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## INCREASING OF FLOODS DURATIONS AND LEVEL IN TISZA VALLEY AS THE MAIN IMPACT ON THE STA- BILITY OF HYDRAULIC

### AZ ÁRVÍZEK TARTÓSSÁGÁNAK ÉS SZINTJÉNEK NÖVEKEDÉSE A TISZA-VÖLGYBEN, MINT A VÍZÉPÍTÉSI MŰTÁRGYAK ÁLLÉKONYSÁGÁRA GYAKOROLT JE- LENTŐS HATÁS

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#### **Abstract**

*In this article, the authors present in detail the reasons for the rising of flood waves in the Tisza Valley as one of the most determining elements of the failure of hydraulic structures. Decreasing of river's flood conveyance and increasing of flood waves were observed in the Tisza River Valley. As water levels rise, their time duration significantly increased, with the combined effect of severe stress on structures built more than a hundred years ago. Changes in the frequency of flood waves observed since the onset of water level observations analyzed separately. The authors analyze separately the changes in the formation and run-off of the flood waves since the beginning of the observation of the water level of our rivers. The document in detail analyses of the reasons for the filling of the floodplain, and the growth of the point bars. The article briefly describes the procedures for recalculating the relevant flood design water levels based on probability theory and hydrodynamic methods.*

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**Keywords:** flood wave, flood conveyance, hydraulic engineering structure, failure, water level, frequency, time durability, and time duration.

### **Absztrakt**

*A cikkben a szerzők részletesen bemutatják a Tisza-völgyben levonuló árhullámok növekedésének okait, mint a vízépítési műtárgyak tönkremenetelének egyik meghatározó elemét. A folyók vízszállító képességének csökkenésével az árhullámok magasságának fokozatos emelkedését figyelhetjük meg. A vízszintek emelkedésével jelentősen megnövekedett azok időbeli terjedelme, tartóssága, amelyek együttes hatása komoly igénybevételt jelent különösen a több mint száz évvel ezelőtt épült vízügyi műtárgyakra és azok szerkezeti elemeire. Az utóbbi évtizedekben egyre gyakrabban fordulnak elő a rendkívüli magasságú árhullámok. A szerzők külön elemzik a folyóink vízállás észlelésének kezdete óta megfigyelt árhullámok kialakulásában, levonulásában bekövetkezett változásokat. Részletezik a hullámtér feltöltődésének, a partél, az övzátony növekedésének okait. Röviden ismertetik a mértékadó árvízszintek újraszámításainak valószínűség elméleti és hidrodinamikai módszereken alapuló eljárásait.*

**Kulcsszavak:** árhullám, vízszállító képesség, vízépítési műtárgy, tönkremenetel, vízszint, gyakoriság, tartósság.

## **INTRODUCTION**

Climate change is having an impact on all areas of the human living space. As a result of climate change, our weather will become increasingly extreme. The frequency of water scarcity and also water excess periods will also increase. As a result of the already well-known human interventions and natural changes, the floods on our rivers, are getting higher and higher and they are increasingly endangering the settlements, industrial or agricultural facilities located in the floodplains of Hungary, and so citizen livelihoods. Hungary is located entirely in the river basin area of the Danube River. Due to the geographical peculiarities and to some extent the climatic conditions, Hungary has the most risk of flooding in Europe. The flood protected area make up 23% of the whole country. About a quarter of the Hungarian population lives endangered areas. Due to the geological conditions, the terrain slope is very small in most of the country, so uncontrolled flooding would immediately be a problem in large areas. The length of the built flood

protection dykes exceeds 4 200 km, and a number of reservoirs, pumping stations and other complex hydraulic structures provide security against the 100-year-period flood events undertaken by the state. In our article, we analyze in detail the reasons for the increasing of flood waves in the Tisza Valley as one of the most important elements of the failure of hydraulic engineering structures.

## **INCREASING OF FLOOD WATER LEVELS IN TISZA RIVER**

Looking back at the flood history of our country, in order to preserve the more significant settlements and more valuable areas - in accordance with the technical possibilities of the age - some technical solutions have been always used. Professionally based, organized flood protection - which started mainly with the regulation of the Tisza River, has a tradition of more than a century and a half<sup>3</sup>. The country has had a unified water service for the entire spectrum of water management for almost 70 years. There have been and will be more unfavorable weather conditions in the history in our watercourses and rivers than in recent decades, with floods exceeding the maximum flood levels so far. Our rivers including the flood protection structures, crossing structures of the flood protection dike, the bridges, dams, embankments and sluices. As the flood waves increased and the flood's durability increased, the load of flood protection structures due to water pressure also increased significantly. Certain elements of flood protection structures are among the critical technical infrastructure elements, for which a legal identification procedure carried out, as it has a significant impact on the safety of the population living in the affected area and on the economic and industrial values<sup>4</sup>. Many foreign studies deal with the "aging and the degradation of hydraulic structures and the reasons of the failure process<sup>5</sup>.

Guillermo A. (2014) calculates the future evolution of the failure of hydraulic structures in a mathematical, probabilistic way, involving the

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<sup>3</sup> Kovács S., Lovas A., Gombás K.: Magyarország árvízvédelme az integrált vízgazdálkodásban a Tisza folyó példáján, Hidrológiai Közöny, 2016. 4. szám, 11-12. o.

