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MŰSZAKI
KATONAI
KÖZLÖNY

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The Incision of the Riverbed on the Upper Hungarian Danube and the Rába, in the Region of the Confluence of the Moson-Danube

The phenomenon of bed subsidence on our channelised rivers is a well-known fact for a long time. In the upper reach of the Danube in Hungary, this process seems to have accelerated in recent decades due to the construction of hydroelectric power plants on the German, Austrian and Slovak sections of the river and other anthropogenic effects. As a result, similar processes are also present in the lower reach of the Moson-Danube and Rába rivers, which are hydromorphologically significantly influenced by the Danube. In our study, we quantify the magnitude and temporal changes of this phenomenon by examining the hydrological time series of the Danube between the gauging stations of Dévény and Komárom and of the Rába between Sárvár and Győr. We estimate its impact on floods, navigation and the safety of drinking water resources.

Keywords: *hydrology, hydromorphology, trend analysis, flood protection, navigation, river basin, Danube, Rába, riverbed incision*

Introduction

Since the end of the 19th century the Danube River, especially on its Bavarian and Alpine region is affected by several anthropogenic effects causing morphological changes in the riverbed.[4] There are two main reasons for the high levels of bed erosion in the river. On the one hand, the long-term impact of river channelisation and river regulation works throughout the catchment

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4 Pessenlehner et al. 2016.

in the German and Austrian parts of the river basin, where river regulation began in the 18th and 19th centuries. Most of the hydraulic structures were built in the German and Austrian reach and these have the greatest impact on the river.[5] In the whole river basin upstream Komárom, the continuity of the flow is interrupted by 1,688 hydraulic structures, of which 600 are reservoir dams. The first hydropower plants were built in the 1890s on the smaller tributaries. On the main branch of the Danube the first hydroelectric power station was built in 1927 (Kachlet–Passau) and the most recent in 1996 (Freudenau). There are 22 hydroelectric power plants on the main branch in Germany, 9 in Austria and 1 in Slovakia. The total length of the impoundment-affected sections is approximately 290 km.[6] As it is shown in Figure 1, in the second half of the 20th century practically the entire catchment of the upper Danube is installed by an uninterrupted chain of hydropower plants. Furthermore longitudinal river regulation works were done due to navigational requirements, since the Danube River is part of the Pan-European Transport Corridor VII.[7]

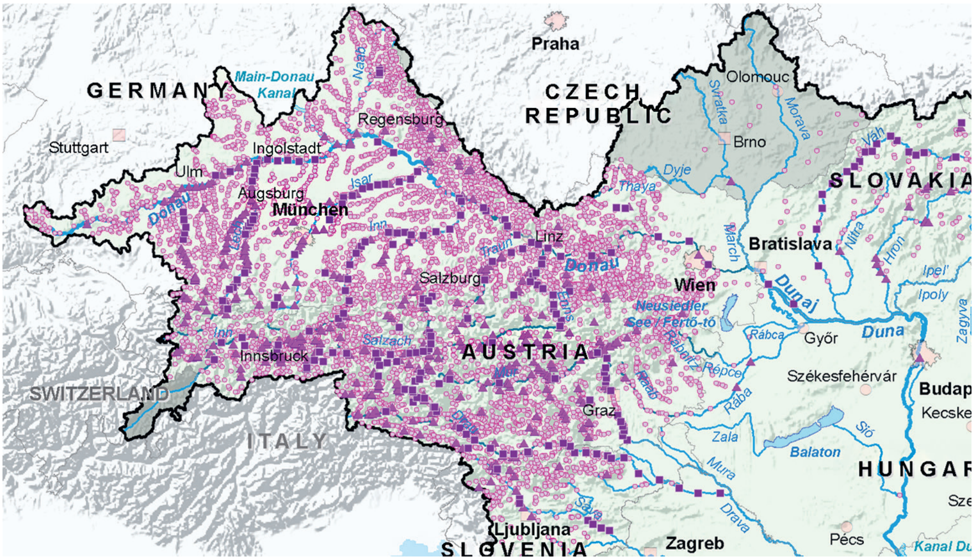

Figure 1: Hydraulic structures on the Danube and its tributaries
Source: ICPDR 2009

5 Vadas 2013: 267–286.
6 General Directorate of Water Management (OVF) 2021.
7 Pessenlehner et al. 2016.

On the other hand, there was another effect that had an almost immediate impact on the riverbed erosion on the Hungarian upper section of the river. The riverbed incision on this section was caused by the intensive dredging activities of the 1970s and 1980s.[8] At that time, the volume of this dredging significantly exceeded the needs of river regulation, largely to meet the mineral requirements of the construction industry.[9] The integrated effect of these circumstances caused a severe sediment deficit by changing the slope and thus the sediment transport capacity of the river by directly removing large amounts of sediment.

These hydromorphologically harmful processes caused similar phenomena in the estuary reach of the Moson-Danube and Rába too by threatening the drinking water resources, navigation and the cityscape of Győr. In this paper by using hydrological statistics methods we took a quantitative evaluation onto the magnitude of this effect.

Materials and methods

Description of the Danube River Basin upstream Komárom

The evolution of Europe's present-day river network is determined by the main European watershed between the Atlantic Ocean and the Ural Mountains, which runs approximately NW to NE. The areas to the north of the basin are flowing into the Atlantic Ocean or the Arctic Ocean and their inland seas, while the areas to the south of the basin are flowing into the Mediterranean or the Black Sea or the Caspian Sea. The Danube is the most important river in the southern basin following the Volga. It ranks 20th in length and 25th in catchment area among the world's rivers.[10]

The Danube conveys the waters of the southern part of central Europe into the Black Sea. The entire length of the Danube can be segmented into three characteristic reaches. Each receives the waters of some large basins: the Upper Danube, the Bavarian and the Austrian Basin, the Middle Danube the Carpathian Basin, the Lower Danube collects the waters of Wallachia, the Romanian Plain. The first two sections are separated by the Devín Gate while the Iron Gate separates the latter two. The total catchment area of the Danube River is 801,463 km^2, its entire length is 2,778 km (from the confluence of the Breg and Brigach) and its average estuary discharge is 6,550 m^3/s.[11] The entire river basin of the Danube is shown in Figure 1.

8 EDUVIZIG 2014.
9 Károlyi 1979.
10 CIA 2023.
11 Almazov et al. 1963; Stancik et al. 1988.

Figure 2: The entire river basin of the Danube
Source: Geology Page 2014

Study area

Our examination reach begins at Devín (Dévény in Hungarian), where the Danube leaves the Viennese Basin and crosses the border between the Alps and the Carpathians before leaving Bratislava and entering the Hungarian region, Kisalföld. Here it flows over a large alluvial fan, this reach of the Danube is known as "Upper Danube" in Hungary. From Bratislava to Szap, the river has a surface slope of 35–40 cm/km, and below Komárom only 8–10 cm/km.[12] As a result of the decreasing slope, the river deposits a significant part of its sediment.

