Flow Regime Characteristics and Hydrologic Statistical Analysis of the Extraordinary Low Waters of the Danube between Vámosszabadi and Esztergom in 2018

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Abstract: *In the August – October period of 2018, extremely low water levels were observed on the Hungarian section of the Danube. The observed water levels were below the lowest ever recorded water levels (abbreviated to LKV in Hungarian) in several water gauges in Hungary. In addition to low water levels, extremely low water discharges were also measured in most profiles. In my paper I deal with a simple statistical analysis of the measured hydrologic data of the Danube's Hungarian upper section, between Vámosszabadi and Esztergom. By evaluating the obtained results, I take into account the changes of the Danube riverbed in the past decades and their impact on the flow regime.*

Keywords: *Hydrological statistics, Danube, Low-flow, Trend-analysis, Distribution functions*

1. Meteorological history

With the analysis of monthly meteorological assessments published by the Austrian Central Meteorological and Geodynamic Institute (ZAMG), the weather in the catchment area of the Danube can be evaluated, which is important for the runoff, through the precipitation and temperature conditions in Austria. From March to October 2018, precipitation deficit was almost continuous and significant on the northern side of the Alps (and probably also in the upper Danube basin) compared to the average for the period 1981-2010, and average monthly temperatures in these areas were significantly above the average values. The anomaly from the multi-year average of the monthly accumulated precipitation and the monthly average air temperatures for the whole territory of Austria is shown on Fig. 1.

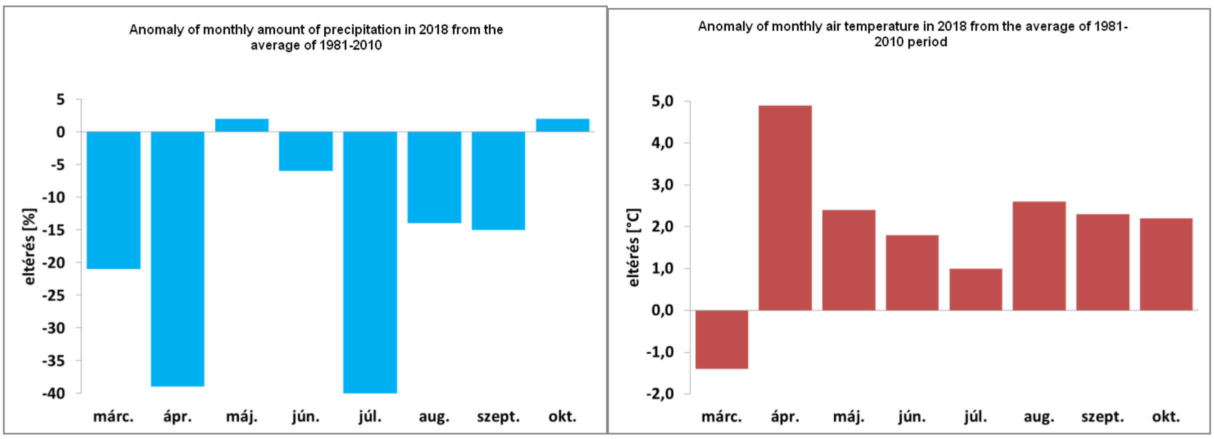

Fig. 1. Air temperature and precipitation anomaly (2018) in the whole territory of Austria [1]

In case of precipitation, it can be seen that only in May-June and October, was close to or reached the average, otherwise there was a significant lack of precipitation. Monthly average temperatures have been consistently and significantly above normal since April. The lack of precipitation and the high average temperatures indicated an increased evaporation loss on the river basin. As a result of this, the surface water runoff also decreased significantly in this time period on the whole Danube catchment area, which was also reflected in the flow regime.

2. Measured water levels and water discharges on the Danube between Vámosszabadi and Esztergom, August-October, 2018

The evaluated Danube section belongs to the North-Transdanubian District Water Directorate (EDUVIZIG) as its property manager. The layout plan of the Vámosszabadi – Esztergom section with the evaluated water gauges is shown on Fig. 2. Vámosszabadi is in the 1806 rkm, Esztergom is almost 100 km lower, in the 1715 rkm.

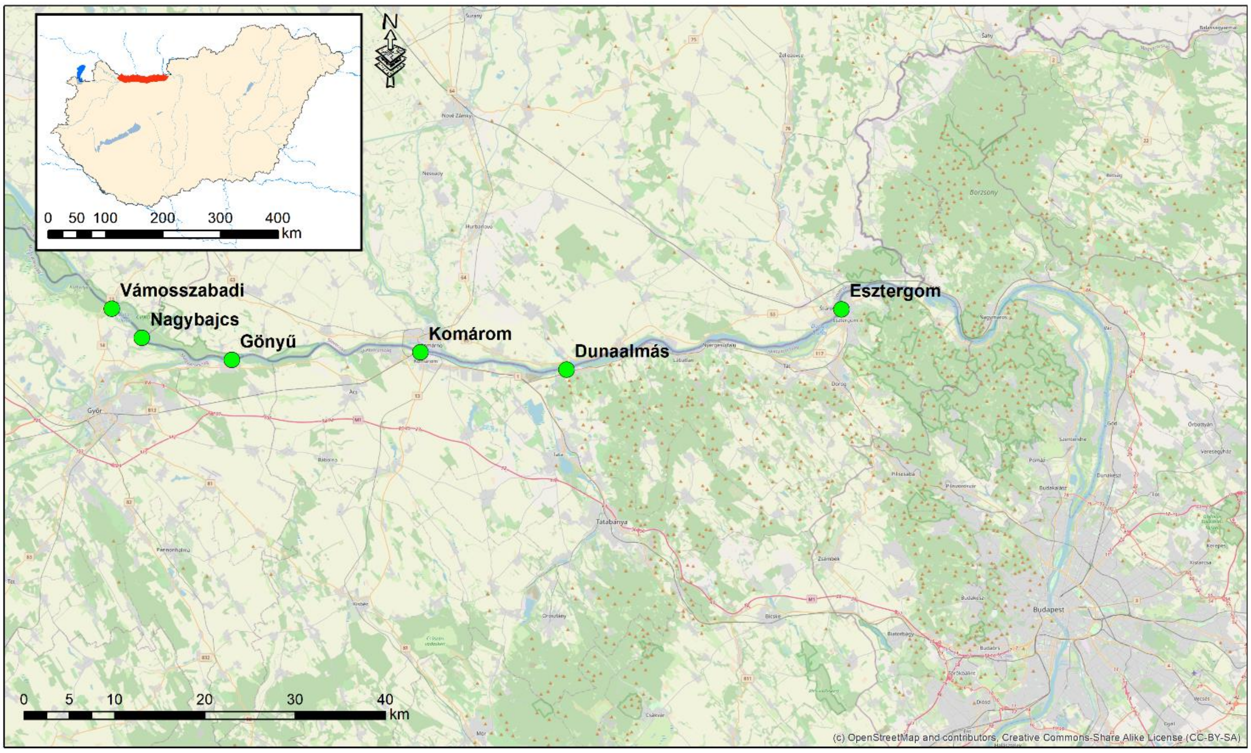

Fig. 2. The evaluated section of the Danube [2]

Since March 2018 the average monthly water discharges of the Danube has been below the long-term (1981-2010) average at all hydrographic stations on the territory of the Directorate. In January, due to two small flood waves, the water discharge was above the month's long-term average. Then in February it was temporarily above average, and then stayed below the average values month by month. By the end of summer and then by the end of October, the low water status became so extraordinary that the water levels and water discharges in the whole Hungarian section were below the previous minimum values (abbreviated in Hungarian to LKV and LKQ) in several places.

