THE MAIN CHARACTERISTICS OF THE SURFACE HIGH-WATERS OF THE TISZA WATER SYSTEM

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The Tisza water system occupies an important place in the hydrography of the Hungarian Plain: although the Tisza leads off a relatively low proportion of the waters flowing through the country, in spite of the frequency of the low-waters the Tisza is nevertheless an important Hungarian river from the aspect of water-supply management.

It is known that at the beginning of the 18th century there were still extensive standing waters and periodic inundations on the Plain section of the unregulated Tisza water system (Fig. 1). The ancient marshes controlled a significant area on the Plain, this area increasing or decreasing in the course of history. The destruction of the forests during the periods of Turkish and Austrian rule completely altered the hydrographic picture of the region in certain parts of the catchment area. Even by the beginning of the 18th century it was not possible to speak of appreciable results of the water-regulation work: the succes was limited and of no great importance.

The regulation of the Tisza waters, the great work of István Széchényi and Pál Vásárhelyi, was begun in 1846 and, not including certain later supplementary work, was by and large completed in 1908. However, the embankment system was practically ready predominantly on the lines of the present embankments after the first 25 years of work, that is by 1872 (though naturally much less extensive and much lower than the present system).

At the same time, of the 101 intersections constructed throughout the total length of the river up to 1908 and which remained, 59 became mother-beds, 21 developed well, and the remaining 21 did not develop further. The transitional period of the regulation between 1846 and 1872 gradually changed the water-course of the Tisza. This was manifested in the elevation of the high-waters, and the reduction of the -low waters. A new period followed in the life of the river between 1872 and 1908, during which the water-course was finally constrained to the new line given by the embankments and the intersections. Compared to the later ones, this concluding period was perhaps characterized by a relatively even milder nature to the extremes, since at that time bursting of the embankments could still occur here and there, and thus the maximum floodwater levels could not occur everywhere in their entirety. After 1872, however, the bulk of the water levels of the flood waves essentially reflected the new conditions of the water-course of the river.

Although it is true, therefore, that 100 years have not yet passed since the completion of the regulation in 1908 until the present, 1976, nevertheless from the aspect of the water-course we consider it justified to regard the period 1876—1975 as the