<sup>4</sup> Horváth L.: A közép-tiszai árvízvédelmi fővédvonalba épített vízepítési műtárgyak életkor- és állapotelemzése, HADMÉRNÖK, 15. évf. 2020. 1. szám 79-90.

<sup>5</sup> Rowland J.: Aging Dams and Clogged Rivers An Infrastructure Plan for America's Waterways, Center for American Progress, Washington 2016.

Markov chain<sup>6</sup>. In this article, explaining the methods for predicting infrastructure degradation can be classified into deterministic and probabilistic categories. Deterministic-based models are those in which there is no coincidence in the future developments of the deterioration of hydraulic structures. Given the past and present state of the system, these models calculate the future evolution of the deterioration. Probability-based models judge deterioration states and failure parameters “random” by treating the system as probability variables to predict changes in the state of the structure. These models calculate the future evolution of the deterioration given the past and present state of the system. Probability-based models “randomly” determine the deterioration states and the failure parameters by treating the system as probability variables to predict changes in the state of the hydraulic structure. On the Tisza River and the Hungarian Tisza tributaries, a significant increasing trend observed in the flood water levels as a result of the natural and human farming-related processes and the interventions in the floodway channel. The deterioration of the flood conveyance capacity of the floodway channel varies between 1 and 4 cm in some sections of the Tisza after 1970 (Figure 1).

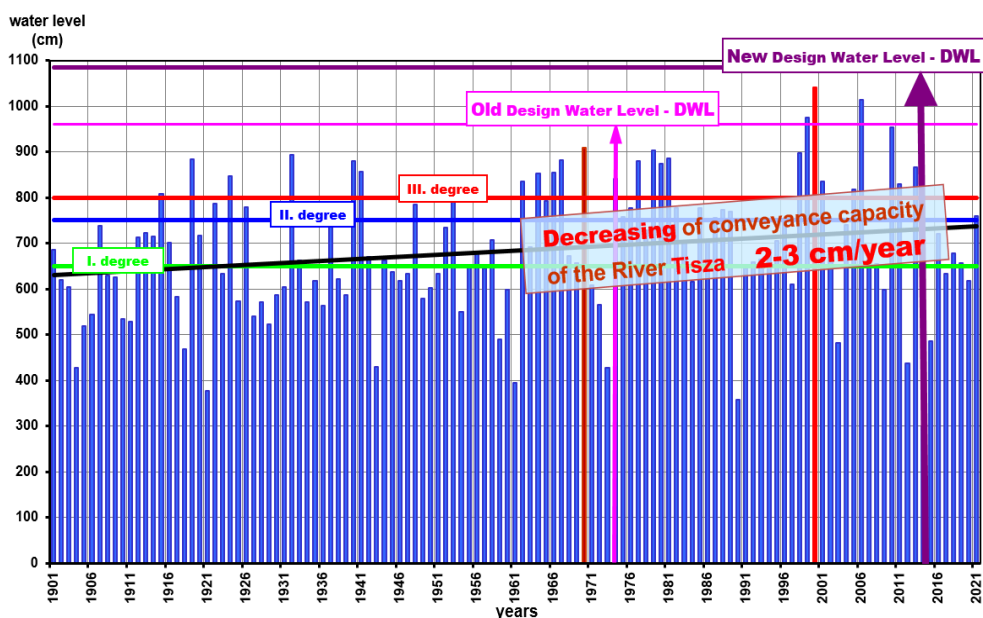


Figure 1. Annual Water-Level – Tisza, Szolnok (Source: editing by authors)

<sup>6</sup> Guillermo A.: Predicting Future Deterioration of Hydraulic Steel Structures with Markov Chain and Multivariate Samples of Statistical Distributions, US Army Engineer Research and Development Center, Vicksburg, 6 May 2014.

If the hydrometeorological situation in the Tisza River basin formed similar floods as in 2000 and 2006 in the near future, as 15-21 years have passed since then, the flood wave in the Middle Tisza section would have been higher several decimetres than Those times. The situation on the Upper Tisza in the event of a recurrence of the hydrometeorological conditions in 2001 would be similarly unfavorable.

In addition to rising flood levels, increasing the time duration of floods is a growing problem too. The duration of the flood waves above the given water level has been analyzed starting from 1881 - our data series divided into 30-year periods. Between 1881 and 1910, the flood wave was an average of 5 days per year above 650 cm in the Middle Tisza, currently this value is over 20 days, and the old flood time duration has increased almost fivefold (Table 1). It is important to note that after 1999, flood waves peaked above 950 cm and 1000 cm.

DURABILITY OF THE WAVE IN DAYS, CONCERNING THE ANNUAL AVERAGE BETWEEN 1881-2000, TISZA – SZOLNOK (SOURCE: EDITING BY AUTHORS)

Table 1.