The next table shows the new minimum water level and discharge values on the evaluated section.

Table 1: Previous and new extreme values on the evaluated Danube section [3]

Hydrographic station	Profile (rkm)	Ref. Point (masl)	Lowest water level (old)		Lowest water level (new)		Lowest discharge (old)		Lowest discharge in october 2018	
			Date	value (cm)	Date	value (cm)	Year	value (m3/s)	Date	value (m3/s)
Vámosszabadi	1805.6	108.40	30.11. 2011	-73	24.10.2018	-106	2006	669	24.10.2018	650
Nagybajcs	1801.0	107.40	26.10.1992	-31	24.10.2018	-32				
Gönyű	1790.6	106.04	26.10.1992	-93	-	-	-	-	-	-
Komárom	1768.3	103.88	01.01.2016	18	24.10.2018	-12	1938	595	24.10.2018	735
Dunaalmás	1751.8	103.12	04.01.1909	0	24.10.2018	1*	1985	802	24.10.2018	773
Esztergom	1718.5	100.92	30.08.2003	-2	25.10.2018	-21				

* - the measuring probe ran out of range, the minimum value was estimated by linearized regression

The measured water levels on this section developed as is shown on Fig. 3.

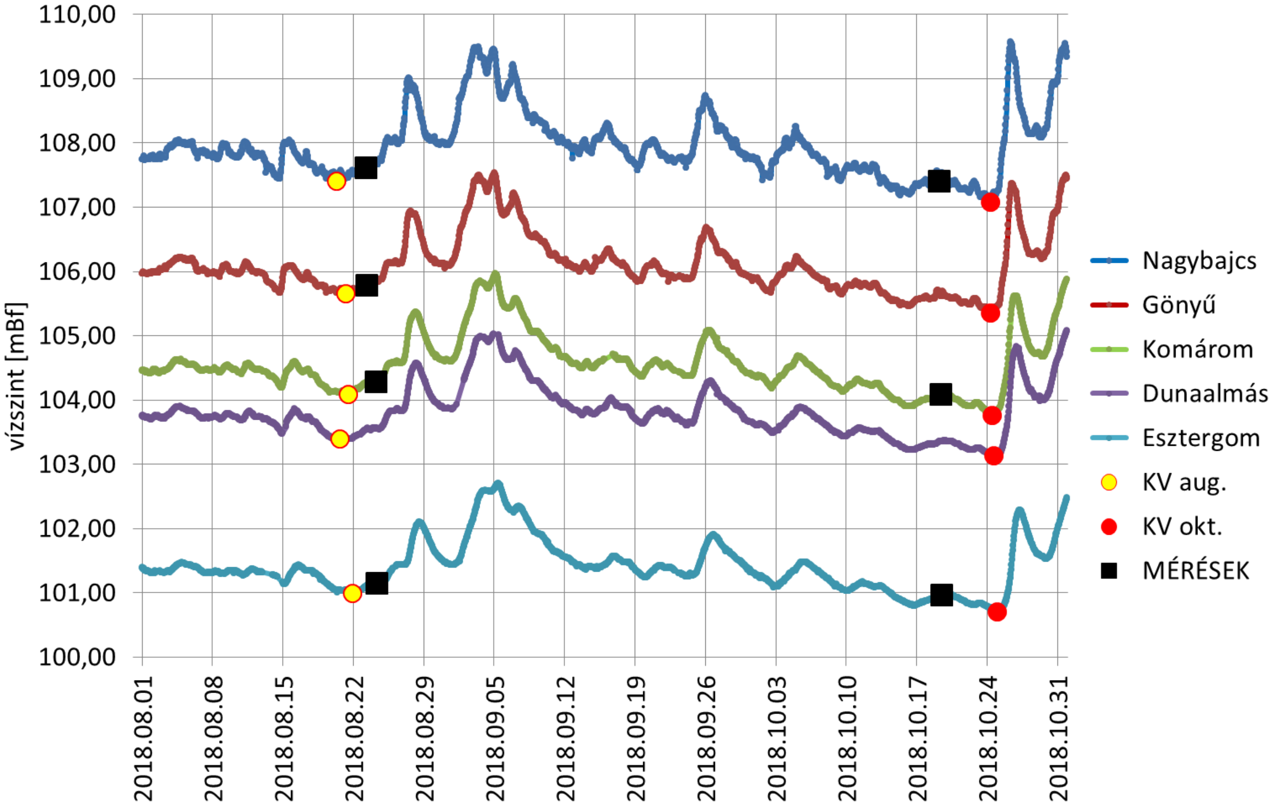

Fig. 3. Observed water levels on the Danube, August-October 2018 [3]

The figure also shows the location of the August and October extremes (yellow and red dots), as well as the results of water discharge measurements (black squares).
There were 3 measurement campaigns in August and in October, when the water discharges were measured by EDUVIZIG. The results of these measurements are shown in table 2.

Table 2: Measured water discharges on the evaluated Danube section [4]

Hydrographic station	Profile (rkm)	Ref. Point (masl)	august 23		august 24		october 19	
			H (cm)	Q (m3/s)	H (cm)	Q (m3/s)	H (cm)	Q (m3/s)
Vámosszabadi	1805.6	108.40	-53	847	-	-	-65	747
Gönyű	1790.6	106.04	-27	908	-	-	-	-
Komárom	1768.3	103.88	-	-	39	911	20	765
Esztergom	1718.5	100.92	-	-	21	994	3	896

The measurement conditions were established in a quasi-permanent status on the whole section, so the measured results were appropriate to evaluate the water discharges in the critical time period. Nevertheless, the measurements can be characterized by a larger standard deviation. This may cause by the operation of the Gabcikovo power plant, because the low water discharges are easily influenceable with the power plant. With the help of the long-term time series available at EDUVIZIG, the statistical properties of the low-water levels and low-water discharges can be determined at each hydrographic station.

3. Hydrologic examination of the water levels

In the first step I examined the trend changes of the annual minima of the water level time series on the affected Danube section's water gauges. These trend analyses are shown in the following figures.