The reach analysed in our study extends from the gauging station of Devín (1,875 rkm) to the gauging station (GS) of Komárom (1,768.30 rkm).[13] The catchment area of the Komárom GS is 150,820 km^2. The multi-annual mean discharge increases from 1,850 m^3/s to 2,100 m^3/s along this reach.[14] The monthly averages of the discharges at Komárom over the last 30 years are shown in Figure 2.

[12] National Atlas of Hungary 2018: 72.
[13] General Directorate of Water Management (OVF) 2019.
[14] General Directorate of Water Management (OVF) 2023.

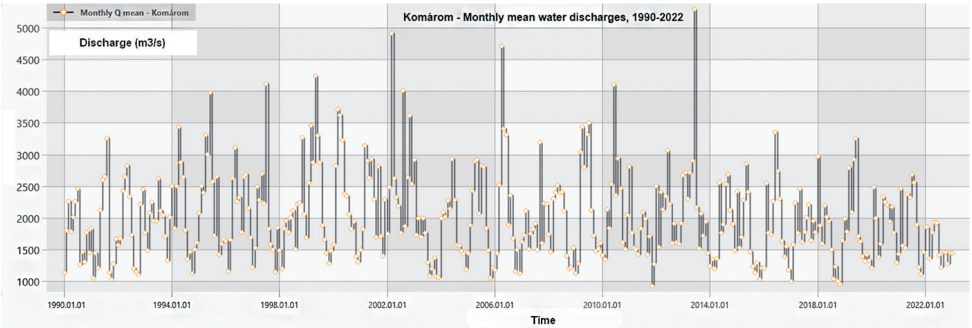

Figure 3: Discharge time series, Danube, Komárom GS
Source: General Directorate of Water Management (OVF) 2023

The Rába River is one of the most significant tributaries of the Danube in Hungary. Its origin is in Styria province of Austria, in the Fischbach Alps, at an altitude of around 1,200 m above sea level, from two branches. It crosses the Austrian–Hungarian border at Szentgotthárd, flows across the Kisalföld region of Hungary, and reaches its receiving river Moson-Danube in the city of Győr. The total length of the river is 283 km, and its reach in Hungary is 211.5 km. The catchment area is 10,270 km^2.[15]

In our study we evaluate the hydrological time series on the downstream/lowland part of the river, from Sárvár to Győr, where the Rába reaches its recipient, Moson-Danube. On this reach of the river the long-term average discharge is around 30 m^3/s, at Árpás GS.[16] This stations' monthly average discharge time series is shown in Figure 3. Figure 4 shows the position of the evaluated gauging stations.

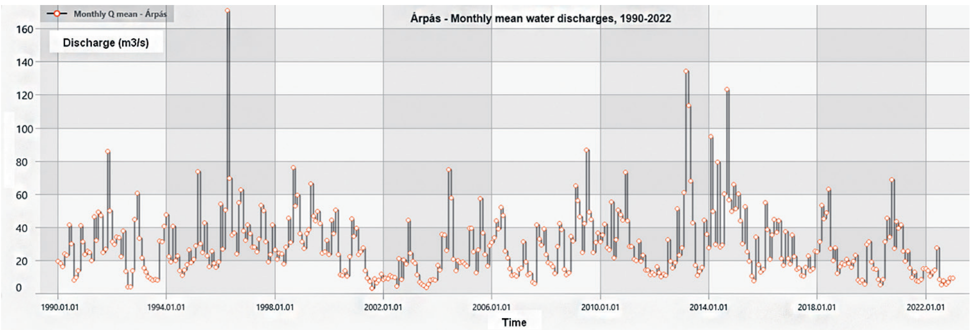

Figure 4: Discharge time series, Rába, Árpás GS
Source: General Directorate of Water Management (OVF) 2023

15 West-Transdanubian Water Directorate (NYUDUVIZIG) 2007.
16 General Directorate of Water Management (OVF) 2023.

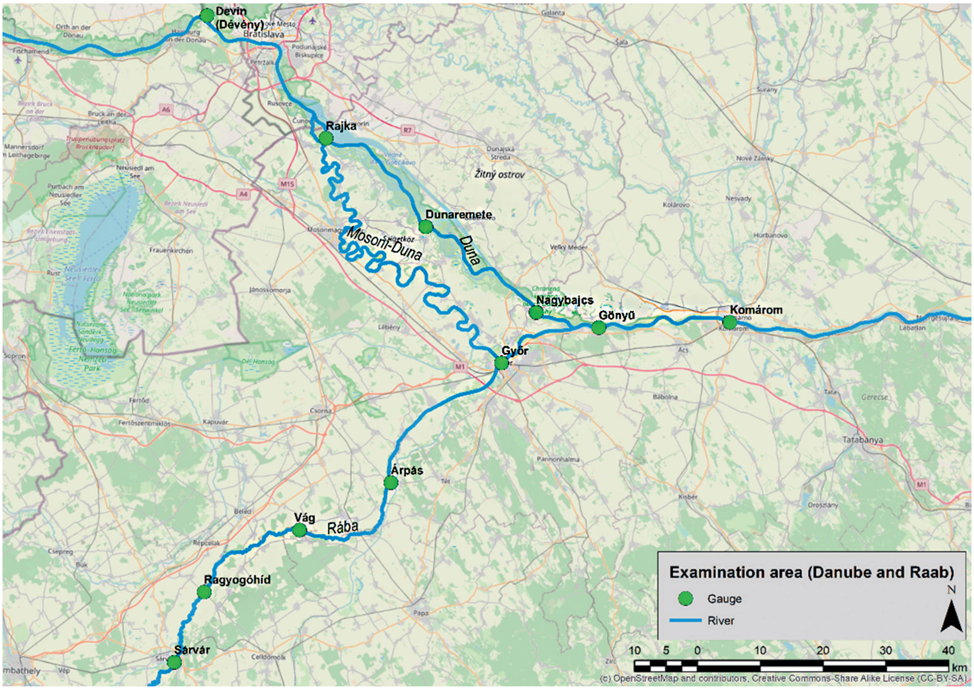

Figure 5: Overview map of the examination area
Source: ÉDUVIZIG 2023

Methods

Linear trend estimation

To estimate the effect of the riverbed incision, long-term water level and discharge time series were evaluated by using linear trend estimation based on the principle of least squares.