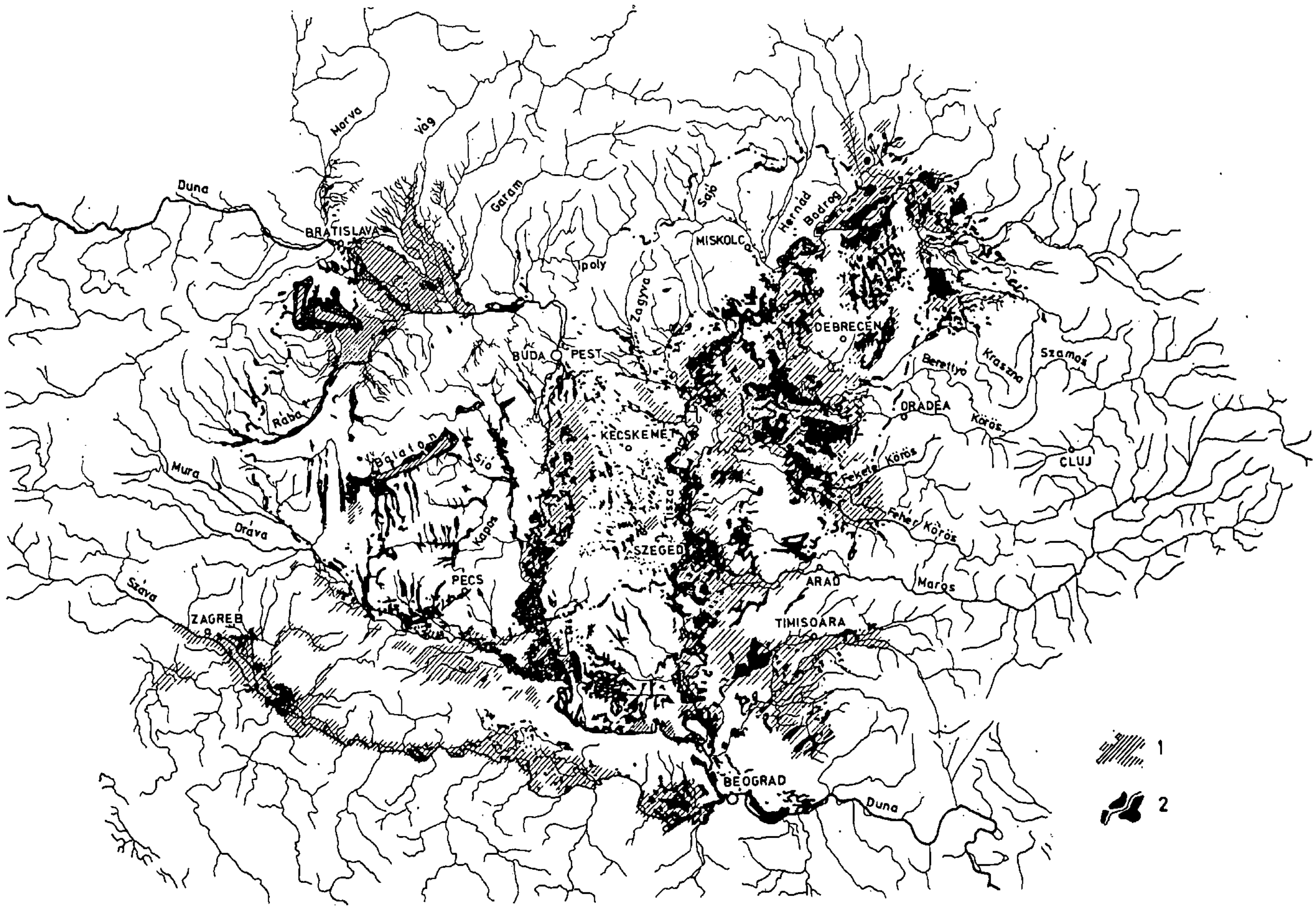

Fig. 1. Map of Hungary prior to river regulation and elimination of floods.
1: Areas periodically covered by water
2: Areas permanently covered by water

first century of the regulated Tisza and to examine this as a unity. This is otherwise confirmed by the favourable results of the statistical homogeneity examinations to be reported later.

The data we shall give are elements of a statistical multiplicity. The mass of the facts expressed by numbers explain everything, without any special directions, and we could thus remain objective even to the point of dryness in our conclusions. Individual facts are the more surprising, the more they rėmain mere facts, at times strengthening our previous hydrological picture, at times modifying it. Accordingly, our intention was simply to review the individual hydrological facts for the first 100 years of the regulated Tisza (and within these the facts relating to the floodwaters) in our own classification and with our own conclusions.

The main natural geographical components of the surface water turnover the water system

The capricious behaviour of the water of the Tisza frequently causes unexpected hydrological events on the Hungarian Plain. Its incalculability is further enhanced by the effects of the tributaries. The violence of the behaviour is naturally manifested in extreme water deficits too. It often occurs that only the natural basic water reserve is to be found in the bed of the Tisza in summer and autumn. In the case of either extreme, we are faced hydrographically with a natural feature which demands active intervention urgently. The factors giving rise to a floodwater situation in the water system are now known exactly. Abnormal hydrometeorological conditions and the orographic (surface-relief) characteristics of the catchment area can be denoted as the primary inducing causes. Whereas the latter factor can be recognized geographically, at present it is not possible to give reliable predictions of the occurrence in time of the dydrometeorological factors and of their qualitative and quantitative changes. On the basis of our experience, we can perform calculations referring only to the frequency of occurrence, but these do not indicate the concrete time of the expected occurrence. Nevertheless, as regards floodwater defence, even this knowledge is indispensable. The flood wave series in 1970 (but also the bulk of the higher floodwaters occurring during the preceding century) was characterized by the fact that the behaviour of the rivers of the water system differed considerably from the regularity corresponding to the average conditions.

