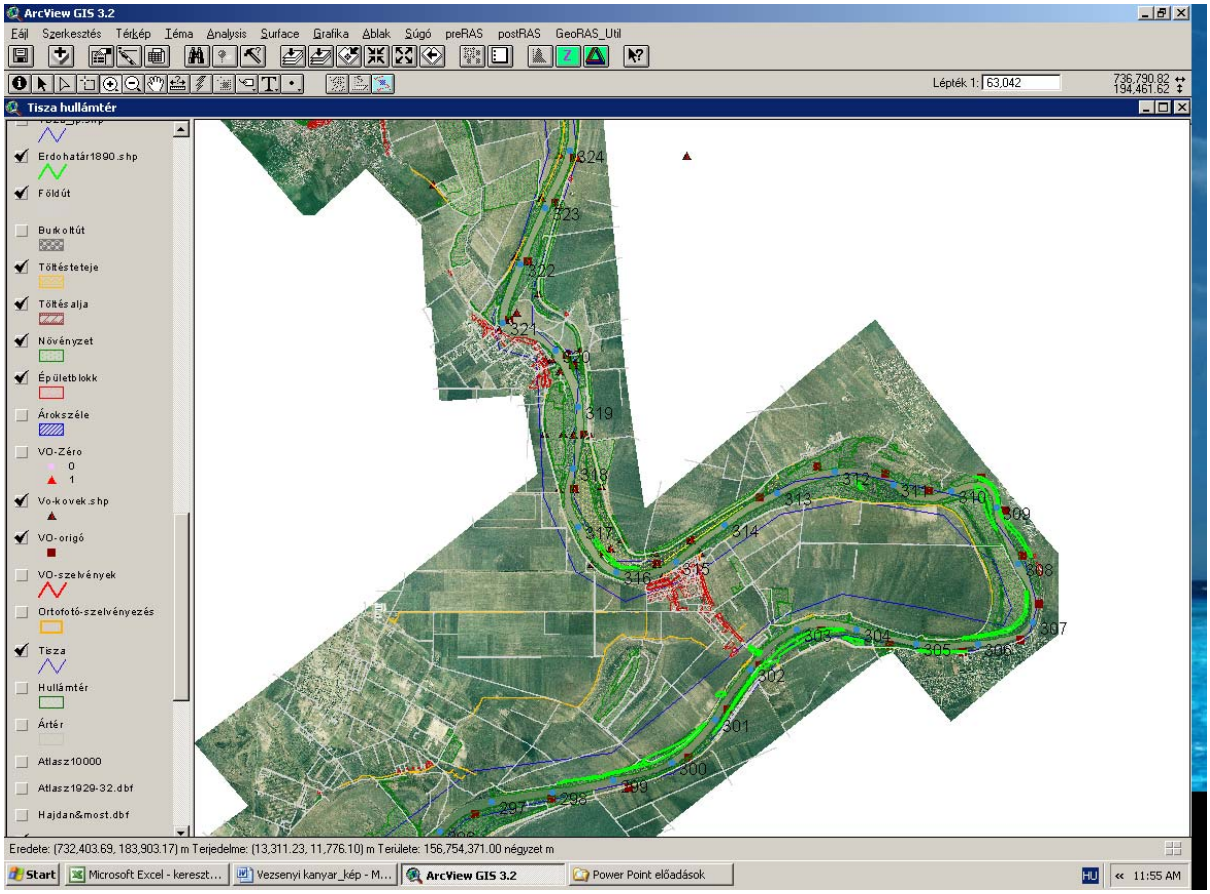


Fig. 19. Interpretation of forest conditions in 1890 on recent ortophotos, Vezseny bend

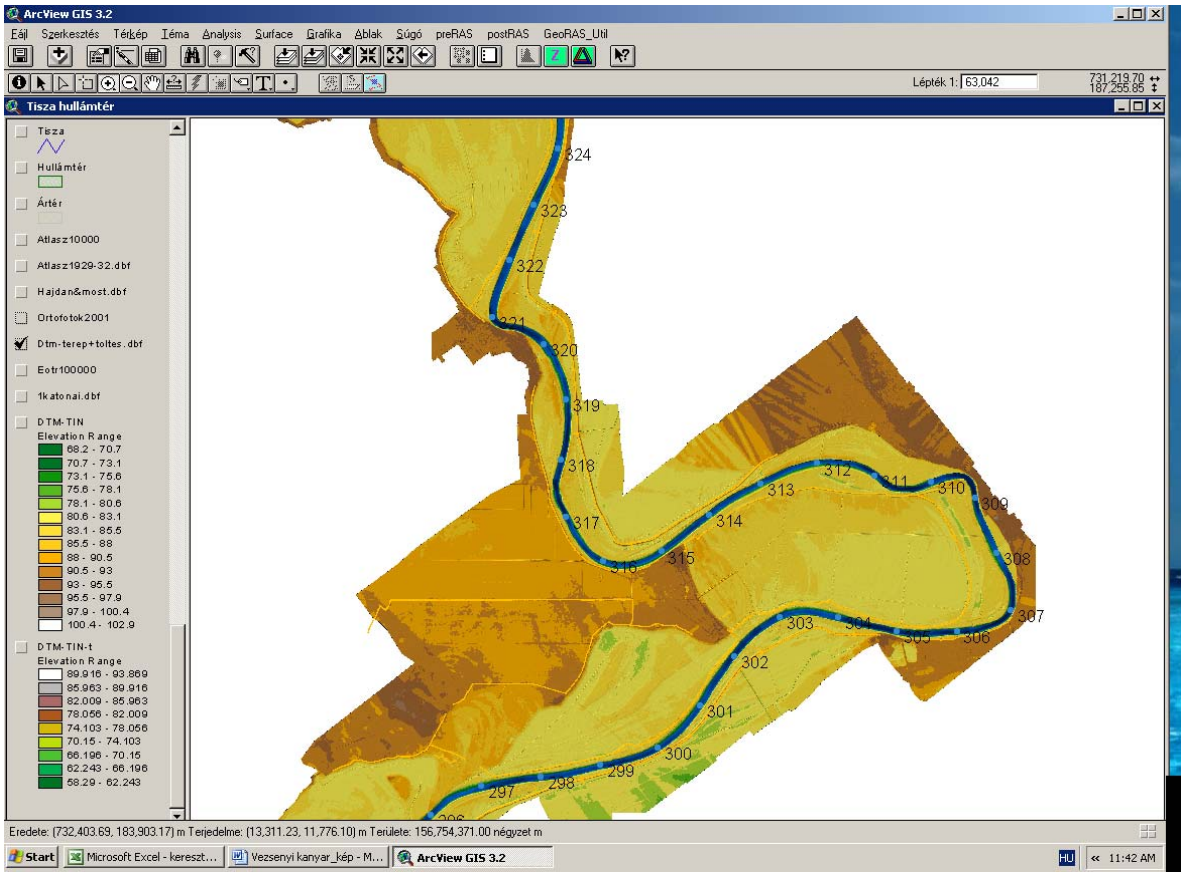


Fig. 20. DTM, Vezseny bend

2.1.1 Processing mapping information

Processing of mapping information required first of all the adjustment of all maps to a unified frame of reference. Since the first products, as it was mentioned earlier, were made without a projection system, monument churches were used as reference points for the adjustment. Then, the intermediate segments were adjusted to those already referenced. Finally, all products were transformed to the unified national projection system (in Hungarian abbreviation: EOV system, which is the national standard). The white background of the hydrographic maps was changed for transparent, enabling their easy comparison with the aerial photos, DTMs or earlier raster maps. Comparison of different products is shown in *Figures 19* and *26*.

Part of the processing is the vectorisation of the information having importance or relevance from water management point of view (rivers, water courses, flood extent, wetlands, dikes, canals, forests, roads, etc.).

The database is uploaded on the central server of the Middle-Tisza District Environment and Water Directorate in *Szolnok* and can be used under ArcView 3.2 *(Lovas, A – Vajk, Ö. 2003)*.

2.1.2 Cross sections

For the regular check and registration of changes in river morphology, the Hydrographic Department of the National Hydrotechnical Directorate established a cross section registration system in 1890-91, still in use. For the stabilisation of the measuring sections the so called VO-stones (VO stands for the Hungarian abbreviation of Hydrographic Department) as benchmarks have been placed (*Photo 1* and *2*) and their coordinates have been registered.

Surveyed and registered cross section data of 1890, 1929, 1957, 1976, 2000 and 2001 have been digitized adjusted to the elevation system based on the *Baltic see level at Kronstadt* and to the left side VO-stone. Changing cross section with characteristic water levels is shown in *Fig. 21*.



Photo 1. Basic point established in 1890



Photo 2. VO section stone

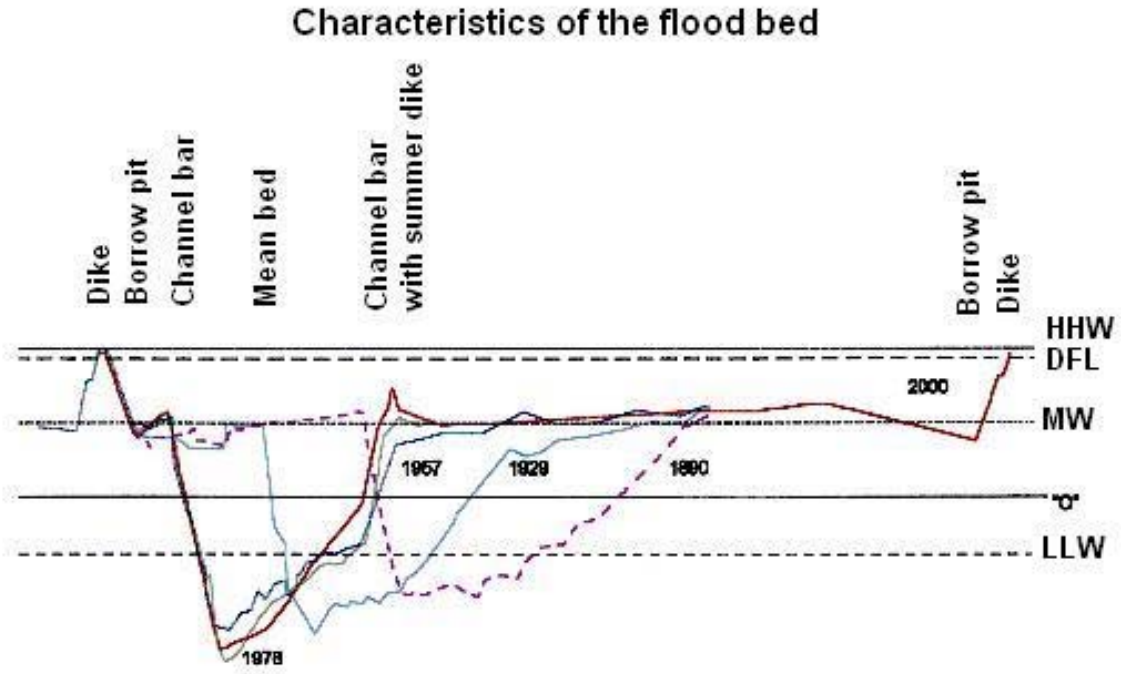


Fig. 21. Characteristics of the flood bed

Results of analysis of the changes in the flood bed, together with historical information *(Váradi, J. – Nagy, I. 2003)* on the reduction of the flood bed along the *Middle-Tisza* are compiled in *Table 2*.

Table 2. Reduction of the flood bed

River bank	Location of intervention	Period	Character/purpose	Reduction in area, ha	Reduction in V*, Mm^3
1888 - 1950					
Left	Csongrád, Hármas-Körös mouth – Tiszasas-Csépa	1929-31	Dike relocation	8,200	439.8
Right	Tiszakécske high ground – Szolnok,	1929-31	Dike construction	16,065	319.2
Left	Szolnok, Alcsi – Szajol (161/1 vo)**	1890-91 1929-31	Dike construction	5,500	162.0
Left	Szajol 166vo – 165 vo	1929-31	Dike relocation	285	5.7
Left	Pityóka – Tiszabő (159/2 vo–155/2 vo)	1929-31	Dike relocation	1,480	56.6
Right	Downstream Kisköre, Akolhát (144/1 vo – 143/2 vo)	1929-31	Dike relocation	650	17.8
Left	Upstream Kisköre, Cserőköz	1929-31	Dike relocation	900	16.0
Total between 1888-1950				33,080	1,017.1
After 1951					
Left	Szolnok, new section of road No.4.	1989-91	Dike construction	445	16.9
Left	Tiszabura	1968-73	Dike relocation	81	3.3
Left	Abádszalók	1968-73	Dike relocation	72	2.4
Total				598	22.6
Sum total				33,678	1,039.7

*retention volume lost below DFL in force now
**mark of registered cross section

Results of the above analysis show that along the *Middle-Tisza*, between *Tiszafüred* and *Csongrád* in the period of 1890-1931 the reduction in the flood bed exceeded 33 thousand hectares and thus lost almost the half of its flood retention capacity. In case of a flood equalling the design flood level, this lost territory could accommodate more than 1 billion m^3 of water.

As regards to the interventions of 1968-1991, their impact on retention capacity reduction is not as significant, resulting in only 23 million m^3 loss. It means that 97,8% of the total loss was 'produced' still in the first half of the 20th century.

2.2 Data collection on the changes in the mean riverbed

Analysing the collected cross section measurements of different period it can clearly be seen that the river training and the subsequent erection of flood embankments that concentrated the flow to the mean river bed lead to the continuous narrowing and deepening of the mean river bed. *Figure 22* illustrates this process very convincing. The tendency of the process is the same until 1976. The cross section of 2000 shows aggradation on the river section downstream *Szolnok* which is the result of the river barrage put into operation in 1973 at *Kisköre* (403,1 fkm). Due to the operation of this barrage the river bed is continuously deepening along the *Kisköre-Szolnok* river reach, while the bed load of this section is filling the downstream section of the *Middle-Tisza*.

Comparison of the area of wetted cross section of the different measurements (see *Fig. 23-25.*) demonstrates the continuous reduction of the mean river bed along the *Middle-Tisza* downstream *Szolnok*.

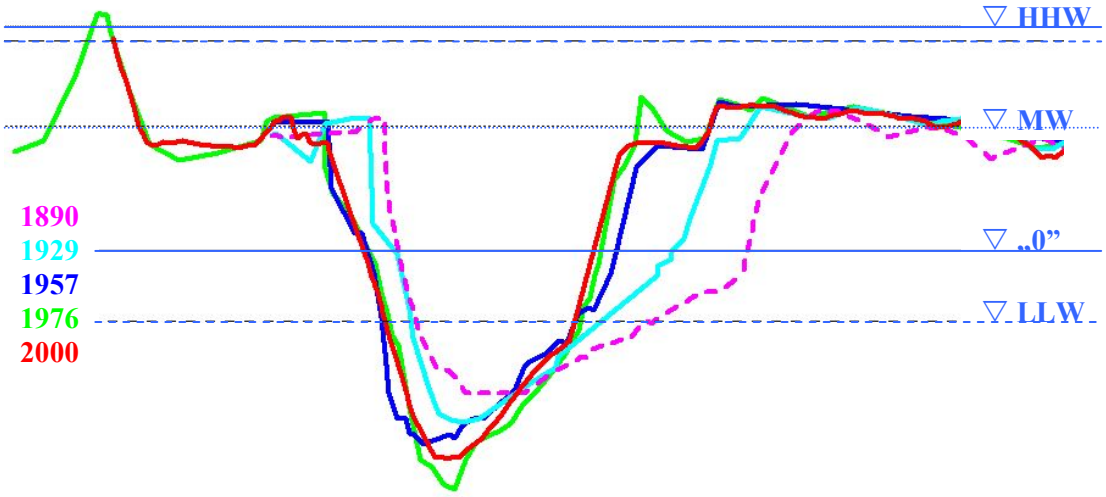


Fig. 22. Development of the mean bed

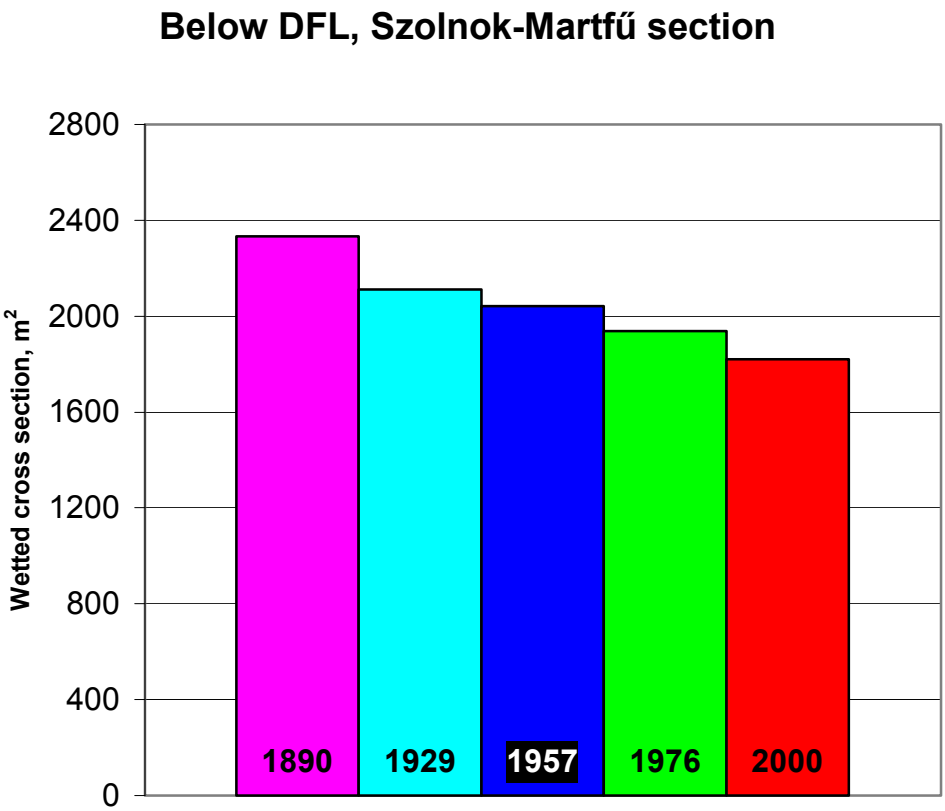


Fig. 23. Reduction of the wetted cross section of the mean bed, Szolnok-Martfű (335-306 fkm)

Reduction of the wetted cross section from 1890 to 2000 is 22%.

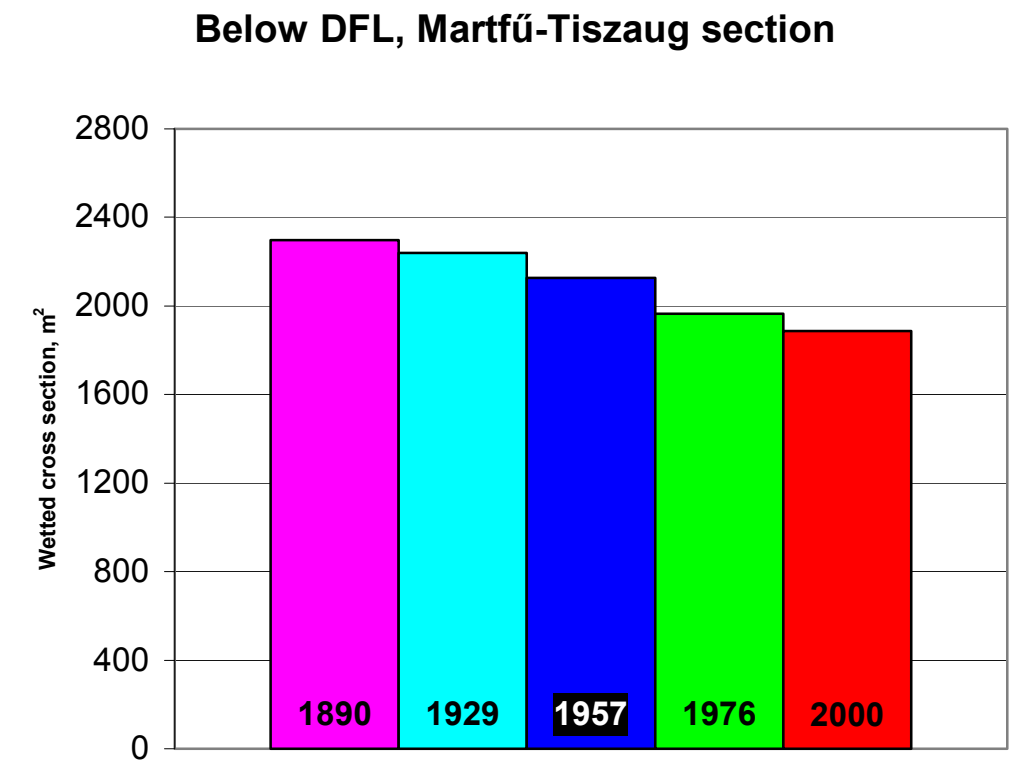


Fig. 24. Reduction of the wetted cross section of the mean bed, Martfű-Tiszaug (306-268 fkm)

Reduction of the wetted cross section from 1890 to 2000 is 18%.

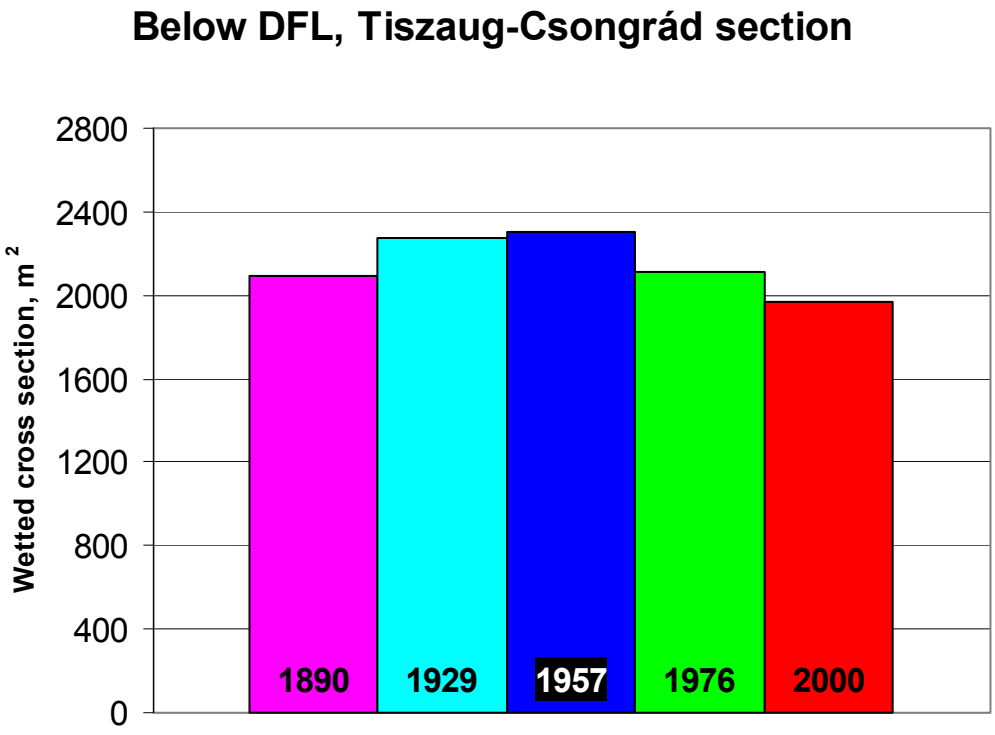


Fig. 25. Reduction of the wetted cross section of the mean bed, Tiszaug-Csongrád (268-244 fkm)

Reduction of the wetted cross section from 1890 to 2000 is 6%, from 1957 to 2000 is 15%.

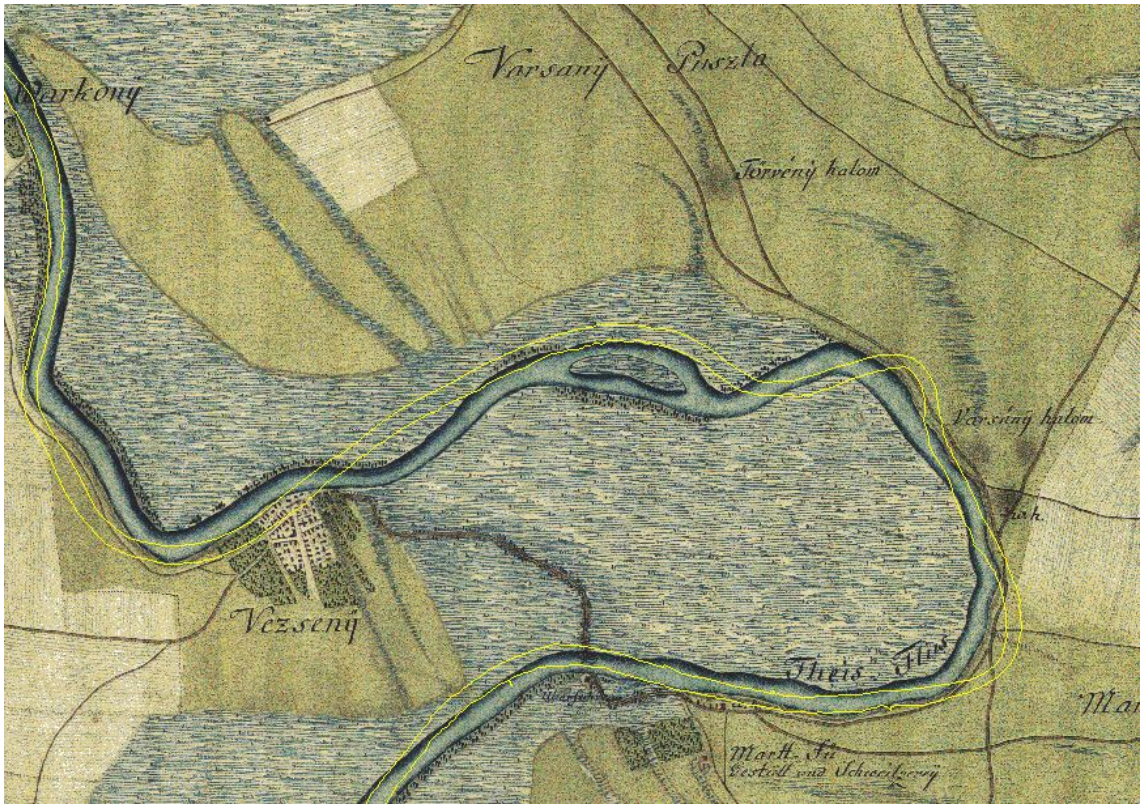


Fig. 26. River bed migration in the Vezseny bend demonstrated by the comparison of morphology in the first military survey with that of the recent conditions

2.3 Data collection on the artificial structures erected in the floodway including summer dikes

According to the results of analysis of the data collected, no artificial structures, buildings were erected in the flood bed between 1780 and 1892 except for bridges and road ramps accessing those.

The *summer dikes* appeared first in 1892. The summer floods of *River Tisza* being lower than those of the spring floods, in order to grow mainly stoop crops on the fertile, extensive lands in the floodway, summer dikes were erected to protect these lands from inundation by frequent floods. The summer dikes were built on the natural sand bars, height of which was in the range of the 600 cm water stage at the *Szolnok* gauging station, to minimize efforts and costs of construction. In the beginning their height was in the range of 0,5 m only, and, as long as the early 1950-s their height did not exceed substantially the height of the channel bars, or in other terms, the level of flood alert I.