Principle of least squares: the function describing the relationship between the variables and its parameters are defined so that the sum of the squares of the differences between the measured dependent variable values and the values calculated by substituting the same independent variable from the relationship is minimal. In the simplest case the equation of a line is fitted to a point cloud.[17]

The equation of a line is:

$$y = a + b * x$$

Based on the principle of least squares, the most probable values of the parameters are: the minima of the sum of the squares of the deviations of the dependent variable calculated from the function and the measured variable.

[17] Hüse 2001.

$$Q = \sum_{j=1}^{n} (y_j - f(x_j))^2 = \sum_{j=1}^{n} (y_j - a - bx_j)^2 = min.$$

In the equation we consider the parameters of the function (a, b) variable, and the measured value pairs xj and yj are fixed. The condition of minima:

$$\frac{\partial Q}{\partial b} = 0; \qquad \frac{\partial Q}{\partial b} = \sum_{j=1}^{n} -2(y_j - a - bx_j)x_j = 0$$

$$\frac{\partial Q}{\partial a} = 0; \qquad \frac{\partial Q}{\partial a} = \sum_{j=1}^{n} -2(y_j - a - bx_j) = 0$$

these equations ordered and simplified are the following:

$$\sum_{j=1}^{n} x_j y_j = b \sum_{j=1}^{n} x_j^2 + a \sum_{j=1}^{n} x_j$$

$$\sum_{j=1}^{n} y_j = an + b \sum_{j=1}^{n} x_j$$

In these form the 'a' and 'b' parameters can be determined directly:

$$b = \frac{n \sum_{j=1}^{n} x_j y_j - \sum_{j=1}^{n} x_j \sum_{j=1}^{n} y_j}{n \sum_{j=1}^{n} x_j^2 - \left(\sum_{j=1}^{n} x_j\right)^2} = \frac{\overline{x * y} - \overline{x} * \overline{y}}{\overline{x^2} - \overline{x}^2}$$

$$a = \frac{\sum_{j=1}^{n} y_j - b \sum_{j=1}^{n} x_j}{n} = \overline{y} - b * \overline{x}$$

The difference between the value pairs x_j and y_j and the y values calculated from the calculated equation of the line defined by the parameters a and b is called the residue. Based on this, the residual standard deviation can be calculated with the following formula:

$$S_{res}^{*2} = \frac{\sum_{j=1}^{n} \left[\left(y_j - a - bx_j\right)^2\right]}{n-2} = \frac{\sum_{j=1}^{n} \left(\Delta y_j\right)^2}{n-2}$$

where $\sum_{j=1}^{n} \left(\Delta y_j\right)^2$ is the sum of the squares of the deviation. This quantity is the fit standard deviation and it describes the regression fit. The residual standard deviation defines a confidence interval around the regression line in both directions, which can be used to examine the quality of the fit. By using the equation of line, the standard deviation of the 'b' parameter (the slope of line) can also be determined:

$$S_b = \frac{S_{res}^*}{S_x \sqrt{n}} = \frac{S_{res}^*}{\sqrt{\sum^n (x_j - \bar{x})^2}}$$

$$S_x = \sqrt{\frac{\sum_{j=1}^{n} (x_j - \bar{x})^2}{n}}$$

The confidence interval is the following:
$b \pm t_Q * S_b$

where
t_Q is the probability value of the distribution 't' with probability 'Q', so it can be stated with probability 1-Q, that the true value of parameter 'b' is within this interval.[18]

Kolmogorov–Smirnov homogeneity test

A homogeneity test is an examination of the approximation of the empirical distribution and the theoretical distribution of time series, measuring the degree of approximation (tightness, adequacy, goodness). For the purpose of the homogeneity test, the so-called Smirnov–Kolmogorov test was used. In the case of the Smirnov–Kolmogorov test, the probability of fit is calculated from the largest difference between the empirical and theoretical distribution function (d_{max} – in absolute value). The method uses the condition that parts of the data set have the same distribution as the entire data set. Therefore, the data set is divided into k and l samples (at the assumed inhomogeneity point – no measurement, break, or jump in the time series figure).[19]

Results

Riverbed erosion/incision on the Danube and Rába Rivers in the region

The integrated effect of the above mentioned phenomena can be shown via the analyses of historical water level and water discharge time series. The long-term water level trend analysis of Gönyű GS is shown in Figure 5, for the yearly water level minima, maxima and means.

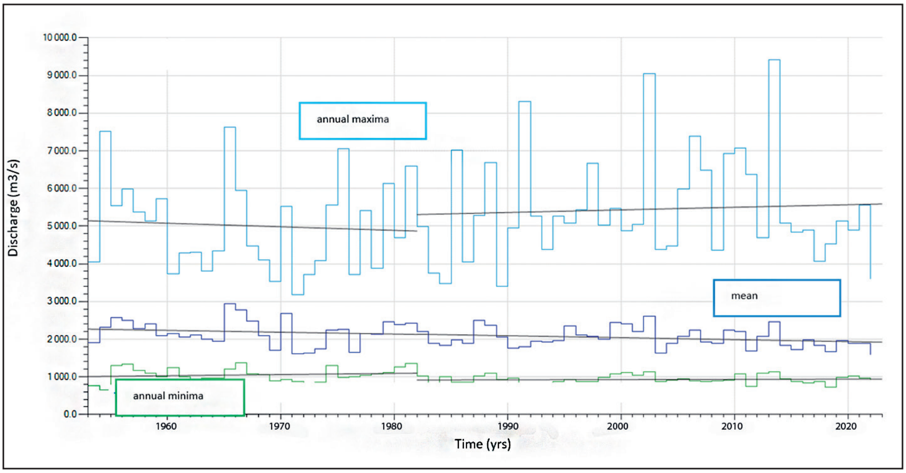

Figure 6: Water level trend analysis, Gönyű GS, 1953–2022
Source: ÉDUVIZIG 2023

18 Hüse 2001.
19 4iG Nyrt. 2015.

This phenomenon can be clearly observed in the annual minimum and mean water levels of the Gönyű GS by the negative slope of the linear trend line.

The effect of industrial dredging on the low and medium water levels can be illustrated by dividing the trend line into two parts. It can be seen that water levels decreased in a concentrated way over a few years in the early 1980s, due to the artificial deepening of the riverbed.

Meanwhile, there is no significant decreasing trend in annual minimum and average water discharges. These graphs for Komárom GS are shown in Figure 6.

As a result, it is safe to consider that there are morphological reasons of the decreasing water level, i.e. the incision of the riverbed.