Period	above 650 cm	above 700 cm	above 750 cm	above 800 cm	above 850 cm	above 900 cm	above 950 cm	above 1000 cm
1881 - 1910.	5.4	2.9	1.2	0.6	0.0	0.0	0.0	0.0
1911 - 1940.	14.0	7.1	3.6	1.9	0.8	0.0	0.0	0.0
1941 - 1970.	21.1	14.7	9.6	5.2	1.2	0.2	0.0	0.0
1971 - 2000.	25.8	17.4	10.5	5.7	3.4	1.3	0.8	0.4
<b>2001 - 2021.</b>	<b>20.2</b>	<b>14.9</b>	<b>9.2</b>	<b>7.1</b>	<b>3.3</b>	<b>2.0</b>	<b>1.1</b>	<b>0.4</b>

The same process illustrated graphically in Figure 2 below.

One of the most significant floods from a hydrometeorological point of view is 1888, when the water level of the Tisza at Vásárosnamény, which located in Upper-Tisza and Szamos estuary, exceeded 800 cm for 16 days, and at the same time, the water level of the Tisza tributaries was remarkably high. In the Vásárosnamény section, the time duration of the floods of recent years over 800 cm did not exceed 3.5 days in any case.

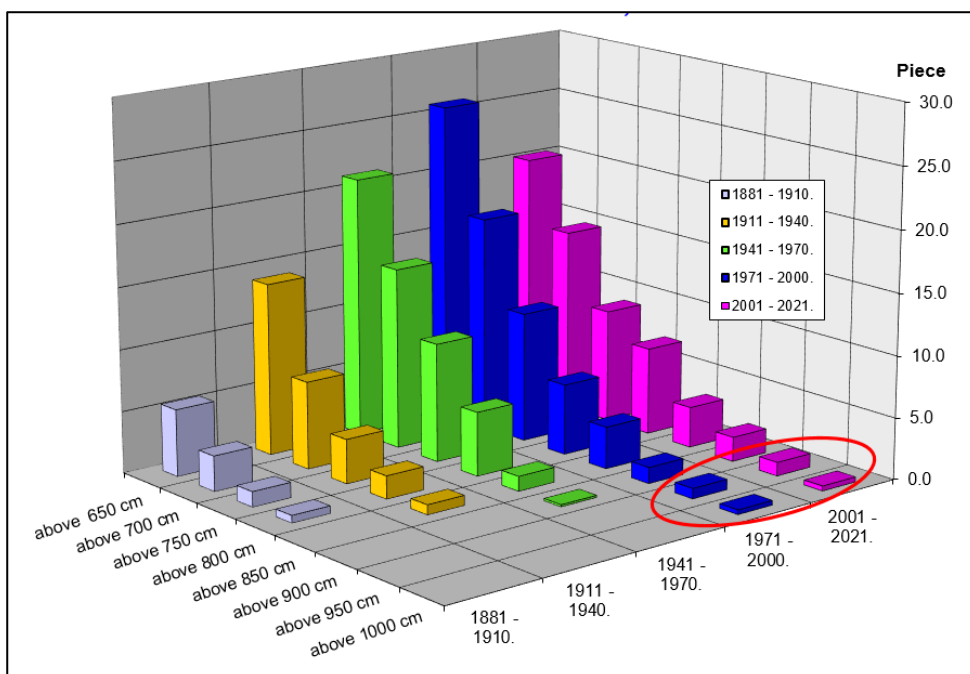


Figure 2. Durability of the Wave in Days, Concerning the Annual Average between 1881-2000, Tisza – Szolnok (Source: editing by authors)

In 1888, on the other hand, the peak flood water level was 900 cm at Vásárosnamény – despite the inundation of 300,000 ha – and there was hardly any flood protection dike along the tributaries, and the flood washed away the former flood protection dikes.

Hydrometeorological and hydrodynamic programs are of great help in the analysis of the processes taking place in the river basin and in the rivers. Model systems built on the entire Tisza Valley could help evaluate the formation of historical flood waves and analyze the flood propagation on the riverbed. Using the 1D hydrodynamic model created for the Tisza section from Tiszabecs to Titel, we ran the hydrological parameters of the 1881 flood wave in the current riverbed (Figure 3).

The hydrodynamic results showed that the flood peak water level above 1100 cm was not surprising, but this flood time duration above 1000 cm was astonishing. In 2000, the flood water level was above 1000 cm for 11 days, the flood wave of 1888 would exceed this water level for 21 days under the current runoff and riverbed conditions. With the existing flood detention reservoirs, we can reduce the height of the flood wave close to 1000 cm, but the time duration can still double. This

long-time durability flood would seriously endanger the stability of flood protection structures.