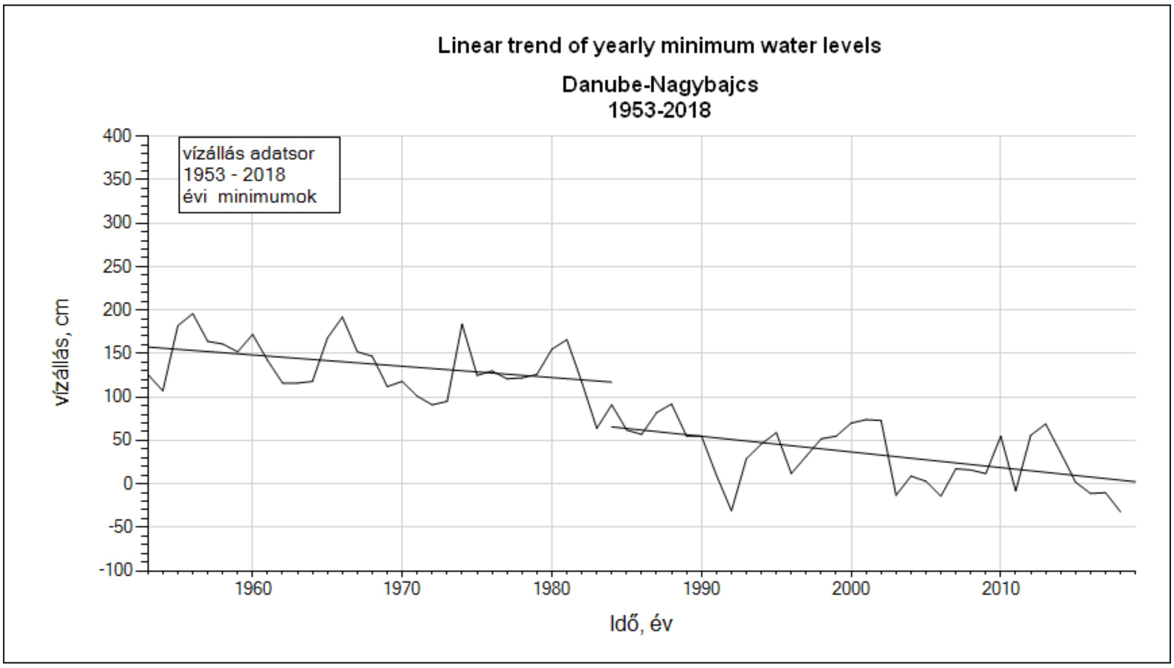

Fig. 4. Linear trend of yearly minimum water levels, Danube-Nagybajcs [5]

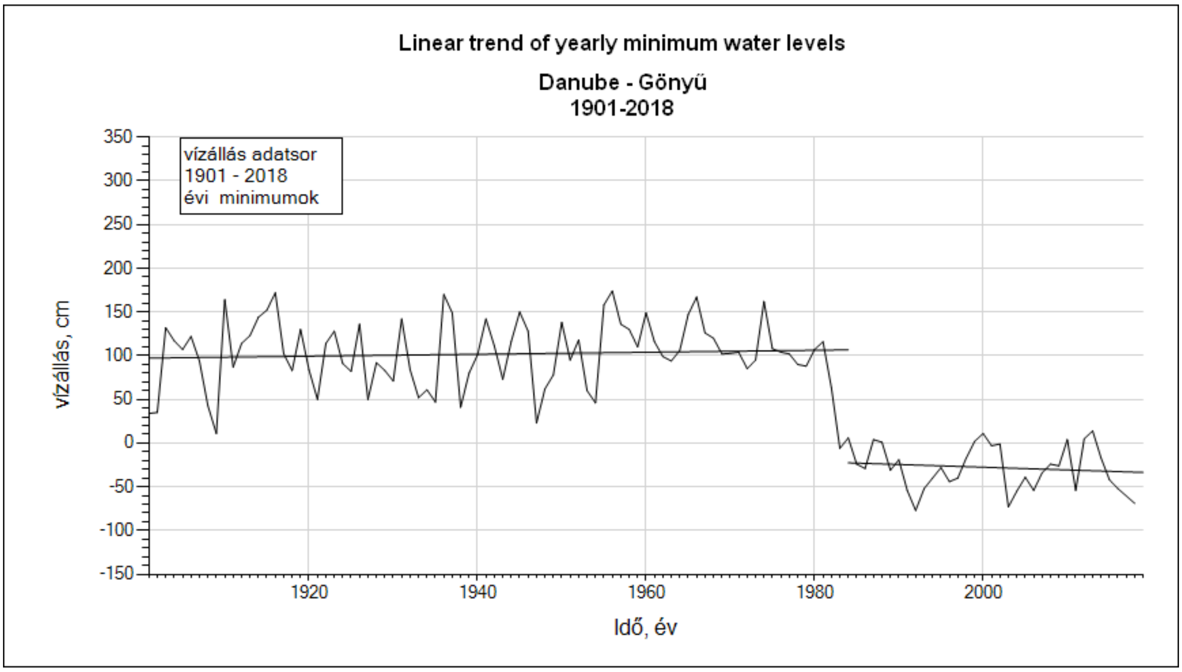

Fig. 5. Linear trend of yearly minimum water levels, Danube-Gönyű [5]

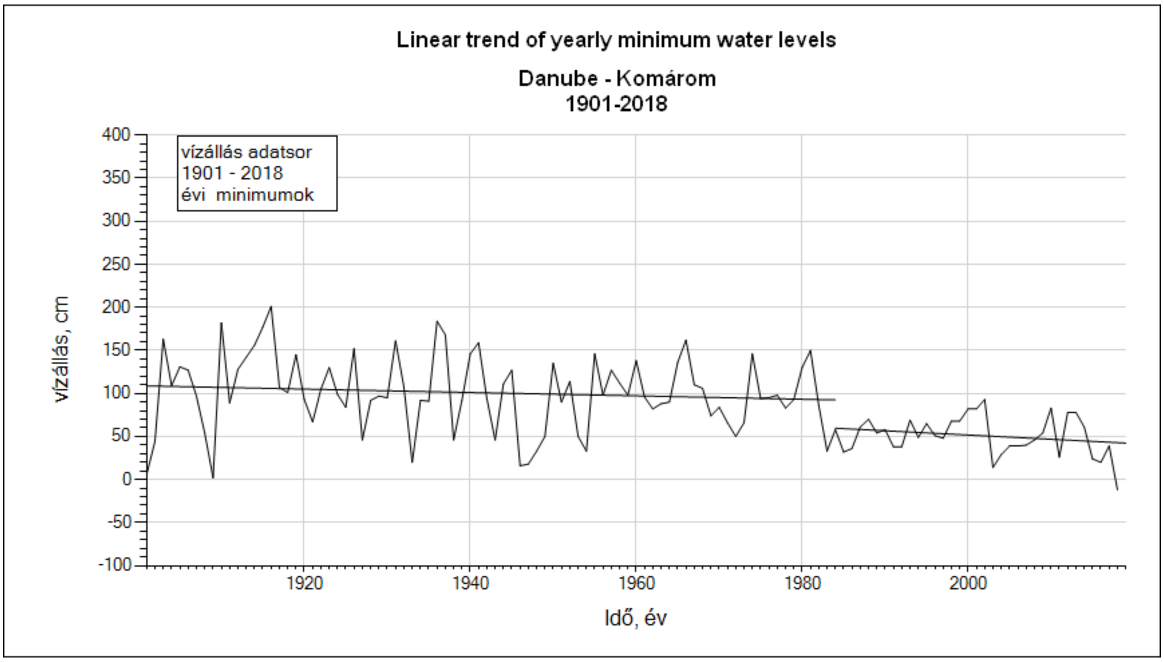

Fig. 6. Linear trend of yearly minimum water levels, Danube-Komárom [5]