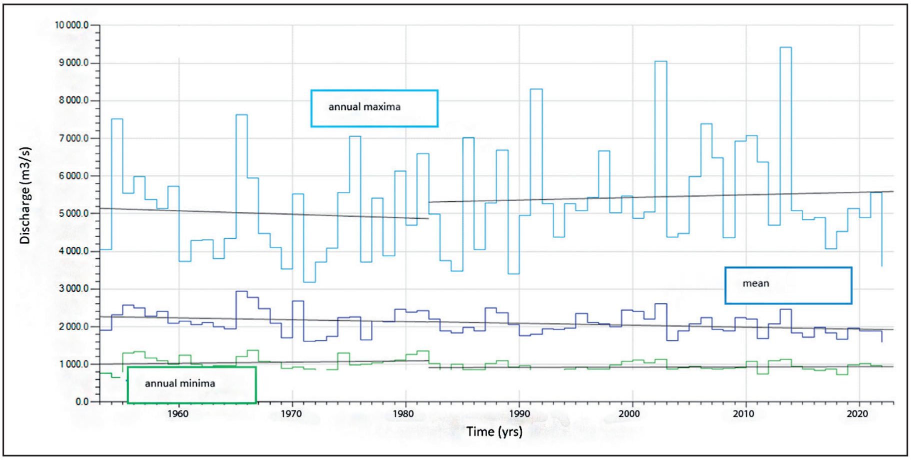

Figure 7: Water discharge trend analysis, Komárom GS, 1953–2022
Source: ÉDUVIZIG 2023

The same phenomena can be observed on the Rába at Árpás GS.

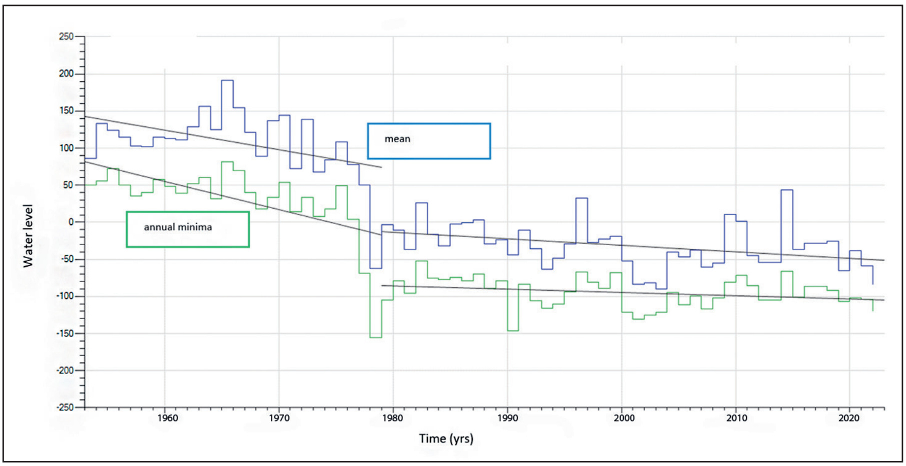

Figure 8: Water level trend analysis, Árpás GS, 1953–2022
Source: ÉDUVIZIG 2023

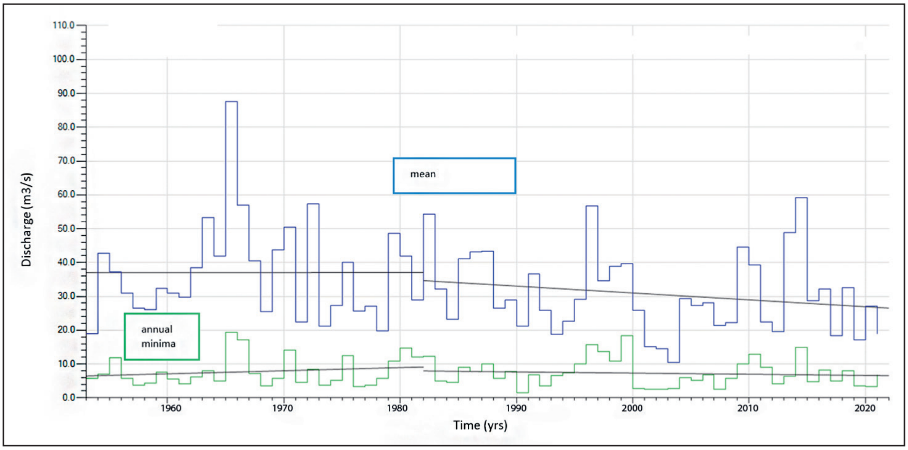

Figure 9: Water discharge trend analysis, Árpás GS, 1953–2022
Source: ÉDUVIZIG 2023

In case of the Rába River, only the low and mean water characteristics are shown due to the different magnitudes of the annual maximum water discharges. The slow decrease in the linear trend of mean water discharges on the Rába may indicate a change in the climatic conditions of the catchment, but the evaluation of this phenomenon is not the subject of the present study. The trend parameters are shown in Table 1 below.

Table 1: Water level and discharge trend parameters, Gönyű GS, Komárom and Árpás

Gönyű water level	**Maxima**		**Mean**		**Minima**	
Time period	1953–1981	1982–2022	1953–1981	1982–2022	1953–1981	1982–2022
Initial value, cm	613	511	296	173	121	–14
Increment, cm/year	–2.845	0.886	–1.74	–1.215	–0.487	–0.49
Increment, %/year	–0.46	0.17	–0.59	–0.70	–0.40	3.44
Árpás water level	**Maxima**		**Mean**		**Minima**	
Time period	1953–1979	1980–2022	1953–1979	1980–2022	1953–1979	1980–2022
Initial value, cm	409	258	148	–14	88	–84
Increment, cm/year	–3.55	–1.89	–3.23	–0.84	–4.47	–0.51
Increment, %/year	–0.87	–0.73	–2.18	5.87	–5.08	0.61
Komárom discharge	**Maxima**		**Mean**		**Minima**	
Time period	1953–1981	1982–2022	1953–1981	1982–2022	1953–1981	1982–2022
Initial value, m^3/s	5145	5311	2268	2133	1009	918
Increment, $m^3/s/year$	–9.43	6.86	–4.39	–5.17	3.04	0.59
Increment, %/year	–0.18	0.13	–0.21	–0.24	0.30	0.06
Árpás discharge	**Maxima**		**Mean**		**Minima**	
Time period	1953–1979	1980–2021	1953–1979	1980–2021	1953–1979	1980–2021
Initial value, m^3/s	253.07	223.93	36.64	35.19	7.20	9.05
Increment, $m^3/s/year$	–0.63	–1.98	0.04	–0.21	0.02	–0.07
Increment, %/year	–0.25	–0.88	0.10	–0.59	0.21	–0.78

Source: ÉDUVIZIG 2023

Homogeneity tests were also performed on the statistical sample of the hydrologic time series. The results of the Kolmogorov–Smirnov tests are shown in the next Figure (Figure 10). The different behaviour of the empirical distribution functions in case of water levels and discharges shows the effect of riverbed incision.