Based on the hydrographic regularities occurring in the water system, the behaviour of the water of the Tisza is characterized by the appearance of three floodwaves (not always all observed) annually. This regular behaviour may be modified significantly in the exceptional cases, since the precipitation on the catchment area is a phenomenon connected primarily to the period, and not to a definite season.

Extreme weather is frequently accompanied by regionally appearing extensive differences in precipitation, but this can give rise to flooding of an inestimable extent.

Both the average and the absolute precipitation values indicate the fairly unbalanced hydrimeteorological features of the water system; the reason for this is mainly that the water system lies geographically in a temperate region where air massės of different types (continental, oceanic, Mediterranean, Arctic) frequently interact actively with one another. The amospheric aggression extending to the whole of the basin is generally not of uniform precipitation distribution; intensive precipitation activity of high yield is mainly restricted only to a smaller area. The reason for this may be sought in the surface relief (Fig 2). It can readily be seen from Fig. 2 what precipitation values must be reckoned with in the regions, taking into account the many-years' averages. The data reflect well that an annual precipitation of 600 mm is characteristic on more than half of the catchment area. This is less than the evaporation value for the given area. The picture changes in the higher regions of the hilly districts, for the situations of the highlands, their shapes, heights, slopes, surface vegetation, etc. are all important factors of the orographic precipitation formation.

The known extent of the increase in the amount of precipitation with elevation above the relief has different values in the different highlands. The individual highlands in the parth of the air currents carrying the precipitation are in a favourable geographical situation, whereas others are unfavourably situated from this respect. If the factors inducing precipitation and the many-years' averages of the precipitation are taken into consideration, four characteristic geographical regions can be differentiated on the catchment area.

a) The Hungarian Plain and the peripheral parts of the highlands. The annual precipitation is 500—700 mm, with the precipitation maximum in June, and the minimum in January. The precipitation distribution may vary both in time and location.

b) The area of the Erdélyi basin and the smaller intermontane basins. The annual precipitation is 600—700 mm, with the precipitation maximum in June, and the minimum in January. Compared to that on the Hungarian Plain, the precipitation distribution is of a less extreme nature.

c) The area of the Erdélyi-sziget mountains and the North highlands. The annual precipitation is 900—1000 mm, with the precipitation maximum in June, and the minimum in January. A characteristic feature is the larger snow accumulation in the winter periods.

d) The main chain of the Carpathians. The annual precipitation is 1100—1200 mm, with the precipitation maximum in June, and the minimum in January.

As regards the regional average of the surface water intake, the lowest monthly value is observed for January in every section on the catchment area of the Tisza. The maximum occurs in June for the predominant part of the catchment area. During the spring snow-melting (March-April), an intensive increase in water intake is experienced on the vast majority of the catchment area, and a second maximum arises. Since those regions of the Tisza catchment area which lie at 2000 m above sea-level are very small in area, the snowmelt on these regions does not cause a significant difference, and in time is mixed in with the water quantity arising from the summer rains.

In contrast with this, in the regions of the Central highlands at 500—800 m above sea-level the water intake exhibits a double maximum. The main maximum is associated with the intensive precipitation at the beginning of summer, and the second one with the snow-melting in March. The same phenomenon arises in higher regions too (at 1500 m), wit the difference that here the main maximum is provided by the snow-melting, which occurs later (Table 1, compiled after y. PÉCZELY). The courses of the surface water intake of the catchment area in time and space may be of various extents, but in the upper reaches of the Tisza the maximum water intake always lies in April, while elsewhere the June maximum predominates.