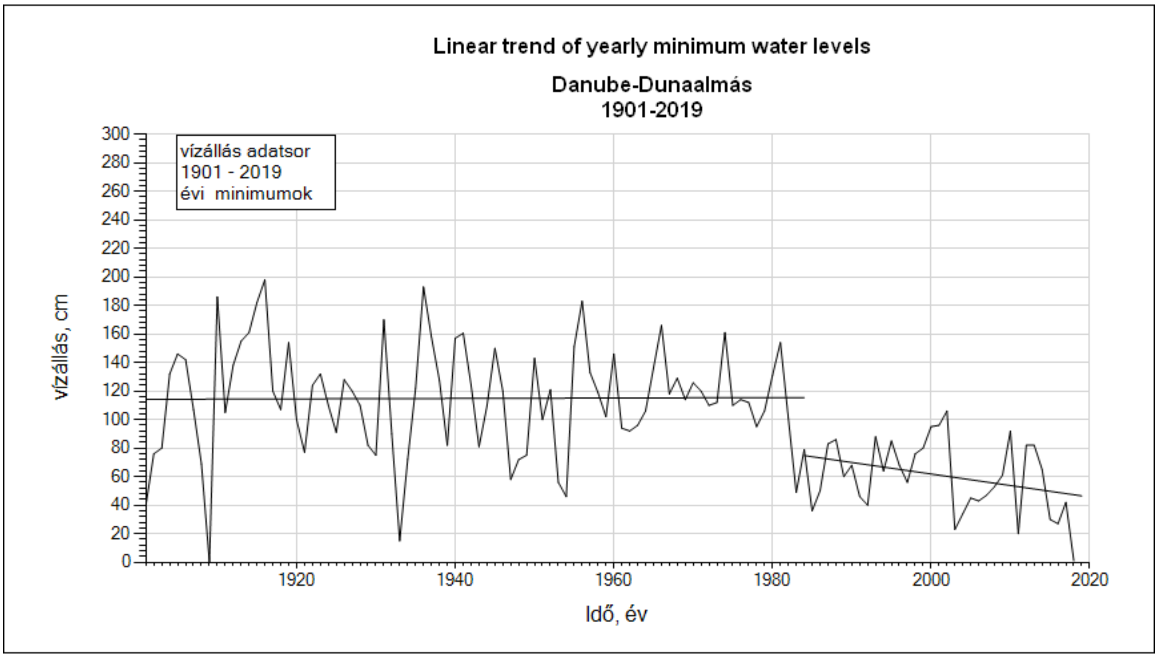

Fig. 7. Linear trend of yearly minimum water levels, Danube-Dunaalmás [5]

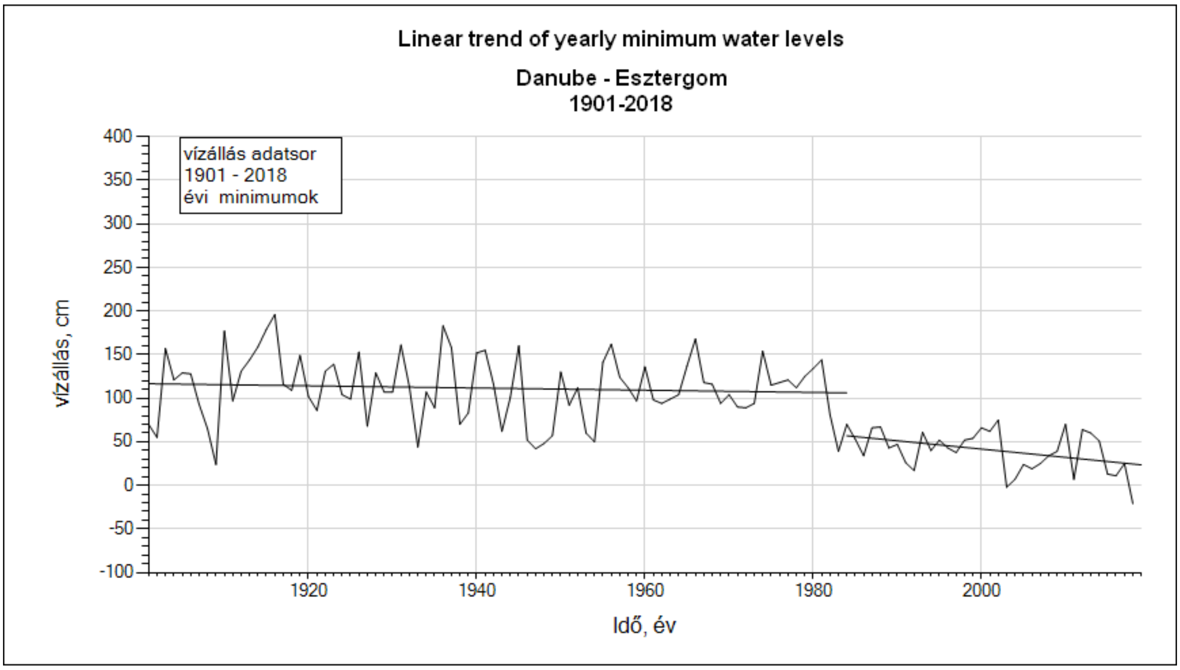

Fig. 8. Linear trend of yearly minimum water levels, Danube-Esztergom [5]

The formerly known significant changes of the Danube riverbed sinking, which began in the first half of the 1980s, are well illustrated by the staggered trend line plotted on the long-term data series. This phenomenon has significant impact on water regime, the low water levels are continuously decreasing. For this reason, the complete time series cannot be considered statistically homogeneous in any way. Despite the better fit, distribution function examinations for the whole period (1901-2018) of the time series would not provide reliable estimations on the behavior of the 2018 low-water levels, so I evaluated the primary stochastic variable, the water discharges.

The table below summarizes the average values of the linear trends fitted to the water level minima for each station.

Table 3: Linear trend analysis of the water levels

Hydrographic station	whole period	average trend (cm/year)	period1	average trend (cm/year)	period2	average trend (cm/year)
Nagybajcs	1953-2018	-2.8	1953-1983	-1.3	1984-2018	-1.8
Gönyű	1901-2018	-1.3	1901-1983	0.1	1984-2018	-0.3
Komárom	1901-2018	-0.6	1901-1983	-0.2	1984-2018	-0.5
Dunaalmás	1901-2018	-0.6	1901-1983	0.0	1984-2018	-0.8
Esztergom	1901-2018	-0.8	1901-1983	-0.1	1984-2018	-1.0

The annual minima of the Danube water levels show a decreasing trend for the whole period from Nagybajcs to Esztergom, but the extent of this sinking is significant only in the upper part of the examined Danube section. Prior to the 1980s, there was no significant change in the values of the annual minima (the time series in Nagybajcs is significantly shorter than the others). In the last 34 years there has been a definite decrease in the water levels in the area of Nagybajcs and Esztergom.