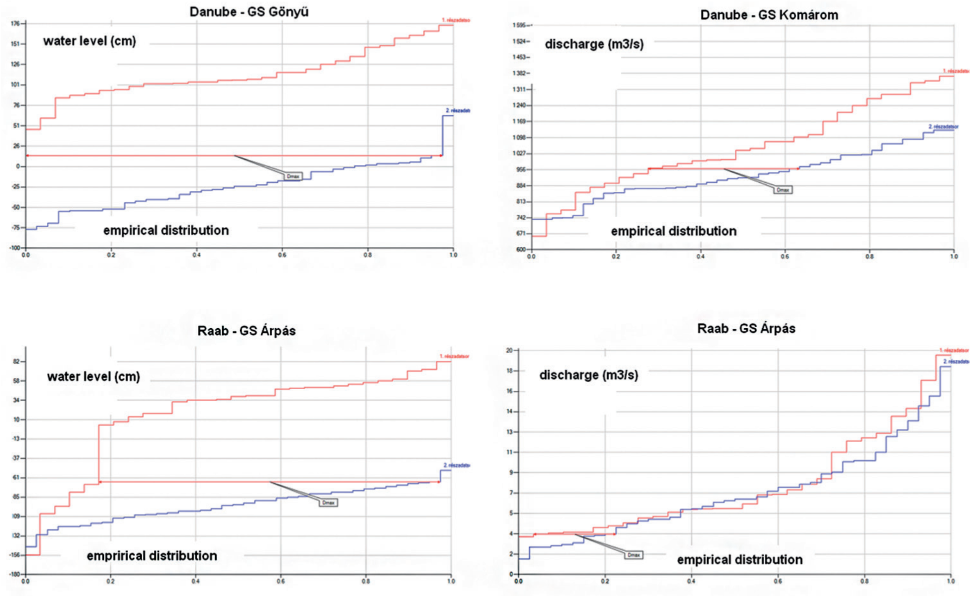

Figure 10: Kolmogorov–Smirnov homogeneity tests, Gönyű, Komárom, Árpás GS
Source: ÉDUVIZIG 2023

The numeric results of the homogeneity test are shown in Table 2.

Table 2: Numeric results of homogeneity tests, Gönyű GS, Komárom and Árpás

Kolmogorov–Smirnov homogeneity tests, parameters Time period: 1953–2022					Method: dividing at given year Cutting point: 1981				
	Water levels								
	Minima			**Mean**			**Maxima**		
	D_{max}	1–L(Z)	H.gen?	D_{max}	1–L(Z)	H.gen?	D_{max}	1–L(Z)	H.gen?
Gönyű	0.974	0.000	No	0.923	0.000	No	0.246	0.267	Yes
Komárom	0.685	0.000	No	0.616	0.000	No	0.156	0.805	Yes
Árpás	0.802	0.000	No	0.836	0.000	No	0.562	0.000	No
	Discharges								
	Minima			**Mean**			**Maxima**		
	D_{max}	1–L(Z)	H.gen?	D_{max}	1–L(Z)	H.gen?	D_{max}	1–L(Z)	H.gen?
Komárom	0.358	0.026	No	0.373	0.018	No	0.302	0.090	Yes
Árpás	0.191	0.575	Yes	0.221	0.086	No	0.365	0.023	No

where
D_{max} – maximum absolute difference between the divided distributing functions
1-L(Z) – distribution function of Kolmogorov distributed probability variable; this parameter representing the measure of homogeneity
Source: ÉDUVIZIG 2023

These two effects on the deepening of the riverbed can be illustrated by plotting the changes in the characteristic water levels and the changes in the navigation low water levels defined for the Danube.

In the following figure, the time series of the annual minimum water levels for each gauge and the characteristic data series of the annual average of the monthly minima are plotted against the 1966 navigation low water level (Étiage navigable – EN) as a reference level.

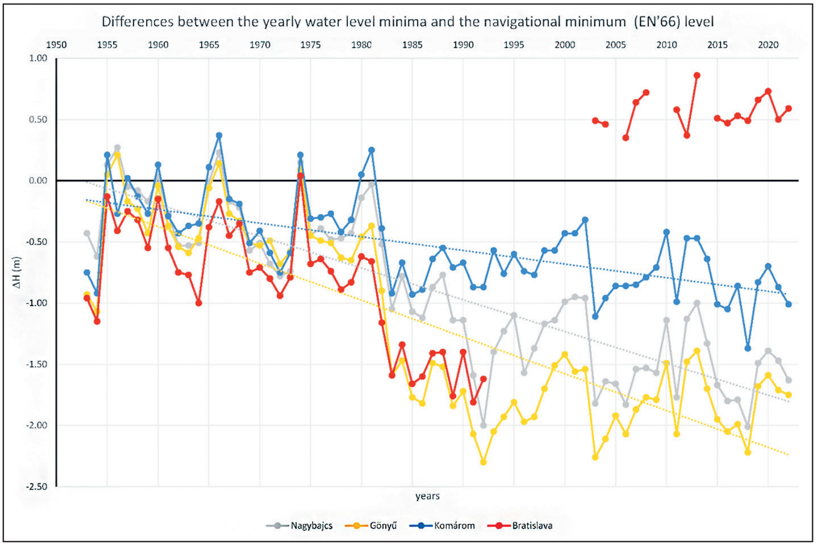

Figure 11: Water level differences compared to EN'66, 1953–2022
Source: ÉDUVIZIG 2023

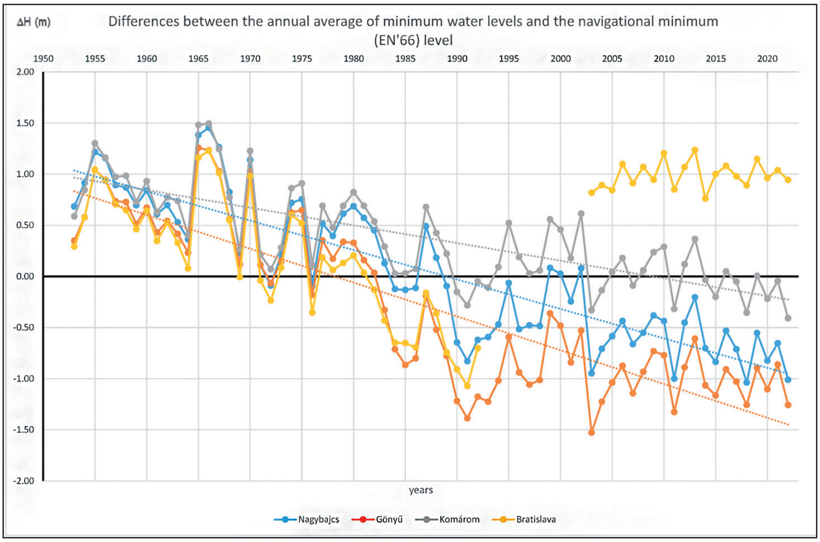

Figure 12: Water level differences compared to EN'66, 1953–2022
Source: ÉDUVIZIG 2023

The upper figure shows the deviation of the annual minimum water levels compared to EN'66. This figure also shows the significant effects of the dredging operations in the 1980s. The lower figure shows the time series of annual averages of monthly minimum water levels, which do not show significant short-term changes, but the trend indicates a clear bed subsidence, reflecting the impact of river regulation and channelisation that were performed upstream.