In the early 1900-s erection of the summer dikes was even supported by the water authorities to accelerate the development of the newly crosscutted riverbed sections, especially where the floodway was very wide, for example at *Vezseny* (the Vezseny summer dike possessed permission from 1914).

In the period of 1910-1950 the crosscutted river sections became developed as a result of the low water training of the river. In the 1950-s, with the availability of the high performance earthwork machinery, a boom in the construction of summer dikes started along the *Middle-Tisza*. Ten new summer dikes have been erected in a few years between *Kisköre* and *Csongrád*. Average height of the summer dikes reached the range of 680-740 cm water stage according to the *Szolnok* gauging station *(Szín, I-né – Ivaskó. L. 2003)*.

Process of heightening of existing summer dikes as well as building recreation houses in the floodway (in the vicinity of *Tiszapüspöki, Tiszaug, Doba, Nagykörü, Szolnok*, in many cases not meeting the permissions) accelerated in the early 1960-s, in the so called consolidation period after the repressions and victimization that followed the revolution of 1956. Heightening of the summer dikes over the permitted crest level by the agricultural collectives could be observed especially from the 1970-s and in many cases their height reached and even exceeded the level of flood alert III by 0.5-1.0 m.

Total length of 13 summer dikes in the *Middle-Tisza* region in 1981 is 81.4 km, extension of the protected area is 13,151 ha.

Investigation of the causes of anomalies in the raising of the flood crests along the *Middle-Tisza* started and repeated after the floods of 1970-1974-1979, however, decision was only made in 1981, when the Economic Committee issued a resolution obliging the stakeholders, namely the Ministry of Agriculture, the Ministry of Finance and the National Water Authority to examine the hydrotechnical and economical conditions of the reconstruction of summer dikes, to elaborate the phasing and the regulation of implementation. The elaborated proposal projected to demolish 2 summer dikes of the existing 13, lowering the crest of one by almost 1.0 m and relocation of the rest 10 by 100-400 m. Law enforcement that time was too weak, unfortunately, therefore the implementation failed.

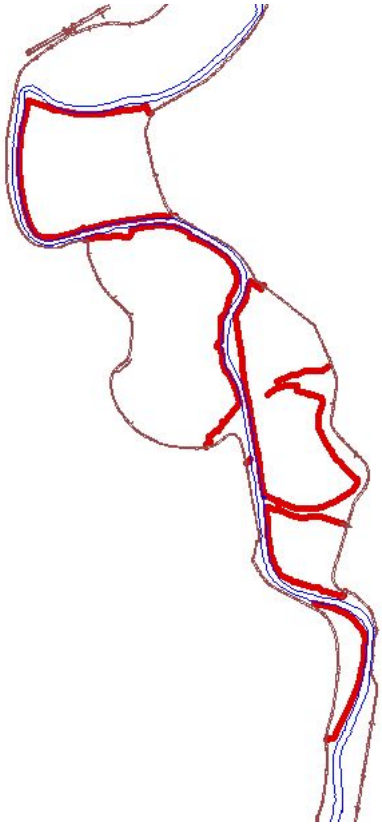
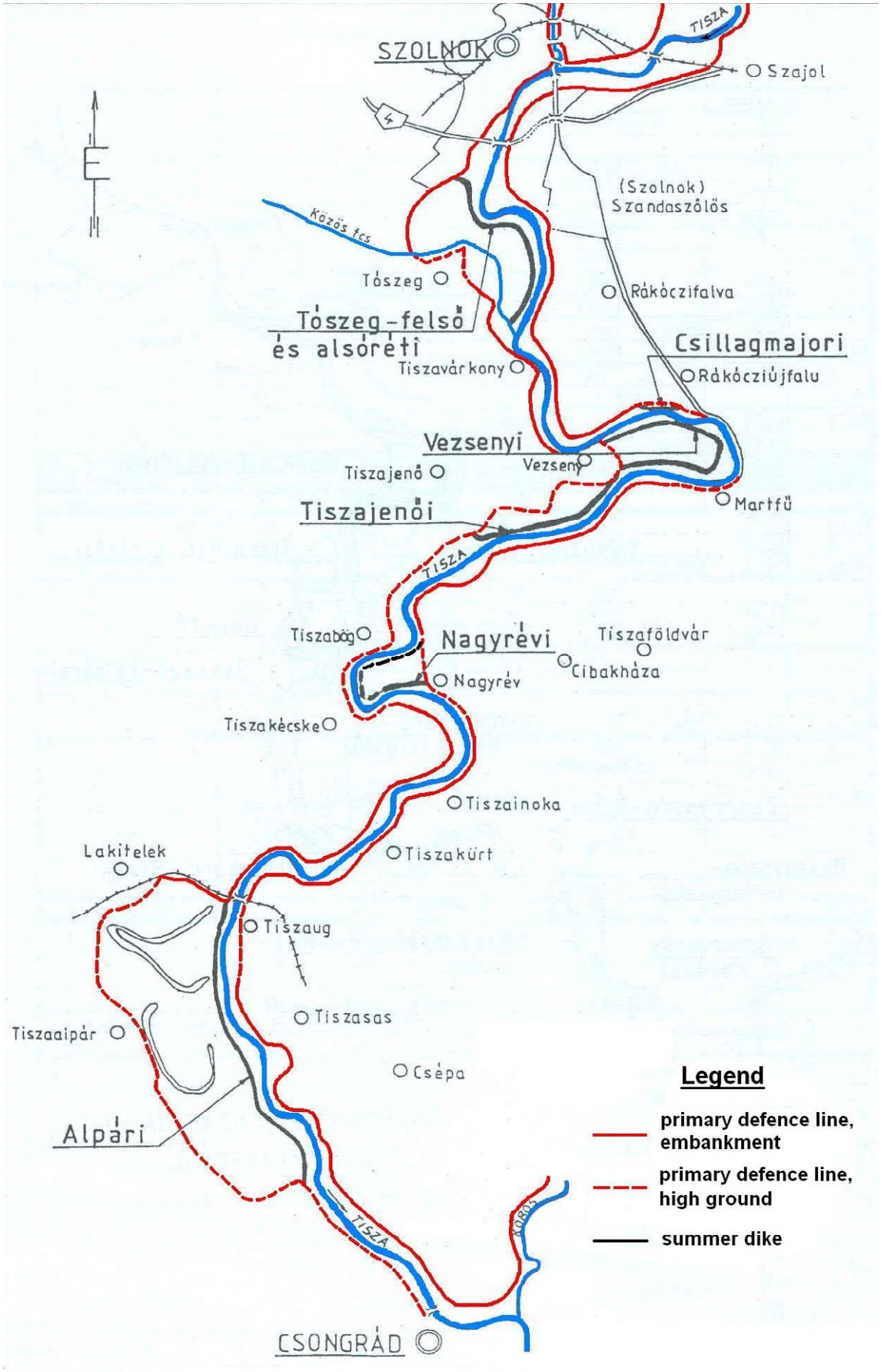


Fig. 27. Summer dikes at Tiszaroff-Tiszasüly (369-394 fkm)

No further obstacles of flow were erected from 1997, this is the year when the Middle Tisza District Water Authority started the cutting back of the summer dikes to the permitted height.

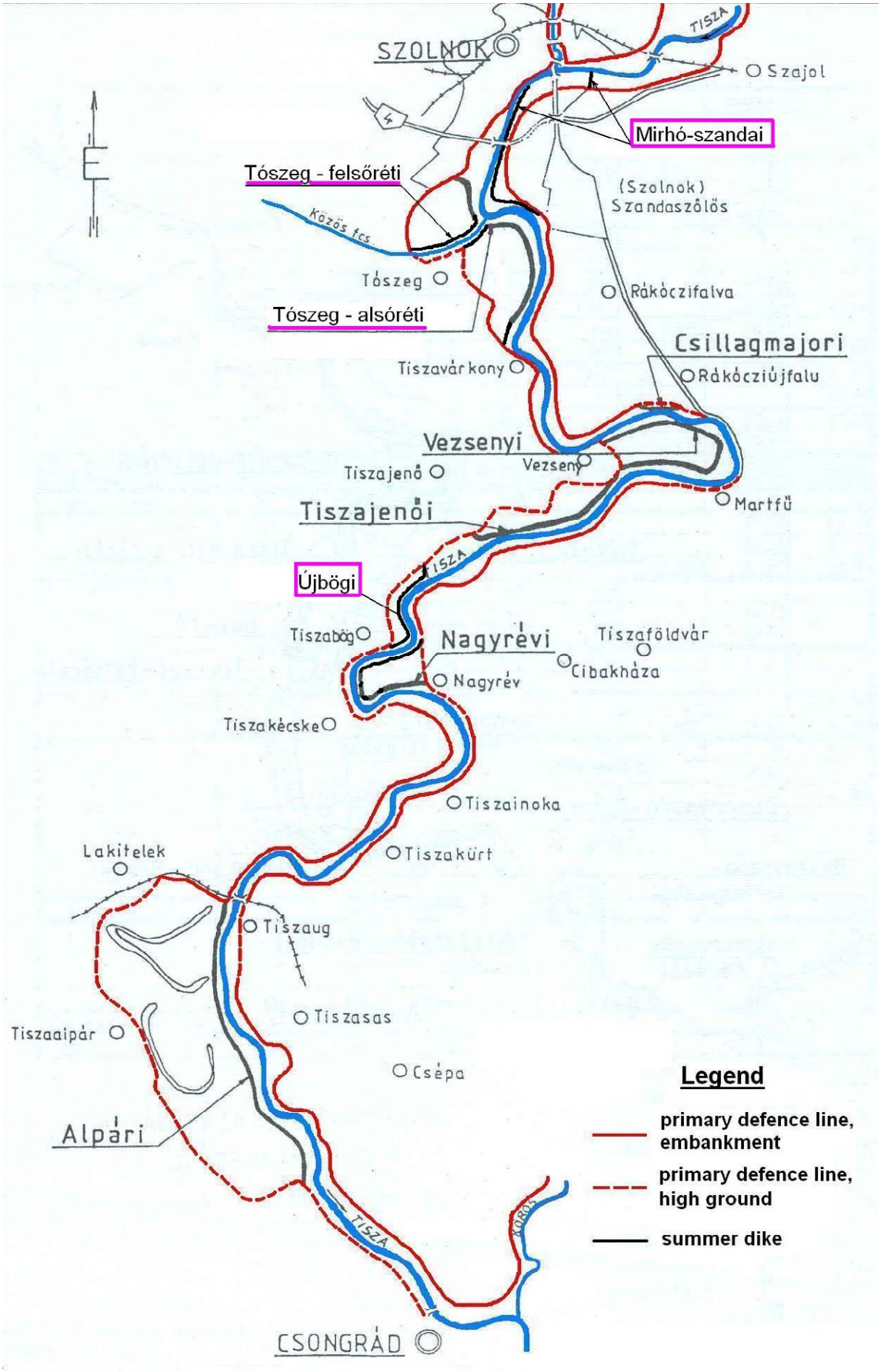
Figures 28. and 29. show the summer dikes of the Middle-Tisza in the *Szolnok-Csongrád* section in the 1950-s and in the 1980-s. From the comparison it can be seen that three new summer dikes were built in the 1980-s (*Mirhó-szandai, Újbögi*) and one another, the *Tószegi* was splitted by the correction of the track of the *Közös (Gerje-Perje) main canal*.

Fig. 28. Summer dikes as of 1951-1960



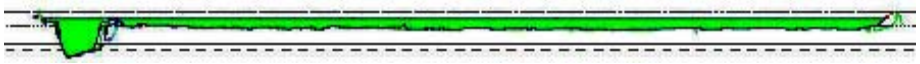
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Fig. 29. Summer dikes as of 1980-1981



Some characteristic example on the impact of some summer dikes on the contraction of the wetted cross sections

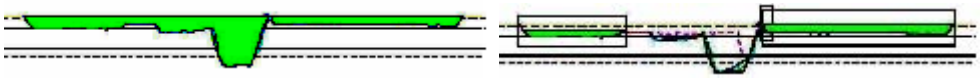
Tiszasüly



Below the level of summer dike: 10,792 m^2

Main bed: 1,637 m^2 Reduced by summer dike: 9,155 m^2 loss of wetted cross section: 85%

Szolnok



Below DFL: 6,568 m^2 *Reduced by summer dikes: 730 + 1,823 = 2,568 m^2*

loss of wetted cross section : 39%

Vezseny – see Fig. 48. loss of wetted cross section below HHW: 67%

Forest technical dikes

Forest technical dikes, which are in fact the depots of collected stubs after clearing appeared from the 1980-s. As the below illustration shows, they are deposited in many cases across flow direction. Additionally, they are producing a very dense stand of woods *(Lovas, A – Vajk, Ö. 2003)*.

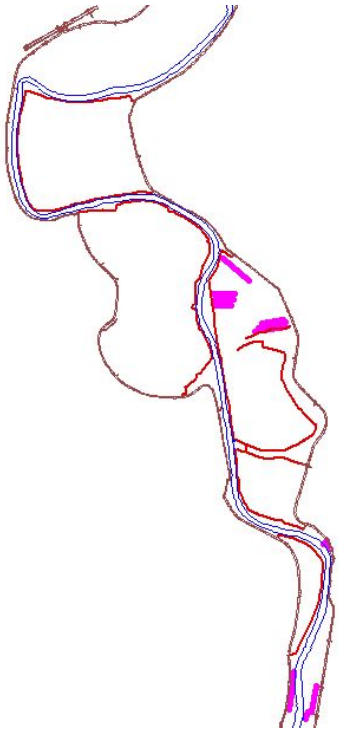




Photo 3.

Forest technical dikes – stub depots in the vicinity of Tiszasüly

Fig. 30.

2.4 Data collection on the raising of the natural sandbars on the riverbank

Results of measurements demonstrate that the natural sandbars accompanying the riverbank (see *Fig. 21* and *22; Photo 4* and *5*) are growing continuously everywhere, where the main bed is more or less stable and no lateral migration occurs. Rising of the level of the sandbars is in the range of 1.0-2.5 m

since the river training, according to measurement results. Measurements in cross section VO 109 demonstrate these developments cross section-wise (see *Fig. 31.*), while *Fig 32.* illustrates the tendencies along the *Szeged-Tiszabura* river reach in a length of 350 km.

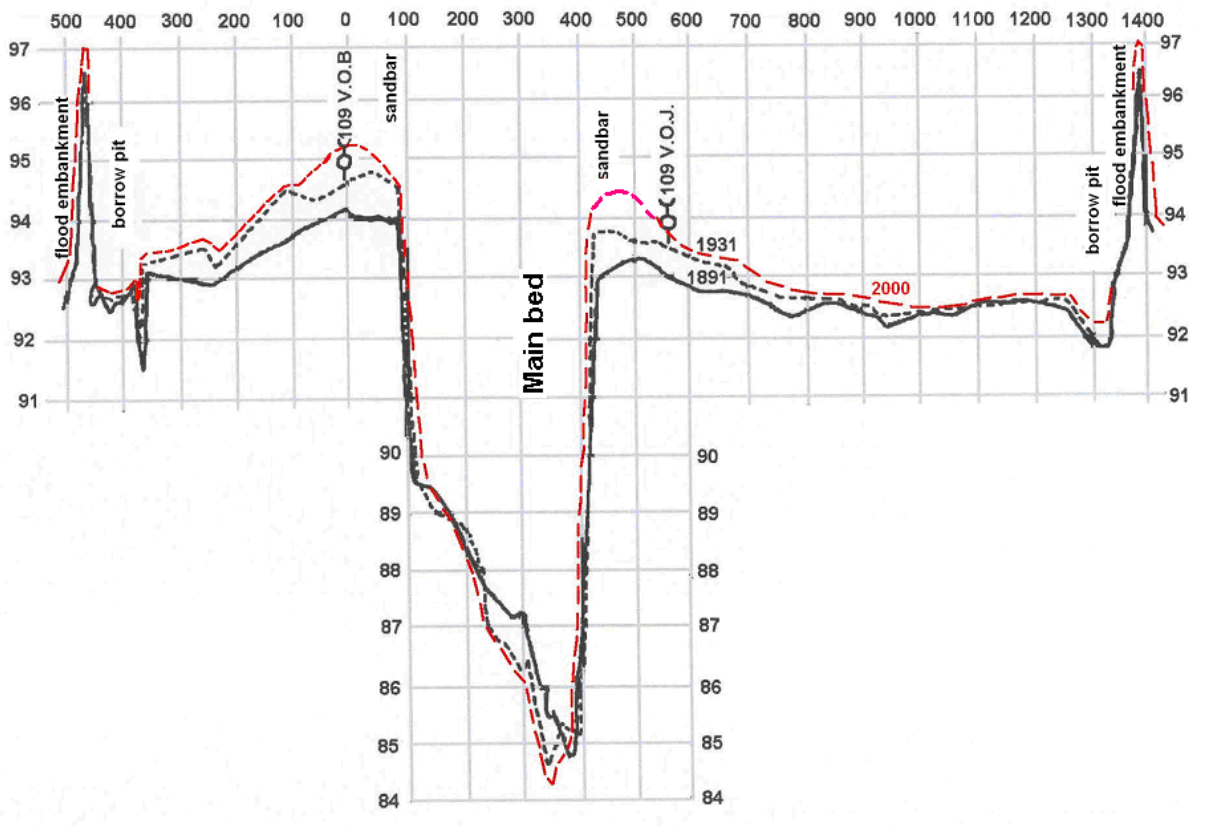


Fig. 31. Development of sandbars in cross section VO 109

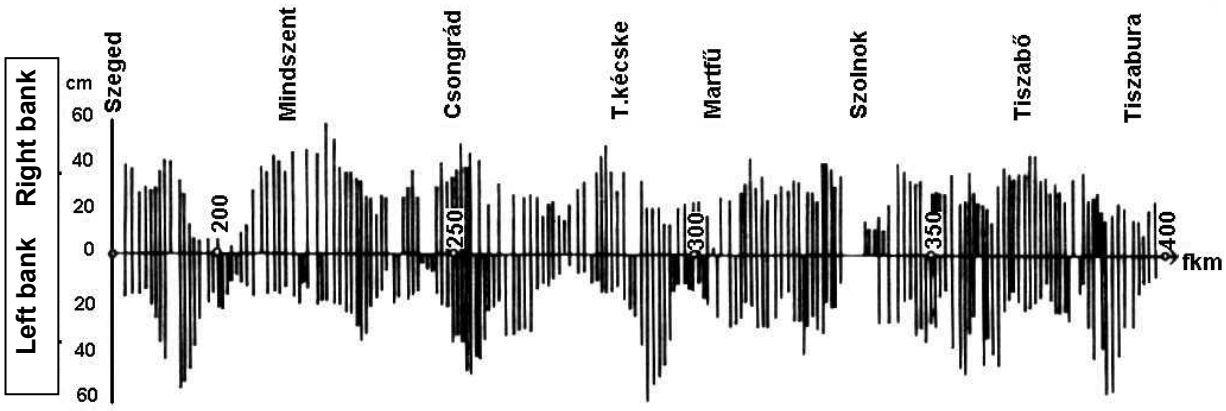


Fig. 32. Raising of sandbars along the Middle-Tisza between 1890-1931

Fig. 33. represents extract of the results of surveys of the cross sections made in the period of 1998-2001. The figure shows the highest natural elevations of the river bank (the sandbars) in a longitudinal profile and also some sections of summer dikes or even the primary flood defences being near the bank of the mean bed. The profile also contains envelop curves of characteristic water stages related to *Szolnok* gauging station. It is important to note that the 650 cm water stage corresponds to Alert I, while 750 cm to Alert II and Alert III is to be announced at 800 cm. The figure clearly demonstrates that the elevations of sandbars are in the range of Alert II, especially in the close vicinity of and upstream *Szolnok*. Channel bars are also illustrated in *Photos 4* and *5*.

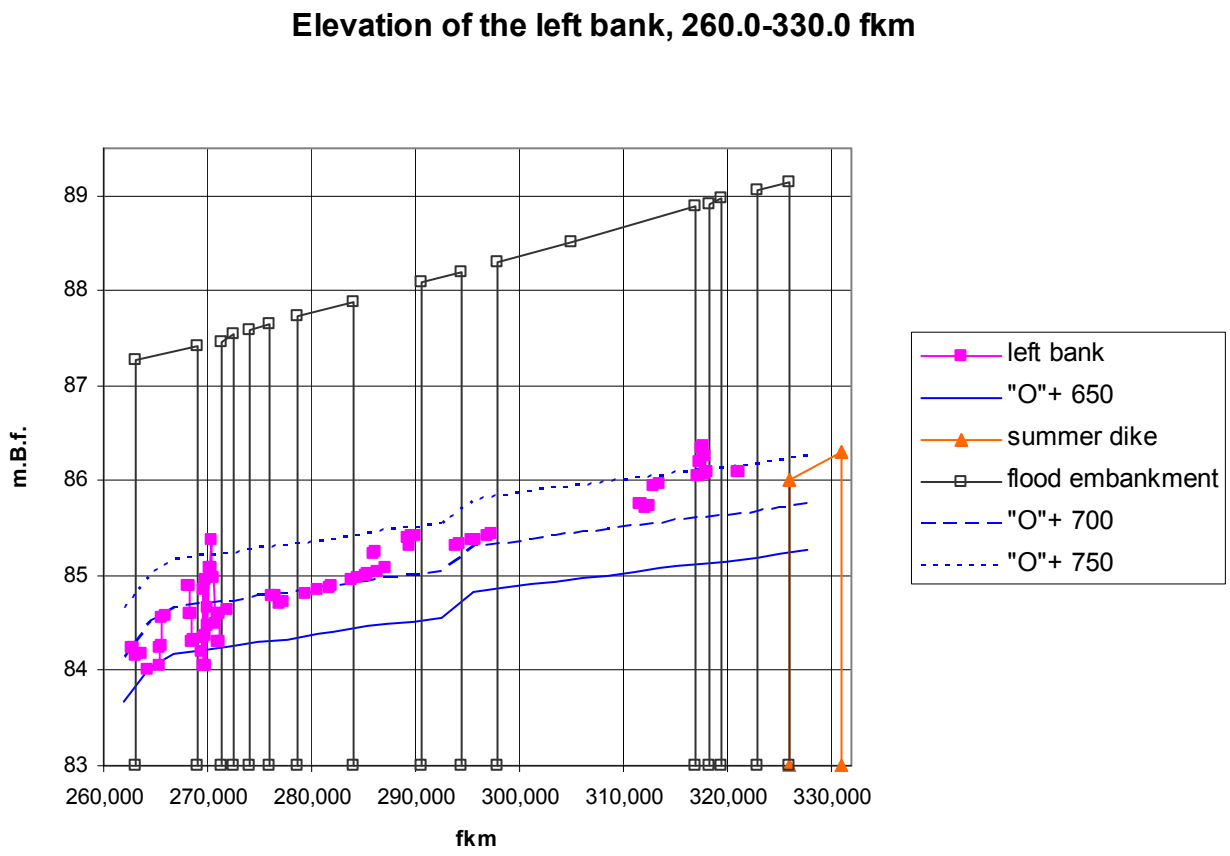


Fig. 33. Longitudinal profile of the sandbars on the left bank

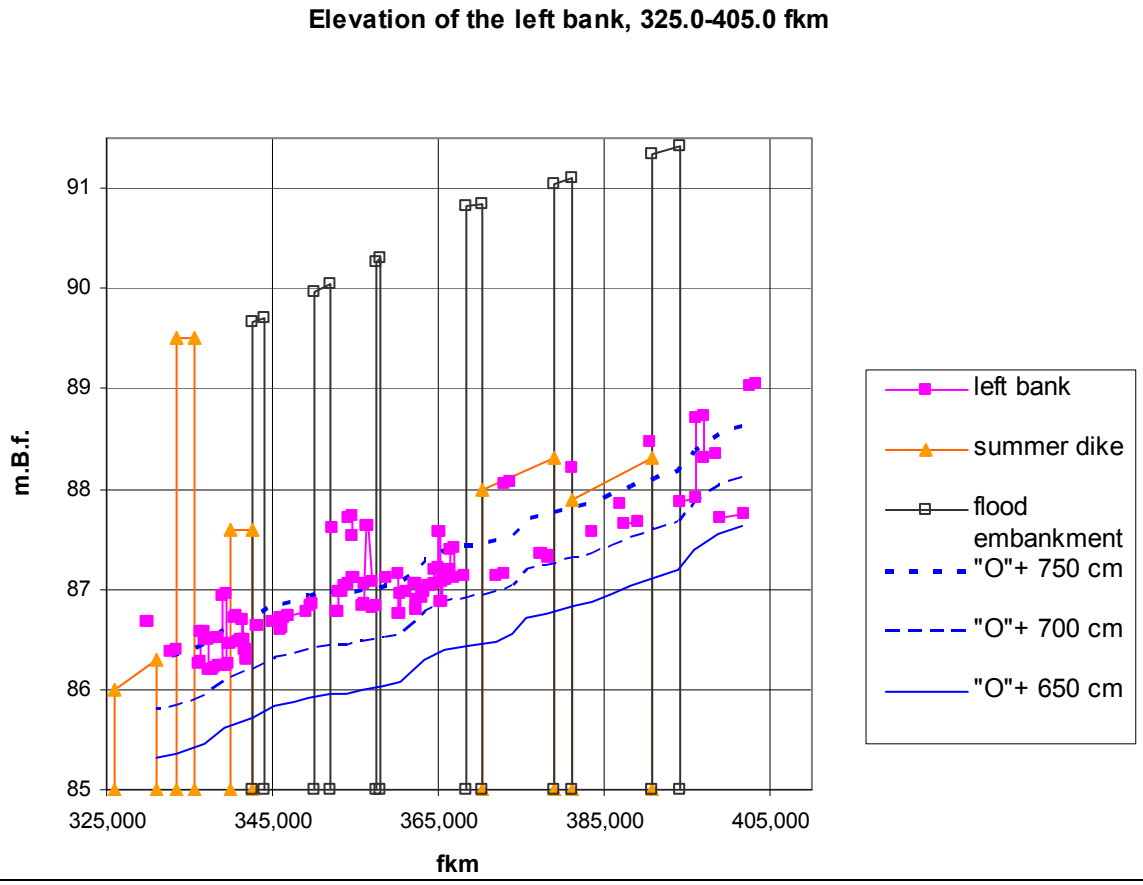




Photo 4. Channel bar with inlet



Photo 5. Channel bar on the river bank

In order to gain information on the development of the sandbars in time an in-situ investigation was made in *Szolnok*, on the left bank of the river, where the sandbar was cut through in a depth of 2,5 m and samples were taken to analyse the layers on the one hand and their age in the other.