4. Hydrologic examination of the water discharges

The trend analysis results of the annual water discharge minima for stations with water discharge statistics are presented in the following figures.

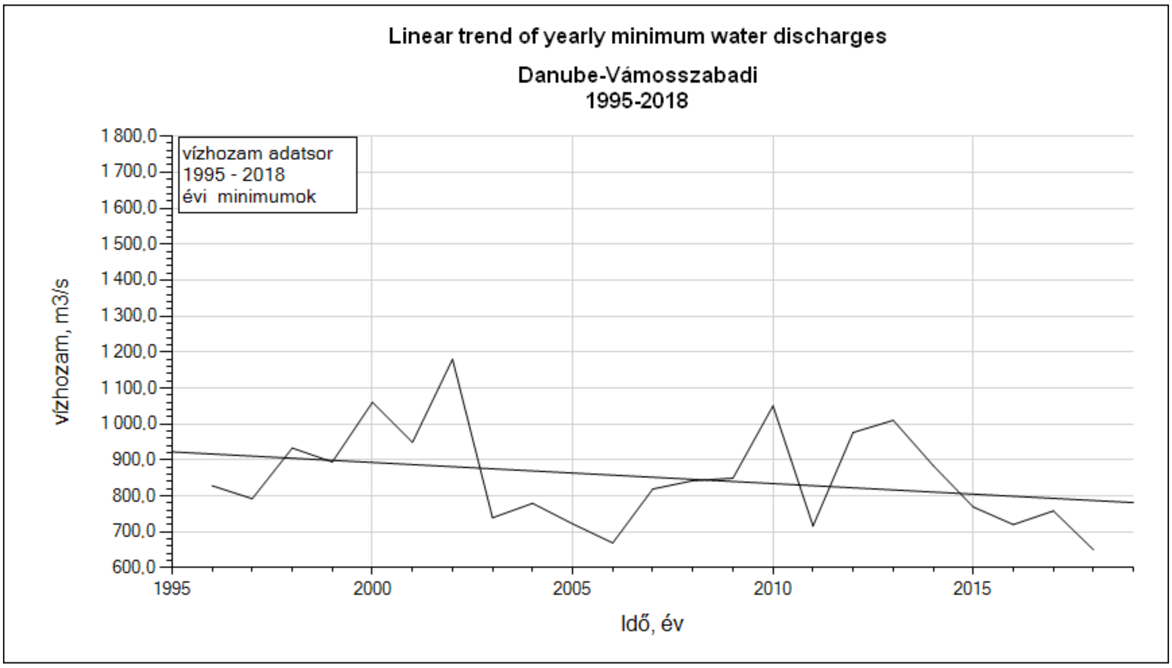

Fig. 9. Linear trend of yearly minimum water discharges, Danube-Vámosszabadi [5]

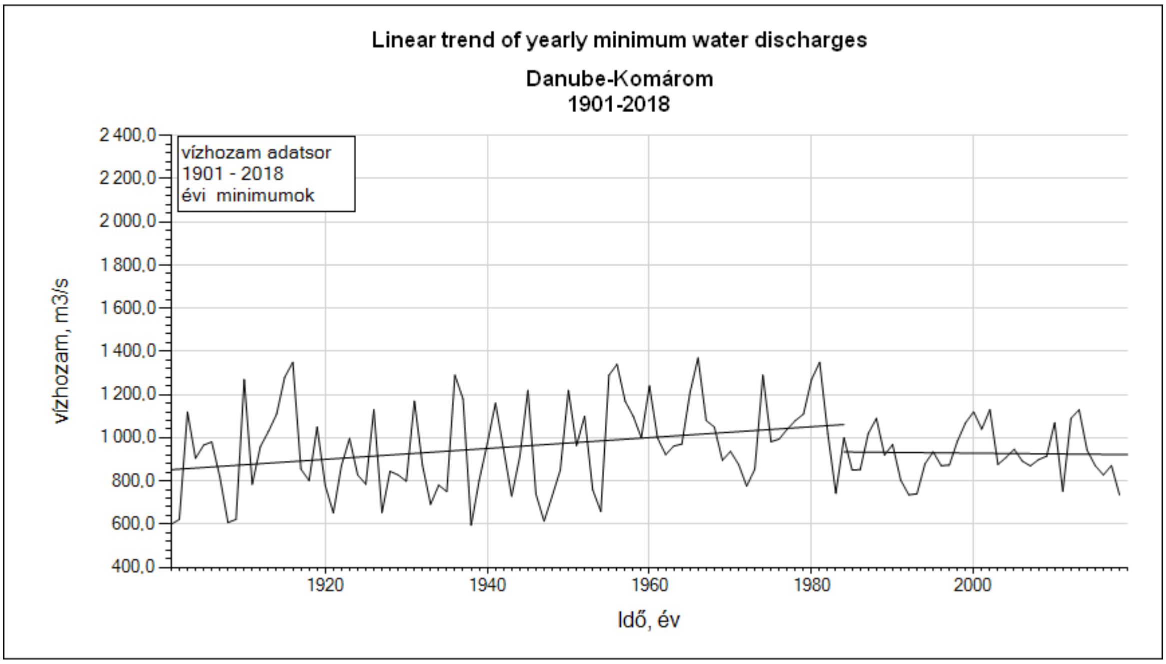

Fig. 10. Linear trend of yearly minimum water discharges, Danube-Komárom [5]

