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Analysis of nature based flood management in the Tisza River Valley, Hungary

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ABSTRACT

The floodplains of the Tisza River, stretching across the eastern part of Hungary, are often affected by riverine and inland excess water flooding and draught. This paper investigates a possible solution to this problem utilizing the water retention capabilities of old floodplains. In this study, the effect of the position of the inlet structures of a floodplain, near Csongrád town, was examined with HEC-RAS 1D-2D coupled model. Based on the results, the rules of the deep floodplain selection were determined. On the extended model, the possibilities of a deep floodplain storage area chain have been explored. According to the estimate, more than 2.36 km³ potential storage capacity is available along the Hungarian section of the Tisza River.

KEYWORDS

deep floodplain, HEC-RAS code, 1D-2D coupled model, flood, water retention, nature-based solution

1. INTRODUCTION

The effects of climate change can be already observed on the Great Hungarian Plain. Groundwater table have been dropped by several meters in the last decades at certain zones [1]. Although the total volume of annual precipitation has not been changed significantly, it has been becoming more variable in space and time. It is well known that the uncertainty of the prognosis generated by climate change forecast models is high. Nevertheless, the forecasts show that the evaporation, the possibility of the flash floods and the droughts will increase and the decreasing recharge of groundwater is foreseeable [2]. The changing climate, making extreme meteorological phenomenon more likely, will most likely strengthen the adverse effects of these phenomena. It is therefore becomes necessary to save available water resources. To achieve this, as a prerequisite, the review of the existing approaches of water management is needed.

The flood waves between 1998 and 2001 generated the highest water levels from year to year without significant growth in measured discharges. A series of flood waves between 1998 and 2001 resulted in increasing flood levels year by year. The ever heightening of the levee's crests is not a sustainable solution. Due to the vast sediment deposition across the flood channels, the further rise of the flood levels is expected. The sedimentation ratio in the Middle-Tisza Section is about 1.1 cm year⁻¹, and in the Lower-Tisza section 0.8 cm year⁻¹ [3, 4].

The solution from the official Hungarian water management was the 'Further Development of Vásárhelyi's Plan' (FDVP) [5]. Pál Vásárhelyi was the designer of the Tisza River regulation. The concept of the FDVP was to build storage areas on the selected deep floodplains and launch a new, integrated water management [5]. Till today not all the planned storage areas have been built, and existing ones are only be used in critical cases to reduce flood peak.

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The aim of the present study was to investigate the opportunities of a nature-based flood management solution in the Tisza River Valley, Hungary. Based on previous investigations, many deep floodplain areas have been identified along the Tisza River. These areas were formerly integrated parts of the Tisza River's floodplain. Since the river regulation works and levee constructions of the 19th century, the deep floodplains have been cut from the river by the flood levees and the direct hydraulic contact with the river has been lost. It seems to be logical that recovered and reattached deep floodplains can be used as storage areas [6–8]. To reach this, there is no need for the destruction of the dikes. The construction of sluice gates could provide the connection between the storage area and the river. The inflow and the outflow can be securely managed. The formerly approximated total capacity of the storage areas is 2.5 cubic kilometer [9]. A more precise estimation is given in this paper. This nature-based solution offers multiple positive effects: on one hand, the flood risk mitigation, while on the other, it can be an effective tool to mitigate drought and excess water flood risk. The feasibility is caused by the peculiarity of the Tisza Valley. As it is pointed out in the National Water Strategy ('Jenő Kvassay Plan') [10], while in the upper section of the Tisza Valley, riverine and excess water flood risk are more common, in the lower section, all three risk factors occur together. The essential of the deep floodplain storage method is the 'calm' water withdrawal. The filling of the reservoirs goes on simultaneously with the rising water level in the river channel. The sluice gates close when the water reaches the allowable level in the reservoir. Thus, water flows do not damage the vegetation [11].