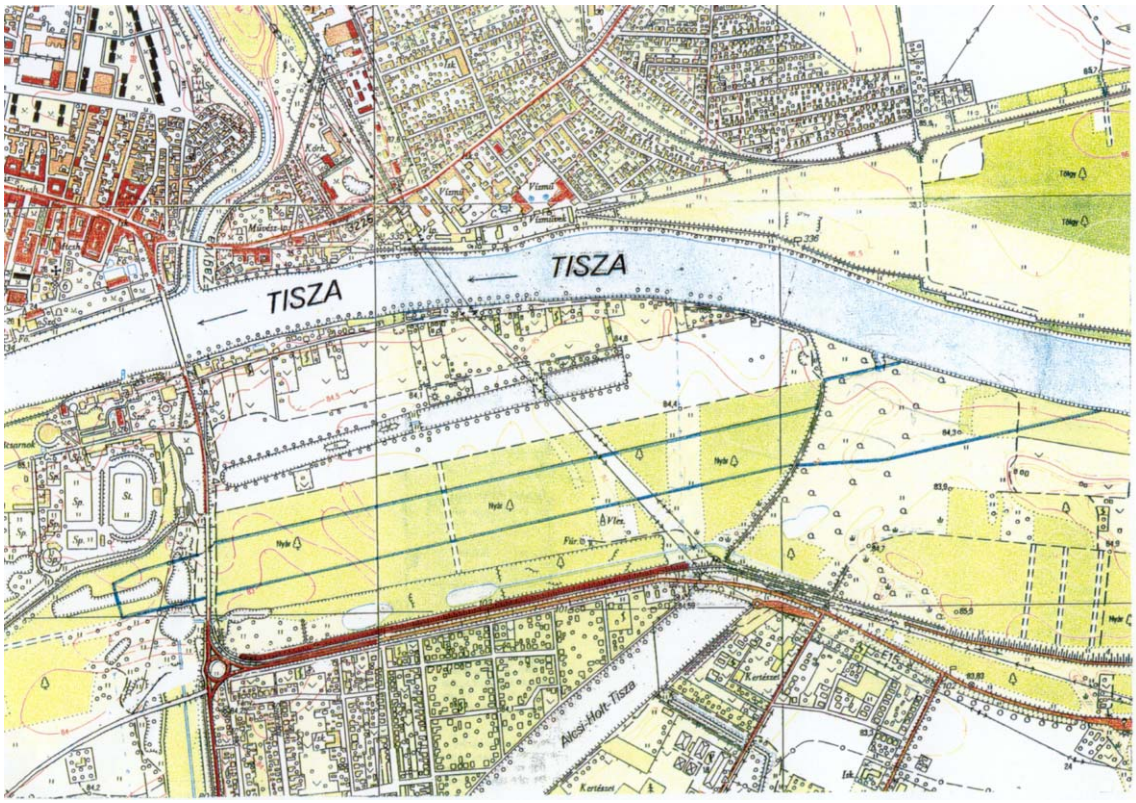


Fig. 34. Szolnok, River Tisza, sampling site

The cross section of the sandbar with characteristic water stages is shown in *Fig. 35*. The cut wall of the sandbar did not show any sharp boundaries of different layers. Different radiometric investigations were performed. Carbon isotopic and absolute age determinations were disturbed by roots and the limited financial resources therefore the investigation concentrated on metal components and radio isotopic elements, deposition of which can be linked to the finest fractions of clay and silt (*Nagy, I. – Schweitzer, F. – Alföldi, L., 2001*).

The age of sediment depositions was determined with the help of radioactive sediments, fairly accurately. Results and explanation to occurrence of the different elements in different depth are summarized in *Fig. 36.*

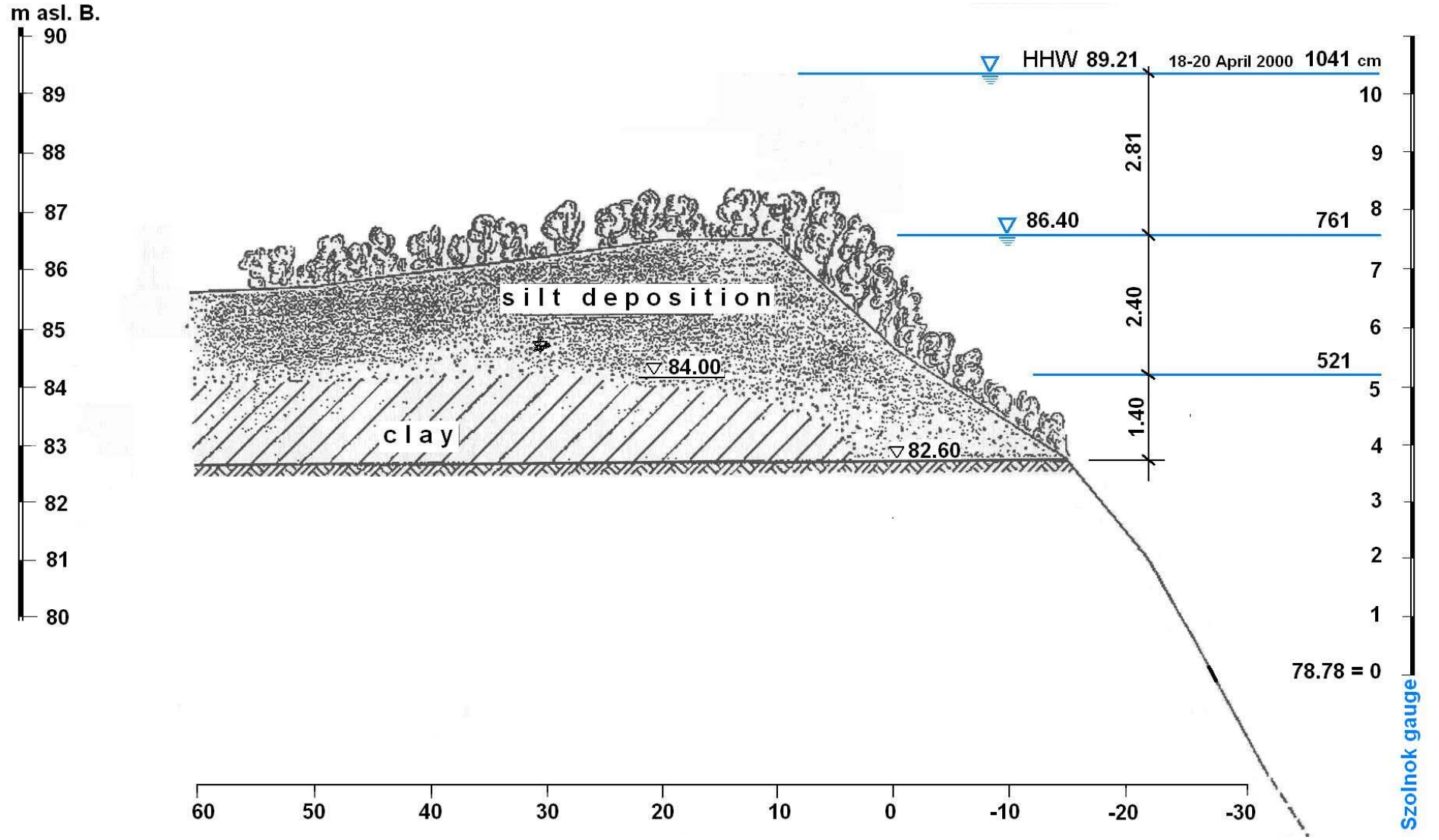


Fig. 35. Cross section of the investigated sandbar at Szolnok

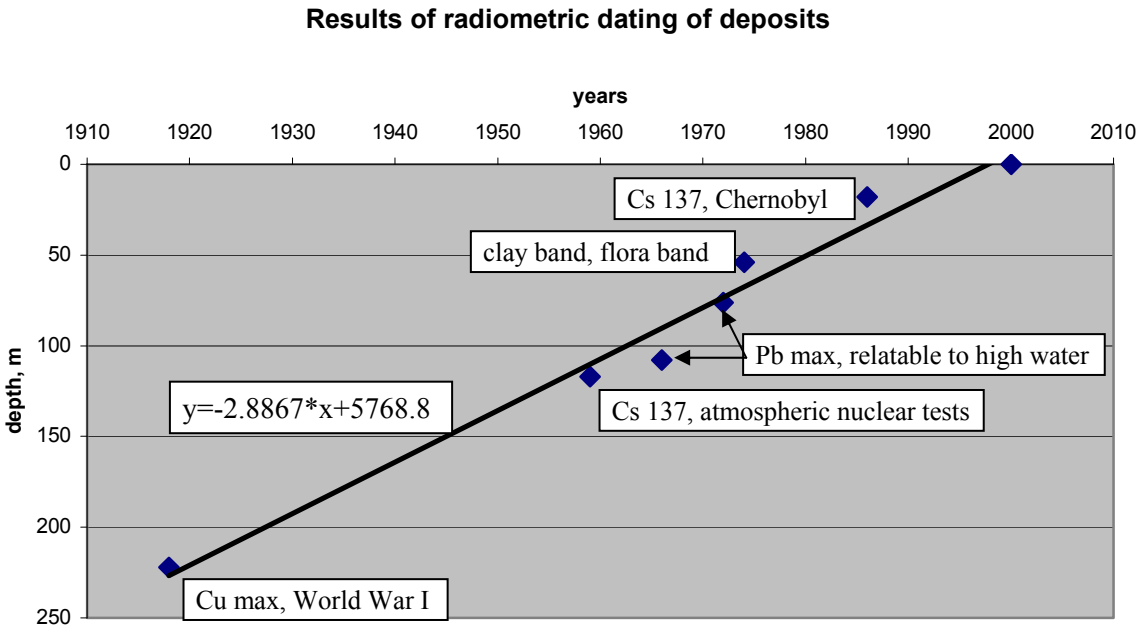


Figure 36. Results of radiometric dating of deposits

Investigation of the samples taken from sandbar at *Szolnok* proved that great floods each may contribute to the raising of the sandbars by even 0,1-0,45 m.

2.5 Data collection on the changes in the land use of the floodway

Analysing the maps of the first military survey it can be revealed that on the territory of nowadays floodway forested area can only rarely be observed. According to this map on one embankment of *River Tisza* sparse trees can only be seen, while on the other is free of woods, being served as tracker road. Most of the territory was marshland, the majority of the rest was pasture, only a few served for plough land. Sandy lands of higher elevation were occupied by orchards and vineyards.

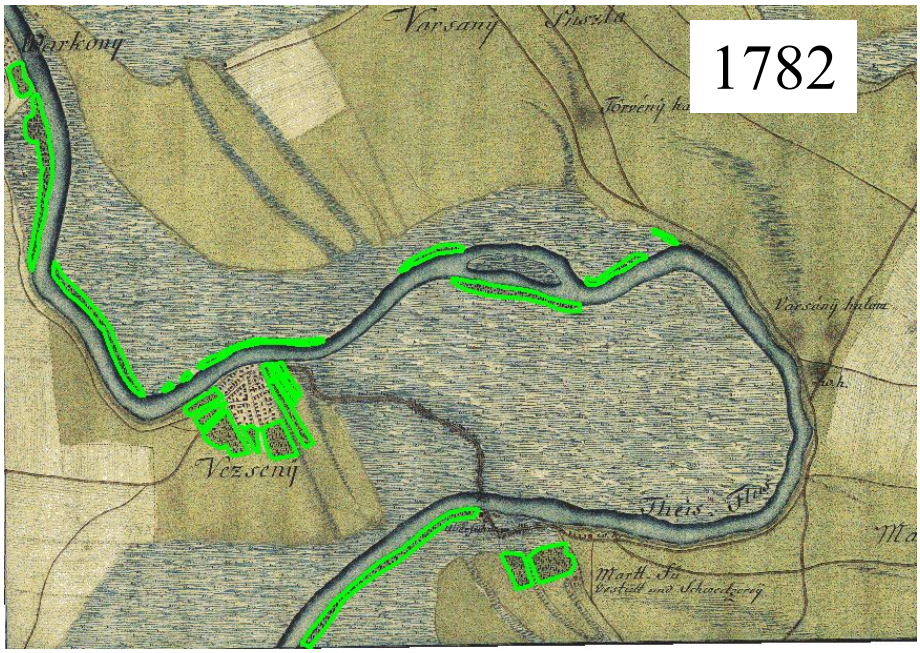


Fig. 37. Forest conditions in the Vezseny bend in 1782.

Forest belts planted for wave erosion protection of the newly built flood embankments appear first on the maps of the second military survey made in the 1890's. Protecting role of these forest belts was extremely important because continuous, uninterrupted forests in the floodway could rarely be found. Characteristic prevailing land use remained marshlands, pastures and plough land.

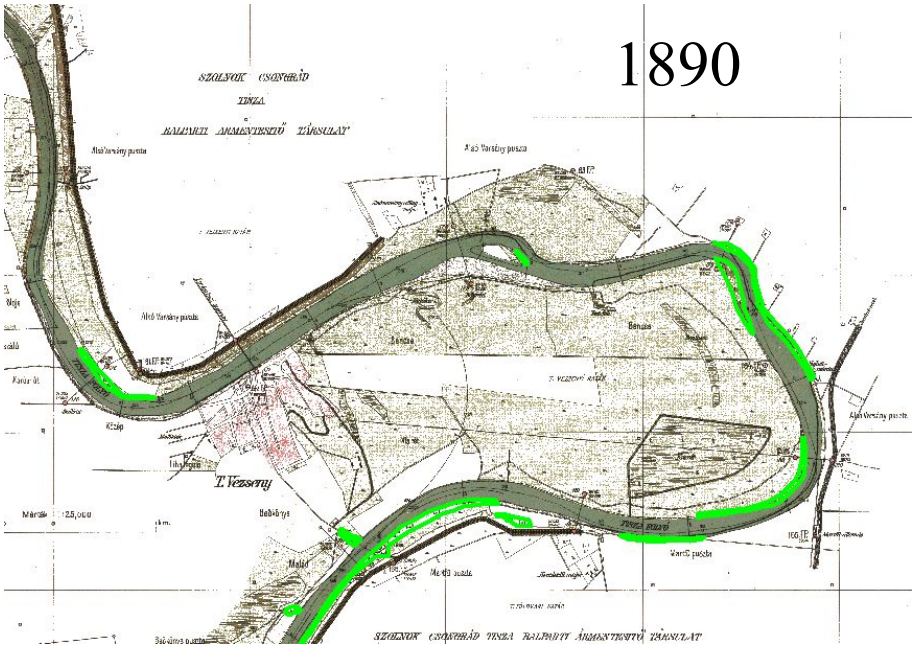


Fig. 38. Forest conditions in the Vezseny band in1890.

Table 3. Land use conditions in 1902

River section	Pasture		Plough land		Forest		Marshland, standing water, borrow pit	
	ha	%	ha	%	ha	%	ha	%
Körös mouth – Szolnok	11,855	69	1,399	8	767	5	3,126	18
Szolnok – Tiszaderzs	9,793	62	2,246	14	1,400	9	2,410	15
Tiszaderzs – Ároktő	19,944	70	2,003	7	1,998	7	4,232	16
Middle-Tisza total	41,592	68	5,648	9	4,165	7	9,768	16
Tisza in Hungary (Titel-T.újlak)	74,610	53	24,464	17	20,238	14	21,344	15

Rapid growth of forest stand started in the socialist area after the establishment of soviet type agricultural collectives, that was accompanied by the falling back of grazing, thus by the reduction of floodplain pastures. Cleaning of undergrowth in the forests as well as cleaning of slopes of river and canal beds continuously decreased as the demand for firewood reduced by changing over oil heating, later gas heating. As long as the early 1960-s the undergrowth in the forests were cleaned, the water could flow under the trees without considerable resistance *(Váradi, J. –Nagy, I. 2003)*.

Plough land cultivation was limited in the floodway to the territories defended by higher summer dikes from the 1970-s. Rest of the territory was afforested or waste ground. On the waste grounds several meter high, imperviously dense woodland developed within several years. As a result of the series of floods in the end of the 1990-s cultivation of the rest of plough lands and pastures became impossible, and on these territories extremely dense woodland of pioneer species is growing in a rapid pace.

The aerial photos of 2001 and the results of field inspections in 2002 resulted in 3-5% of cultivated land, plough land and pastures, the rest is wild woodland and forest. Since the characteristic slope of free surface along the *Middle-Tisza* is 3-6 cm/km, these conditions create significant flow obstacle.



Fig. 39. Forest conditions in the Vezseny band in 2001.



Fig. 40. Comparison of forest conditions of 1850 and 2001in the Tiszaroff-Tiszasüly section

Forestation of the floodway with inappropriate, adventive species like *desert false indigo* (*amorpha fruticosa), green ash (fraxinus pennsylvanica)* and *box elder (acer negundo)* and lack in maintenance of these floodplain forests lead to the development of very dense undergrowth, which, coupling with other invasive flora, like river rank grape or frost grape– *vitis riparia* created a compound representing real obstacle for water flow *(Czeglédi, I. 2003)*.

The below photos are to illustrate the forest conditions in the floodway of *River Tisza*.



Photo 6. Dense undergrowth in the floodplain forest



Photo 7. River Bank Grape or Frost Grape– vitis riparia



Photo 8. Box elder, green ash and river bank grape



Photo 9. Green ash – fraxinus pennsylvanica



Photo10. Desert false indigo – amorpha fruticosa

3. 1D hydrodynamic modelling of the water system of the River Tisza

3.1 Selection of the model to be used

Modelling has been accomplished by applying the *HEC-RAS* software. When selecting the hydraulic model, it was of fundamental importance to work with a program that

- operates on good physical bases,
- is easy to handle with short running time,
- displays the results in a well structured form,
- possesses a stable background of development, and
- internationally recognised and accepted.

Taking also into account the five-lateral cooperation of the countries sharing the Tisza River Basin in the Tisza Water Forum aiming at joint elaboration of a sustainable flood management concept, in the selection process we paid special attention that the countries on the catchment area might connect to the structured system or to a certain segment of joint interest of that *(Hegedűs, P. 2003, Kovács, S. – Váriné Szöllősi I. 2003*).

3.2 The stream network

In its current structure, the database of the model includes the 740 km long river section between *Tiszabecs* (Hungarian-Ukrainian border) and *Titel* (conjunction to Danube River), as well as 8 main tributaries (*Szamos, Kraszna, Bodrog, Sajó-Hernád, Zagyva, Hármas-Körös, Maros* rivers) mouthing into the main stream, moreover. Another three tributaries (*River Borzhava, River Túr* and *Lónyai Canal*) are taken into consideration as concentrated load *(Kovács, S. – Váriné Szöllősi I. 2003*). The total length of streams involved into calculations exceeds 1.500 km (*Fig. 41*).



Fig. 41. – Stream network of the River Tisza in the model

3.3 Cross section data

The HEC-RAS model (like many of other 1D models) is suitable for inputting cross sections determined by the traditional distance-height point couples as well as for operation of databases based on geographic informatics systems (GIS).

Cross sections between *Kisköre* and the southern border of the country, including the pilot section (324.847 fkm - 296.681 fkm), have been extracted from the digital terrain model of the river section. The DTM was composed from ortophotos made by Eurosense Ltd. in 2001-2002, low water cross sections surveyed by Raab Ltd. by GPS controlled ultrasonic depth measurements and completing geodetic and GPS surveys to connect the measurements made on land surface and under water. On the strongly overgrown flood plain areas, in the line of channel bars, the data of DTM were corrected by additional geodetic measurements. Data acquisition costs of HEURAqua covered the above completing and additional geodetic surveys, while the costs of ortophotos and ultrasonic underwater measurements were part of the project called *Update of the Vásárhelyi Plan* (UVP).

The section between the Hungarian-Ukrainian border and *Kisköre* was structured mainly on the base of measurement results accomplished after 1999 but within this river reach also some old cross sections measured in 1976 were used. Cross sections of the river between the southern boundary of Hungary and the mouth were made available by the Serbian water management.

The stream system of the *River Tisza* and its tributaries has been described by more than 1.550 cross sections, 84 bridges and 11 flood reducing structures are also installed into the model.

3.4 Roughness (smoothness) coefficient

In the course of calibration of the model the roughness (smoothness) factor ranges given in *Table 4*. were taken into consideration for the calculation of the water discharge capacity of the mean bed as well as for the evaluation of the effect of the flood plain (flood way) cultivation branches.

Table 4 – Roughness / smoothness coefficients

Serial Number	Type	n ($s/m^{1/3}$)		k ($m^{1/3}/s$)	
		min	max	min	max
0	Main bed	0.060	0.017	16.67	58.8
1	Pasture	0.050	0.025	20.00	40.0
2	Plough-land	0.050	0.020	20.00	50.0
3	Sparse thicket	0.080	0.035	12.5	28.6
4	Dense thicket	0.160	0.040	6.25	25.0
5	Forest without undergrowth	0.120	0.030	8.33	33.3
6	Forest with undergrowth	0.200	0.080	5.00	12.5
7	Coarse gravel	0.070	0.030	14.3	33.3

Cultivation branches on the flood plain/flood way have been determined by evaluation of aerial photographs (ortophotos), as well as by the results of on-site inspections. The roughness factor was changed crosswise according to flood plain cultivation branches. The roughness (smoothness) factor assigned to these was determined on the base of the prescriptions of the Hungarian standard, as well as on the base of values applied also by HEC-RAS and proposed by *Chow (1959)*. The smoothness factors assigned to individual cultivation branches overlap each other as there is no possibility for making sharp difference between the categories of "sparse thicket" and "dense thicket".

3.5 Calibration

3.5.1 Principles and conventions followed

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

1.) Longitudinal variation of the smoothness factor in the mean river bed has been determined for flood waves still remaining in the mean bed (such flood waves do not exceed the banks of the mean bed, floodplain/floodway is not inundated). Thus water levels in the range of the Alert I. were modelled with sufficient accuracy. At the same time, we accepted that this convention results in greater failure in the range of low waters.

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

3.) High water calibration of the model was completed in a manner that the smoothness factors assigned to the flood plain zones, related to a certain section of *River Tisza* were changed,

paying special attention to remain within the smoothness ranges given in the above table. (*Fig. 42*).

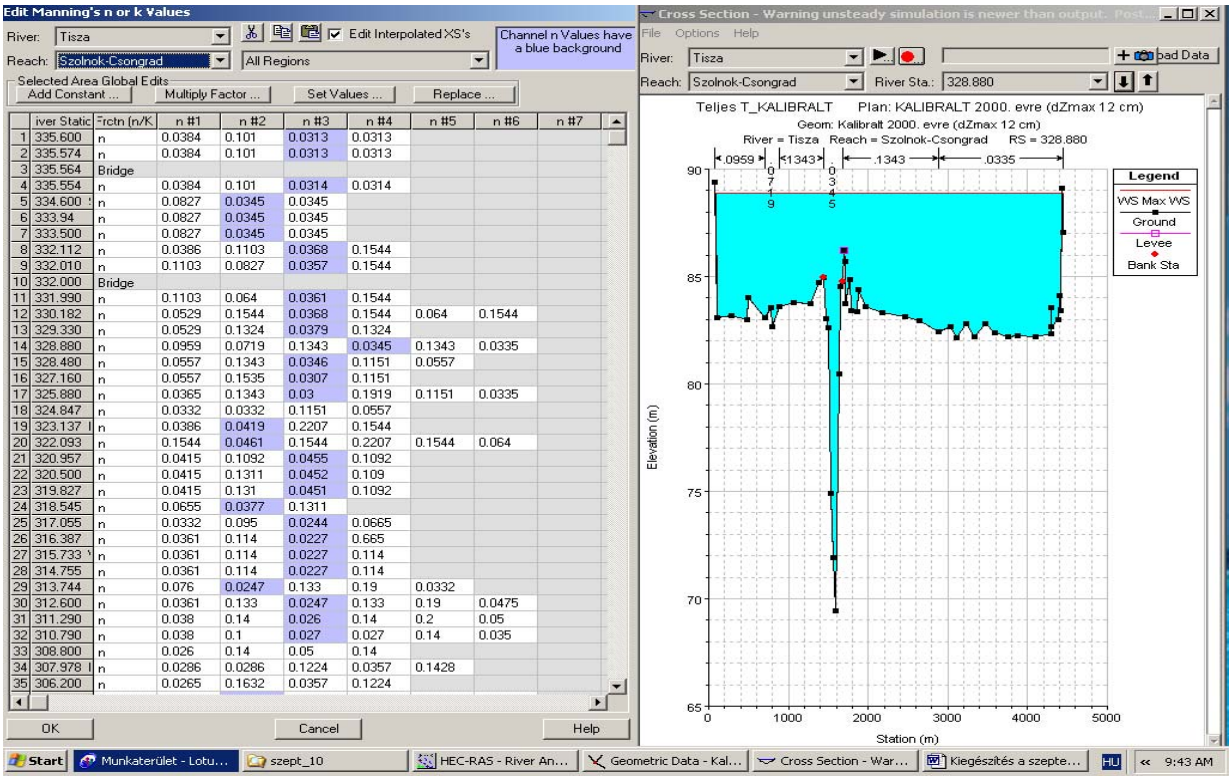


Fig. 42. – Detailed demonstration of roughness factors in the cross section

The advantage of such calibration method is that in case of analysing different engineering scenarios the roughness factors to be changed can be given simply and bound to the physics of the river system. Following the principle described above, during the modelling of the effects of the 'hydraulic corridor' to be created to improve river capacity:

- we can determine the width of modified floodway belts (either by modifying the width of existing belts or by creating new ones);
- we can order the corresponding smoothness/roughness factor to the modified floodway belts according to the category of the prevailing land use type.

In the course of planning works calculations were performed by specification of the horizontal roughness factor. However, further development of the model also needs the vertical modification of the roughness coefficient.

With the different roughness factors we practically divide the flow zones of the river into "layers". The horizontal division of the roughness factor is definitely necessary in case of rivers with broad flood plain or floodway. On the flood plain the vegetation, forests, meadows and the different agricultural cultivation branches are located in an intermittent pattern. The water discharge capacity of the river (the roughness coefficient) is changing according to this pattern, too.

During high flood waves the depth of the main bed, especially in river bends, may reach 24 to 26 m. In case of such water depths it is necessary to distinguish vertical layers as well. 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 (*Photo 11*). In the case of meandering rivers with rather wide 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 and their main streams are crossing (*Fig. 43*).