As a result of the construction of Gabcikovo (Bős in Hungarian) Hydropower Plant in 1992–1993, the Bratislava gauging station became part of its dam's impoundment section, so its water levels are not following the natural water regime of the Danube.

The longitudinal changes of this difference is shown in Figure 13 for different time periods. It can be seen that the deepening of the riverbed reaches almost 2 metres at the confluence of the Moson-Danube.

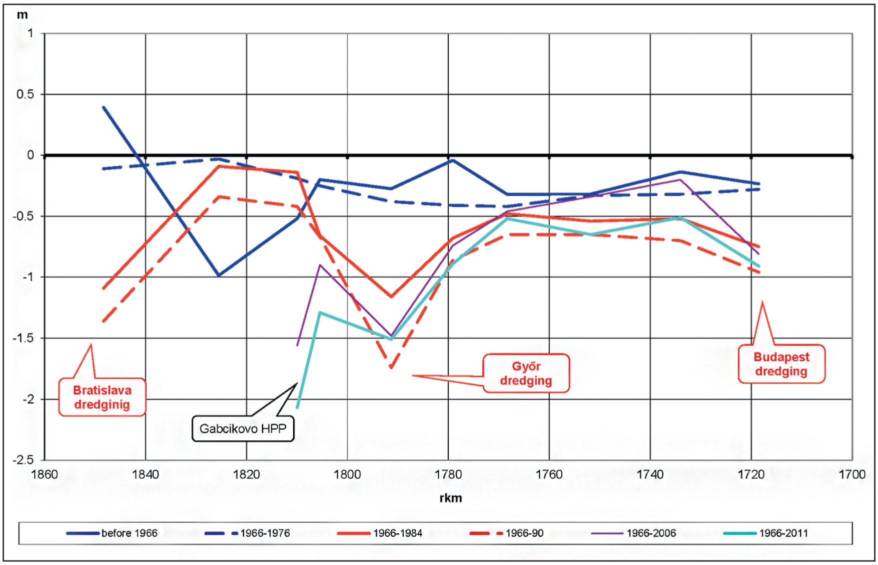

Figure 13: Longitudinal sections of water level differences compared to EN'66, 1966–2011
Source: ÉDUVIZIG 2023

The following graphs show the variation of annual minimum water levels at each GS on the Danube and the Rába over the past 70 years, based on 10-years intervals averaging as in Tamás et al. 2021. As suggested by Kalocsa and Zsuffa in their publication (1997), the decrease is shown compared to the first year of investigation, i.e. the minimum water level observed in 1950 is zero on the vertical axis. The decrease which was concluded in 1997 continued at Komárom, Nagybajcs and Gönyű stations, and the increase that was reported for the period between 1901–1990 for the Dunaremete GS has reversed and now this station shows a decrease, too.

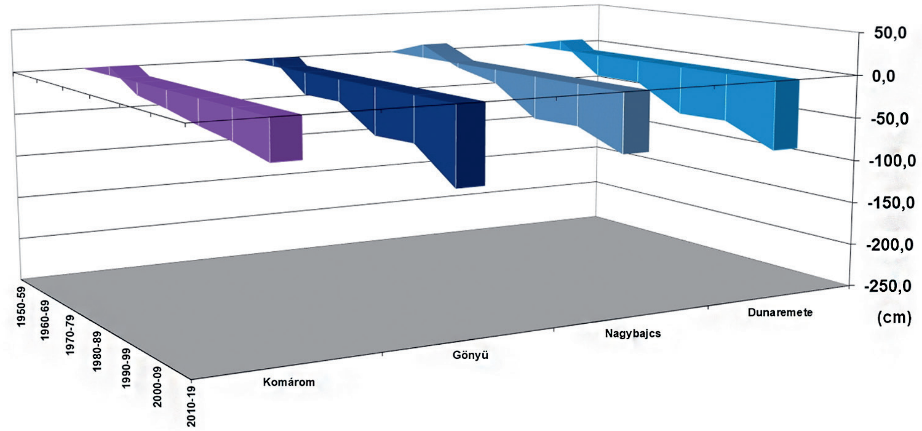

Figure 14: Integrated effect of riverbed incision and long-term changes of low water discharges on the Danube between 1950 and 2019
Source: ÉDUVIZIG 2023

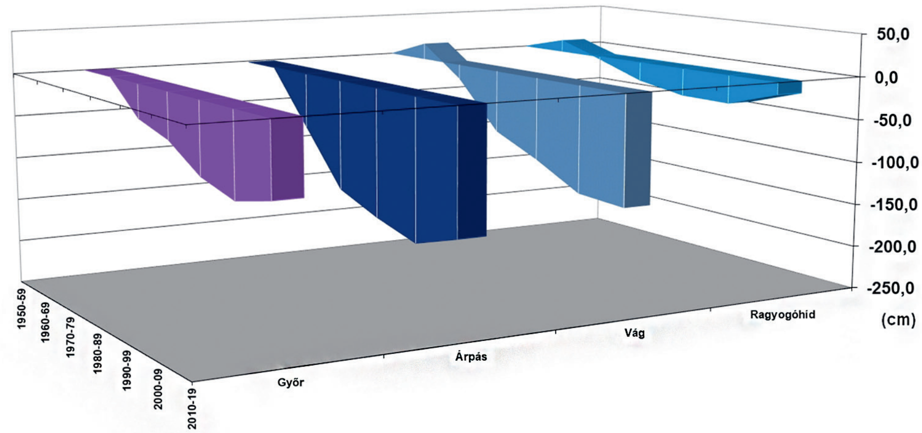

Figure 15: Integrated effect of riverbed incision and long-term changes of low water discharges on the Rába between 1950 and 2019
Source: ÉDUVIZIG 2023

Consequences of the riverbed deepening in the region

A secondary consequence of the deepening of the riverbed is the depression of groundwater levels in the area. In the section of the Danube between Szap (where the tailrace of the Gabcikovo HPP joins the Danube) and Gönyű, where the incision of the bed is most significant, groundwater levels have also shown a significant decreasing trend in the decades since the measurements started. In Győr area, this has been more than 1 m over the last 60 years. The phenomenon is illustrated by linear trend graphs of some monitoring wells in the area.