The previous phase of the research showed that natural deep floodplains may function properly as a flood risk mitigation system in a different way than the flood peak reduction method [12]. The goal in the current phase is to examine the effect of the position of flood control structures on the flood levels and identify the possible areas for the deep floodplain storage system. Utilizing deep floodplain storage capacity is only the first step in a new planned, integrated, nature-based water management strategy subject to research. The further functions of the reservoirs are reducing the risk of flooding, act as Managed Aquifer Recharge (MAR) areas and supply storage water background reservoirs far from the river. The precondition of implementation of aforesaid elements in the current water management is the changes of the land-use on the affected areas. The prevailing land-use nowadays on these areas are crop fields. As natural reservoirs, grasslands, wetlands, pastures, and floodplain forests are the recommended land uses. With this land-use change, drought and inland excess water risk can be mitigated. Furthermore, restoring the water-related ecosystem can increase biodiversity, which has a positive impact on ecosystem services. As a MAR tool, the trend-like decline in the groundwater level is expected to slow down, moreover, the groundwater level is expected to increase. Approximation of these effects will be the topic of the next research phase, however, based on previous research, positive effects are expected [13–15].

2. METHODOLOGY

According to a previous comprehensive analysis [12], flood risk could be efficiently mitigated on deep floodplains, which was regularly covered by water before the river regulation works. The aim is to analyze the effect of the position of the inlet structures and identify further deep floodplain areas suitable for flood mitigation, preparing the model to the next research phase.

The following data and information were available for our investigations:

- 25 × 25 m cells Digital Elevation Model (DEM) for Hungary, Google Maps;
- Cross section data of the Tisza River along the Hungarian longitudinal section;
- Time series of the floods between 1998–2001;
- Data about the structure and the operating rules of Tiszalök and Kisköre hydropower plants;
- Historical map database [16] and historical ethnographical and land use descriptions [17, 18].

As a first step a comprehensive comparative study was carried out analyzing the possible technical solutions. The combined 1D/2D model has two parts. The 1D Saint-Venant equations were used for the Tisza River. The detailed examination of the inundation process on storage area was carried out with the 2D solver that gives the Diffusive wave approximation of the Shallow Water (DSW) equations using the Reynolds-Averaged Navier-Stokes equation (RANS). The connection between these model components were provided by a sluice gate [19]. For optimization of the reservoir operation the 2D model was replaced by a simplified 0D storage model, which results in targeted operation of the sluices. Based on the DEM an elevation-volume curve was used to describe the reservoir storage capacity [20]. In the frame of the first simulations it was assumed there will be a two-structure system. An inlet structure on the upstream site and one outlet structure nearby the downstream site on a deeper point were assumed. The operation regime of these structures is equivalent to the current reservoir operation of that of the FDVP reservoirs. In the second case, based on the descriptions of the historical land use, just one multifunctional structure was used nearby the floodplain embankment on the deepest point. This alternative was used to provide a simulation of the ancient traditional floodplain management methodology. The essential of this approach is filling up the floodplain from the deepest point because it results a moderate inundation velocity and the sedimentation will happen on the deepest point. Meanwhile the drainage of the storage the outflow will work against the sedimentation. With the help of this approach the decrease of the maintenance work was targeted [11, 17].

In the first phase, the 1D Tisza River model was applied between Kisköre hydropower plant the river mouth at the Danube, south of Titel. For the calibration procedure the river discharge/stage data of year 1999 was used, while river