Photo 11. – The main bed of the River Tisza

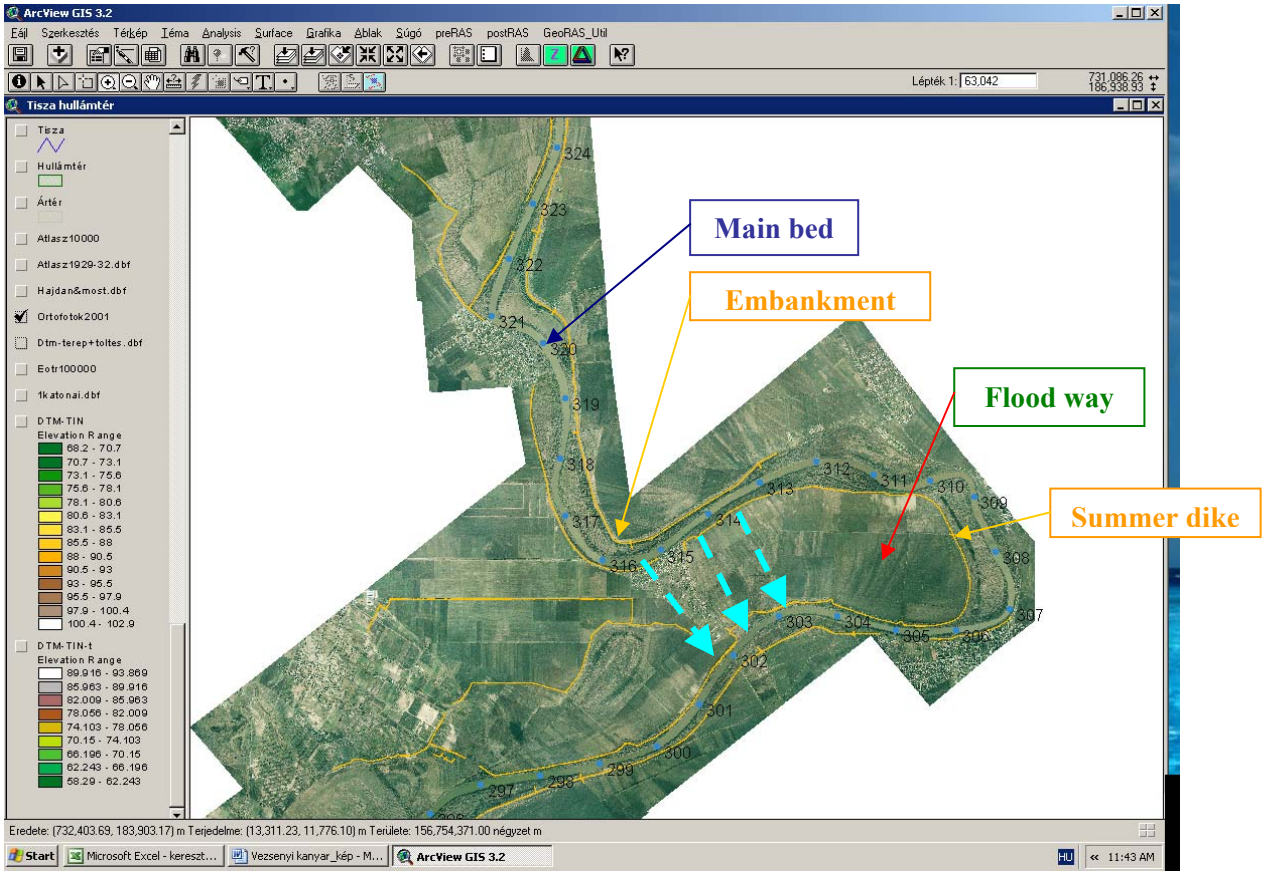


Fig. 43. – Aerial photo of the Vezseny bend, River Tisza

Results of water discharge measurements performed during floods have justified 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 *Fig. 44* and *45*. According to the results of measurements accomplished during the floods 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 650 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 *(Kovács, S. – Váriné Szöllősi I. 2003*).

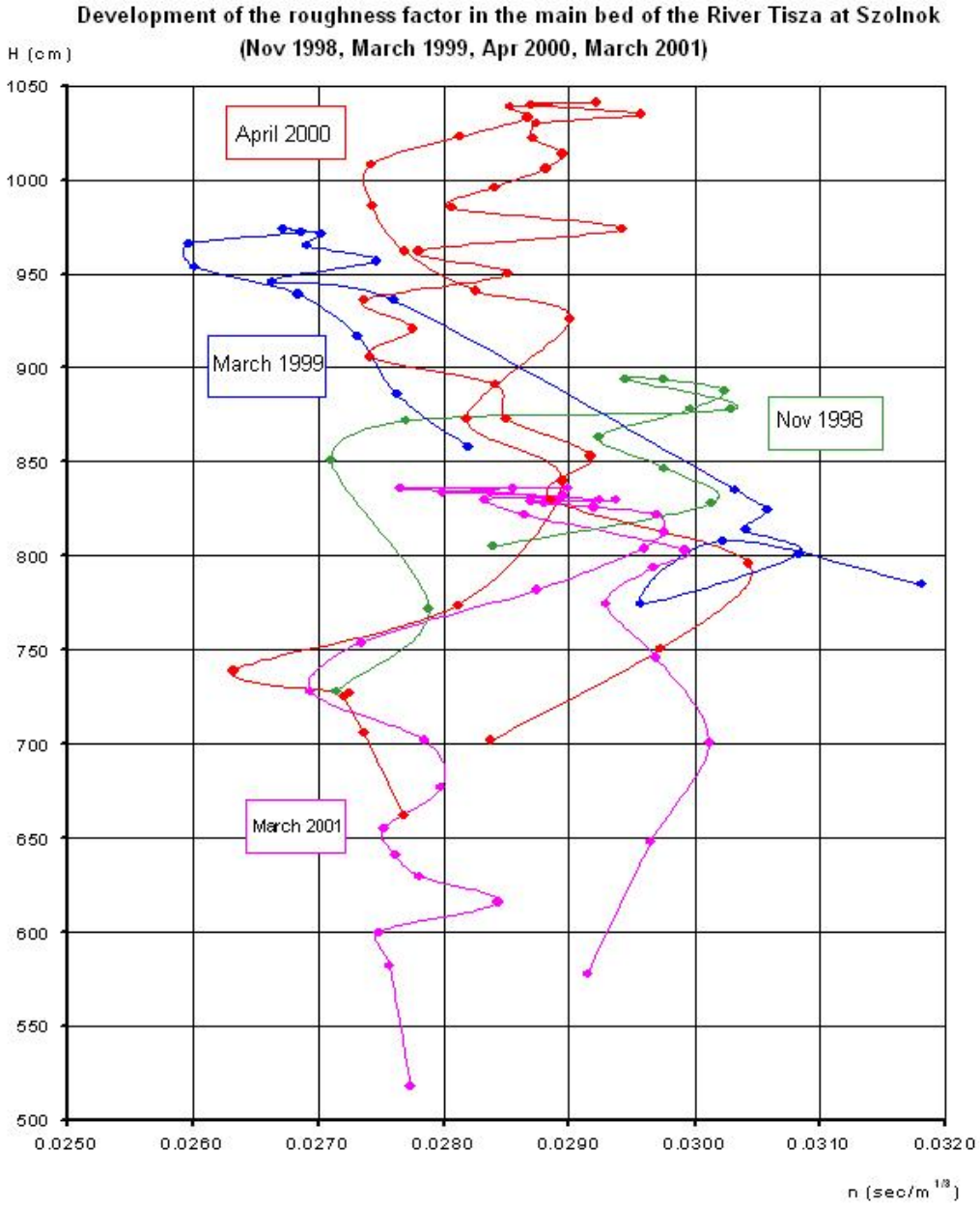


Fig. 44 – Development of the roughness factor in the main bed of the River Tisza

The roughness factor was varying between significantly wider limits (0,025-0,048) on the flood plain than in the main bed. In 1998, we could observe the gradual increase of the roughness factor along with the increase of the water level. In 1999, the "n" scarcely varied as a function of the water level.

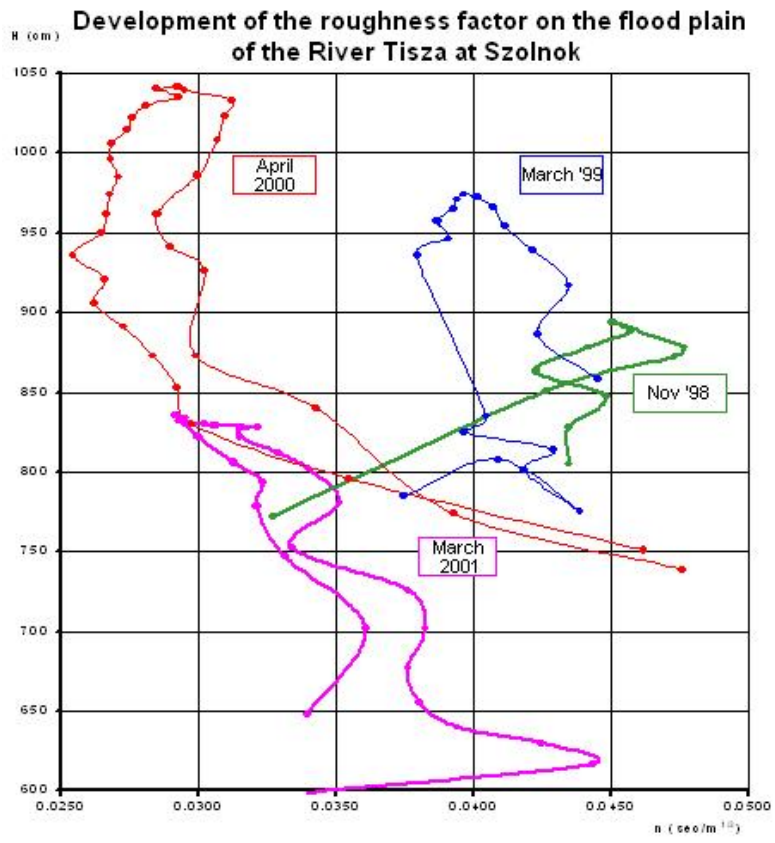


Fig 45. – Development of the roughness factor on the flood plain of the River Tisza

However, in 2000, the roughness decreased from 0,048 to 0,030 in the range between 750 and 900 cm, and slightly increased above 900 cm. In the case of the flood wave of the year 2001 we experienced the slight decrease of the roughness factor with the increase of the water level.

The reasons of variation of the roughness coefficient can be summarized as follows:

1998. – There was no significant flood wave on the middle section of the *Tisza* for 17 years. The flood plain was overgrown with vegetation, mainly the woodbine and desert false indigo have spread.

1999. – Although to a small scale, but the flood wave of the previous year (in autumn, 1998) has "cut a passage" on the flood plain.

2000. – In March, 1999, the flood wave further improved the passing conditions on the flood plain. On shorter sections the summer dikes have been demolished.

2001. – As a result of joint effect of previous flood waves, the cleaning of the floodplain the area of *Szolnok*, the opening of the channel bars and the demolishing of summer dikes on longer sections the water discharge capacity of the river was further improved *(Kovács, S. – Váriné Szöllősi I. 2003*).

3.5.2 Hydrological basic data and boundary conditions for calibration

The hydrological database for the calibrations included the values of hourly water levels (Z) and the flood discharges (Q) of flood waves occurred between 1998 and 2000.

Beyond the above mentioned data, we utilised also almost 50 time series of 1 hourly water levels having measured at staff gauges and at special flood gauges (guards' gauges) for the calibration and verification of the model.

The upper boundary condition was: *Tiszabecs* $Q= f(t)_{2000}$
Tributaries: $Q= f(t)_{2000}$
Lower boundary condition: *Titel* $Z= f(t)_{2000}$

When building the boundary conditions time series of Z and Q in 1 hourly time steps were taken from the hydrological database for the *River Tisza* and the tributaries for the following staff gauging stations:

- *River Tisza – Tiszabecs, Tokaj, Kisköre, Zenta,*
- *Tributaries: River Szamos – Csenger, River Kraszna – Ágerdőmajor, River Bodrog – Felsőberecki, River Sajó – Felsőzsolca, River Hernád – Gesztely, River Zagyva – Jásztelek, River Hármas-Körös – Gyoma and River Maros – Makó.*

Impact of another three tributaries (*River Borzhava, River Túr* and *Lónyai Canal*) – due to lack of sufficient data series – was taken into consideration as concentrated load of assessed mouth discharge.

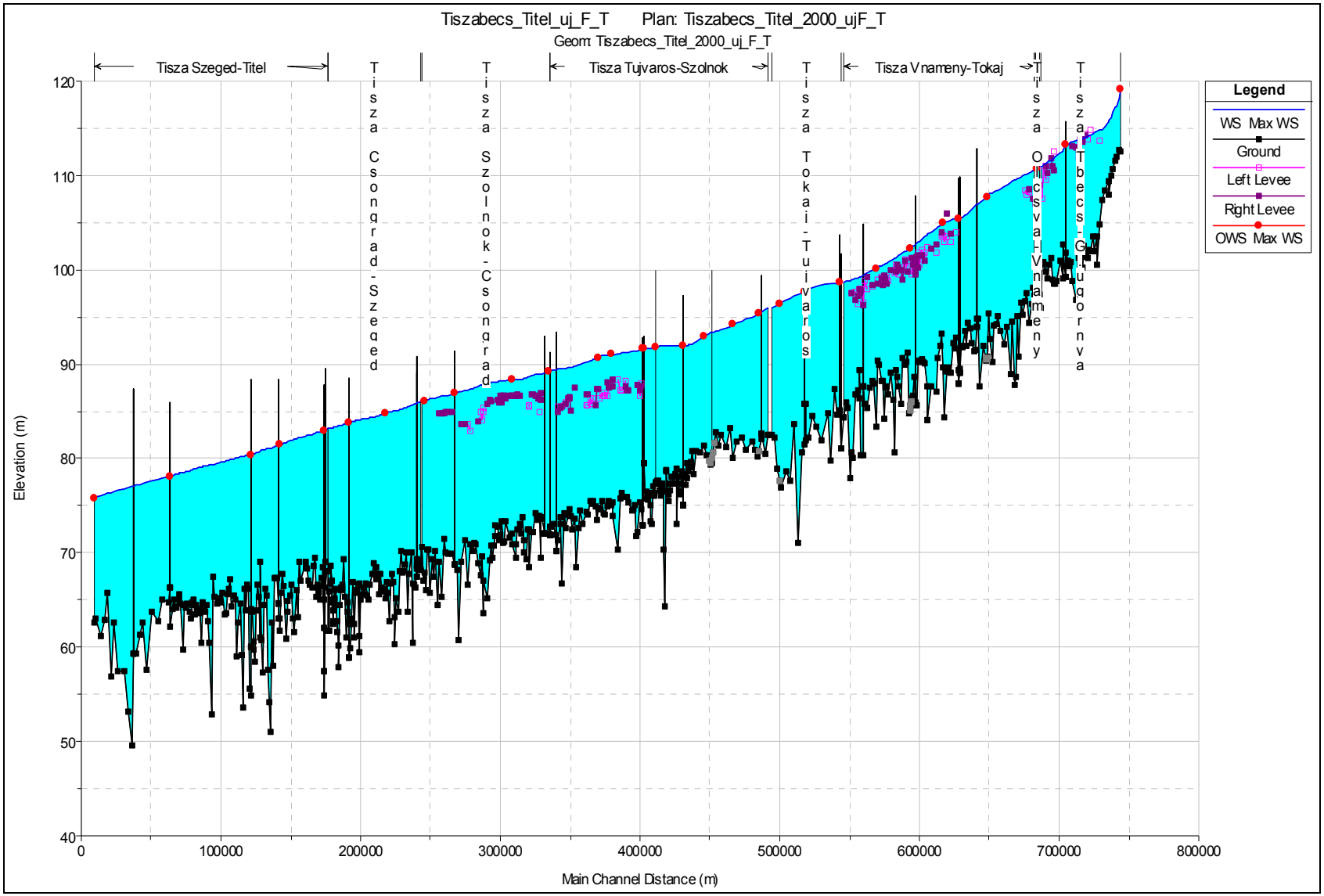


Fig. 46. – The results of calibration on the river section between Tiszabecs and Titel

3.5.3 Calibration process and results

The calibration of the model was accomplished gradually, starting with the shorter sections. In the first step calibration of the *Kisköre – Zenta* and *Tiszabecs – Tokaj* sections took place. Second step was the extention of the *Kisköre – Zenta* section with the cross sections of the *Tokaj – Kisköre* sections and the calibration of the extended *Tokaj – Zenta* river reach. Finally the upstream section (*Tiszabecs- Tokaj*) was fitted to gain the full river section between *Tiszabecs* and *Titel*.

Fig. 46. illustrates the results of the calibration process. The continuous line (with a blue coloured field there under) in the figure represents the envelope of calculated water levels (longitudinal section of culminations), while the red dots show the maximum water levels measured at staff gauges and those at guards' gauges during the flood in 2000.

At the culmination of the flood wave the difference between the calculated water level and that of observed was along the *Kisköre – Zenta* river section in the range of 0 – 5 cm, along the *Tokaj – Zenta* river section in the range of 0 – 10 cm, finally along the *Tiszabecs – Zenta* section between 0 and 12 cm in absolute values, which can be considered as a very good result.

3.6 Verification

The calibration of the model (or the calibrated river bed) has to be verified that it is valid not only to that event onto which it has been calibrated (since in case of sufficient free parameters to be calibrated the model can be calibrated to any flood wave), but can be extended to discretionary flood waves, too. For this reason the verification of the model has been performed by running of an independent event in such a manner, that the parameters have not been modified in the meantime.

Verification has been performed for the river sections and time intervals listed below:

- *Kisköre - Zenta* section, February 20 – May 10, 1999,
- *Tokaj - Zenta* section, February 20 – May 10, 1999,
- *Tiszabecs - Tokaj* section, January 1 – June 30, 1999 and January 15 - June 30, 2000,
- *Tiszabecs – Zenta* section, February 20 – May 10, 1999.

The flood wave of the year 2000, which was taken for calibration purposes, and the one in 1999 applied for verification occurred in the same season of the year and the vegetation on the flood plain was in an identical condition.

Running the model for verification purposes resulted in maximum deviation of 24 cm between the calculated and measured culmination values with the exception of a few cross section with protuberant differences. Reasons for these protuberant differences are partly known (and can be related to some cross sections where the data are too old and incomplete), however, there are some further cross sections or shorter river reaches where more detailed and more accurate data are needed for the improvement.

Fig. 47. illustrates the results of the verification process. The continuous line (with a blue coloured field there under) in the figure represents the envelope of calculated water levels (longitudinal section of culminations), while the red dots show the maximum water levels measured at staff gauges and those at guards' gauges during the flood in 1999.

Although the maximal deviation of 24 cm may seem to be too high, we have to take into consideration that the models are driven by time series of discharge values, accuracy of which is in general ±5%. In case we use time series of discharge values derived from water stage time series by using rating curves, standard deviation of Q values will even be higher, especially in the range of high waters where the measurements are rather rare. For example, during the flood in 2000 maximum discharge measured at the *Kisköre* barrage was 2,950 m^3/s, 5% of which is 147.5 m^3/s: corresponding in the upper range of the rating curve to 49 cm in water level. It means that the resulted maximum error of 24 cm of verification corresponds to the half of the error of discharge measurements.

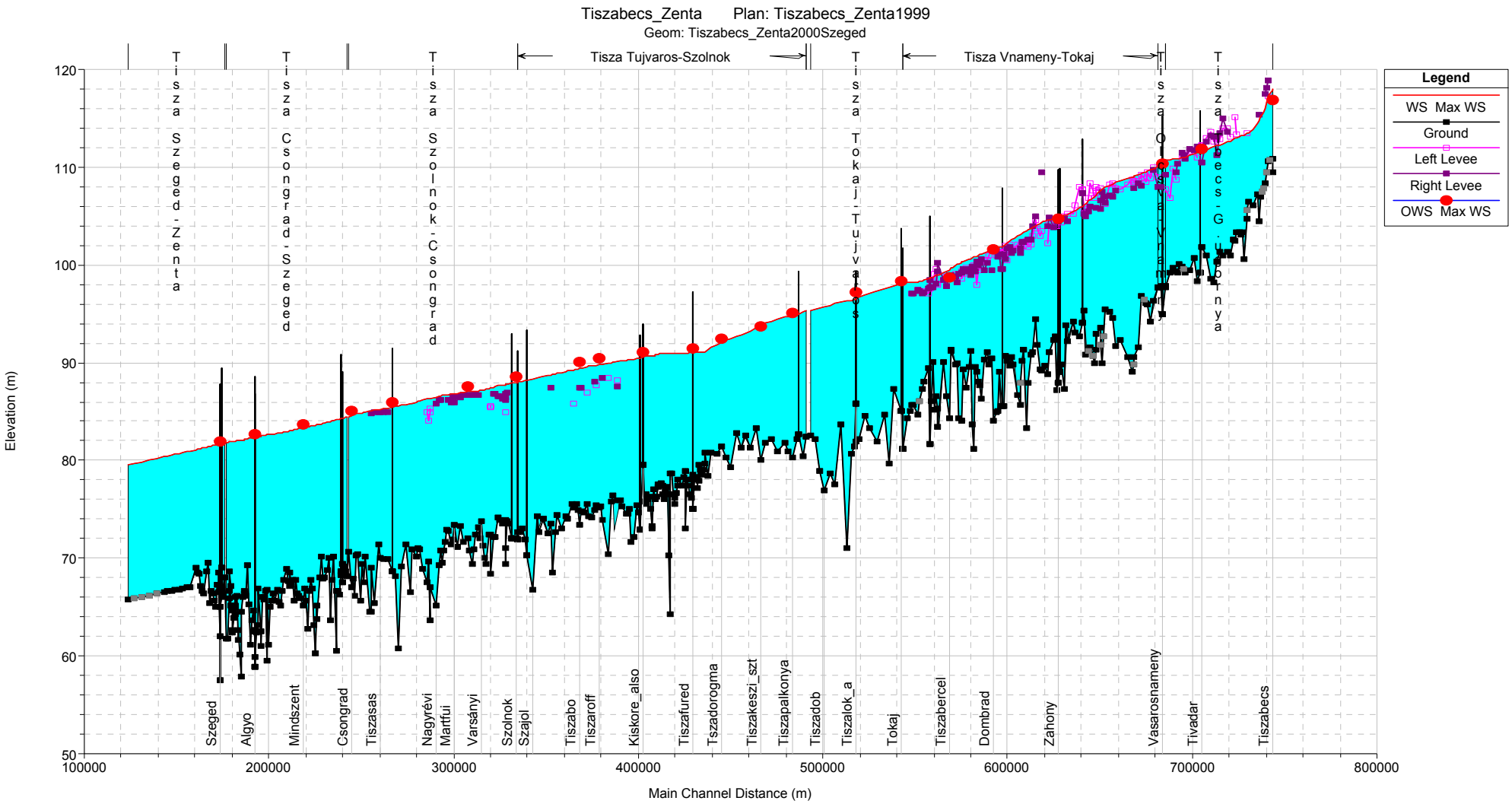


Figure 47. Results of verification of the HEC-RAS model along the Tiszabecs – Zenta section of River Tisza

4. Impact assessment of flood plain interventions

Under 1.2.2 it has been demonstrated that the flood conveyance capacity of the high water bed, especially that of the floodway is subject to continuous deterioration. It has also been clarified that the wetted cross section of the flood bed has significantly been reduced, mainly as a result of human interventions (erection of summer dikes on the natural sandbars of the mean river bed, inappropriate land use change especially in the past century, including overgrown forests). Additionally, forestation of the floodway with inappropriate, adventive species and lack in maintenance of these floodplain forests lead to the development of very dense undergrowth, which, coupling with other invasive flora, created a compound representing real obstacle for water flow.

Flood-time discharge measurements as well as modelling demonstrate the velocity distribution between the mean bed and the floodway (see *Fig. 48*.) however, flood plains with a width of more kilometres have got important role in the discharge of flood mass (for instance, the flood plains at *Tószeg, Vezseny* and *Nagyrév* convey the half of total water output).

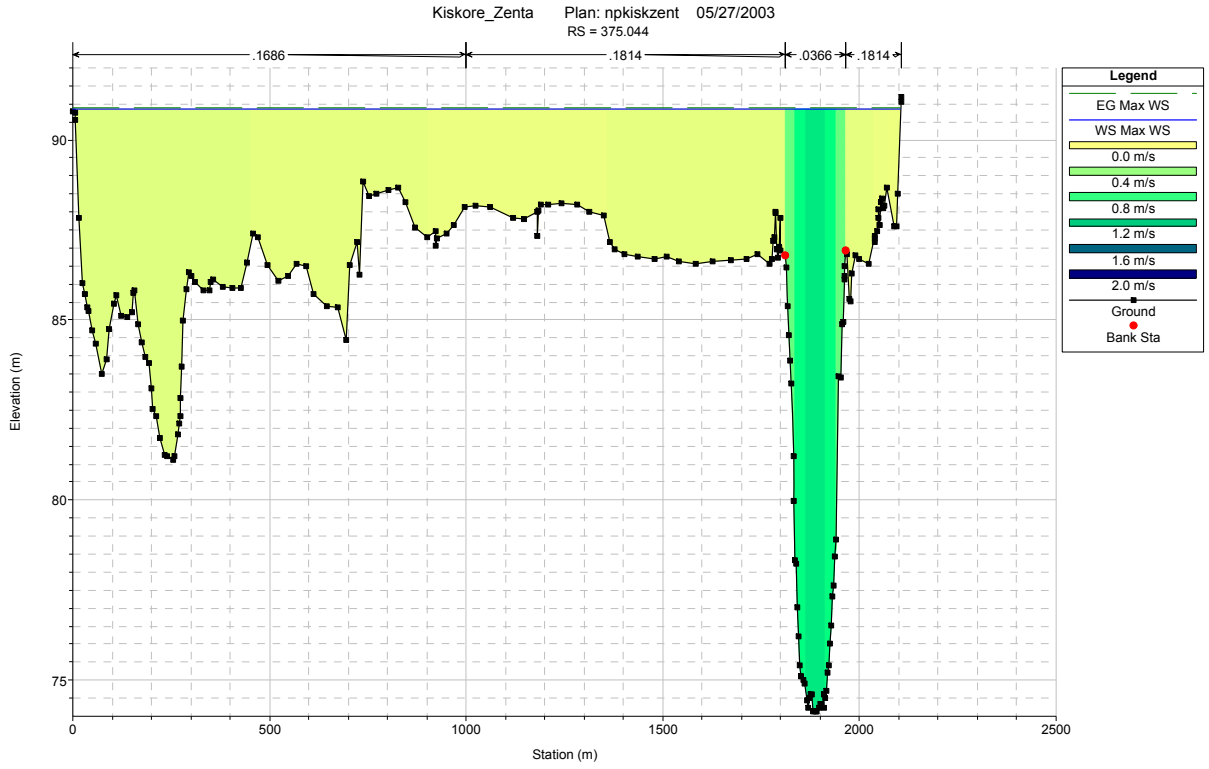


Figure 48. Velocity distribution between the mean bed and the floodway

To improve the river capacity, regulation of the floodway – creation of a so called **'hydraulic corridor'** – is planned **in a width of 600 m**, by

- relocation of embankments, especially at bottlenecks,
- relocation and partial or complete demolition of summer dikes in the corridor,

including

- demolition of channel-bars in the corridor,
- thinning vegetation, change land use by rehabilitation of pastures and mosaic-type woodland in the corridor,
- increasing the flow capacity of bridge sections
- hollowing out natural elevation or silted up terrain where necessary and appropriate

are envisaged along the river section between *Kisköre* and the southern border of the country.

The fundamental aim of the regulation of the floodway is to restore the flood conveyance capacity of the *River Tisza* to the level of prior to the year 1970. Therefore – based also on the results of earlier

studies – within the hydraulic corridor calculations were made with roughness factor values in the range of n = 0,100; k = 10.

Determination of the track of the hydraulic corridor was the task of the designing company with due regard to hydraulic efficiency, first of all. In case of sensitive spots or sections, results of 2D modelling made at the Department for Hydraulic Structures of Budapest University of Technology by Dr. J. Józsa were also important inputs *(Szlávik, L. – Bálint, G –Józsa, J. 2003)*. Modelling of the *Vezseny-bend* and the subsequent designation of the hydraulic corridor is demonstrated in *Figures 49*. and *50*.