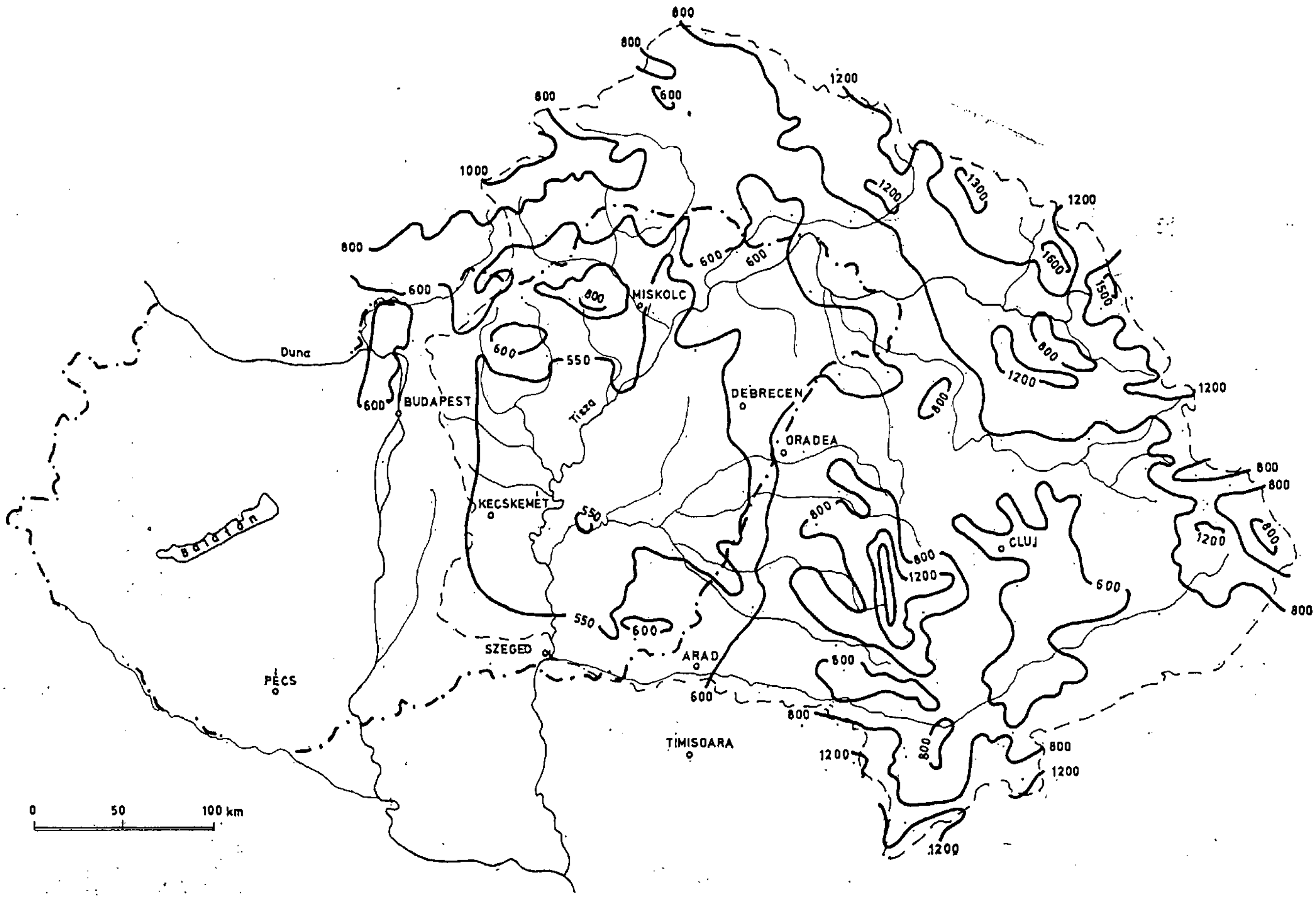

Fig. 2. Annual precipitation in mm (based on the 40-year average) on the catchment area of the Tisza.