data of 2000 have been used for validation purpose. After the hydrodynamic simulations, the model was extended for the whole country. That means, the model's new upstream boundary is at Tiszabecs, where the Tisza River enters Hungary. With using the US Army Corps of Engineers Hydrologic Engineering Center River Analysis System's (HEC-RAS) mapper module, the morphological model of the riverbed was exported using linear interpolation. The Tisza River's bed data were integrated into the DEM using a separate Geographic Information System (GIS) software. The DEM covers the area of Hungary, therefore where the Tisza River separates Hungary from the neighboring countries, the river bed data was missing. Based on the Google maps, the satellite pictures, and the original cross section data the missing parts were replaced with a synthesized triangulated network. Thereafter the 1D schematic for the extended Tisza model was drawn. The cross sections with the new composite terrain data was inspected and overwritten. Based on the new model layout, potential deep floodplain reservoirs have been explored. Existing FDVP storages were also taken into consideration. The Bodrogzug area act like a reservoir, therefore it has been built into the model as a storage area, with open connection to the river. It is an important part of the Tisza River Valley, but it is not a part of the deep floodplain reservoir system, because the inflows and outflows are uncontrolled.

The rules for selecting the floodplains were the following:

- The permissible normal water level by operation can cause 1.5–2 m deep average inundation;
- By this average depth, the storage capacity must be greater than 20 million m^3 ;
- The boundary edge of the reservoir follows the alignment of the existing infrastructures, estate borders or the high banks;
- If the reservoir area overlaps with villages or bigger farm complexes, the affected area will be protected with ring levee where it is necessary;
- The multifunctional structure can be used.

3. MODEL ANALYSIS AND CALCULATION RESULTS

3.1. The effects of the structure position

The study area is located on the right side of the Tisza River, south of Csongrád, east of Felgyő. The elevation versus volume relationship gives the storage capacity curve shown in Fig. 1. Based on the selection rules of the deep floodplains, the allowable normal water level is 81 Meters Above Sea Level (MASL). For that level, the capacity of the reservoir is 51.43 million m^3 .

The structure for the outflow control in both cases was a 2×10 m wide sluice gate, with the bottom sill on 78.1 MASL. The operation inundation level was at 81 MASL. For the 2D inundation mapping, the sluice gate opening time series for the calibration flood of year 2000 were used. The

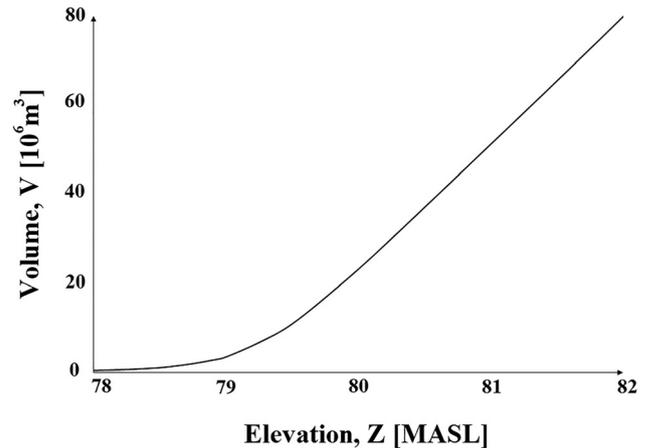


Fig. 1. Reservoir capacity curve

different approach of the 0D and 2D simulation can cause differences in the emerging water levels. First, the inundation spreads from the northeasterly part of the deep floodplain. The maximal water surface was 80.90 MASL in this case. The arrival time in the upper quarter of the storage area was under 12 h. The inundation propagation is strongly influenced by the existing drainage or irrigation canals. After 24 h approximately the half of the studied area was flooded. It took a little over 96 h to reach the allowable water level, but after 48 h the whole area is under water-cover. The results can be studied in Fig. 2. The maximal discharge of the sluice gate was $198.95 \text{ m}^3 \text{ s}^{-1}$. At the water gauge near Szeged town, the maximal mitigation of the flood level was 12 cm peaking on 03/17/2000.