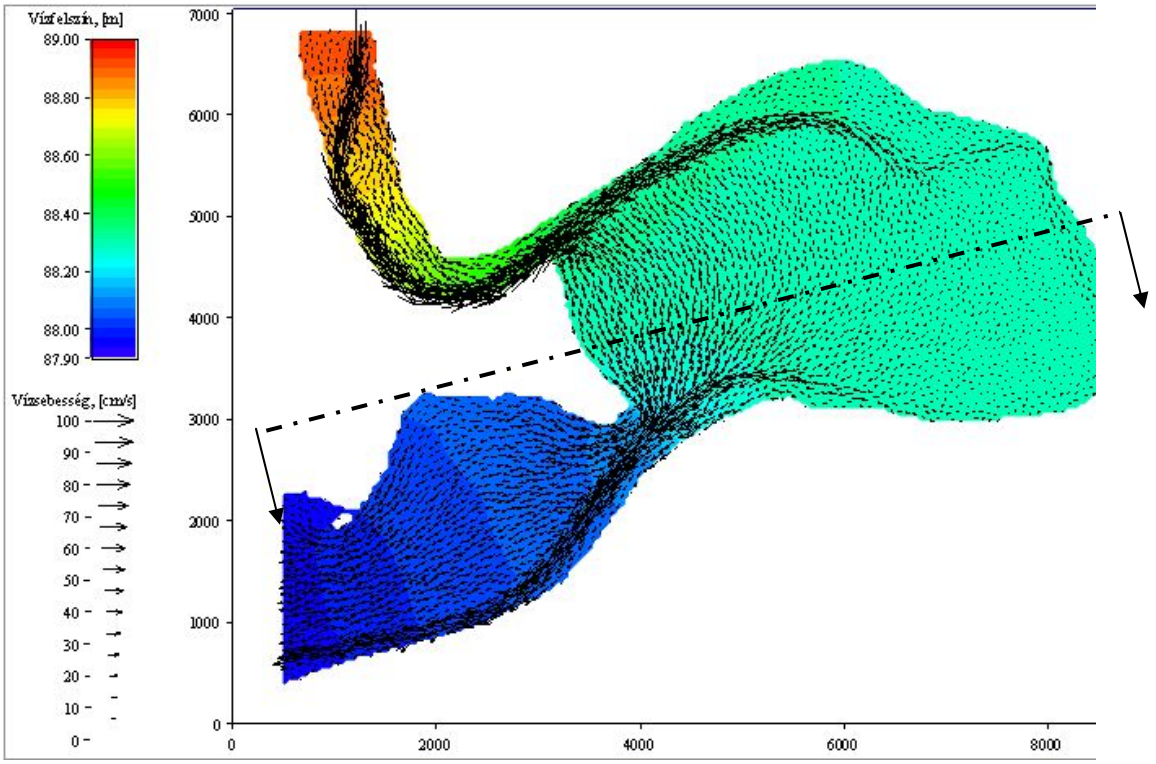


Figure 49 Investigation of flood routing conditions in the Vezseny-bend by 2D numerical modelling

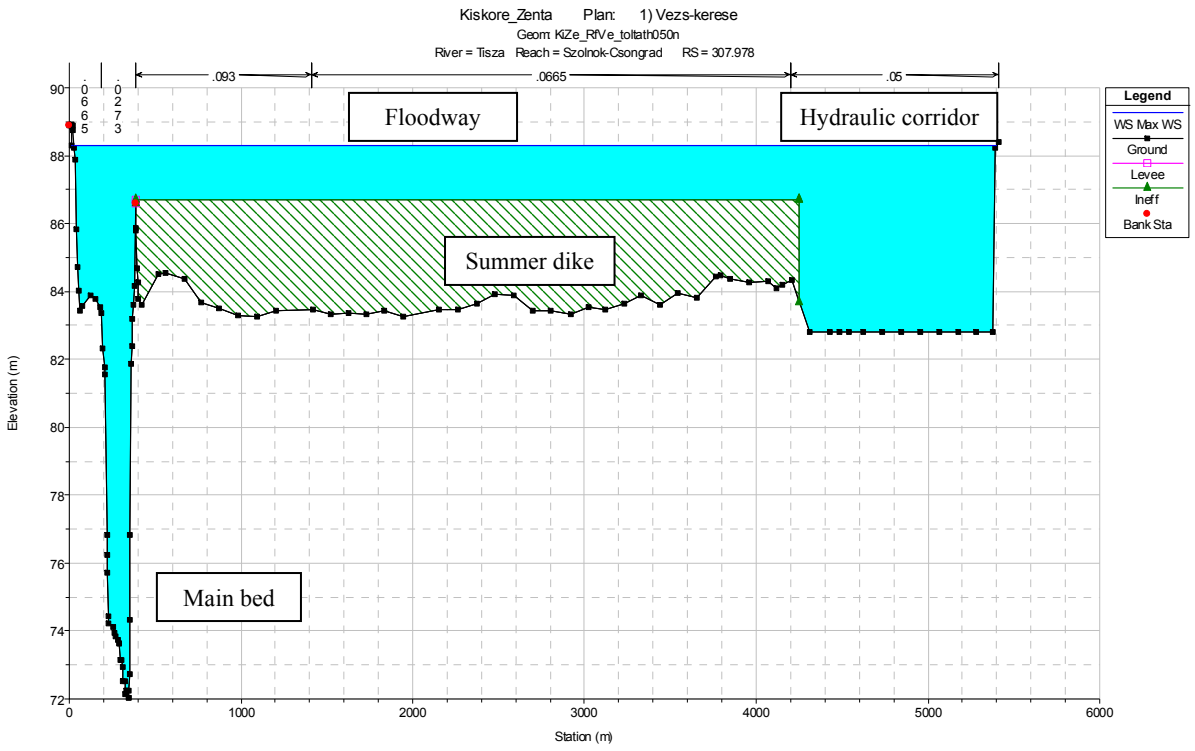


Fig. 50. HEC-RAS cross section of the Vezseny-bend floodway regulation

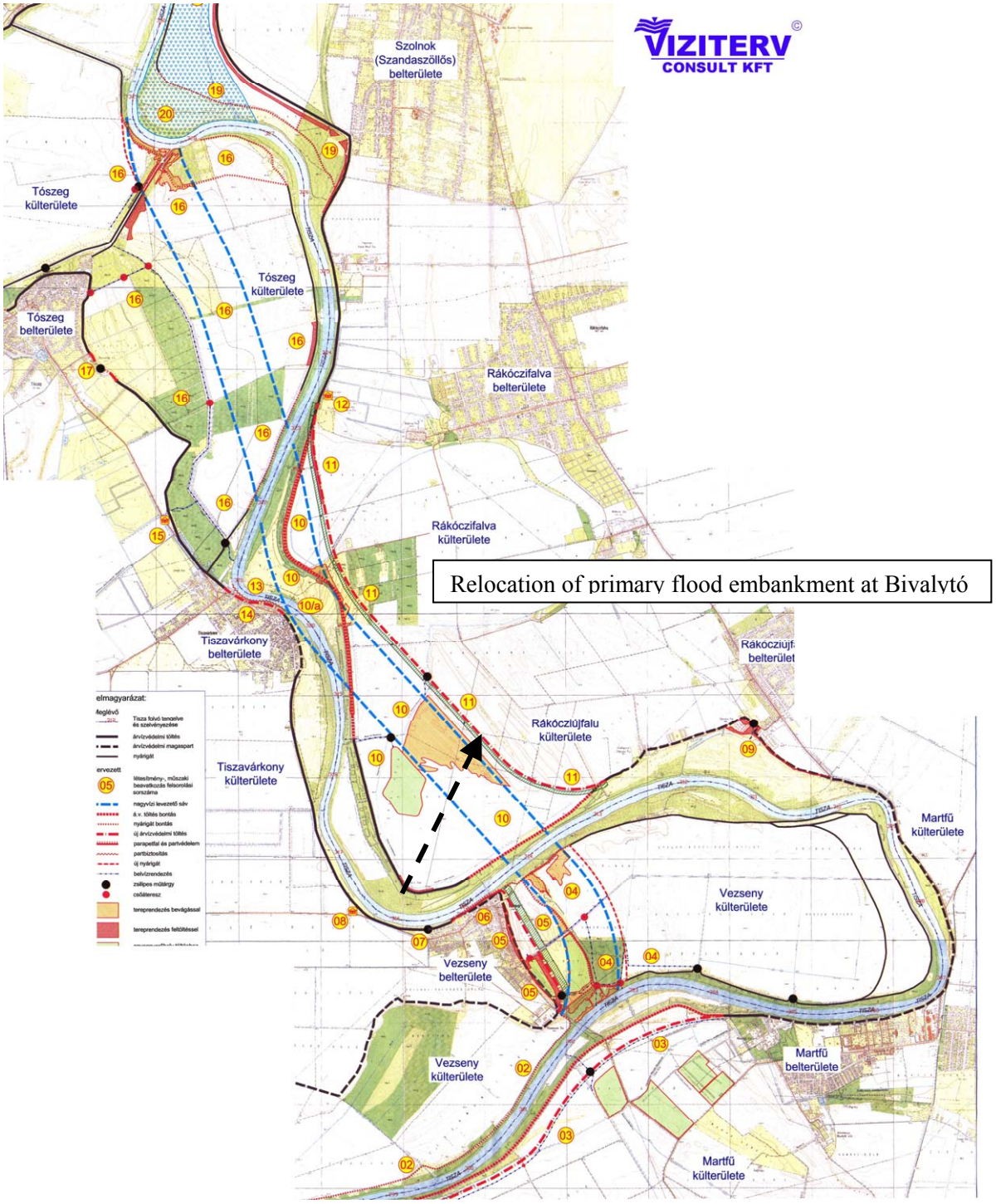


Fig. 51. The planned and investigated hydraulic corridor between Vezseny and Szolnok(300-330 rkm)

Concerning the individual effects of the interventions in the floodway it has to be generally mentioned that the favourable water level reduction effect of thinning vegetation (modification of the roughness), if it is made only along a rather short (1 to 2 km) river reach, prevails only on a very short section as the non-prismatic character of the river (longitudinal variability) eliminates the effect very soon. The impact of continuous thinning out of vegetation along longer river sections – within certain limits – will be integrated. Impacts of local technical interventions (relocation of embankments, summer dikes, etc.), besides thinning vegetation superpose onto this integrating line.

The results of the modelling are shown in *Fig. 53*, showing the depression of flood crests related to those during the extreme flood of spring 2000 as individual results of demolition of summer dikes and regulation of floodway, respectively, and the combined effect of these interventions.

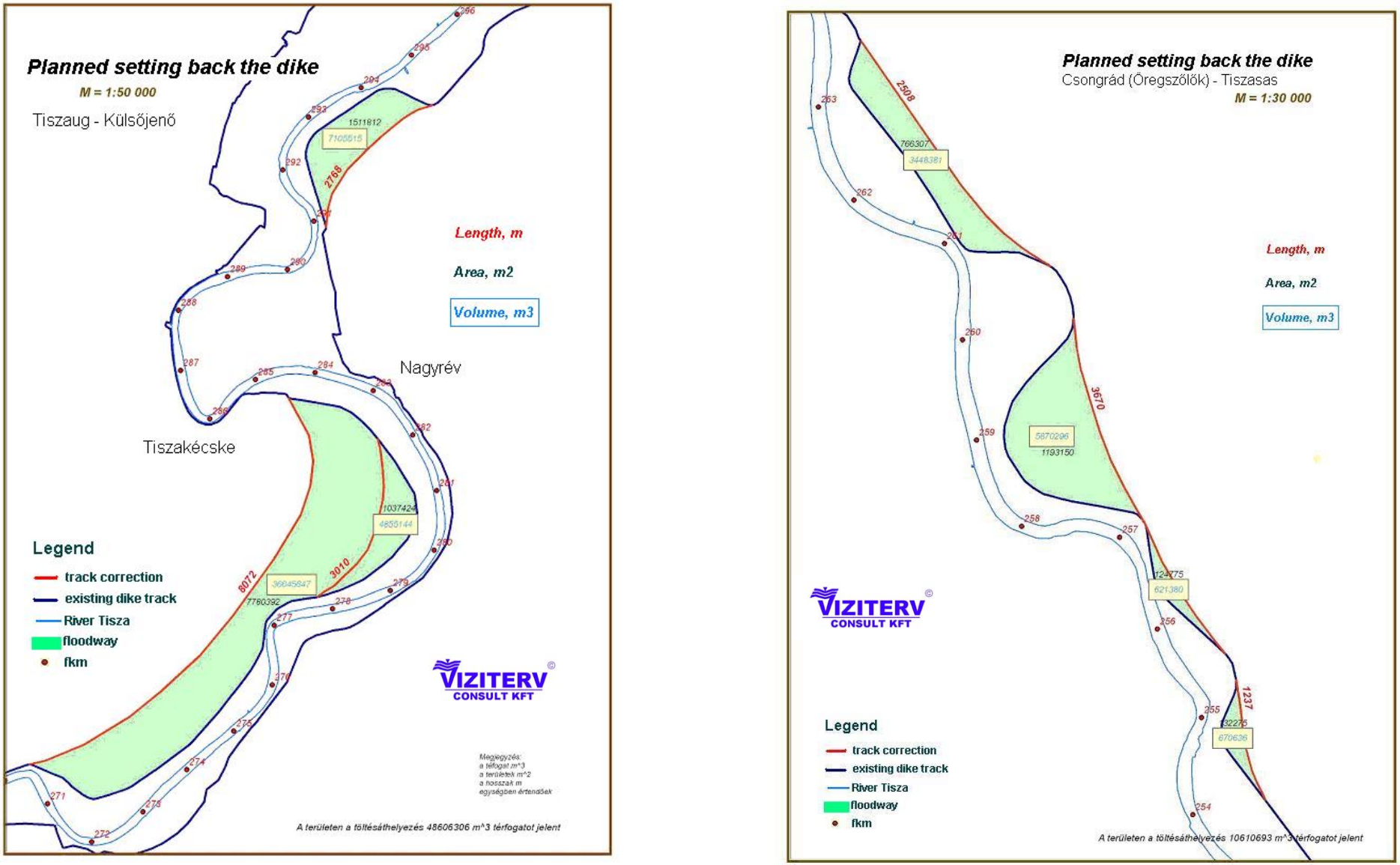


Figure 52. Dike relocations to create the hydraulic corridor along Külsőjenő-Tiszaug (rkm 296-270) and Tiszasas-Csongrád (rkm 264-254) sections

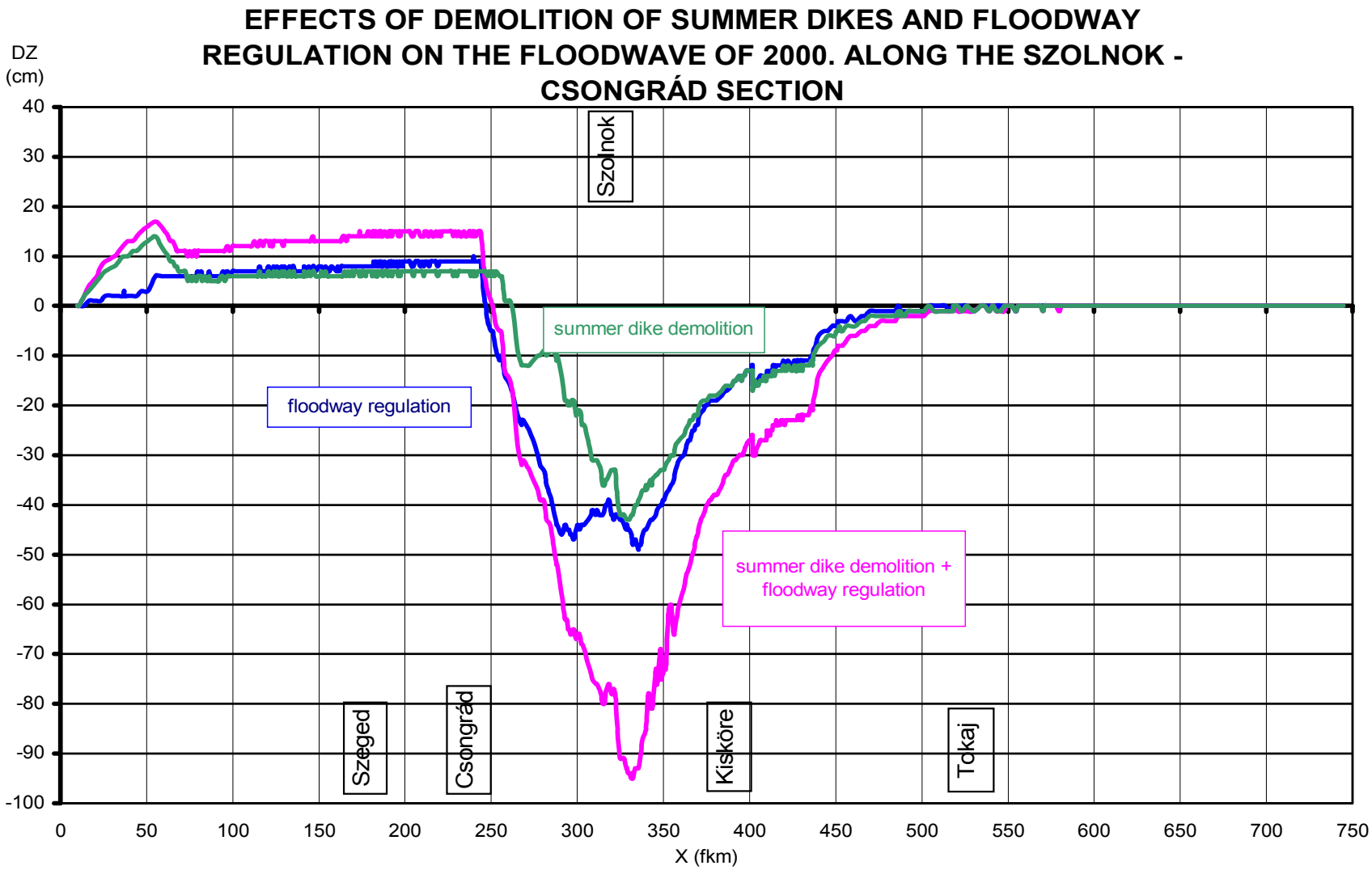


Fig. 53. Effects of interventions in the floodway on the depression of flood crests

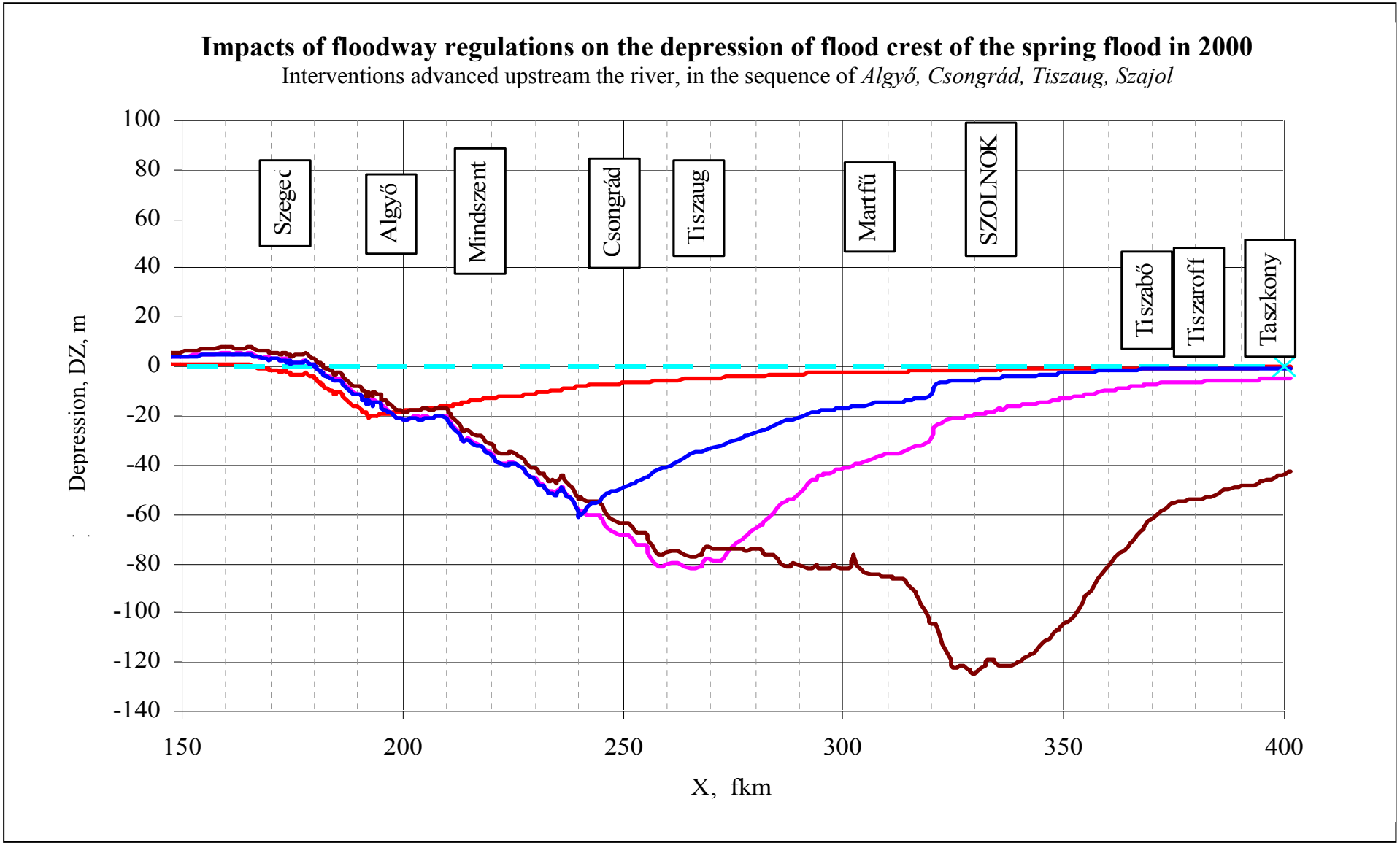


Fig. 54 Impact of floodway regulation interventions advanced section by section upstream the river on the flood crests of the spring flood in 2000

Analysing the results of model calculations accomplished along the **Middle- and Lower-Tisza** section it can be declared, that

- demolition of the summer dike sections crossing the designated hydraulic corridor has a water level decreasing effect varying between **5 to 42 cm** along the river reach of 250- 450 rkm sections between **Csongrád and Tiszadorogma** (the roughness factor was taken into consideration with the value of n = 0,0667 s/m$^{1/3}$, and k = 15 m$^{1/3}$/s, respectively),
- as a result of **dike relocations and land use change** or changes in cultivation branches to create the **600 m wide hydraulic corridor** a **further decrease in water level of 5 to 48 cm** can be reached in the section between Csongrád and Kisköre,
- the **integrated effect** may result in a reduction of **10 to 95 cm** on the river section between **Csongrád and Kisköre**, at the same time the interventions may result in an **increase of water level 10-15 cm** on the section between **Szeged and the southern border** of the country; this effect also extends to the Serbian section of the river (*Fig. 53.*).

In case the floodway regulation is extended to the Lower-Tisza as well, and the interventions are implemented section by section in a recommended sequence advancing from downstream to upstream, the negative effects observed in the previous case can be eliminated as demonstrated in *Fig. 54*.

Scenario analysis of partial floodplain reactivation with controlled inundation

1. Introduction, antecedents

The concept of increasing flood safety against the increasing flood risks in the Tisza Valley in Hungary, the so called "**Update of the Vásárhelyi Plan (UVP)**" has determined the below main goals:

- heightening and reinforcement of the primary flood embankments where their parameters do not meet the prescribed parameters yet, to provide protection against the 1 in 100 years' floods;
- decreasing flood peaks/crests by:
  - the improvement of the flood conveyance capacity of the high water bed (we have just discussed);
  - partial reactivation of the flood plain with controlled inundation, e.g. creation of a system of flood detention basins in the protected floodplain to reduce flood volumes passing down the river.

The aim concerning reduction of flood crests was to find a solution by creating an appropriate system of flood detention basins which is capable of lowering the flood crests of the 1 in 100 years' floods by 1,0 m. In fact, such a solution would provide safety against the 1 in 1000 years floods as well, taking into consideration the expectable impacts of climate change.

To reach the above aim, a preliminary study estimated the total volume of flood detention to be in the range of 1.5 billion m^3 and included an overall investigation of 30 potential locations of flood detention basins along the *River Tisza* (see *Fig. 55*.).

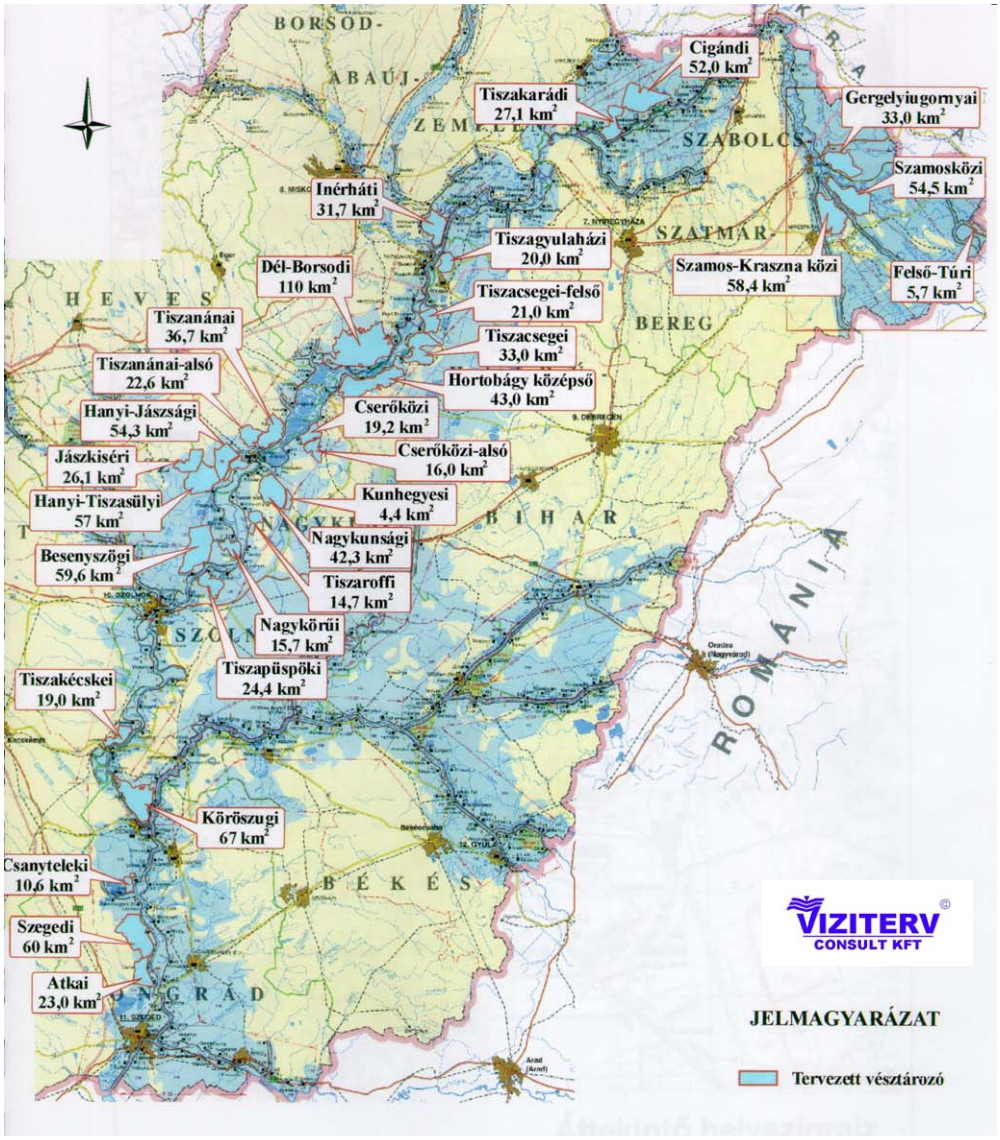


Figure 55. Potential location of flood detention basins along the River Tisza – version of 30 basins)

The preliminary study contained a multicriteria analysis for the selection of the detention basins to be applied. Aspects of the comparative evaluation were:

- hydraulic efficiency (lowering of the flood crests in case of flood discharges equalling with that of in the year 2000 by min. 1.0 m)
- C/B ratio
- further applicability in improving water resource management in the region
- physical planning and rural development
- protection of environment, heritage, values and assets
- acceptability (by the stakeholders and the public)

As a result of the above investigation, a version of 11 basins was finally selected (see *Fig. 56*.)