Along the estuary of the Rába, the groundwater level is decreasing by more than 1.5 m due to the Danube's incision. At Komárom, at the lower part of the analysed Danube section, there is a slight, but detectable decrease in groundwater levels.

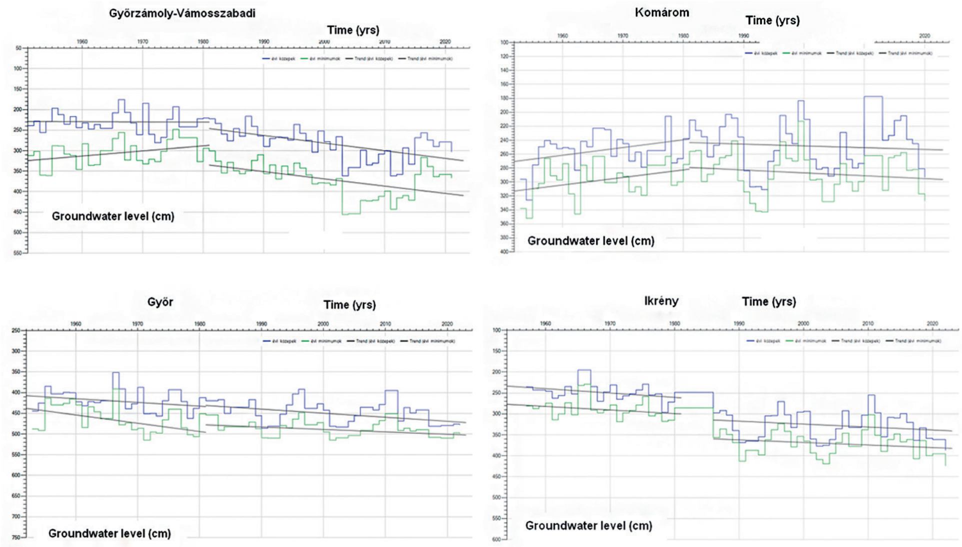

Figure 16: Groundwater trend analysis, 1953–2022
Source: ÉDUVIZIG 2023

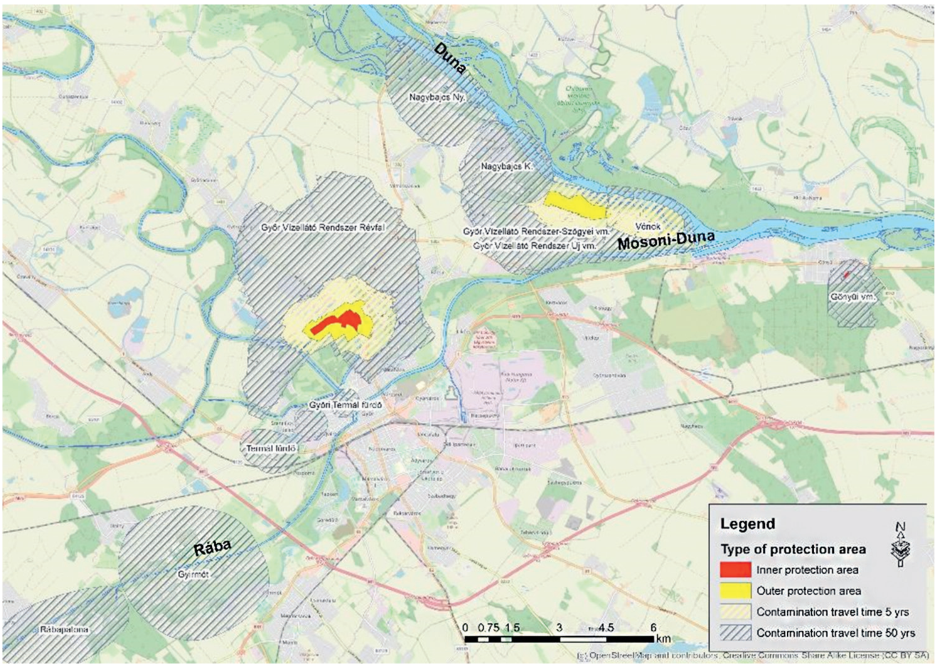

Figure 17: Overview map of aquifer protection in the Győr area
Source: ÉDUVIZIG 2023

The city of Győr is indirectly supplied with drinking water from the Danube, by using a bank filtration water supply. The water supply wells are located on the right bank of the Danube, in the area of Szőgye. The Szőgye aquifer has a protection area granted by authorisation. Its extent is shown on the map below.

The subsidence of the Danube water levels is threatening the operation of the so-called 'radial wells', which collect water from under the Danube bed and purify it through a colmated natural filter of the bed material. Thinning of this filter layer due to sediment erosion can reduce the efficiency of purification, which threatens the water supply of Győr.

The phenomenon of riverbed incision is harmful to public health, makes water transport difficult, is not aesthetically pleasing and detracts from Győr's urban image. A typical low-water cityscape of Győr is shown in Figure 18.

Figure 18: Low water level in Győr at the Rába gauging station
Source: ÉDUVIZIG 2023

A partial solution to the problem of riverbed incision – Raising the water level in the Moson-Danube estuary

Previous studies and analyses have shown that the restoration of the low and medium water levels of the Moson-Danube and the Rába estuary to the reference water levels of the 1960s is possible by constructing a complex estuary structure. The operation of the complex structure would allow the rehabilitation of wetlands, the provision of navigation, the improvement of the urban landscape of Győr and the enhancement of flood safety by providing a flood gate function.

After several years of modelling, planning, impact assessment and authorisation, the construction of this estuary structure began in 2018 within the frame of the project called: "Water level rehabilitation of the Moson-Danube's estuary reach". The construction works were finished in the first months of 2022; and after two months of test run, the estuary structure began to operate in June 2022. By the operation of this structure the water levels on the estuary reach of the Moson-Danube and Rába have been raised by almost 1.5 m. Last year a seasonally operating rule have been worked out, in order to simulate the water regime of the 1960s, by correlating the Danube discharges at Devín with the resulting water levels in Győr.

As a result of this operation seasonally a quasi-permanent water regime can be observed in the city of Győr, as it can be seen in Figure 19.