In the second case, a multifunctional structure was examined, positioned to the deepest point nearby the floodplain dike. The reached maximal water level was 80.95 MASL. In the first 24 h the deeper trenches were inundated,

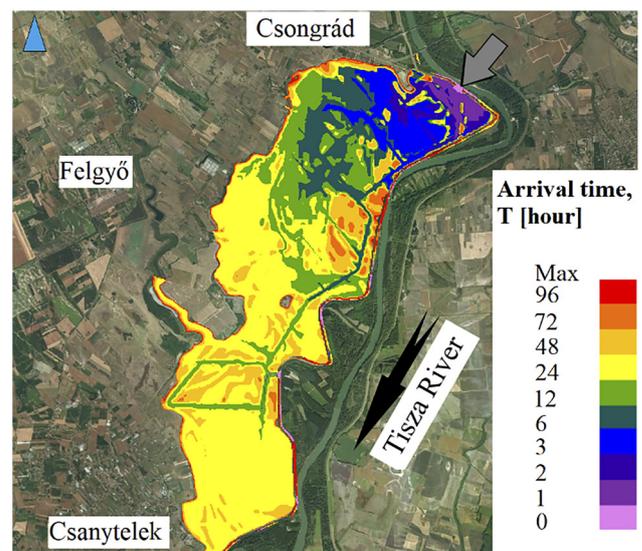
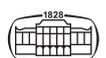


Fig. 2. Arrival time with two structure system, inflow from the northeasterly part



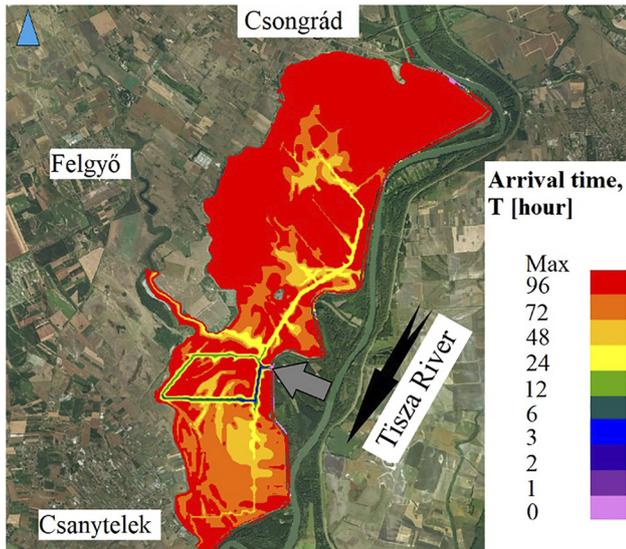


Fig. 3. Arrival time with multifunctional structure system, inflow by the deepest point nearby the embankment

then in the next 24 h the upper trenches. After filling the canals and the nearby deeper plains, it took more than 180 h to flood the entire storage area (see Fig. 3). This means 3.5 days more charging time than the first version. The maximal measurable effect on the Szeged water gauge was 13 cm on 03/17/2000. The maximal discharge on the sluice gate was $153.30 \text{ m}^3 \text{ s}^{-1}$.

Although the charging time is almost double of the two-structure system, from the viewpoint of the eco-friendly inundation the one multifunctional structure system is preferable. The highest velocity occurs in the existing canals. The prevailing practice of water management drains out the deep floodplains on the deepest points to handle the groundwater flood. The advantage of a system similar to the traditional one is that, in theory, the existing drainage channels can be used as multifunctional channels. Furthermore, investment and operating costs can be reduced if only one structure is built.

The arrival times described above do not include the time needed to empty the reservoirs and the retention time.