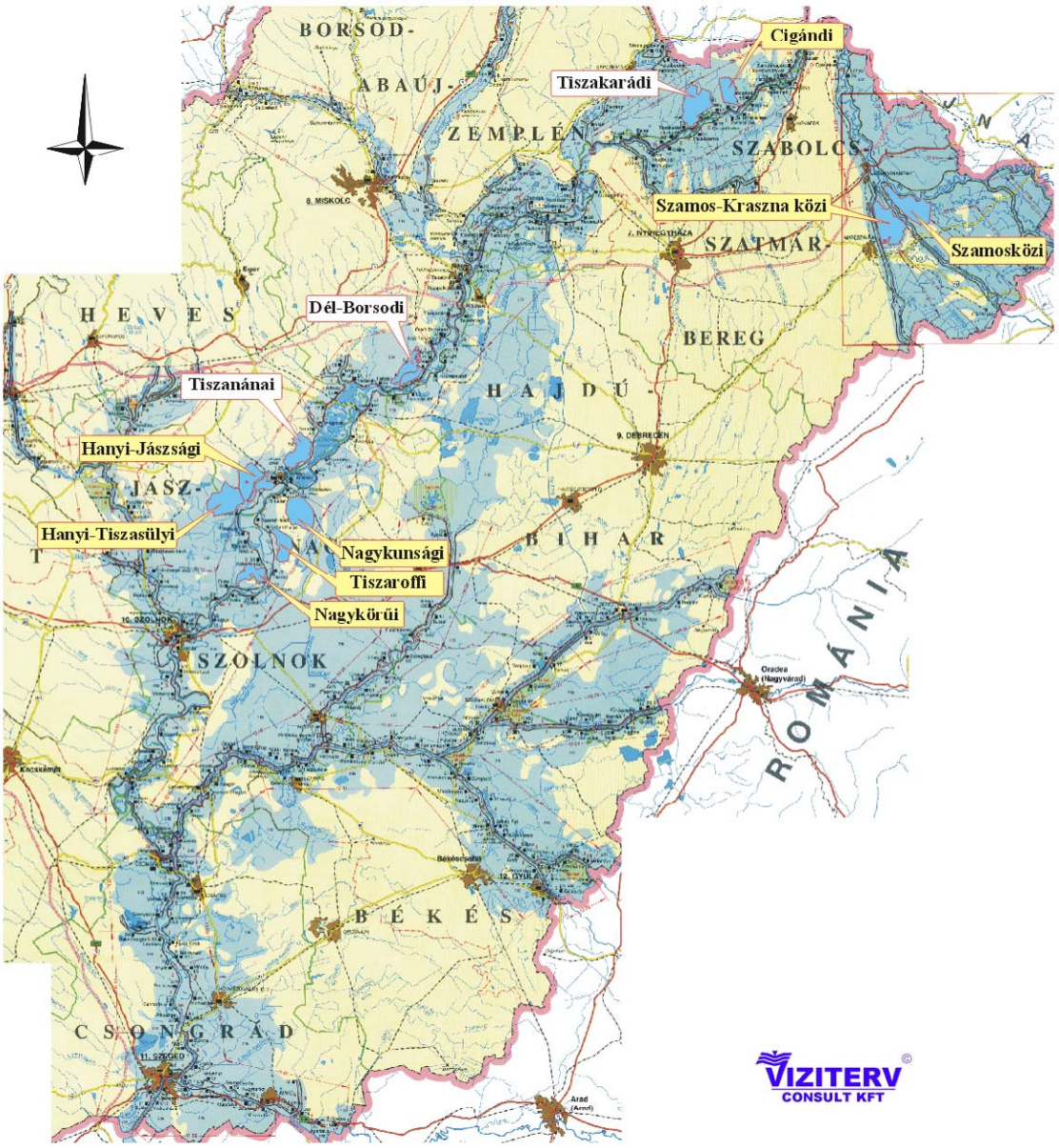


Figure 56. Selected flood detention basins along the River Tisza – version of 11 basins

2. Impact assessment of flood detention

2.1 Technical data of the detention basins

To enable the modelling of the impacts of the flood detention basins it is necessary to provide input data for the 1D hydrodynamic model on the technical and operational parameters of the inlet structures and the stage-volume functions of the detention basins.

Stage-volume functions of the detention basins were derived from the DEM produced by FÖMI[2] from the contour lines of topographic maps scaled 1:10 000. After having finished the impact analysis, DTMs based on the brand new aerial ortophotos made by EUROSENSE Ltd. were received for the territory of five detention basins (*Szamos-Krasznaközi-, Cigándi-, Nagykunsági-, Hanyi-Tiszasülyi-*

[2] Hungarian Institute for Land Survey and Remote Sensing

and *Tiszaroffi)*. There were slight differences between the DTMs of the different techniques, with the exception of the *Szamos-Krasznaközi* detention basin, where 20 % difference was found between the maximal capacities of the DTMs. Therefore the impact assessment related to this detention basin has been repeated.

Table 5. Technical data of the flood reducing detention basins

Detention basin	Location of filling	Type	Filler gate	Sill level	Storage level	Storage capacity	DFL
	fkm		m	mB.f.	mB.f.	M m^3	mB.f.
Szamos-Kraszna-közi	Szamos 20.500	weir	B = 180	112,65	112,65	122 corrected: 147	115,59
Szamos-közi	Tisza 703.500	weir	B = 150	112,50	112,50	122	114,04
Cigándi	Tisza 597.800	Gated sluice	5 pcs 2x3	96,00	99,00	85	103,12
Tiszakarádi	Tisza 577.250		5 pcs 2x3	94,00	96,00	79	101,09
Délborsodi	Tisza. 451.000		3 pcs.2x3	98,50	87,50	73	92,72
Tiszanánai	Tisza 411.400		5 pcs.2x3	83,00	90,46	115	90,66
Nagykunsági	Tisza 406.000				88,10	105	90,66
Hanyi-Jászsági	Tisza 395.100		7 pcs.2x3	84,50	90,26	170	90,46
Hanyi-Tiszasülyi	Tisza 387.500		7 pcs.2x3	83,50	90,05	302	90,25
Tiszaroffi	Tisza 369.900		5 pcs.2x3	82,50	89,74	93	89,94
Nagykörűi	Tisza 354.900		5 pcs.2x3	81,50	88,95	149	98,15

Parameters of the filling hydraulic structures (location, sill level) were provided by the responsible planner (VIZITERV Consult) of those. Concerning other parameters (weir length, number of sluices) preliminary calculations were made with the hydrodynamic model, and these parameters were fine tuned based on the results.

Implementation of the *Update of the Vásárhelyi Plan* will be made in two phases. Phase I comprises the improvement of flood conveyance capacity and the implementation of the detention basins shaded in yellow in *Table 5* and presented in *Fig. 57*. Our work focused on the analysis of the impacts of Phase I interventions.

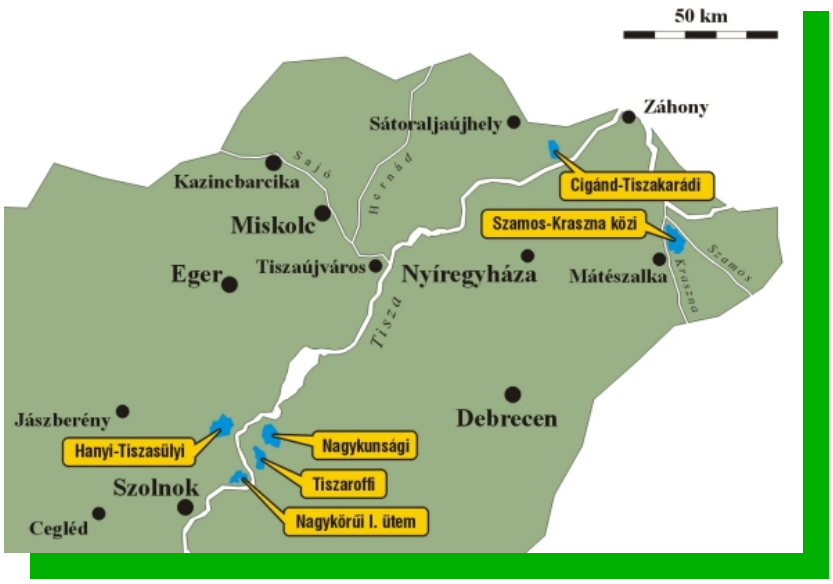


Figure 57.

Detention basins to be implemented in Phase I.

2.2 Modelling the impact of flood detention

In order to model the individual and combined impact of the flood detention basins, several variations had to be run. For this purpose we utilised parameters of historical floods and generated floods as well. All the flood variations were modelled in the morphological conditions of the year 2000.

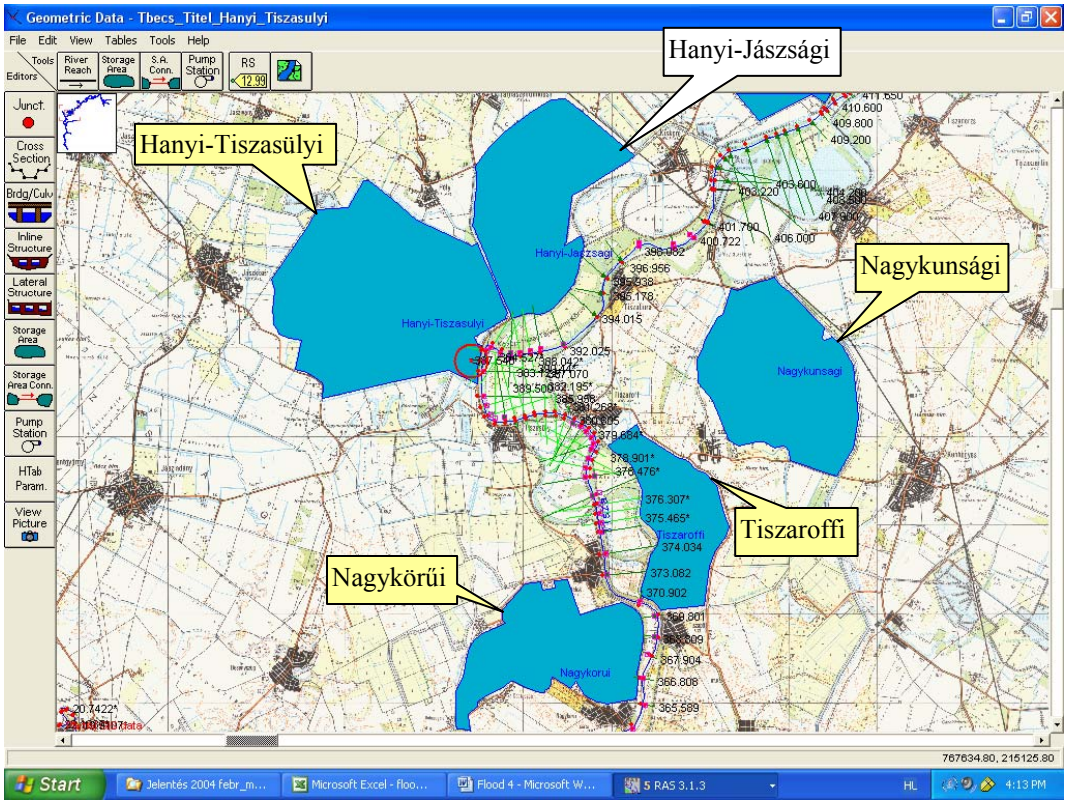


Fig. 58. Location of flood detention basins along the Middle-Tisza in the HEC-RAS

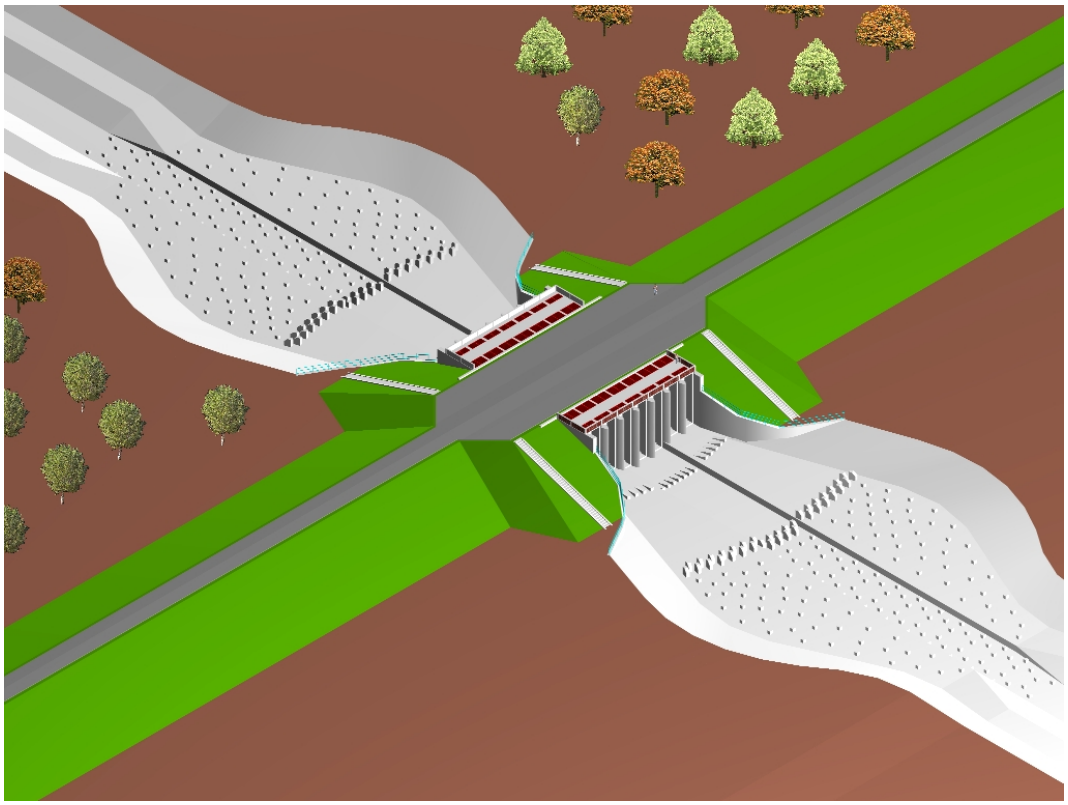


Fig. 59. Typical gated sluice to fill detention basins (VIZITERV Consult)

In the following, illustrations on the results of one of the running with generated flood wave Q_{max}=2,478 m^3/s at the *Tiszaroff* gauging station will be shown in *Figures 60-63, 68* and in *Table 6*.

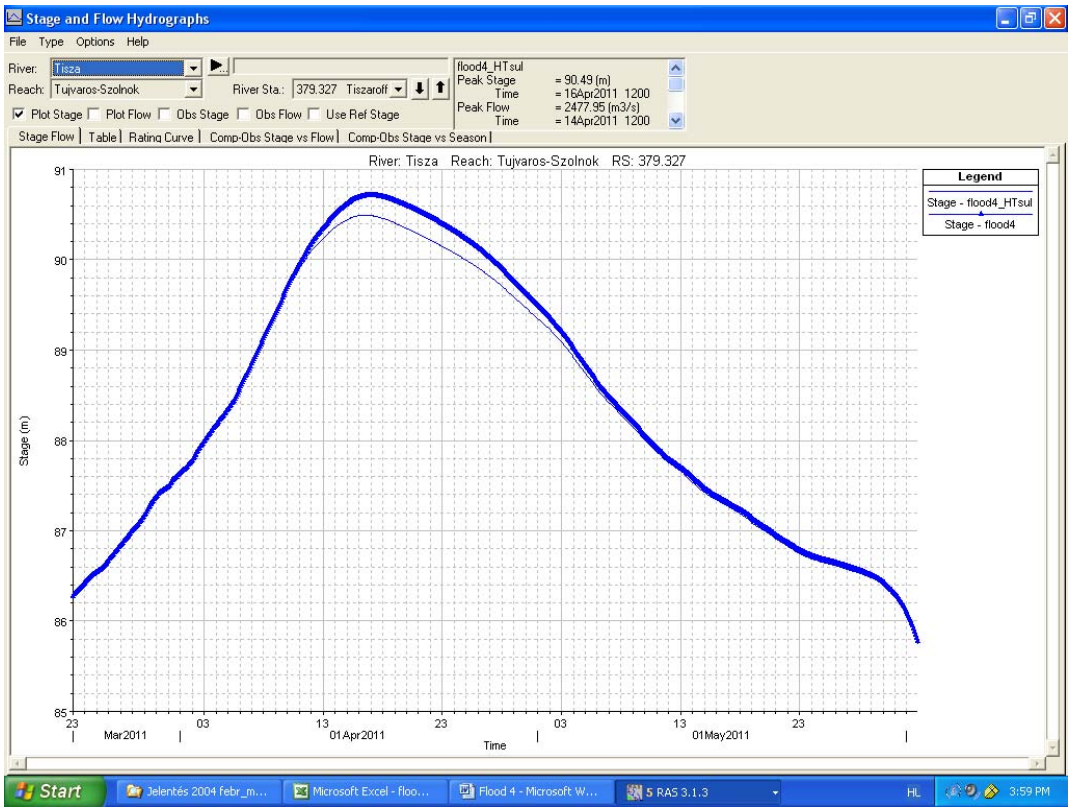


Fig. 60. Impact of Hanyi-Tiszasülyi detention basin on the Tisza flood wave at Tiszaroff gauging station (generated flood wave #4; Q_{max}=2,478 m^3/s)

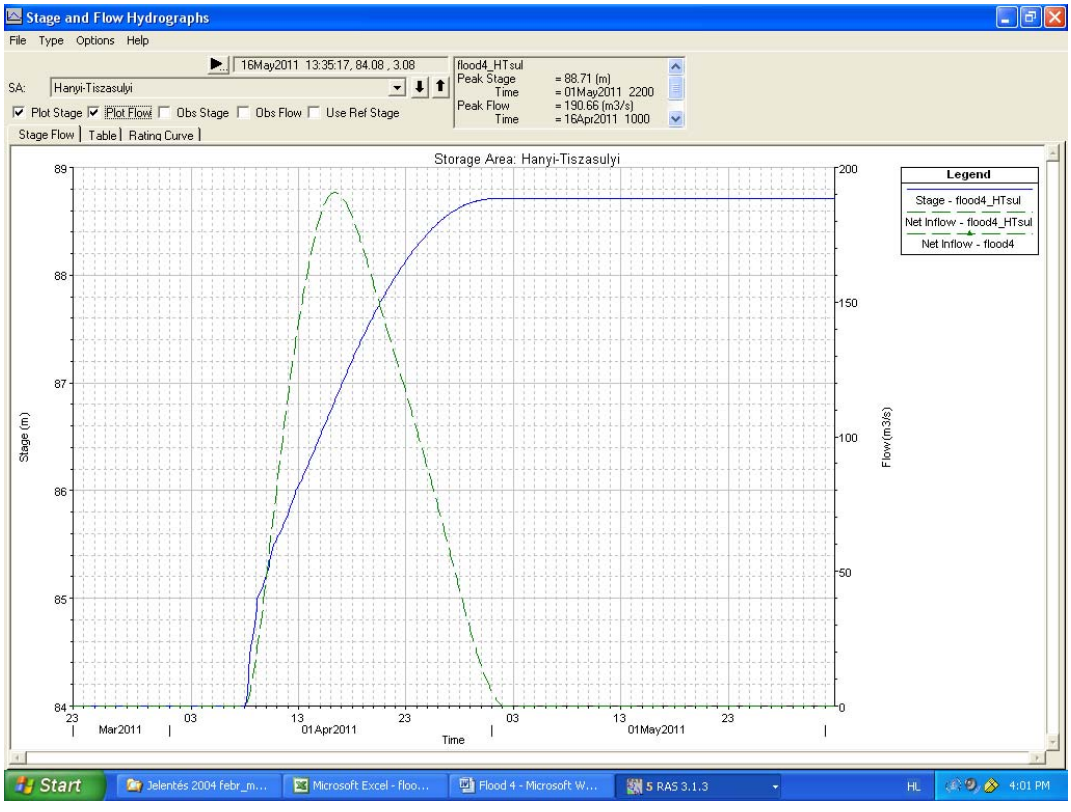


Fig. 61. Water released in Hanyi-Tiszasülyi detention basin (generated flood wave #4; $Q_{intake\ max}$=190.66 m^3/s), time series Q=Q(t) in green, H=H(t) in blue

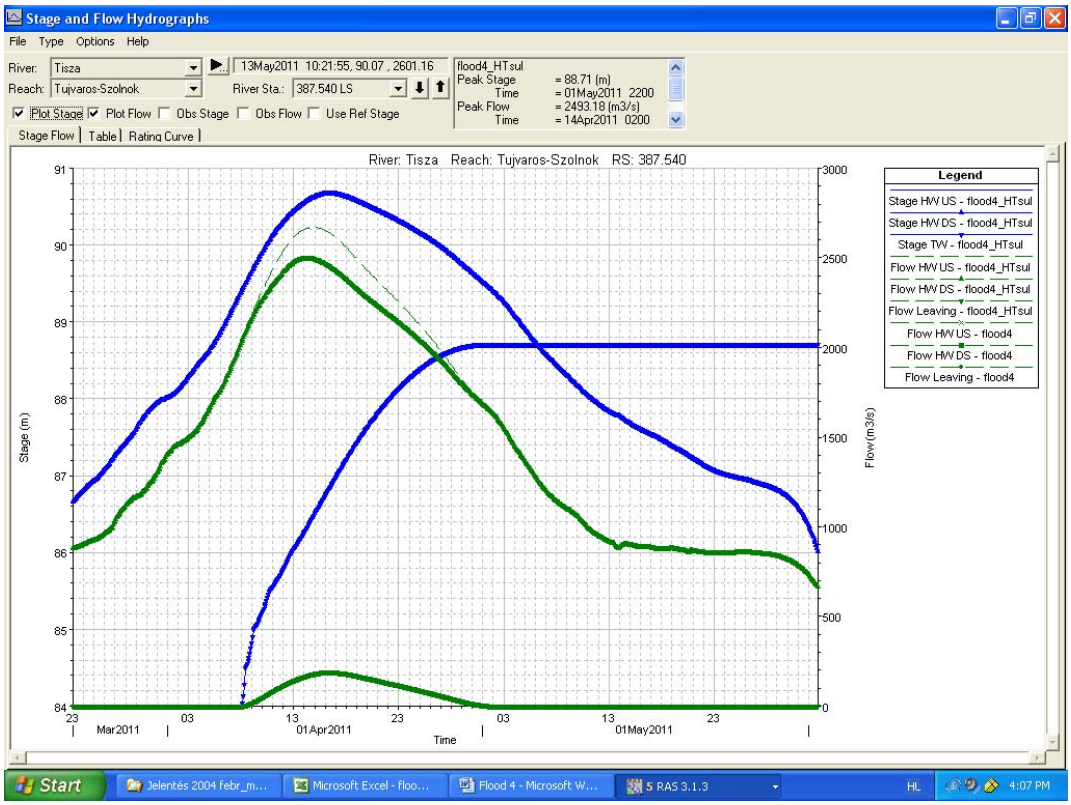


Fig. 62. Water stages (blue) and discharges (green) in River Tisza and in the Hanyi-Tiszasülyi detention basin (generated flood wave #4)

Individual effect on the reduction of flood crests of the generated flood wave No. 4. are illustrated in *Fig. 63*. In this series of investigation impacts of all the detention basins were modelled. Name tags of the basins being part of Phase I interventions are shaded in yellow.

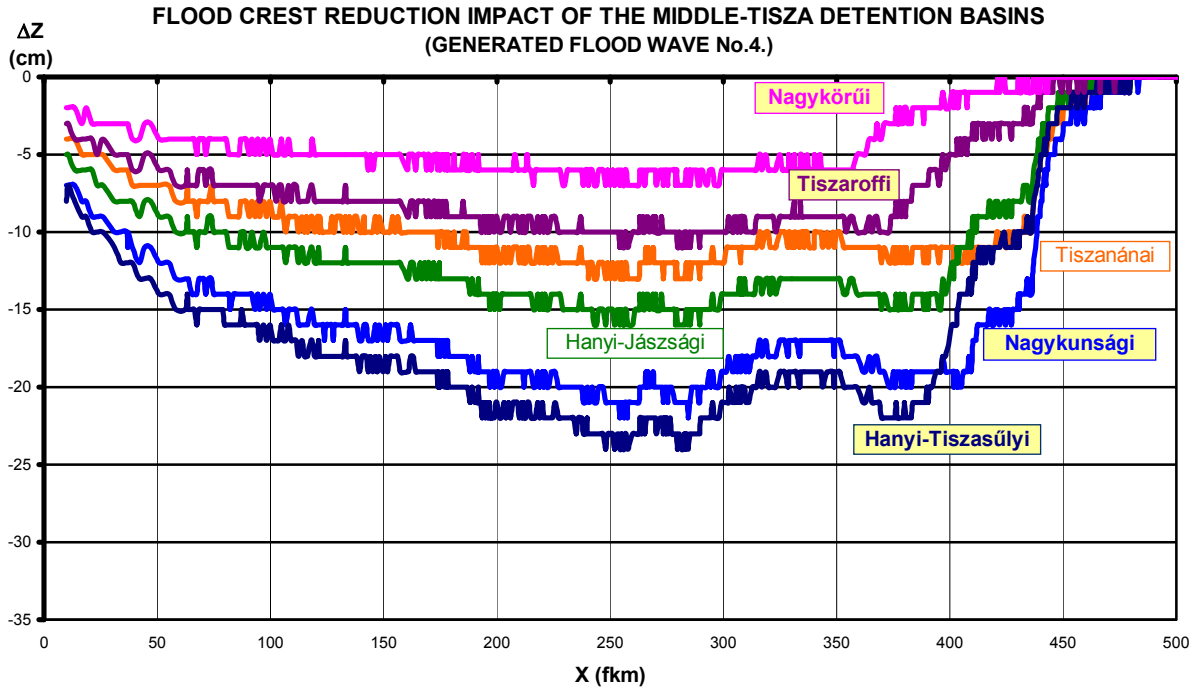


Figure 63. Individual effect on the reduction of flood crests of the Middle-Tisza detention basins in case of generated flood wave No. 4

The flood detention basins in the Upper-Tisza are shown in *Fig. 64* (those shaded in yellow belong to Phase I interventions).