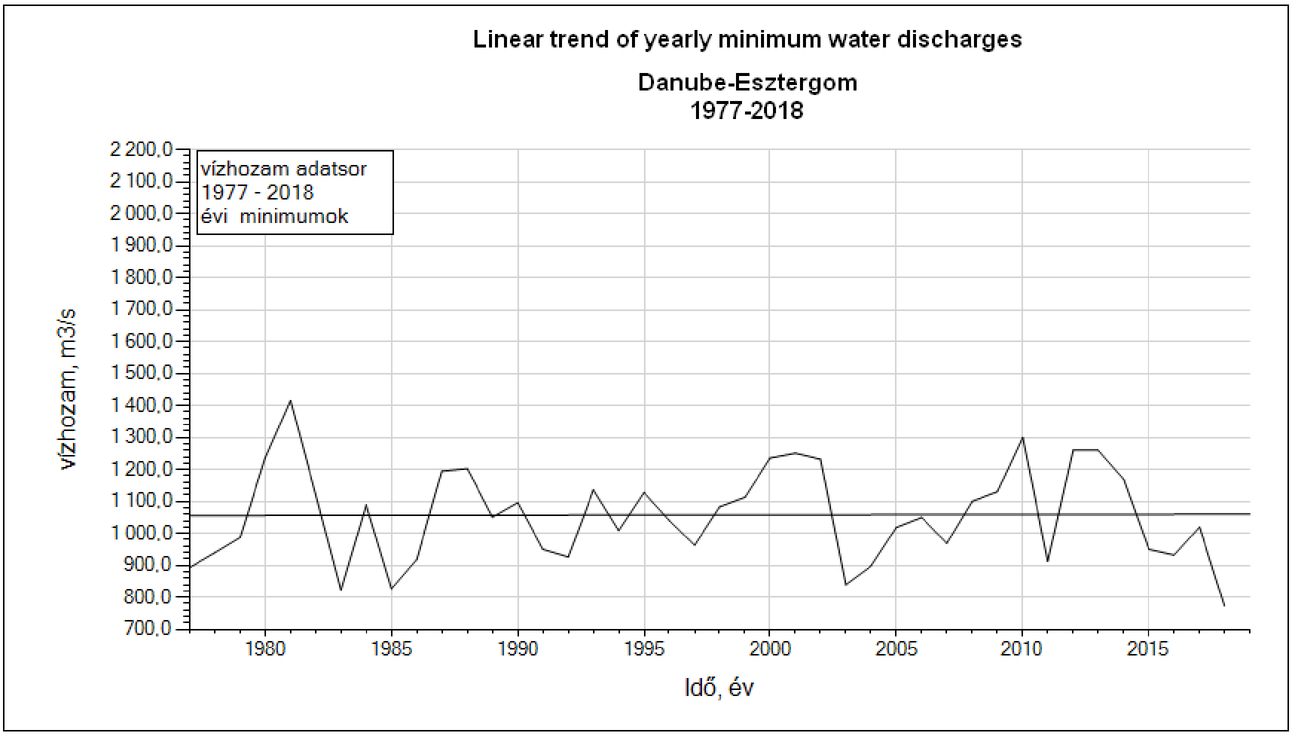

Fig. 11. Linear trend of yearly minimum water discharges, Danube-Esztergom [5]

In case of the annual minima of water discharges, the historical time series only at Komárom water gauge are long enough to show the effect of the changes of the 1980s in the trend analysis, where a slightly upward trend ceases and the standard deviation of the values is almost halved ($D_{1901\text{-}2018}$ = 187 m^3/s, $D_{1901\text{-}1983}$ = 211 m^3/s, $D_{1984\text{-}2018}$ = 114 m^3/s).

In the area of Nagybajcs (Vámosszabadi) the short data series shows a definite decrease, but this cannot be considered significant due to the shortness of the data series. The Esztergom time series does not show relevant a change in the values of low-water discharges since the beginning of the measurements.

The following table shows the average values of trend parameters.

Table 4: Linear trend analysis of the water discharges

Hydrographic station	whole period	average trend (cm/year)	period1	average trend (cm/year)	period2	average trend (cm/year)
Vámosszabadi	1995-2018	-6	-	-	-	-
Komárom	1901-2018	1	1901-1983	3	1984-2018	0
Esztergom	1977-2018	0	-	-	-	-

Overall, the trend analyzes show that the annual minima of water levels follow a detectable, decreasing trend, while in the case of water discharges this can only be observed in the short data set of Nagybajcs (Vámosszabadi). The two types of trend analyses together prove the known process of sinking and embedding of the Danube riverbed. The extent of this phenomenon is the most significant in the Gönyű area. The figure below shows the long-term changes in the annual minimum water levels and discharge data observed in the Danube-Komárom water gauge. The water level data set apparently undergoes a marked change since the 1960s and is forced into a “trend channel” (red graph). The increasing frequency of extreme small waters (even LKV) can also be attributed to this declining trend.

Looking at the data series of water discharges, we can talk about a different process from the change in water levels. From the 1980s onwards, low-water discharges - probably due to the reservoirs established in the upper section of the Danube - are scattered in a narrower range than before, the trend channel is horizontal and unchanged (green graph).

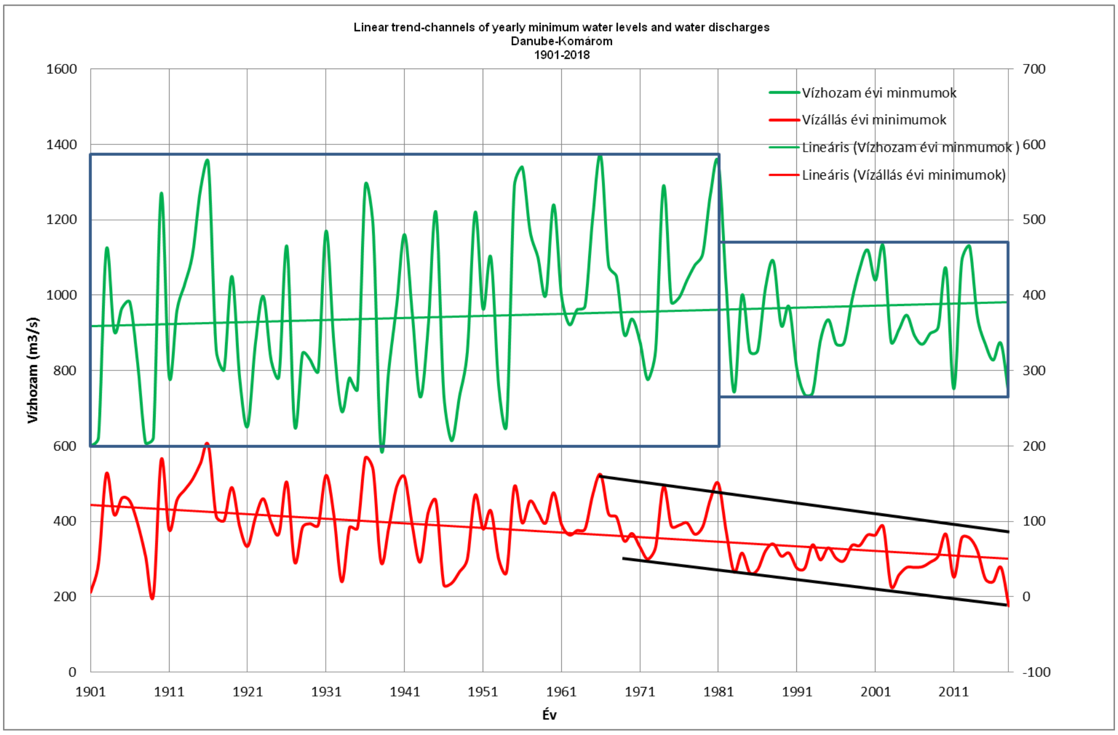

Fig. 12. Linear trend-channels of yearly minimum water levels and water discharges, Danube-Komárom

In the case of the Komárom water discharge minima, the period function of the long-term data series also well reflects the changes, in line with the trends.