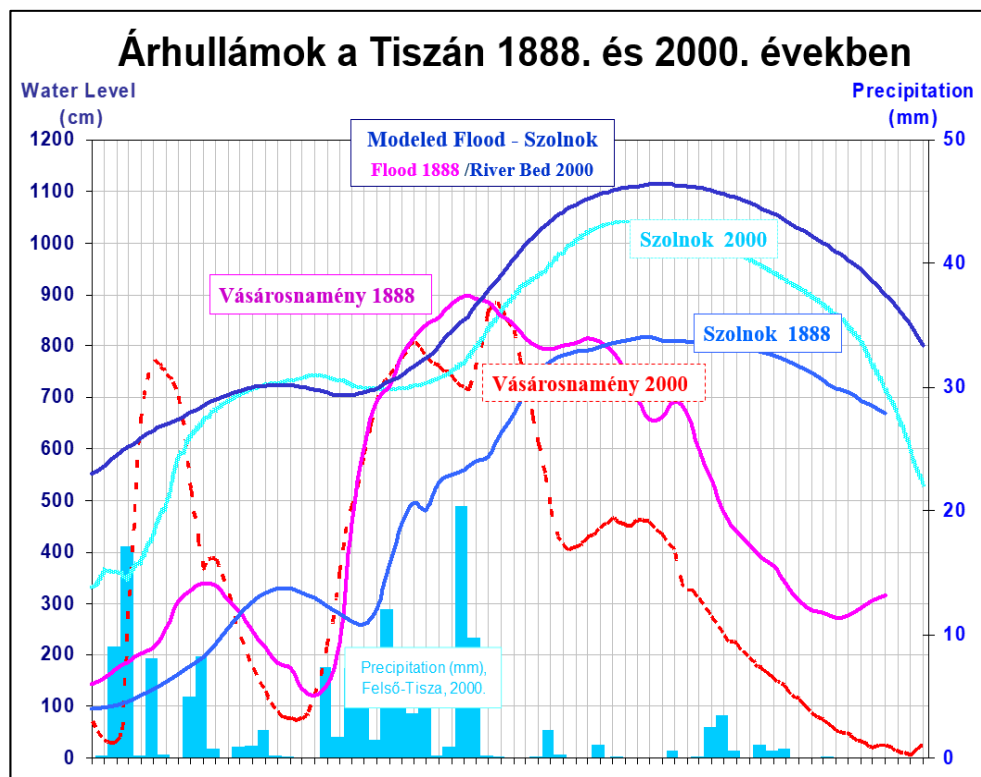
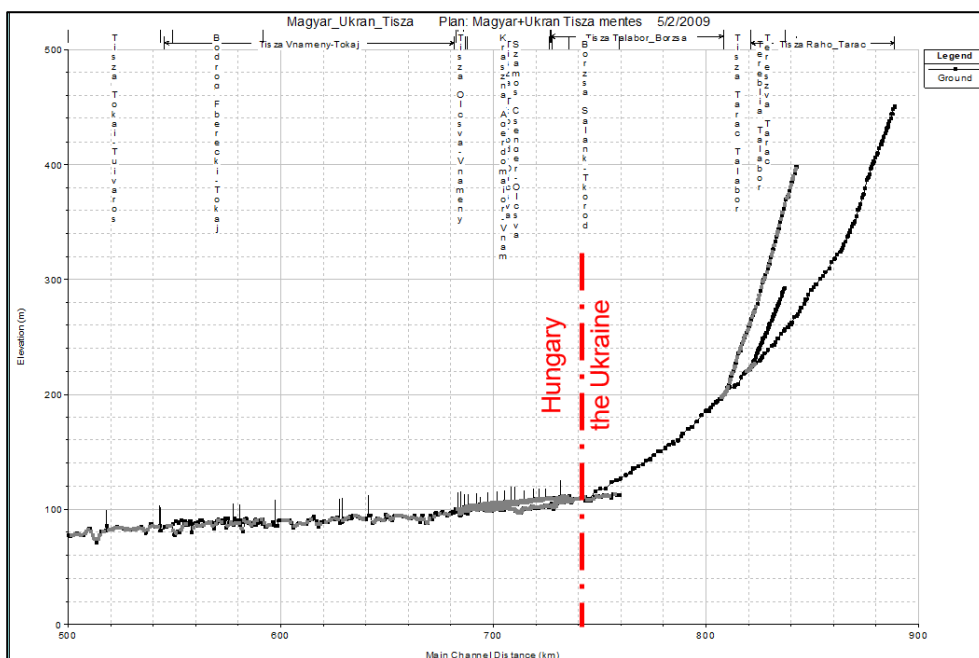


Figure 3. Modelled 1881 Flood (---) for Current River Bed Conditions (---) (Source: editing by authors)

The main reasons for the increase of the flood water level in the Hungarian section of the Tisza River and its tributaries can summarize as follows:

The rivers flow to Hungary with a high slope from upstream countries. In the border area, the slope decreases (Figure 4), and at the same time, the flow velocity becomes significantly lower. As the flow velocity decreases, the river drops down and accumulate the sediment. The accumulated sediment increases the height of the flood way channel decreases the flood conveyance. As the flow velocity decreases, the sediment accumulating process is getting stronger, which it further generates water level rise.

The neglected state of the flood way channel (flood riverbed) also slows down the flow velocity, helping to promote the constant strengthening of the process.



*Figure 4. Tisza Longitudinal Profile between Raho-Tisadob (great difference in the slope of the rivers) (Source: editing by authors)*

The flow velocity in the middle and lower section of the Tisza continues to decrease; the process of the sediment accumulation become stronger. The flood volume of the outstanding flood waves exceeds  $10 \text{ km}^3$  in the Middle Tisza and  $15 \text{ km}^3$  in the Lower Tisza. As the flow velocity decreases, the kinetic energy of the river will decrease. Decreasing in the kinetic energy causes an increasing in potential energy, which it results, an increasing water level. Rising in flood water level causes an increasing time duration of the flood wave, which exposes it in increased load for our “aged” and old flood protection dikes.