Table 1. Deep floodplain storage areas in the Tisza River Valley

ID	Name	RKM	Area [km ²]	Max. level [MASL]	Volume [10 ⁶ m ³]
001	Milota	731+100	23.05	118.00	61.83
002	Beregi VTT	706+850	58.63	109.20	32.82
003	Kisar	690+000	75.95	110.80	65.94
004	Gergelyugornya	680+740	39.96	109.40	61.90
005	Cigánd VTT	597+700	25.28	97.80	57.79
006	Dombrád	569+000	163.85	95.80	88.79
007	Tiszakarád	566+400	40.33	96.20	65.30
008	Tiszaladány	512+000	58.64	94.60	60.95
009	Taktakenéz	503+500	27.87	93.70	38.54
010	Tiszalúc	493+500	38.55	94.40	73.76
011	Tiszagyulaháza	488+000	55.24	92.00	42.07
012	Polgár	468+400	25.87	91.90	35.09
013	Tiszacsege	457+000	54.36	90.90	48.59
014	Tiszadorogma	442+000	203.79	90.50	67.45
015	Tiszafüred	434+300	71.31	89.15	65.62
016	Sarud	414+000	26.22	89.50	57.72
017	Tiszaderzs	411+700	68.28	88.60	138.83
018	Tiszanána	404+500	66.54	88.65	98.70
019	Nagykunsági VTT	400+600	40.34	88.00	91.95
020	Tiszaroff sample	391+000	5.58	86.00	7.31
021	Hanyi-Tiszasülyi VTT	388+900	55.73	86.00	27.80
022	Tiszaroffi VTT	370+100	23.37	87.50	45.63
023	Nagykörű	354+300	49.24	85.60	42.16
024	Tiszabó	362+000	31.28	87.50	87.12
025	Tiszapüspöki	351+400	68.01	87.50	197.76
026	Tószeg	321+500	44.62	87.70	35.31
027	Tiszaföldvár	294+500	45.26	83.80	58.46
028	Tizakécske	275+500	29.55	83.50	51.26
029	Tiszasas	249+600	73.64	82.50	126.47
030	Szentes	238+000	70.39	81.50	62.71
031	Csongrád	228+800	29.91	81.00	51.43
032	Mindszent	218+000	57.35	79.70	31.52
033	Ópusztaszer	204+700	70.90	79.60	85.15
034	Dóc	196+700	49.07	79.50	71.30
035	Mártély	204+000	20.30	81.00	31.97
036	Hódmezővásárhely	183+700	158.30	78.50	93.76
	Sum				2,360.75

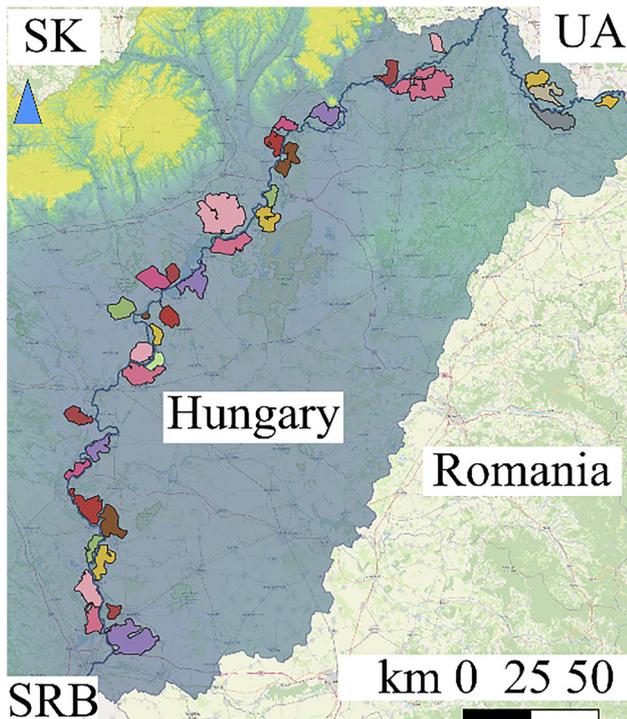


Fig. 4. Deep floodplain storage areas in the Tisza River Valley

The required hydraulic retention time depends on the specific flood wave and the intended use of the stored water. Theoretically, implementing reservoir elements of the complex system, from the deep floodplains the water flows further away and will be used firstly to aquifer recharge. From certain storage areas gravity transfer is not possible a part of the stored water flows back to the river, another part seeps into the soil and/or evaporates.