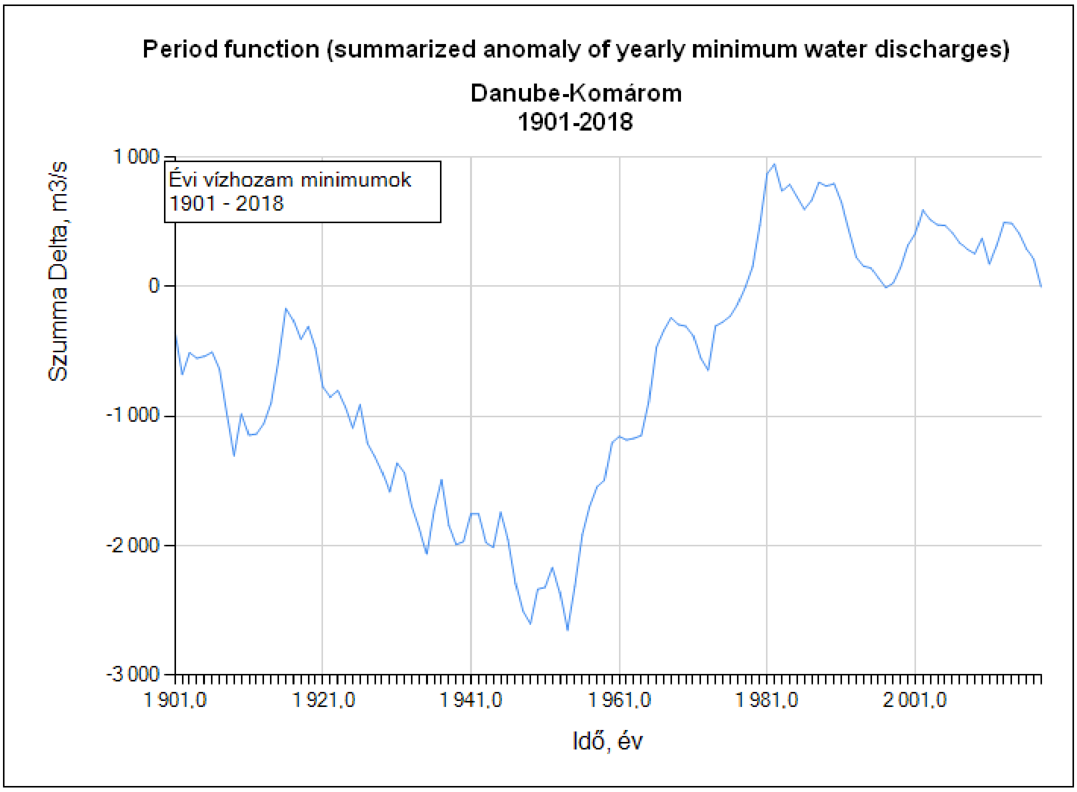

Fig. 13. Period function, Danube-Komárom [5]

The distribution function of the annual water discharge minima was also examined, but for water level data this was omitted, due to the significant inhomogeneity observed in the time series. By separating the water discharge data sets in 1984, we obtained samples that can already be considered homogeneous, although the size (number of items) of the samples is rather small. Based on the results the probability of the occurrence of low-water discharge values occurring at each hydrographic station in October 2018 can be estimated, so we can calculate their average return time. The finally chosen Pearson3-type theoretical distribution functions are as follows:

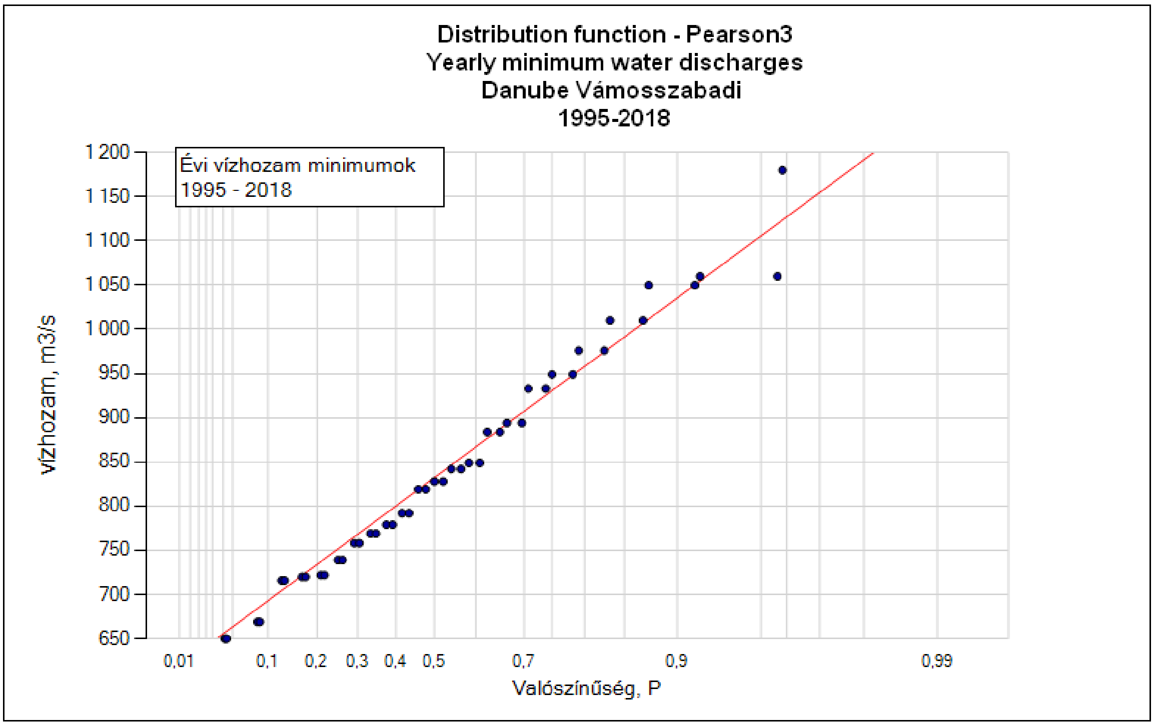

Fig. 13. Pearson3-type distribution function for yearly minimum water discharges, Danube-Vámosszabadi [5]