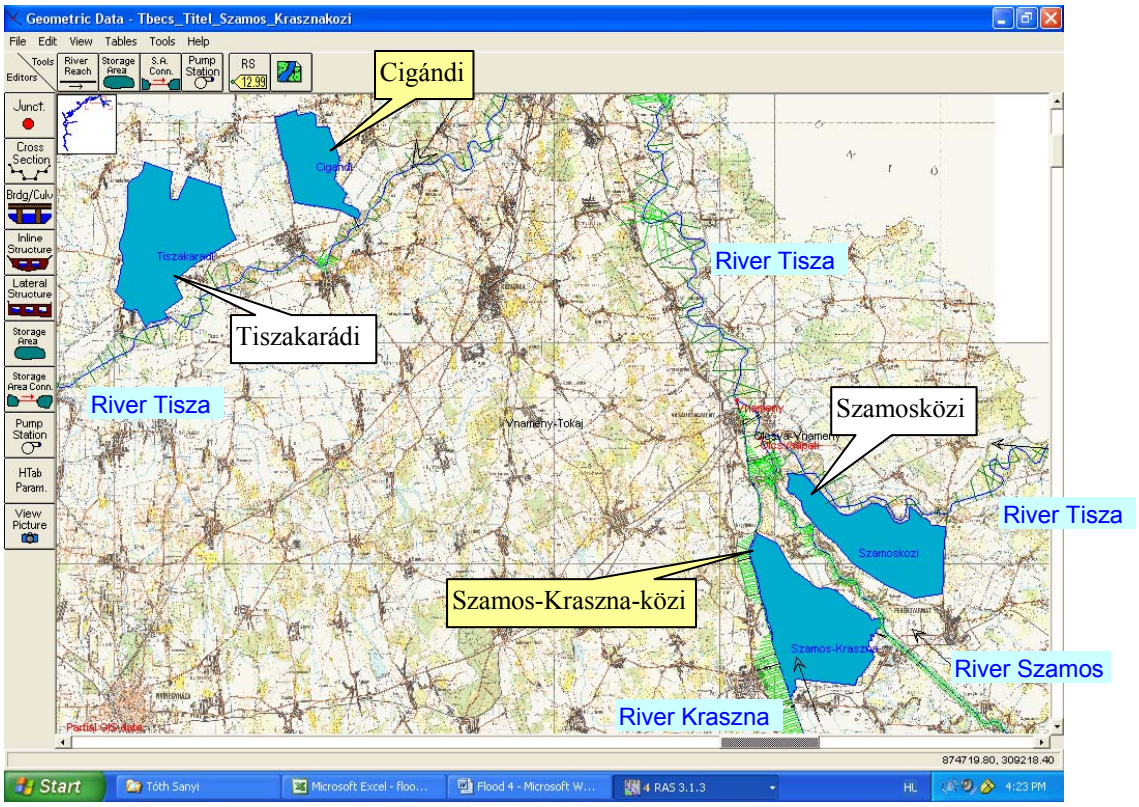


Fig. 64. Location of flood detention basins along the Upper-Tisza

Figures 65-67 demonstrate the impact of the *Szamos-Krasznaközi detention basin* on the *River Szamos* flood wave of 1970 at *Tunyogmatolcs* gauging station and the process of filling the detention basin.

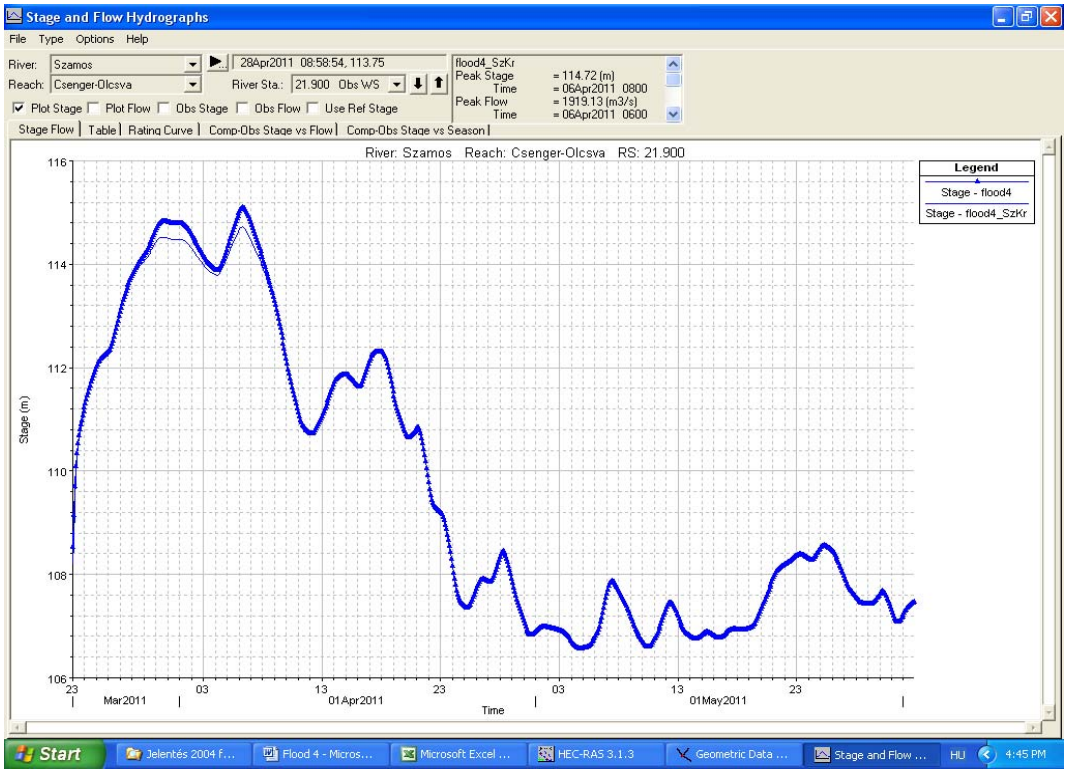


Fig. 65. Impact of Szamos-Krasznaközi detention basin on the Szamos flood wave of 1970 at Tunyogmatolcs gauging station; Q_{max}=1,919 m^3/s

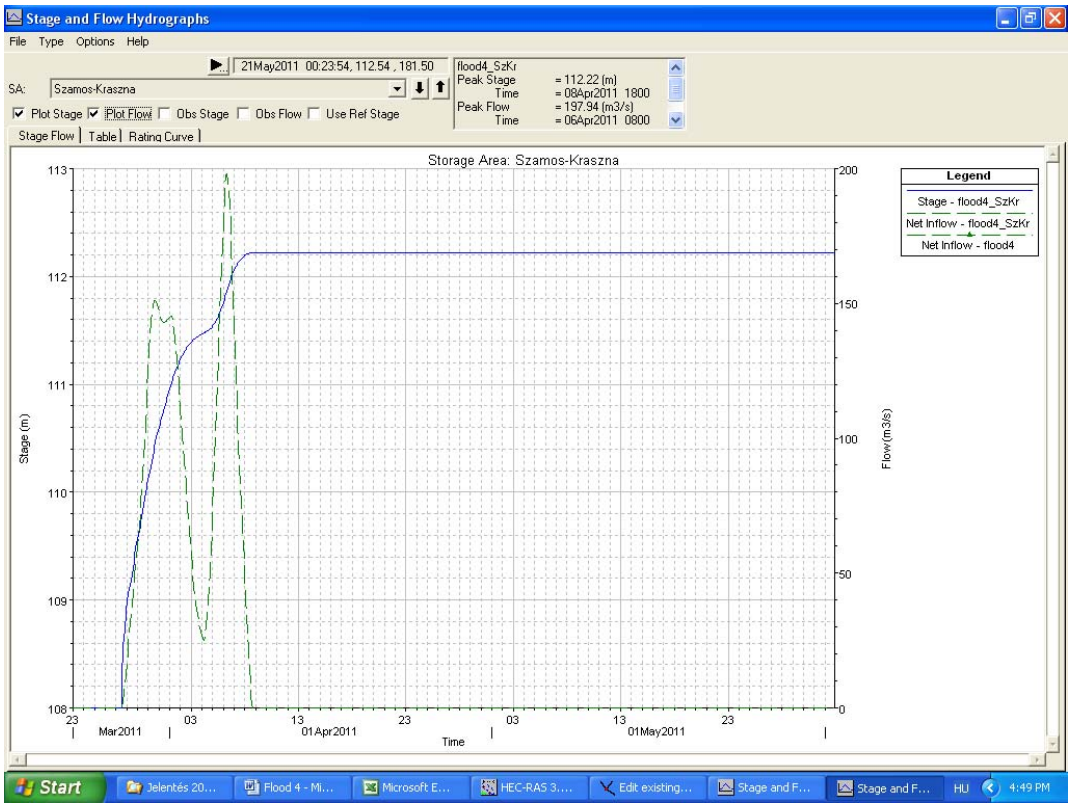


Fig. 66. Water released in Szamos-Krasznaközi detention basin – time series Q=Q(t) in green, H=H(t) in blue – $Q_{intake\ max}$=197.94 m^3/s

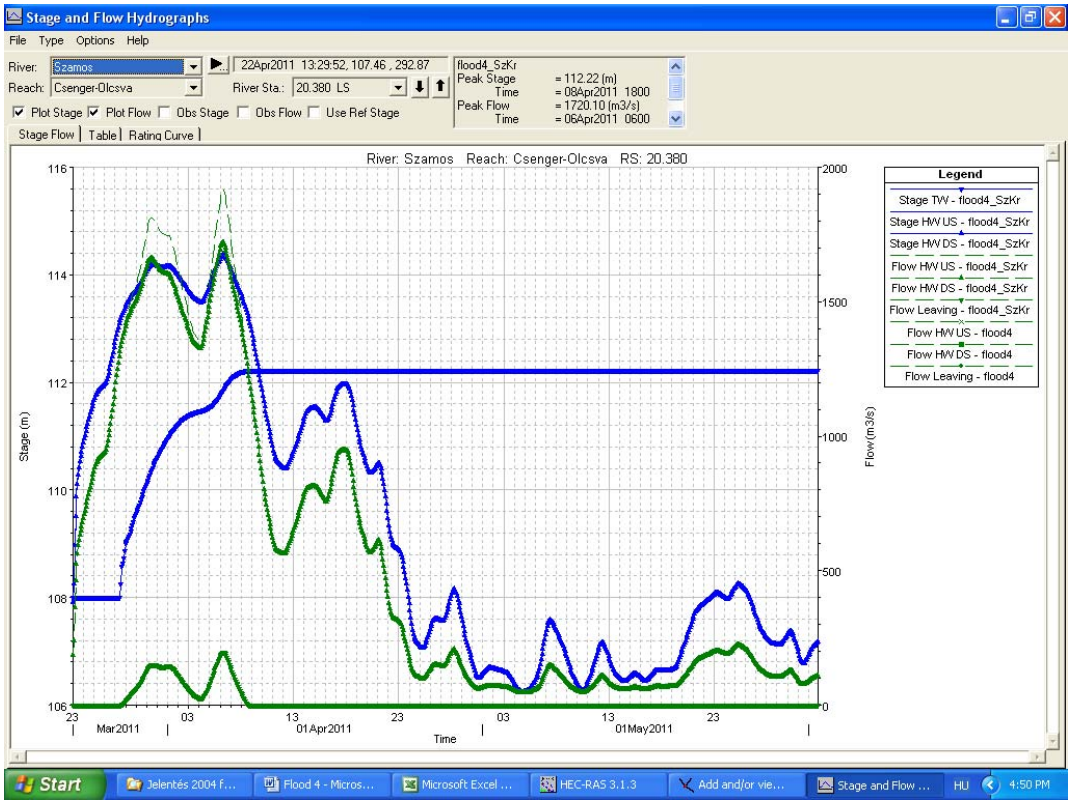


Fig. 67. Water stages (blue) and discharges (green) in the river and in the detention basin

Individual effect of the Upper-Tisza flood detention basins on the reduction of flood crests of the generated flood wave No. 4. are illustrated in *Fig. 68*. In this series of investigation impacts of all the

detention basins were modelled. Name tags of the basins being part of Phase I interventions are shaded in yellow.

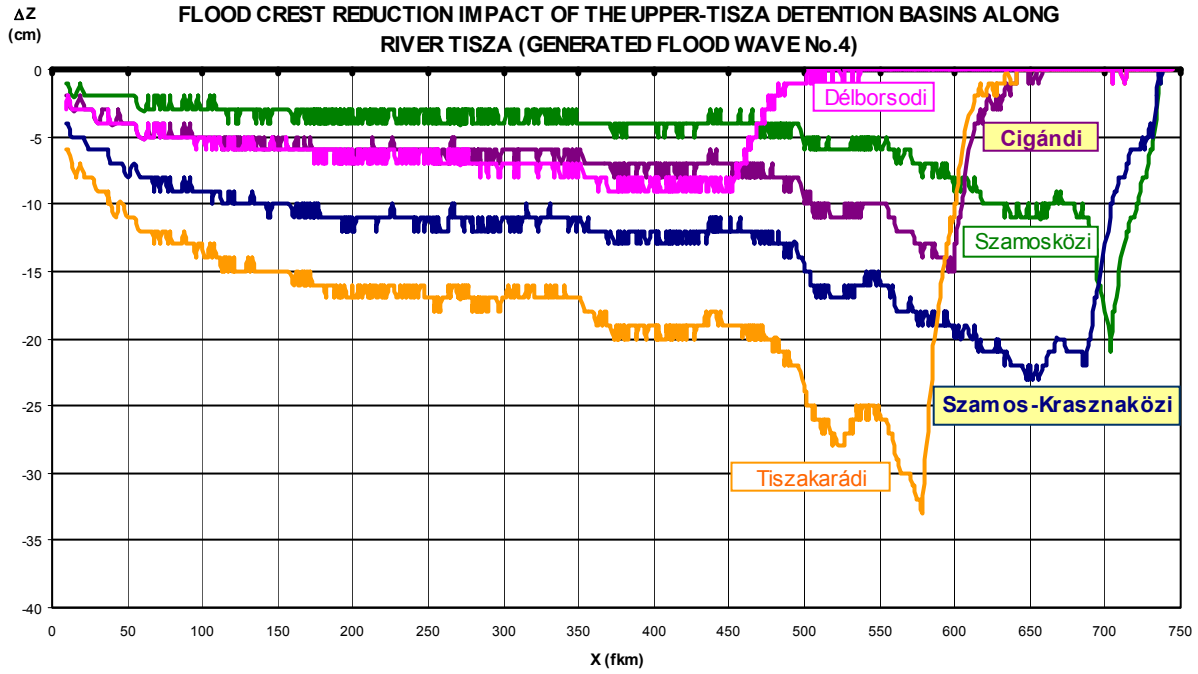


Fig. 68. Individual effect on the reduction of flood crests of the Upper-Tisza detention basins in case of generated flood wave No. 4

Table 6 summarises the conditions and results of the model investigation of the case with the generated flood wave No. 4. As a result of such series of interim investigation, the parameters of the intake structures of the detention basins were fine tuned to enable the effective filling of the detention basins.

2.2.1 Impacts of the UVP Phase I interventions on the 2000 spring flood

Model investigations to derive the impacts of the interventions planned in Phase I of the Update of the Vásárhelyi Plan (UVP) were carried out with the hydrological parameters of the spring flood of 2000 and extended to the individual and combined impacts of

- the floodway regulation to improve the flood conveyance capacity of the flood bed
  - = in the vicinity of the bridge at *Tivadar* on the Upper-Tisza;
  - = along the Middle-Tisza from *Kisköre* to the southern border of the country
- the six flood detention basin (two along Upper-Tisza, four along Middle-Tisza).

Results in *Fig. 69*. show the depression of flood levels achieved in comparison with the flood crests of the spring flood in 2000. Flood detention in the six basins provides alone 40-80 cm depression of the flood crests along the Middle-and Lower-Tisza in comparison with the flood crests of the spring flood in 2000.

Combination of flood detention and floodway regulation results in 50-160 cm depression along the 215-435 fkm river reach (*Csongrád-Tiszafüred*) with a peak of 140-160 cm depression along the *Szolnok-Kisköre* river reach and eliminates the negative impact (+15 cm) of floodway regulation turning to 10 cm depression at *Szeged.*

Table 6. Impact of flood detention on flood crests – generated flood wave No.4.

IMPACT OF FLOOD DETENTION ON FLOOD CRESTS

4. GENERATED FLOOD WAVE

Detention basin	Location, fkm	Weir		Basin max.		Basin actual		max. flow to basin Q (m3/sec)	Depression of flood crest as a result of detention (cm)
		Sill level (mB.f.)	width (m)	volume (1000 m^3)	level (mB.f.)	volume (1000 m^3)	level (mB.f.)		
Szamosközi	703,500	110,80	120	115822	112,50	37320	110,75	127	-21
Szamos-Krasznaközi	20.45*	113,00	140	170233	113,50	125384	112,71	229	-23 (-51**)
Cigándi	597,800	101,50	60	97300	99,50	63268	98,17	91,6	-15
Tiszakarádi	577,250	99,00	100	201150	98,00	174789	97,56	216	-33
Délborsodi	451,000	92,40	120	87954	93,00	59628	92,05	83,3	-9
Tiszanánai	411,400	90,40	100	136010	91,00	108560	90,22	116	-13
Nagykunsági	404,700	90,00	120	230062	91,00	185613	90,08	181	-22
Hanyi-Jászsági	395,900	89,90	120	220578	91,50	132762	89,37	138	-16
Hanyi-Tiszasűlyi	387,540	89,40	120	300918	90,00	211055	88,71	191	-24
Tiszaroffi	369,916	89,40	100	157920	92,50	83156	89,20	92,9	-11
Nagykörüi	354,900	88,60	60	150328	89,00	51471	85,87	53,2	-7

Remark: * fkm on R. Szamos
** flood crest depression on R. Szamos

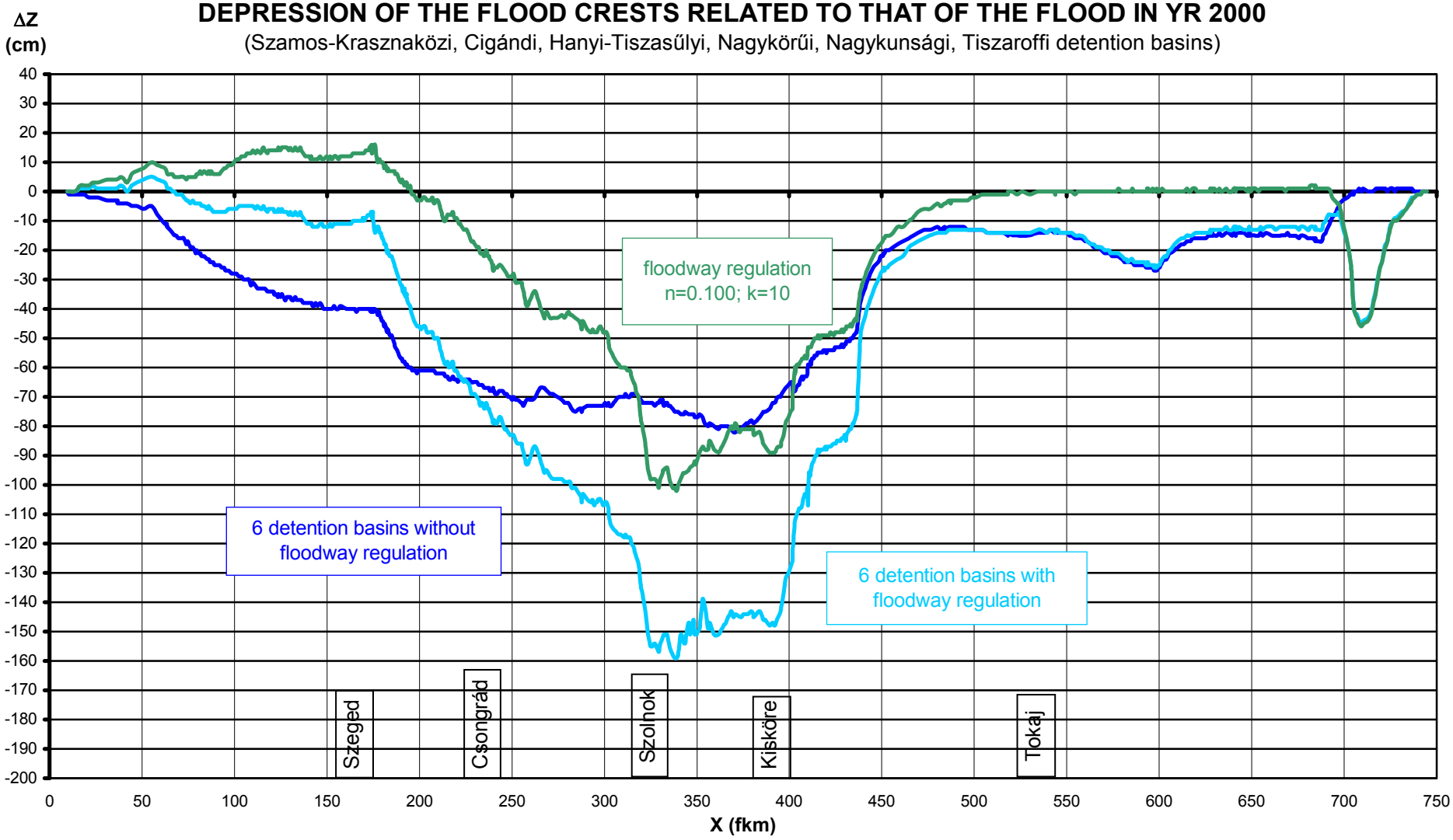


Fig. 69. Impact of Phase I flood detention and floodway regulation on the depression of flood crests of the spring flood of 2000

2.2.2 Modelling the effect of flood detention with the parameters of the spring flood in 2006

While working on this report, another extreme flood passed down the *River Tisza* in spring 2006 therefore we decided to analyse the effects of the detention basins for this flood as well.

2.2.2.1 Brief introduction of the flood in the Tisza River Basin in spring 2006

By the middle of February water reserves accumulated in the snow cover reached 6.5 km^3, 150% of the multiannual average of the given period. Although according to the measurements made on 20 March the water reserves in the snow cover upstream *Szeged* decreased to 5.5 km^3, this amount represents 250% of the multiannual average of that period. Significant amount of snow accumulated not only in the Upper- Tisza region: the water reserves measured in the *Maros/Mures valley* exceeded the multiannual average by 70 %, while in the river system of *Körös/Crisul* by 30 %.

The April Tisza flood was preceded by several floods in February and March generated by snow melting and precipitation that fell out of high humidity air masses arriving from the *Mediterranean Sea* subsequently. The continuing rainy weather as well as the rapid snow melting in the whole river basin triggered simultaneous and significant floods along the Upper-Tisza as well as her main tributaries.

Table 7. Average precipitation in different sub-basins of the Tisza River Basin

Catchments	**25-31 March**	**1-7 April**	**8-14 April**	**15-21 April**	**Σ (mm)**
Upper-Tisza	30.4	21.6	37.5	16.3	105.8
Bodrog	24.3	20.7	35.1	10.9	91.0
Sajó-Hernád	18.2	16.8	26.8	9.8	71.6
Túr-Szamos-Kraszna	16.3	18.5	80.9	19.8	135.5
Körösök	22.3	28.0	73.8	31.1	155.2
Maros	8.9	26.2	64.1	14.1	113.3

The *Tisza* flood culminated at *Tokaj* at 892 cm on 8-10 April, reaching almost the recorded historic maximum of 1999, however, the volume and duration of this flood significantly exceeded that of the one on record. On the other hand, the flood of the *Tisza River* was heavily influenced by that of the *Danube*, having reached on the Serbian river stretch also new historical records thus blocking the conveyance of the Tisza flood. *Tisza* culminated at *Titel* at 818 cm, exceeding the historical record by 27 cm. Although the *Danube* started falling in the middle of April, however, series of rainfall triggered repeated floods on the *Körös/Crisul* and *Maros/Mures* rivers, coincidence of which lead to new flood records along the *Lower-Tisza*.

Table 8. Flood crests at some characteristic sections along the Tisza and her main tributaries

Gauging station	fkm	Prevailing HHW		Flood crest 2006	Culmination date and hour
		cm	date		
TISZA					
Tiszabecs	744,3	736	2001.03.06	414	31 03. 2006. 0:00 - 2:00
Vásárosnamény	684,45	943	2001.03.07	834	02.04. 2006. 19:00 - 03.04. 05:00
Záhony	627,8	758	2001.03.09	662	04 04. 2006. 17:00
Tokaj	543,08	928	2000.04.12	893	08 04. 2006. 10:00
Tiszafüred	430,5	881	2000.04.12	835	09 04. 2006. 14:00-16:0
Kisköre-alsó	403,1	1030	2000.04.17	981	15 04. 2006. 10:00 - 16. 04. 13:00
Szolnok	334,6	1041	2000.04.19	1013	15 04. 2006. 21:00 - 17. 04. 02:00
Tiszaug	267,6	932	2000.04.20	**946**	21 04. 2006. 11:00 - 23. 04. 03:00
Csongrád	246,2	994	2000.04.20	**1033**	22 04. 2006. 08:00 - 23. 04. 00:00
Mindszent	217,7	1000	2000.04.21	**1062**	21 04. 2006. 14:00 - 22. 04. 22:00
Szeged	173,6	960	2000.04.21	**1009**	20 04. 2006. 22:00 - 22. 04. 12:00
Titel	9,5	791	1965	**818**	16 04. 2006. 19:00 - 17. 04. 07:00
HÁRMAS-KÖRÖS					
Szarvas	53,8	954	1970.06.15	**986**	20 04. 2006. 22:00-21 04. 02:00
Kunszentmárton	19,8	987	2000.04.21	**1041**	21 04. 2006. 0:00-2204. 06:00
MAROS					
Makó	24,3	625	1975.07.10	533	19.04.2006.

Remark: figures in **bold** represent new HHW values

The reciprocal backwater effects of the floods of *River Tisza* and her main tributaries, as well as the very slow decreasing of the flood discharge arriving from the upper river sections created extreme duration of water stages over the 1 in 100 years design flood level (DFL) not only along the *Lower-,* but also along the *Middle-Tisza*, where the height of the flood did not exceed the HHW values. Duration of the flood over the previous HHW level was two weeks at *Szeged* and *Mindszent* stations! Acceleration of falling along the *Lower-Tisza* started only on 10 May when the *Kisköre barrage* started impounding again.

Longitudinal profile with the envelope curve of the flood crests of 2006 are given together with that of the design flood level (DFL) and the HHW on record for comparison in *Fig. 68* and *69.*

Summarising: no doubt, very rare is the coincidence of relatively great flood of the four rivers (*Danube, Tisza, Maros/Mures* and the *Körösök/Crisul* system). However, neither the adverse reciprocal effects of these floods, nor the not as much extreme hydrometeorological factors in 2006 explain, why the former HHW values have been exceeded in such an extent.

Table 9. Peak flood discharges recorded in 2006

Gauging station	fkm	HQmax		HQ 2006	Return period
		m^3/s	year	m^3/s	year
TISZA					
Vásárosnamény	684,45	3,930	1970	2,150	< 20
Szolnok	334,6	3,150	1932	2,400	< 50
Csongrád	246,2	2,800	2000	2,320	< 50
Szeged	173,6	4,100	1932	3,730	< 50
HÁRMAS-KÖRÖS					
Kunszentmárton	19,8	1,900	1970	640	< 50
MAROS					
Makó	24,3	2,460	1975	1,000	< 50

According to the discharge data alone the flood of 2006 could be evaluated as insignificant. However, the multipeak floods (16 flood waves came down just on the *Fekete-Körös/Crisul Negru*!) arriving to the middle and lower sections of the rivers produced very high flood volume to be drained. Additionally, the *Danube* extreme flood at the confluence of *River Tisza*, as well as the bottleneck of the *River Tisza* at the *Đala* summer dike in Serbia created exceptional obstacle. Discharge at *Csongrád* reached 2,200 m^3/s on 13 April, and fell below this value on 5 May only!