## REASONS FOR THE DECREASE OF THE FLOOD CAPACITY OF TISZA RIVER

The condition of the flood way channel (flood riverbed), the density of the vegetation, the height of the channel bar, the height of the summer dike, and the existence of various run-off barriers (stumps, resorts) play a major role in the development of flow velocity. The growth procession of the channel bar is schematically illustrated in Figure 5 below.



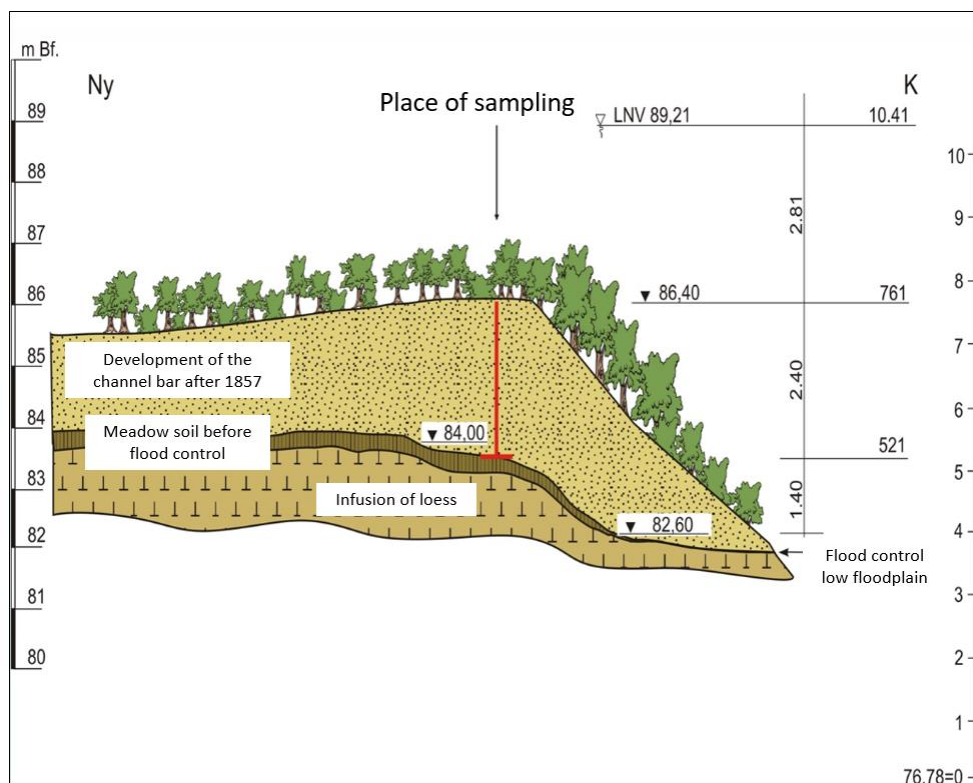


Figure 5. Development of the channel bar at Szolnok<sup>7</sup>

The faculty of the Department of Inorganic and Analytical Chemistry of the University of Debrecen carried out the first isotopic study of the siltation of the channel bars in 2001. Above Szolnok Tisza River section, we cut a channel bar on the left bank - at a height of 760 cm measured at the Szolnok water level gauge - with a depth of 2.4 m. The age of each layer was determined by analyzing layer samples taken every two cm from the cut channel bar. We have found that the rate of development of the channel bar is linear, exceeding 2 cm per year<sup>8</sup>. The height of the channel bars, moving away from the main riverbed, usually decreases rapidly. Where the main river channel does not move laterally, since the river regulation the channel bars have risen 1.0-2.5 meters and continuously close the floodplain bed from the main riverbed. Because of all this, the flood way channel (flood riverbed) cannot participate in flood conveyance in the case of flood waves below the level of the channel bar, and it reduces its flood capacity in the case

<sup>7</sup> Vajk Ö.: GIS database of Middle-Tisza, Szolnok, Power Point Presentation, 2003.

<sup>8</sup> Braun M., Dezső Z., Hadady Gy.: A Tisza balpart, Szolnok Övzátóny (árapasztó) fejlődésének rekonstrukciója. Jelentés, Debrecen, 2001.

of flood waves above this. 110 years ago, most of the channel bars were located between 500 and 600 cm water level.

Another sampling activity took place seventeen years later, in 2018 within the "Development of the plant management and monitoring network" the KEHOP-1.4.0-15-2016-00016 project. As in 2001, we commissioned the teachers of the University of Debrecen and the staff of Isotoptech Zrt. to carry out the examinations. Until we were able to examine only one section in 2001, in 2018 the assignment covered the entire Hungarian section of the Tisza, the following 11 river sections<sup>9</sup>.

The aim of the studies was to analyse the extent and pace of the flood way channel (flood riverbed) filling process of the last 50-60 years on a uniform methodological basis in the following river sections:

- Above the Túr river estuary (725,320 rkm)
- At Vásárosnamény, under the road bridge (681,900 rkm),
- At Tiszapalkonya (481,000 rkm),
- At Egyek (466,100 rkm),
- At Tiszabura (395,340 rkm),
- In the river narrowing of Óballa (357,720 rkm),
- In the river bend of Vezsenyi (314,440 rkm),
- In the river bend of Tiszaug (270,650 rkm),
- Above the beach of Mindszent (215,560 rkm),
- Under the Körtvélyes-meander section (200,900 rkm),
- At Szeged, below the estuary of the Maros (176,680 rkm).