3.2. Review of the potential deep floodplain reservoirs

The hydraulic analysis showed that the integrated multifunctional structure design is a technically appropriate solution. Keeping in mind the rules of reservoir designation and striving for a multifunctional structure design, a total of 36 deep floodplain areas were explored. Six from that is an existing FDVP reservoir. To keep model uniformity, the official data of the FDVP storages were not used. All the elevation versus volume curves were generated using the composite DEM data generated for this study. The selected storage areas meet the requirements, except the storage area N^o020. That is a possible sample area for the future field experiments. It is located north of Tiszaroff town. On the historical land use maps the name of this area is ‘Tó lapos’ in Hungarian, which means plain lake or shallow lake. The potential deep floodplain storage areas of the Tisza Valley are summarized in Table 1.

In Table 1, the reservoirs are listed from upstream to downstream. The positions of these storage areas are illustrated in Fig. 4. The sum of the selected area is 2,046.56 km². The total storage capacity is 2.36 km³. This is 1.48 times larger than Hungary’s largest lake, Lake Balaton (approximately 1.9 km³).

4. DISCUSSION AND CONCLUSION

The analysis performed in the present study proved that both examined systems for the deep floodplain storage method, the separated inlet and outlet structure system and the multifunctional integrated structure system are suitable solution for the reservoir operation. The essential of the method has been validated, ergo the water withdrawal started in the beginning of the flood. The water level in the reservoir changed gradually, water fluxes did not exceed 200 m³ s⁻¹. Moreover, with the multifunctional structure it was under 160 m³ s⁻¹. The maxima of the flood level mitigation at the Szeged water gauge were quasi the same. The one structure system is also advocated by the presumably higher cost efficiency.

The model of the Tisza River was extended to the upstream end of the Hungarian river section at Tiszabecs. For that the digital elevation model was further developed, which provided an opportunity to analyze all the possible locations of deep floodplains. With the use of the selection rules and results of previous research, 36 potential deep floodplain storage areas were explored. The sum volume of these reservoirs is 2.36 km³. It is noteworthy that this capacity is not an exact number. It depends on the applied boundaries of the storage areas and the allowable normal water level. That can be the explanation of the differences in results between this research and the previous works.

The former work pointed out that the deep floodplain storage method can be a nature-based alternative solution for the flood, drought, and inland excess water flood risk mitigation but only in a storage chain system. This paper has shown that the necessary storage capacities are available in the Tisza Valley. The next goal is the optimization of the deep floodplain storage chain operation, after the calibration and validation of the extended Tisza model.

REFERENCES

- [1] G. Mezösi, “Physical geography of the great Hungarian plain,” in *The Physical Geography of Hungary*. Geography of the Physical Environment, Springer, 2017, pp. 195–229.
- [2] B. Nováky, “Climate change and its effects” (in Hungarian), in *Hungary’s Water Management: Situation and Strategic Plans* (in Hungarian). L. Somlyódy, Ed., Budapest: Hungarian Academy of Sciences, 2011, pp. 85–102.
- [3] F. Schweitzer, I. Nagy, and L. Alföldi, “Relationship between the formation of point bars and natural levees and flood bed sedimentation along the middle stretches of Tisza River” (in Hungarian), *Földrajzi Értesítő*, vol. 51, no. 3–4, pp. 257–278, 2002.
- [4] F. Schweitzer, “Decision-making constraint in the Hungarian flood management” (in Hungarian), in *Studies from the Fields of Geomorphology, Geochronology, Hydrography and Mars-research* (in Hungarian). F. Schweitzer, Ed., Budapest: MTA CSFK Földrajztudományi Intézet, 2017, pp. 103–135.