Finally, the parameters of the recent flood confirmed the findings of the floods of 2000-2001 that the flood conveyance capacity of the Tisza River and her tributaries has drastically been reduced in the past *(Bakonyi, P. – Tóth, S. 2006)*.

2.2.2.2 Impacts of the UVP Phase I interventions on the 2006 spring flood

Model investigations were carried out with the extended to the individual and combined impacts of

- the floodway regulation to improve the flood conveyance capacity of the flood bed
  - = in the vicinity of the bridge at *Tivadar* on the Upper-Tisza;
  - = along the Middle-Tisza from *Kisköre* to the southern border of the country
- the six flood detention basin (two along Upper-Tisza, four along Middle-Tisza).

Results in *Fig. 72*. show the local advantages of river capacity improvement; however, this solution leads to 20 cm rise of the flood crest at *Szeged*. Flood detention in the six basins provides 50-60 cm depression of the flood crests along the Middle-and Lower-Tisza.

Combination of flood detention and floodway regulation results in 50-135 cm depression along the 215-435 fkm river reach and turns the negative impact of floodway regulation to 30 cm depression at *Szeged*.

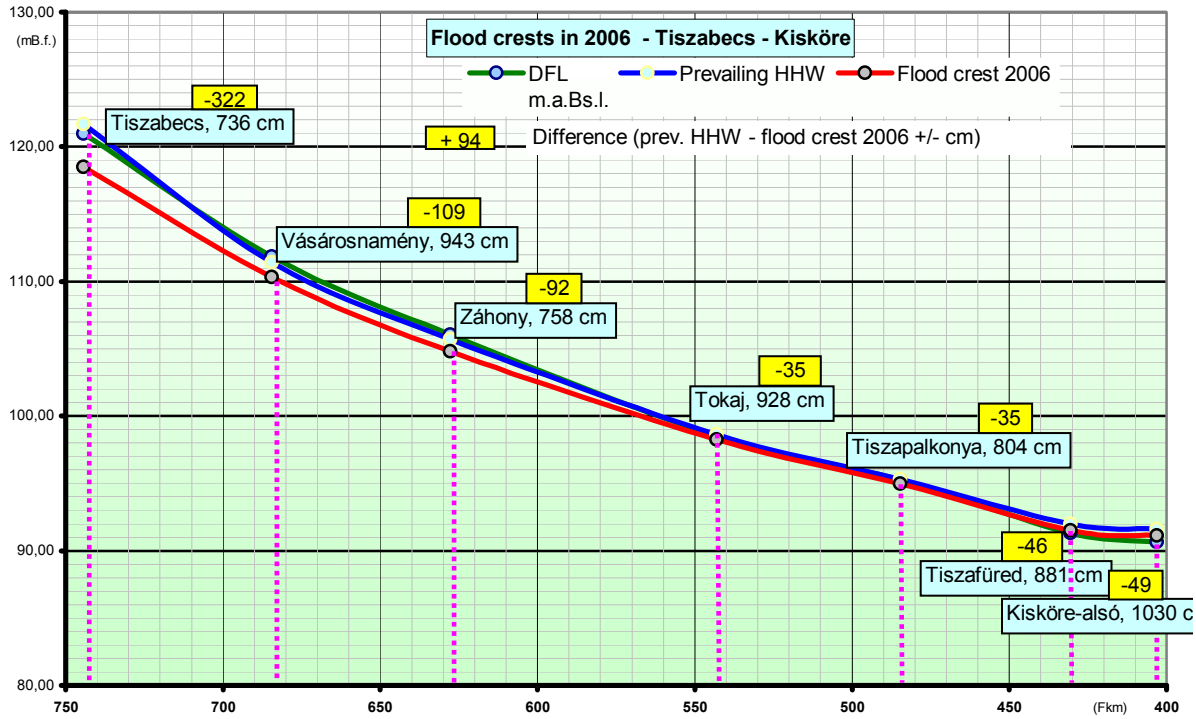


Fig. 70. Flood crests in 2006, Tiszabecs-Kisköre

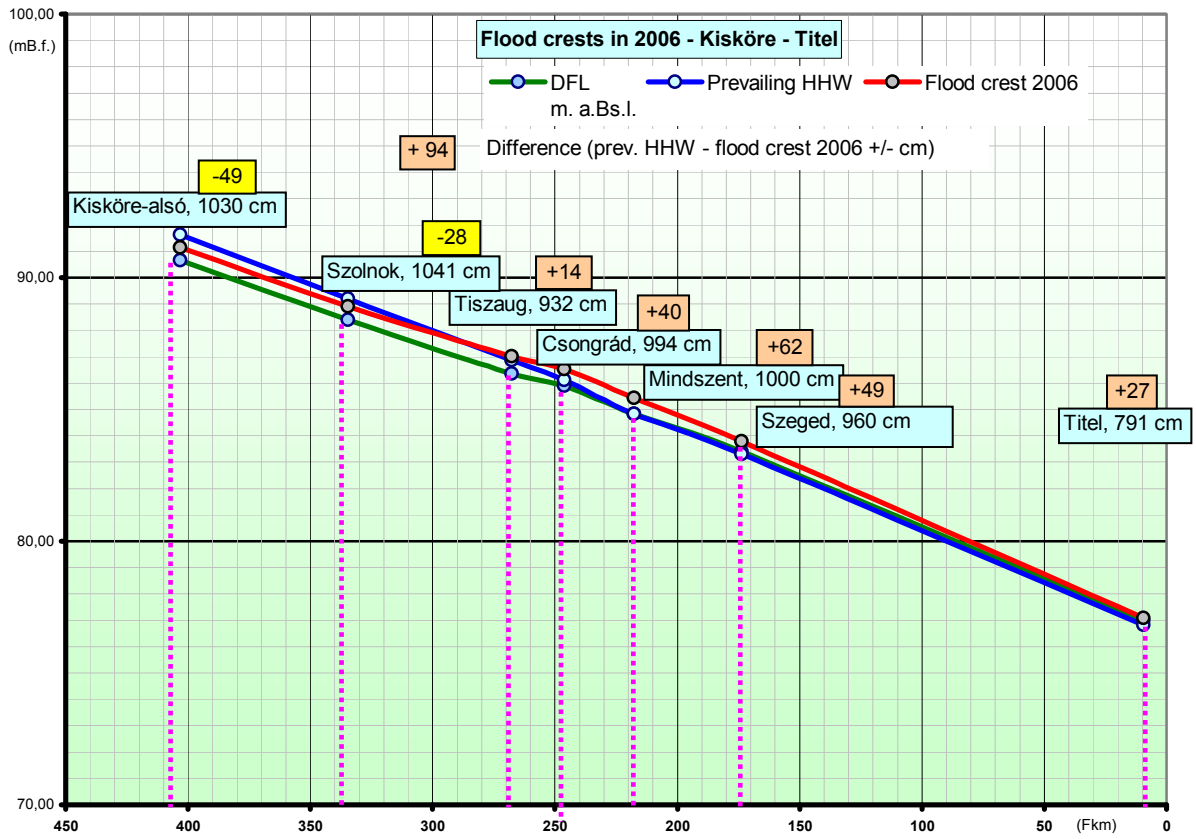


Fig. 71. Flood crests in 2006, Kisköre-Titel

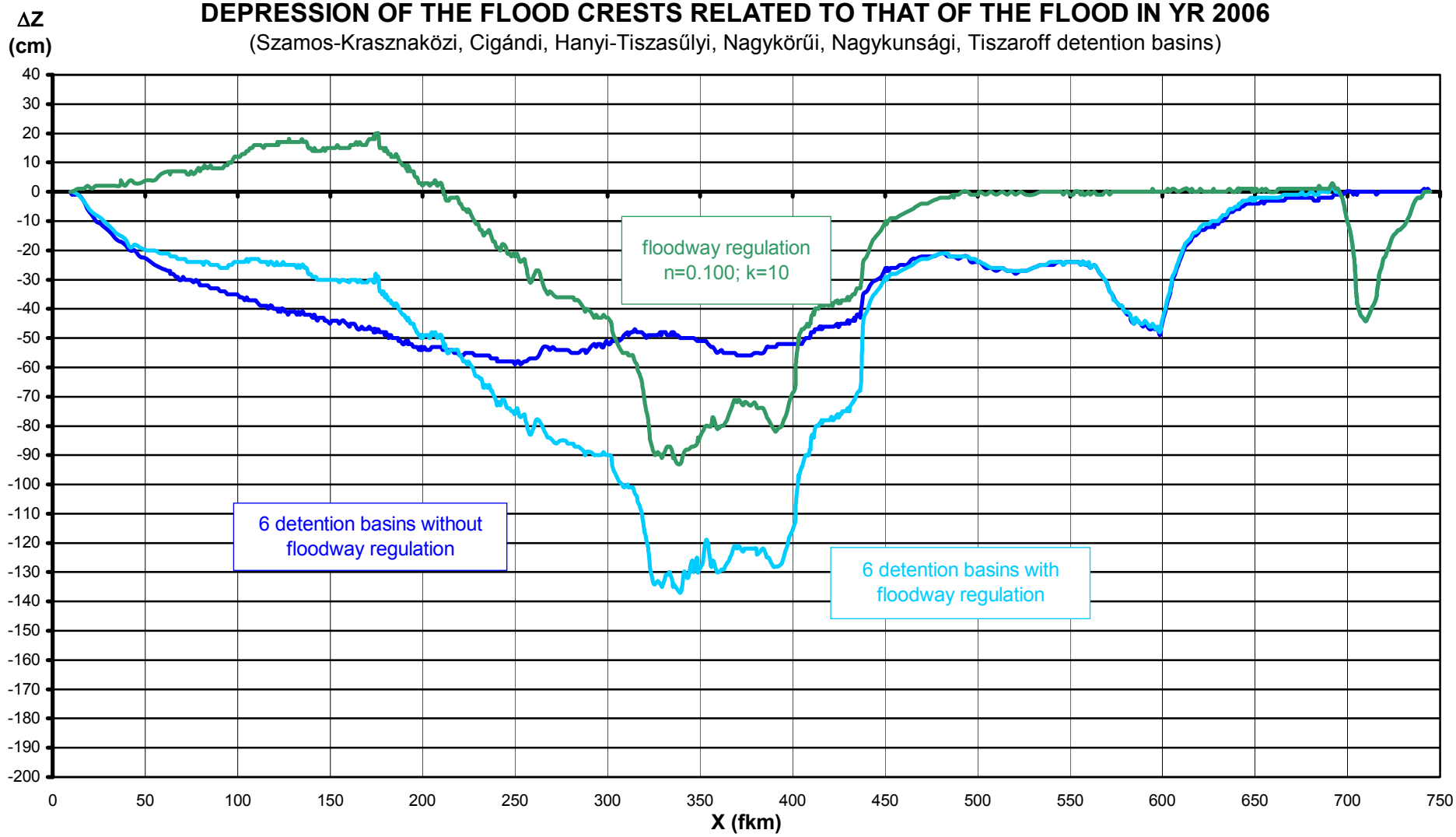


Fig. 72. Impact of flood detention on the depression of flood crests of the spring flood of 2006

2.2.3 Impacts of the UVP Phase I interventions on the DFL+1.0 m flood

Design flood levels along River Tisza are determined as the 1 in 100 years flood. Of course, such flood levels along the entire Hungarian reach of the river can not develop as a result of the same flood. Water levels, the propagation and attenuation of the flood is significantly influenced by the tributaries. In case flood peak of major tributaries of River Tisza coincides at the mouth of the tributary with that of the recipient, the 'flood increasing' effect of the tributary is considered maximal. However, probability of the development of such a meteorological situation, when all the tributaries contribute their own design flood and they would coincide with a design flood of the Upper-Tisza, is very small. Consequently, analysis of the impacts of design floods, or, as in this case, an extreme flood exceeding the design flood with 1.0 m, needs generation of different flood waves for the Upper- and the Middle-Tisza, respectively.

One of the basic aims, formulated by the respective Government Decree on the implementation of the Upgrade of the Vásárhelyi Plan, to develop an effective system capable to manage floods exceeding the prevailing design flood level with 1.0 m, by improvement of flood conveyance capacity and flood detention.

Generation of a flood situation in the hydrodynamic model resulting in a flood meeting the above requirement was based on earlier observed real flood waves of the tributaries, by increasing their peak discharge and/or duration as appropriate. Fig 73. illustrates the DFL+1.0 m flood wave generated for the impact analysis of the flood detention along the Upper-Tisza, especially for the Cigánd detention basin (*Farkas, P. – Kertai, I. – Rosza, P. – Szántó, T. – Takátsné Bajcsay, E. – Rátky, I., 2004*).

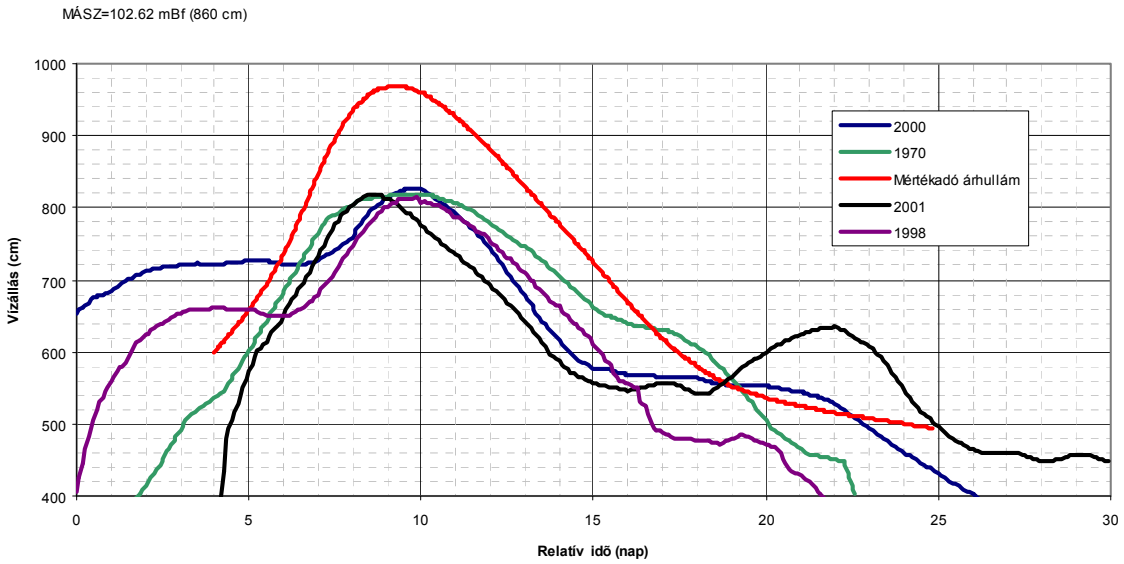


Fig. 73. Flood waves exceeding 800 cm at Dombrád gauging station (Tisza 593.080 fkm)

Investigation extended to the analysis of different single and combined application of the detention basins (Fig. 74). In case of the *Szamos-Kraszna-közi detention basin* located at the mouth of the *River Szamos*, being one of the most significant tributaries to River Tisza, effects on the reduction of the floods of both rivers was analysed.

Effectiveness of the *Szamosközi detention basin* proved to be the best in the reduction of flood level, however, acceptance of this basin by local stakeholders is still pending. Because of this, the presentation of the impacts of all the 4 detention basins is still theoretical, however, very impressive with 60-70 cm depression prevailing along a long downstream section.

Important is the combined effect of the *Szamos-Kraszna-közi* and *Cigándi detention basins*, being part of Phase I interventions. This solution provides a stable 30-40 cm depression along the Upper-Tisza even of this extreme flood corresponding to a 1 in 1000 years event.

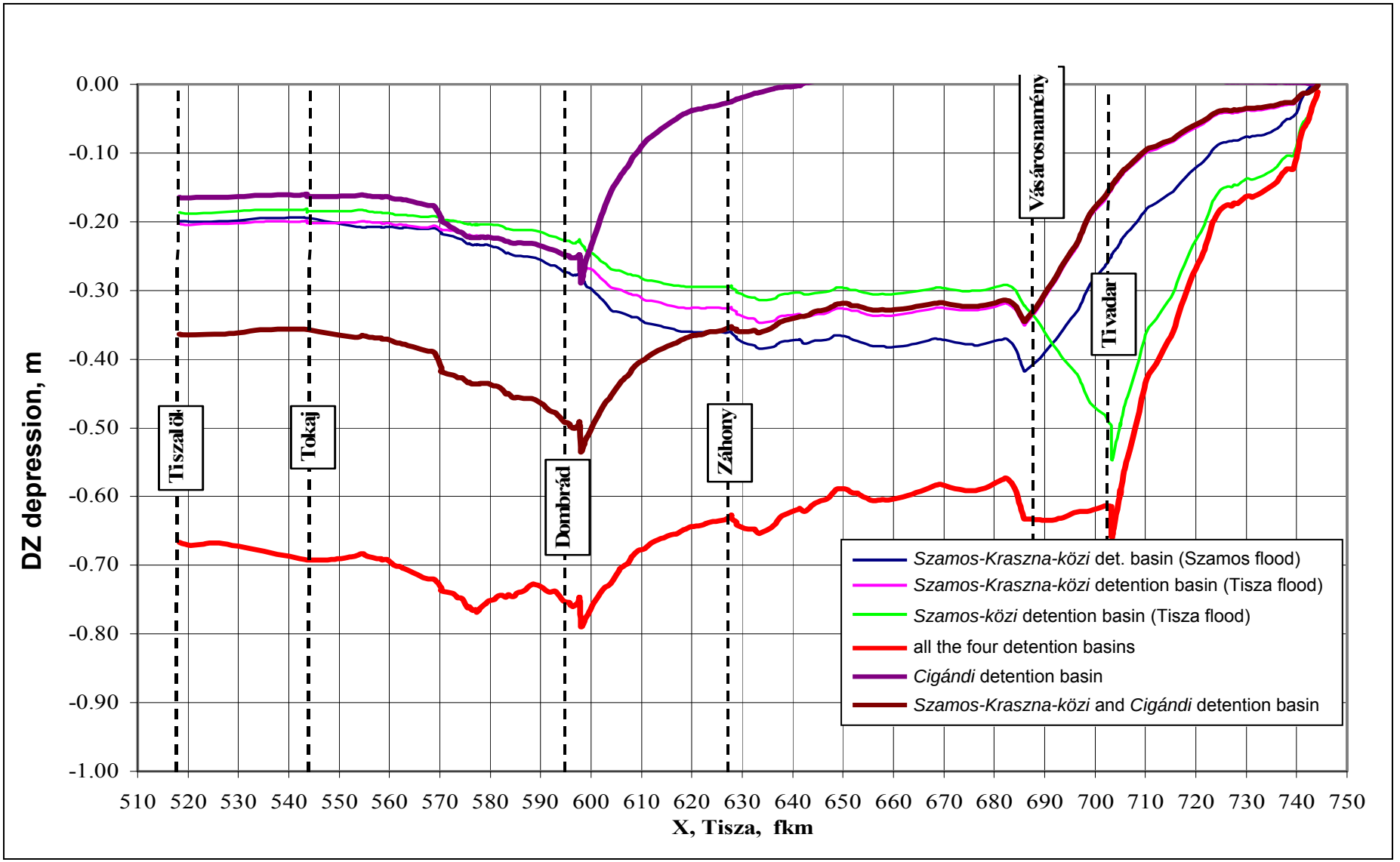


Fig. 74. Impact of the Upper-Tisza flood detention basins on the DFL+1.0 m flood wave

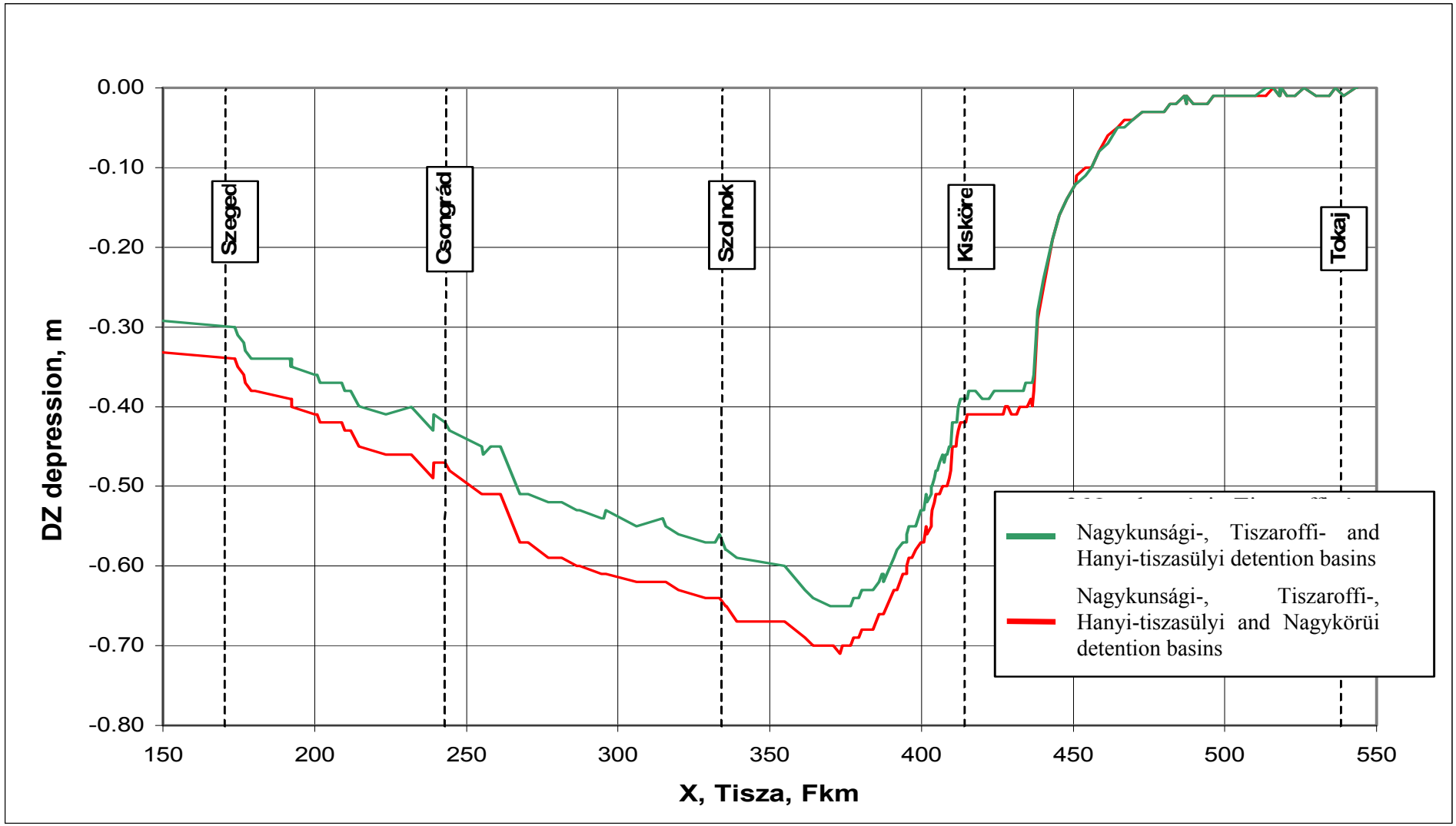


Fig. 75. Impact of the Middle-Tisza flood detention basins on the DFL+1.0 m flood wave

2.3 Evaluation of the modelling results

For the determination of flood level reducing effect of individual flood detention basins and combinations of those as well as for optimal selection of water intake engineering constructions a great number (close to 30) of variations have been run. Modelling results of this great variety justified several assumptions that were based on empirical and approximate theoretical considerations and were proposed in different preparatory studies:

- The **effects of individual flood detention basins approximately add up**. (This means that if the flood level reduction effect of an upper detention basin is 30 cm and the effect of the lower one is 20 cm, then the joint effect of the two flood detention basins will scarcely be lower than 50 cm.).
- The flood level reduction effect of flood detention basins **prevails on a long downstream section**. (For instance, a flood level reduction effect of 33 cm in the section at *Vásárosnamény* is still significant even at *Tokaj*, 140 km downstream; it is close to 20 cm according to the hydrodynamic model.)
- The flood level reduction effect of flood detention basins prevails **only on a short section upstream** depending on and influenced by the rate of non-prismatic character of the river bed. (For instance, the water level reducing effect of 60 cm of the *Szamosköz flood detention basin* decreases to an insignificant rate within a distance of 20 km upstream.)
- In the cases of surveyed flood waves the **flood level reducing effect** of flood detention basins is **approximately in direct ratio to the quantity of stored water** (on a certain section of the river in case of approximately optimal opening and appropriate intake capacity).

Certain parameters of individual engineering structures, location of water intake structures, sill level of floodgates and weirs, have been determined in the course of the engineering process. Other dimensions of engineering structures (like the maximum weir length, number of gated sluices) have been corrected upon the calculations for the preliminary hydrodynamic modelling and the opportunities of technical realization.

In the course of surveys the determination of theoretically "optimal" openings of detention basins has not been targeted, only approximately optimal openings have been applied. (On the one hand, neither in the case of most precise operation instructions can be reached an optimum and, on the other hand, the model surveys indicate, that the optimization of opening time and capacity will scarcely result in significant improvement.)

Considering the flood detention basins in the *Middle-Tisza* section the following cases have been involved into the detailed survey of the case of DFL+1.0 m flood (see *Fig. 75*):

- In case of joint operation of the detention basins of *Nagykunság*, the *Hany-Tiszasüly* and the *Tiszaroff* the stored water quantity of 484 million m^3 reduces the DFL + 1 m water levels on the *Middle-Tisza* section by more than 40 cm on the river section between *Mindszent* and *Kisköre* (approximately on a length of 180 km), and by more than 60 cm within this, in the region of *Szajol* and *Tiszaroff* (approximately on 40 km).
- In case besides the above three flood detention basins also the one at *Nagykörü* will be in operation, then by storing a water quantity of **500 million m^3**, there will be a reduction by **40 cm**, already on the section between **Algyő and Tiszadorogma** (approximately on 250 km), while the rate of the reduction will be of **60 cm** within this section, i.e. on the one between the villages of **Nagyrév and Tiszaroff** (approximately on 100 km).

The **combined effect of flood detention and floodway regulation almost doubles the depression** along the most sensitive river reach of the *Middle-Tisza*. The negative impacts of floodway regulation along the *Lower-Tisza* can be eliminated by the flood detention (*Fig. 69* and *72*).

However, experiences of the flood of 2006 warn that preparation of further flood detention possibilities along the *Lower-Tisza*, especially the *Szeged detention basin* (A=61 km^2; V=187 Mm^3) and possibly the *Körös-mouth basin* (A=67 km^2; V=205 Mm^3 – see *Fig. 55*.) might be inevitable.

2.4 Future research needs

Besides the vulnerability analysis which is still to come in Task 22, further investigation of the impacts and feasibility of flood detention along the *Lower-Tisza*, as well as the optimization of the operation of the system of flood detention basins will be necessary.

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