In the jointly designated 11 river sections, a 3.75-meter-long casing pipe was drilled at the highest point of the channel bar by core sampling. In 3 sections, 5 boring were deepened in the area between the riverbank and the flood protection dike, while 4 (in total 45) boring were deepened on 8 additional sections. In subsamples taken from boreholes determined the total soluble element concentrations of copper,

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<sup>9</sup> Braun M., Czébely A., Papp I., Kállai M., Vidra Zs.: Hullámtér feltöltődés vizsgálatok "Vállalkozási szerződés üzemirányítás és monitoring hálózat fejlesztés komplex megvalósítására a KEHOP- 1.4.0-15-2016-00016 projekt keretében", Jelentés, Debrecen, 2018.

lead, zinc, chromium, nickel, cobalt, sodium, potassium, calcium, magnesium, iron, manganese, barium, strontium from the "aqua regia" extract. Based on the test results, the age of the deposited sediment was determined, and the sedimentation rate was estimated.

Knowing the rate of sediment accumulation is a great help in predicting the increase in flood levels and in calculating the load on hydraulic structures. Among the radiometric methods, the study of the  $^{137}\text{Cs}$  isotope is suitable for estimating the age of the sediment. This isotope was released into the environment with a short half-life due to nuclear explosions and the Chernobyl accident. Going down the sediment, a maximum indicates the 1986 reactor accident, 1963 the maximum of the experimental explosions before the Convention on Nuclear Silence. This isotope certainly does not occur in materials deposited before 1950. Measurement of radioactive cesium usually takes 10 to 24 hours per sample. In order for events to take shape, the entire drilling material must be measured throughout, so it can take up to 3-4 weeks to determine the age of a sample. The first (1945) atomic bomb blast was followed by a large number of experimental atmospheric blasts, the number of which was reduced by the partial nuclear silence agreement signed in 1963. Most of the experiments were in the northern hemisphere, and the material falling from the atmosphere did not escape Hungary or the river basin area of the Tisza. The  $^{137}\text{Cs}$  isotope retains traces of atomic bomb experiments in the sediment for a relatively long time. The maximum  $^{137}\text{Cs}$  associated with 1963 occurred at a depth of about 300 cm in the C1 sample. The Chernobyl reactor accident also resulted in a significant Cs fall out. The maximum of that is located between 100 and 150 cm.

In the sediment deposited in the flood way channel (flood bed) of the Tisza, these maximums occur with a significantly higher intensity compared to the soils and lake sediments. This is because flood waves bring down and spread material that falls in the river basin area relatively quickly. Significant Pb, Cu and Zn maxima can be associated with flood periods. Fortunately, for the period 1986 and 1963, it was possible to find a pattern for these three elements that can be followed along the cross-sections and along the direction of the Tisza River (Figure 6)<sup>10</sup>.

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<sup>10</sup> Braun M., Czébely A., Papp I., Kállai M., Vidra Zs.: Hullámtér feltöltődés vizsgálatok "Vállalkozási szerződés üzemirányítás és monitoring hálózat fejlesztés komplex megvalósítására a KEHOP- 1.4.0-15-2016-00016 projekt keretében", Jelentés, Debrecen, 2018.