Figure 19: Water level rehabilitation in the city of Győr at the Rába estuary
Source: ÉDUVIZIG 2023

Conclusions

This examination of the hydrological time series clearly shows that the phenomenon of bed erosion in the upper reaches of the Danube in Hungary is still a measurable phenomenon. In Austria, morphological studies and interventions in longitudinal river regulation structures have been carried out in previous years to reduce the magnitude of the phenomenon and have reported positive results.[20] In the estuary of the Moson-Danube and Rába, after the first year of the dam's operation, it can be seen that the water level increase solves the primary problem, but generates additional, otherwise known problems, such as the handling of the settling surplus of suspended sediment from the Rába, and sewage disposal problems in the city of Győr. The dam is of course not able to deal with the problems of the Danube riverbed incision, which process is still ongoing. The settling suspended sediment can reduce the magnitude of the erosion on the lower part of the Rába and Moson-Danube but may cause harmful side effects in case of navigation in the long term.

In addition, the flood gate function of the estuary structure in case of a major Danube flood eliminates backwater effects on the Moson-Danube, which has a negative impact on the culminating discharges of the Danube on the Gönyű–Komárom reach. The previous reservoir impact of the lower reaches of the Moson-Danube and Rába will be eliminated by

[20] Pessenlehner et al. 2016.

the operation of the Moson-Danube estuary dam, thus higher peak discharges will occur on the Danube below the estuary of the Moson-Danube. This higher discharge establishes higher water velocities and water levels, which may fasten the erosion of the sediment and the riverbed. This phenomenon should be evaluated at the next flood event as it occurs.

References

Almazov, A. et al. (1963): *Zona de vărsare a Dunării.* Monografie hidrografică. Bucureşti: Editura Tehnică.

CIA (2023): *The World Factbook – Major Rivers.* Online: www.cia.gov/the-world-factbook/field/major-rivers-by-length-in-km/

EDUVIZIG (2014): *Nagyvízi Mederkezelési Terv 01.NMT.09.* Online: http://extranet.eduvizig.hu/nmkt/01.NMT.09.Raba.Vag-Gyor/01NMT09.1-3_muszaki%20leiras.pdf

General Directorate of Water Management (OVF) (2023): *Havi átlagos vízhozamok adatsora, Duna-Komárom [Time series of monthly average water discharges, Danube-Komárom]* Hydrographic database (VRA) https://vmservice.vizugy.hu/BaseDataService/api/

General Directorate of Water Management (OVF) (2023): *Havi átlagos vízhozamok adatsora, Rába-Árpás [Time series of monthly average water discharges, Raab-Árpás]* Hydrographic database (VRA) https://vmservice.vizugy.hu/BaseDataService/api/

General Directorate of Water Management (OVF) (2019): *Paper Chart of Hungarian Danube River Section 1708.2 – 1560.6.* Online: www.danubeportal.com/application/cache/uploads/charts/paper/HU/130/1572426864.pdf

General Directorate of Water Management (OVF) (2021): Az előzetes árvízi kockázatbecslés, a veszély- és kockázati térképek, a kockázatkezelési tervek első felülvizsgálata Jelen állapot értékelésének összefoglalója, Közép-Duna tervezési terület [General Geographical and Flood Hydrological Characteristics of the Central Danube Planning Area]. Online: https://vizeink.hu/wp-content/uploads/2021/05/akk/2/Kozep-Duna_osszefoglalo_2021.pdf

Geology Page (2014): *Danube River.* Online: www.geologypage.com/2014/11/danube-river.html

Hüse, Zsolt (2001): *Egy- és többváltozós regresszióanalízis nemlineáris módszerei hidrológiai alkalmazásának számítógépi programja.* Szeged: ATIKÖVIZIG.

ICPDR (2009): *Danube River Management Plan (DRBMP) 2009.* Online: www.icpdr.org/main/publications/danube-river-basin-management-plan-drbmp-2009

Kalocsa, Béla – Zsuffa, István (1997): A Duna magyar szakaszának vízállásváltozásai. *Hidrológiai Közlöny, 77*(4), 183–192.

Károlyi, Zsigmond (1979): A folyami kotrások története. *Magyar Vízgazdálkodás,* 19(6), 29–31.

National Atlas of Hungary (2018). Online: www.nemzetiatlasz.hu/MNA/National-Atlas-of-Hungary_Vol2_Ch6.pdf

North-Transdanubian Water Directorate (ÉDUVIZIG) (2023): Mosoni-Duna torkolati műtárgy ideiglenes üzemrend és üzemeltetési szabályzat, Megalapozó hidrológiai vizsgálatok [Mosoni-Danube estuary dam provisional operation and management rules, Foundational hydrologic studies] (Available: 9021, Győr Árpád st. 28–32.)

Pessenlehner, Sebastian – Liedermann, Marcel – Tritthart, Michael – Gmeiner, Philipp – Habersack, Helmut (2016): *River Bed Degradation and Morphological Development Before and After River Restoration Measures at the Danube River East of Vienna.* Online: https://hdl.handle.net/20.500.11970/108532

Stancik, S. – Iovanovic, Andrej – Sikora L. – Ürge L. – Miklos D. (1988): *Hydrology of the River Danube.* Bratislava: Priroda Publishing House.

Tamás, E. A. – Đorđević, D. – Kalocsa, B. – Vujanović, A. (2021): Hydrological Indicators of the Riverbed Incision along the Free-Flowing Danube River Reach from Budapest to Slankamen Relevant for the Lateral Connectivity between the River Channel and Floodplains. In Cyffka, B. – Betz, F. – Borgs, T. – Gelhaus, M. – Stammel, B. – Vontz, M. (eds.): *Rivers and Floodplains in the Anthropocene – Upcoming Challenges in the Danube River Basin.* Proceedings of the 43rd IAD Conference, 9–11 June 2021, Neuburg. 62–69.

Vadas, András (2013): The "Waters Leave Their Beds Frequently": A Western-Hungarian Town and the Flooding of the Rába/Raab River in the Seventeenth Century (1600–1658). *Water History,* 5(3), 267–286. Online: https://doi.org/10.1007/s12685-013-0087-x

West-Transdanubian Water Directorate (NYUDUVIZIG) (2007): *Jelentős vízgazdálkodási kérdések/problémák azonosítása a Rába vízgyűjtő-gazdálkodási tervezési alegységen.* Nyugat-dunántúli Vízügyi Igazgatóság. Online: www.nyuduvizig.hu/upload/1.1.4.Raba_kesz-bovitett.PDF

4iG Nyrt. (2015): *Felhasználói Kézikönyv Vízrajzi alrendszer. Műszaki Hidrológia-Statisztikai Programcsomag.* Budapest: Országos Vízügyi Főigazgatóság.