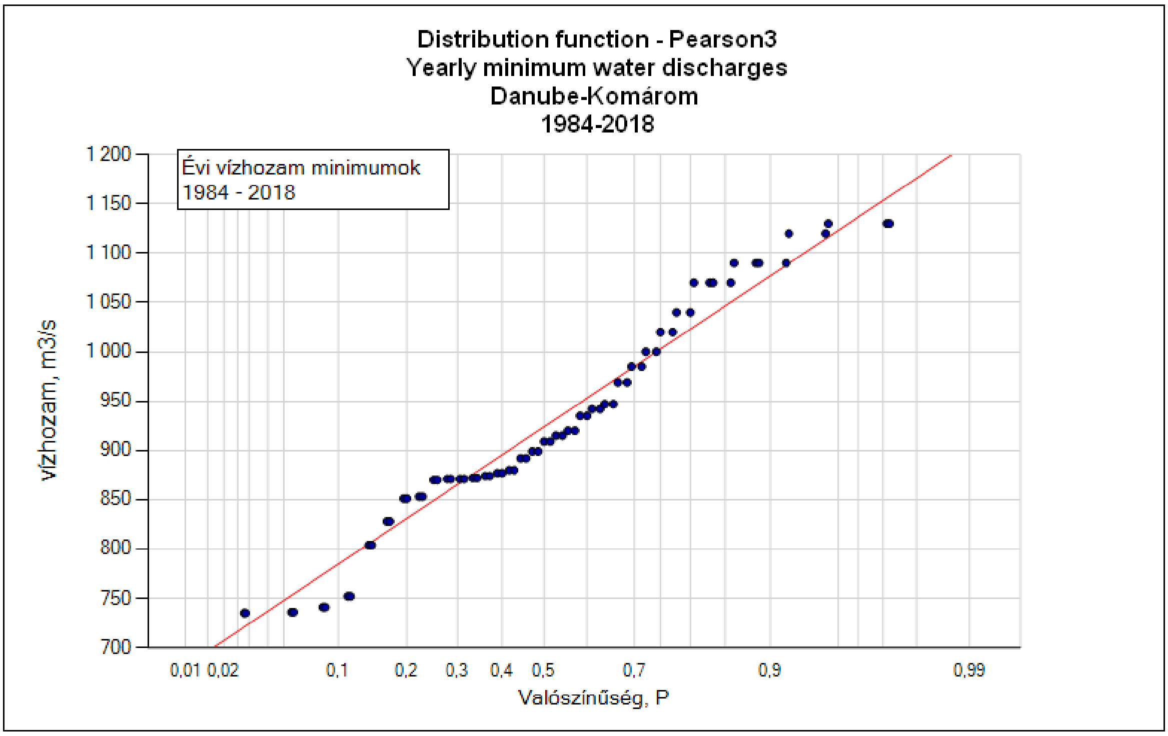

Fig. 14. Pearson3-type distribution function for yearly minimum water discharges, Danube-Komárom[5]

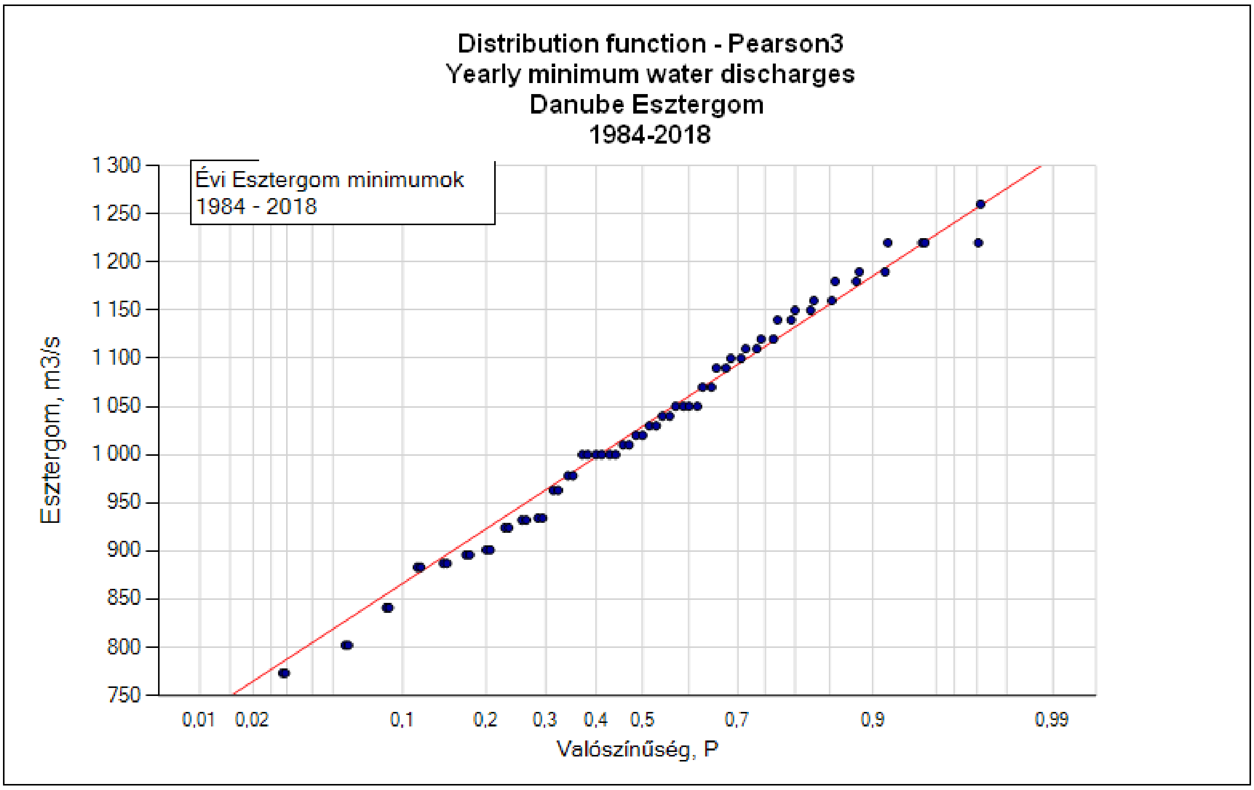

Fig. 15. Pearson3-type distribution function for yearly minimum water discharges, Danube-Esztergom [5]

Based on the empirical distributions of the annual minima of water discharge and the three best fit theoretical distribution functions overall, the estimated low-water discharge return times in October 2018 are given in the table below.

Table 5: Calculated return times of the 2018 low water discharges

Distribution function type	**Nagybajcs**	**Komárom**	**Esztergom**
	1995-2018	1984-2018	1984-2018
Log-Pearson 3	30 years	28 years	49 years
Pearson 3	**30 years**	**26 years**	**43 years**
GEV	25 years	30 years	42 years
empirical	**46 years**	**70 years**	**68 years**

Conclusions

Examining the Komárom data after 1984, or the shorter time series on other stations, we get that the low-water discharges return times in October 2018 can be characterized in the range of 25-50 years. Considering the empirical distribution this range is between 45-70 years. The higher return times are characteristic on the lower stations of the evaluated section.
Based on the basic statistical evaluations, the following conclusions can be drawn:
Due to the natural changes and artificial interventions affecting the Danube riverbed, the available ≈100-year-long water level and water discharge time series cannot be considered statistically homogeneous.
The methodological theses of previous low-water studies, which considered the statistical evaluation of water levels as primary variable, seem to be overturned. It is possible that the water discharge data sets for the period from 1980 to the present seem more realistic as a primary variable for the study of low waters. Using the data of the last nearly 40 years, we get a mostly homogeneous time series, however, when examining annual extreme values, the statistical sample

will be quite small, which can significantly impair the results and reliability of the simple trend and distribution function tests. The studies established different average return times for the low-water level and low-water discharge values in October 2018 at the given hydrographic stations, respectively. In addition to the trend studies, this is explained by the changes in the riverbed that can still be observed in the Danube, which are the most significant in the Gönyű regional section.

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