Table 1. The Water-Income of the Water-System

	J	F	M	A	M	J	J	A	S	O	N	D	Year
	A. Areal averages of surface water intake, mm												
Upper-Tisza	22	42	122	124	101	122	118	116	91	94	73	45	1070
Szamos	21	39	79	72	81	102	91	86	60	64	51	40	786
Bodrog	24	46	87	70	75	98	95	98	71	75	66	47	855
Sajó	20	36	54	51	75	86	83	72	58	54	53	34	676
Zagyva	21	34	50	49	66	74	60	57	47	52	53	34	597
Körös-es	26	40	61	68	76	92	72	71	53	58	52	40	709
Maros	19	32	61	65	84	109	88	80	54	55	41	31	719
	B. Areal averages of snowmelt, mm												
Upper-Tisza	20	40	106	71	12	0	0	0	2	11	25	29	316
Szamos	18	34	59	19	2	0	0	0	0	4	14	22	172
Bodrog	21	40	62	16	1	0	0	0	0	4	15	25	184
Sajó	15	28	32	6	1	0	0	0	0	2	8	16	108
Zagyva	14	24	26	5	0	0	0	0	0	1	6	12	88
Körös-es	17	30	35	19	5	0	0	0	0	3	9	16	134
Maros	14	26	41	16	2	0	0	0	0	3	10	16	128
	C. Proportions of surface water intake from snowmelt (%)												
Upper-Tisza	91	95	87	57	12	0	0	0	2	12	34	65	30
Szamos	86	88	75	26	2	0	0	0	0	6	28	55	22
Bodrog	78	87	71	23	1	0	0	0	0	5	23	53	22
Sajó	75	78	59	12	1	0	0	0	0	4	15	47	16
Zagyva	67	70	52	10	0	0	0	0	0	2	11	35	15
Körös-es	65	75	57	28	7	0	0	0	0	5	17	40	19
Maros	74	81	67	25	2	0	0	0	0	5	24	51	18

In addition to the hydrometeorological factors giving rise to a floodwater situation, important roles are also played by the relief and by the flow density. The values of the surface run-off (Fig. 3) illustrate well that the regions of the individual highland systems augment the contents of the Tisza and its tributaries with a considerable mass of water. A run-off value even greater than 30 $l/sec/km^2$ on one-third of the highland regions means in practice that close to 100% of the total precipitation runs off. The rate of run-off is appreciably influenced by the slope of the surface and by the density of the surface river network (Fig. 4).

On the basis of the flow densities, the catchment area of the Tisza is asymmetric: the sepplementing of the Tisza water and the development of a floodwater situation are determined primarily by the left-hand side tributaries. It may be stated as a fact that the most important regulators of the behaviour of the Tisza are the relief of the left-hand side water system, the density of the water network there, and the distribution of the regional precipitation.

On the basis of the qoutient $D = L/S$ in Fig. 4, there are certain areas possessing very dense water networks and considerable run-off values: the Radnai and Máramarosi snowy mountains, the regions of the Avas, Kőhát, Gutin, and Lápos volcanic highlands, the Borgói, Kelemen, Gyergyói, Csiki, Görgényi, Fogarasi and Ruszka snowy mountains, and the Bihar, Gyalui and Érc mountain systems.