- [5] Concept of integrated territorial development, rural development and environmental development on the areas along the Tisza River (in Hungarian), VÁTI Hungarian Public Nonprofit Company for Regional Development and Town Planning, Budapest, 2004. [Online]. Available: http://www.terport.hu/webfm_send/87. Accessed: May 27, 2021.
- [6] L. Koncsos, "Flood regulation of the Tisza in the Carpathian Basin" (in Hungarian), Magyar Természettudós Szövetsége, Budapest, pp. 4–31, 2006.
- [7] Z. Derts and L. Koncsos, "Ecosystem services and land use zonation in the Hungarian Tisza deep floodplains," *Pollack Period.*, vol. 7, no. 3, pp. 79–90, 2012.
- [8] Z. Derts, L. Koncsos, and Z. Simonffy, "The flood protection situation of the Tisza in Hungary: current practice and alternative possibilities," (in Hungarian), World Wide Fund for Nature – Under review, Budapest, 2018.
- [9] Z. Derts and L. Koncsos, "Flood risk mitigation in the Tisza Valley by deep floodplain reservoirs: The effect on the land use," *J. Environ. Sci. Eng. B1*, pp. 34–40, 2012.
- [10] National Water Strategy – Jenő Kvassay Plan (in Hungarian), General Directorate of Water Management, Budapest, 2017. [Online]. Available: <https://www.vizugy.hu/vizstrategia/documents/997966DE-9F6F-4624-91C5-3336153778D9/Nemzeti-Vizstrategia.pdf>. Accessed: May 27, 2021.
- [11] G. Gábris, G. Timár, A. Somhegyi, and I. Nagy, "Flood storage or floodplain management along the Tisza" (in Hungarian), in *2nd Hungarian Geographical Conference* (in Hungarian), Szeged, Hungary, Sep. 4–5, 2004, pp. 1–18.
- [12] G. Murányi and L. Koncsos, "Examination of a nature-based flood control solution in the Tisza River Valley nearby Csongrád town with HEC-RAS 1D-2D coupled model" (in Hungarian), *Hidrológiai Közlemény* - under review, 2021.
- [13] J. V. Ward, K. Tockner, U. Uehlinger, and F. Malard, "Understanding natural patterns and processes in river corridors as the basis for effective river restoration," *Regulated Rivers: Res. Manage.*, vol. 17, no. 6, pp. 311–323, 2001.
- [14] K. Tockner and J. A. Stanford, "Riverine flood plains: present state and future trends," *Environ. Conserv.*, vol. 29, no. 3, pp. 308–330, 2002.
- [15] L. Koncsos and E. Balogh, "A simulation-optimization methodology for designing the operation of emergency reservoirs in the Hungarian Tisza basin," *Period. Polytech. Civil Eng.*, vol. 54, no. 2, pp. 101–106, 2010.
- [16] G. Timár, G. Molnár, B. Székely, S. Biszak, J. Varga, and A. Jankó, Digitized maps of the Habsburg Empire – the map sheets of the second military survey and their georeferenced version, Arcanum (Budapest), 2006. [Online]. Available: <https://maps.arcanum.com/en/>. Accessed: May 27, 2021.
- [17] B. Andrásfalvy, "Ancient floodplain management and water uses of Sárköz and the surrounding Danube areas before regulation" (in Hungarian), Vízügyi Dokumentációs és Tájékoztató Iroda, Budapest, 1973.
- [18] G. Molnár, "Floodplain management - the basis of economic and political continuity in the Carpathian Basin, part. I - part IX," (in Hungarian), *Országépítő*, vol. 1991, no. 2, pp. 30–34, 1991 – 1994; no. 3, pp. 38–47; no. 4, pp. 30–38; vol. 1992, no. 1, pp. 36–46; no. 3–4, pp. 69–78; vol. 1993, no. 3, pp. 52–61; no. 4, pp. 50–56; vol. 1994, no. 1, pp. 28–34.
- [19] G. W. Brunner, "HEC-RAS river analysis system user's manual, Version 5.0," US Army Corps of Engineers Institute of Water Resources Hydrologic Engineering Center, Davis, CA, USA, 2016.
- [20] G. W. Brunner, "HEC-RAS river analysis system hydraulic reference manual," US Army Corps of Engineers Hydrologic Engineering Center, Davis, CA, USA, 2016.