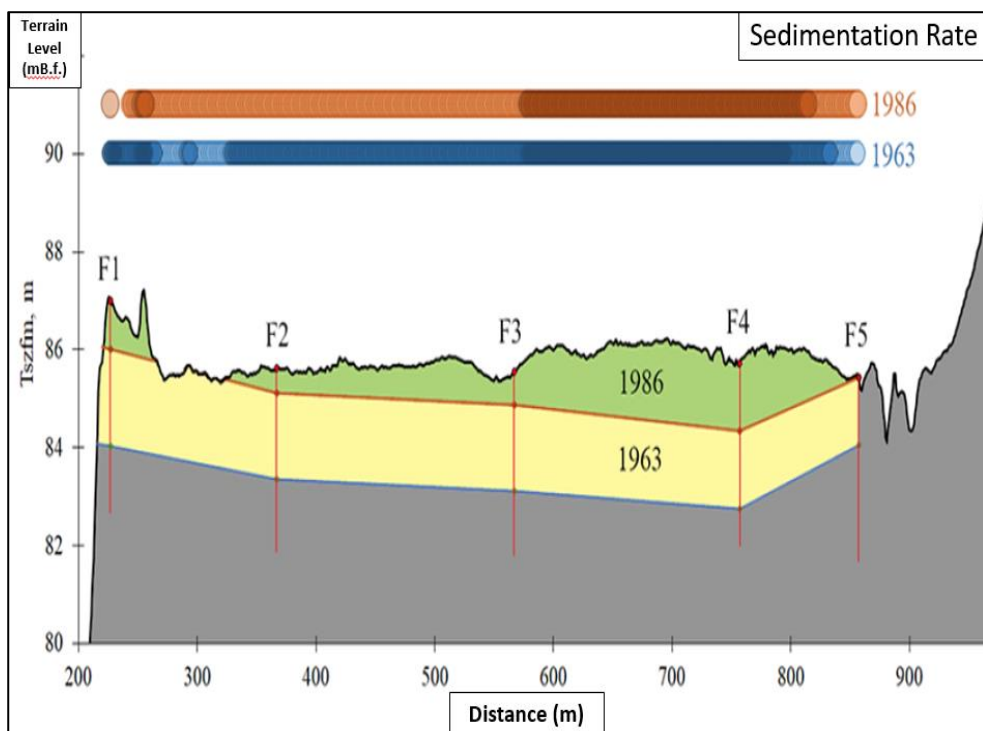


Figure 6. Sediment analysis on the Tisza Floodplain, Tisza, Óballa-Csataszög 357,720 rkm (Source: Braum at al. 2018.)

In the second half of the 19th century, the arable land and the forest expanded in the floodplain areas at the expense of the turf, which provided favorable runoff conditions.

Due to the unfavorable changes that took place after the change of regime (neglected summer dams, landfills near inland canals, abandoned arable land, weeds, bushes, proliferation of invasive plant species, construction of enclosed gardens, construction of buildings, etc.) the flood capacity of the flood way channel (flood bed) was decreased.

The previously agricultural parts of the floodplain still give the impression of a mostly unowned, neglected landscape<sup>11</sup>. (Figure 7).

<sup>11</sup> Vajk Ö.: GIS database of Middle-Tisza, Szolnok, Power Point Presentation, 2013.



*Figure 7. Condition of the Tisza Flood Plain Nowadys (Source: Vajk 2003.)*

## **METHODS FOR CALCULATING OF FLOOD DESIGN WATER LEVEL (DWL)**

The phenomena of floods in the last almost two decades have almost forced a review of the flood design levels in Hungarian rivers, given that the calculated increase in water levels in some sections of the river has exceeded 100-140 centimeters. In the case of the construction in accordance with the regulations of that time - before 2014 - the flood protection dike would not have guaranteed the flood protection safety even with the increase of the extra 1.0-1.5 m. The principle of determining the prevailing flood design water levels is laid down in General Directorate of Water Office (OVH) Presidential College Decree 113 / Coll. / 1974 of 20 December 1974. More than forty years have been passed since then, under this period our observations expanded, the measured time series length got much longer, and our knowledge were extended. In the calculations made in 2014 contained the revised flood design water levels for all river sections in Hungary. The calculations also include the Decree 11/2010 on the significant flood levels of rivers (IV. 28.) on the amendment of Decree 41/2014 of the Ministry of Environment and Water (VIII. 5.) amended data in August 2014.

The calculations were performed as a modernized differently way than before and carried out based on a professionally methodology. 12. The review of DWL with modern hydro informatics methods started in 2012 with the Upper Tisza. 13, It continued with the Danube in 2013 and followed in 2014 by the other river sections of the country. The main purpose of the review is to provide up-to-date data for flood risk management and planning activities, give information about flood bed capacity, flood conveyance.

We use two combine methods, adapting to the different data supply of rivers:

One, analyzing the historical time series of annual maximum water levels using the tools of hydrological statistics, the thresholds with a probability of 1% (NV1%) can be determined by fitting theoretical distribution functions on measured high water levels at the gauge stations.

Adjusting past water levels to trends, we recalculate them to their present value, so we can take account the filling of the floodplain, the embankment of the riverbed, as well as the changes in the hydrometeorological and river basin conditions.

Two fundamentally different sampling and probabilistic calculation methods were used (Figure 8). The first is the sample of the annual maximum water levels and the construction of three-parameter distribution curves approximating the distribution of these data series.

The second is the “intersection method”, above a certain water level (in our case, level I. Degrees water level), samples of independent peaks and generating logarithm functions following the distribution of these data series.

Other main procedure of calculation of DWL, when the DWL is linked to a discharge with a probability of 1% per year (NQ1%) and produced by hydrodynamic modelling of a large number of flood waves induced by synthetic boundary conditions.

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<sup>12</sup> Józsa J. (témavezető), Katona J., Kovács S., Krámer T., Szilágyi J. A mértékadó árvízszintek országos felülvizsgálata - zárójelentés, Budapest, BME, 2014.

<sup>13</sup> Illés L., Dubljak V. D.: A Felső-tiszai határszakasz (Huszt – Dombrád) mértékadó árvízszintjére vonatkozó magyar-ukrán közös szakértői javaslat. Nyíregyháza, 2012.