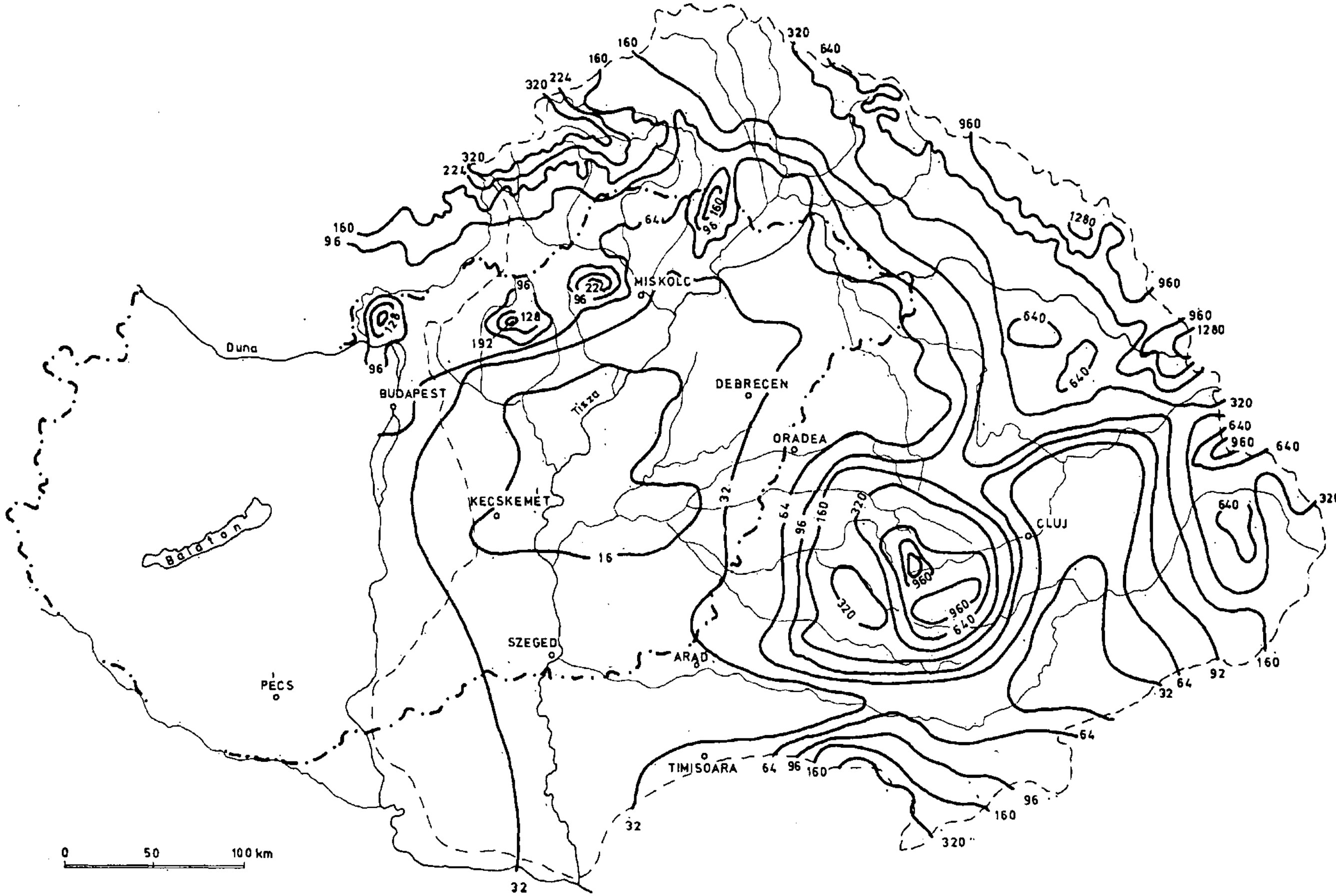

Fig. 3. Many-years' average run-off values in mm on the catchment area of the Tisza.

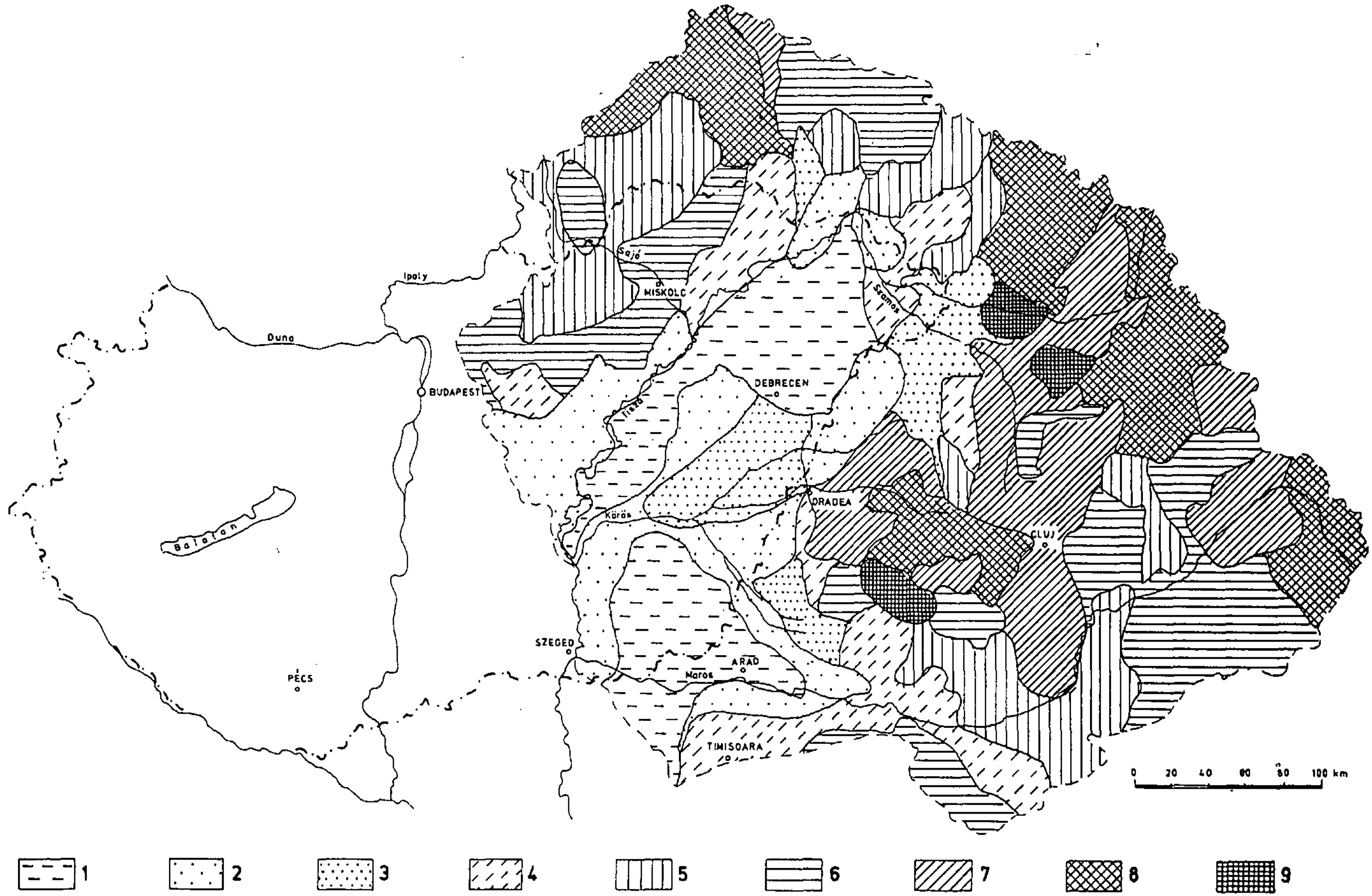

Fig. 4. Surface water-flow density (D=L/S) on the catchment area of the Tisza.
1: 0.0—0.1 km/km² 2: 0.1—0ü2 km/km² 3: 0.2—0.3 km/km² 4: 0.3—0.4 km/km²
5: 0.4—0.5 km/km² 6: 0.5—0.6 km/km² 7: 0.6—0.7 km/km² 8: 0.7—0.8 km/lm²
9: 0.8—0.9 km/km²

The regions of the Szamosi table-land, the Erdélyi basin, the Mezőség and the Szilágyság exhibit moderate water-network densities and run-off coefficients.