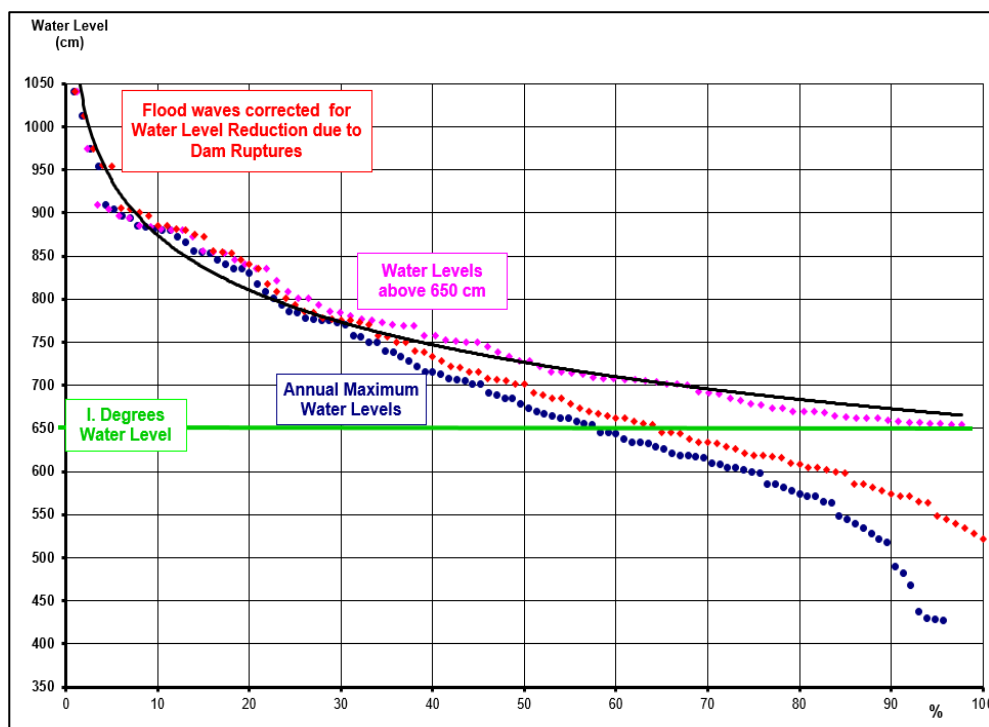


Figure 8. Distribution of the Maximum Water Levels above 650 cm, Tisza-Szolnok (Source: editing by authors)

From the thousands of modelled years, we selected those in which the maximum water flow did not exceed the NQ1% value derived from historical time series. From the maximum water level of the selected years, the new DWL will be designated by the highest from section to section. This also automatically takes into account the coincidence of flood waves on the inflowing rivers, the flattening and the variability of runoff conditions within the section. The second method, based on hydrodynamic modelling, has three main elements:

- The NQ<sub>1%</sub> discharge is determined by hydrological statistical processing of the past discharge data series and the annual maximum discharge data in all discharge registry sections of rivers in Hungary.
- With the hydrological simulation of discharge time series, which are available for us, we produce the time series of the discharge of the dominant tributaries into the incoming boundary sections of the hydrodynamic model for thousands of years at six-hour intervals. Although these time series are artificial, it has statistics observed in the past and make it possible to take into account



the coexistence of flood waves flowing down the tributaries - weighting its probability.

- The development of water levels and discharges of a large number of flood waves excited by artificial time series are calculated using rapid hydrodynamic models along the entire length of the river system, typically at hourly intervals and with a longitudinal resolution of 0.1 to 1 km. By analyzing these numerical results, we determined the longitudinal profile of the highest water levels in the years with a maximum water flow of less than  $NQ_{1\%}$ , that is, the new DWL.

The entry border sections are typically the section of the main gauge stations closest to the country border. The generation of the discharge time series into these profiles is based on the interconnection of a stochastic and a physics-based model<sup>14</sup>. In the stochastic model, we estimate the transient probabilities between the two states (the sign of a water level change in 6 h) for the main river branch. During the rising limb period, Weibull distribution (which is then perturbed by a non-independent random value) then typically lined up for the rising limb period of the flood waves generates daily discharge increases. The falling limbs of the flood waves are described by a nonlinear storage equation.

Hydrodynamic calculations were performed with one-dimensional models describing longitudinal changes. 1D hydrodynamic calculations were performed mainly with the HEC-RAS 1D program. On the Danube, however, the model had to be built in a very short time in order to perform the discharge time series.

Measurements of the last one or two decades have shown that the models are suitable for calculating the peak discharges and water levels of 1% of floods with sufficient accuracy. It meant uncertainty in some rivers (eg Szamos, Drava) that there has not been a reliable flood data (eg Ipoly) approaching this recently, or that the flood course is difficult to model with a 1D model. In establishing DWL, we relied primarily on the longitudinal distribution of past flood water levels and water level statistics in these sections.

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<sup>14</sup> Józsa J. (témavezető), Katona J., Kovács S., Krámer T., Szilágyi J. A mértékadó árvízszintek országos felülvizsgálata - zárójelentés, Budapest, BME, 2014.



## SUMMARY

As a result of human intervention and natural changes, the height and duration of floods are constantly increasing. Climate change can be well observed in all sectors of the human living space, in the increasing load (physics - increase in water pressure, chemical - corrosion) on water management and hydraulic structures. Increasing in the length of flood waves (time duration of floods) and in flood water levels, the old flood protection dikes and the hydraulic structures built into the dikes are under increasing pressure. In our article, we have analyzed in detail the reasons for the increase in flood waves, especially the changes in the flood conveyance capacity of rivers. We examined the growth of the channel bars and the siltation of the floodplain separately. We have briefly described the latest methods for calculating the Flood Design Water level (DWL).

Both field surveys and studies, as well as hydrodynamic and probability theory calculations can a great help in understanding the processes taking place and forecasting these phenomena in time in our watercourses.

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