The surface water-network density and the surface run-off are very low in the basin of the Hungarian Plain.

Types, extents and frequencies of floodings

For a simple, but nevertheless representative characterization of the hihgwaters of the Tisza, we shall consider the four water-gauges that can be regarded as the most important: those at Vásárosnamény, Tokaj, Szolnok and Szeged. There is no doubt that most arguments support the choice of these four water-gauges. At Vásárosnamény the Tisza has already taken up the water of one of the most important left-hand tributaries, the Szamos. At Tokaj another important tributary, the Bodrog, this time on the right-hand side, enters the Tisza. Tokaj is otherwise mentioned by Bogdánfy as the upper-Tisza end-point of the increase of the descending floodwater yields (the other such, lower-Tisza end-point is Szeged), above which the maximum water yields still increase, coming downstream in the longitudinal section, and below which they already decrease because the tributaries can no longer counterbalance the levelling-out effect of the floodwaves. Szolnok is the most important, and as it were the central water-gauge of the given section of the middle-Tisza. At Szeged the Tisza has picked up its final and largest tributary, the left-hand Maros, following the confluence of the similarly left-hand Körös. Every drop of water which falls onto and runs off the surface of the Tisza catchment area must therefore flow through the Szeged section. At the same time, Szeged is also the last water-gauge station on the Tisza in Hungary; below this the effect of the Danube can also be felt in its floodwaters.

A further question is what water-levels should be regarded as "flooding". For the sake of uniformity and simplicity, agreement and some slight concession must be made here. The water-level of 600 cm is a round value, and also a typical one, and in the regions of all four selected water-gauges this level lies close to that below which the river remains in its bed or, in certain sections where it would already possibly overflow the edge of the bank, it can be kept in the bed with certainty even by protection means and forces that are fairly primitive, equivalent to those existing before the technical development of the 19th century. Accordingly, exceeding of the water-level of 600 cm was taken as the criterion for the study as to whether or not there was floodwater in the Tisza during the periods selected (in the present case 4-monthly periods were examined).

In the interest of numerical evaluation, again a little arbitrarily, but with the possibility of readier consideration ensured, the year was divided up into three periods corresponding to the winter-spring flooding, the summer flooding and the autumn flooding, from January 1 to April 30, from May 1 to August 31, and from September 1 to December 31, respectively. A possible source of error here is perhaps that, mainly in the lower-Tisza, certain winter-spring floodwaves, which peak there already at the beginning of May, are classified as summer floodwaters. Similarly, any rarely-occurring December melting leads to the typically winter water being classified as autumn water. However, the significance of these undoubted deficiencies is not large.

Those 4-monthly periods in which the water-level at most attained 600 cm on the water-gauge, but did not exceed this, are given the code number 0, while those in which the 600 cm level was exceeded are given the code number 1. Hence, any year may be characterized in one of eight different ways. The characterization 000, for example, means that there was no flooding, i.e. no water-level in excess of 600 cm, throughout the year according to the water-gauges examined. The classification 111 indicates that the 600 cm water-level was exceeded at least once in each of the three 4-monthly periods in that year. The code 100 is the symbol for spring flooding only, 010 denotes summer flooding only, and 001 autumn flooding only. Similarly, the codes 110, 101 and 011 indicate flooding in two of the three 4-monthly periods. This coding method does not show separately whether the 600 cm level was exceeded on more than one occasion in any given 4-monthly period.

The maximum highwater (HM) levels on the individual water-gauges in the different periods were taken from the Hudrographical Yeardooks, end further evaluations were carried out from these, as a source of basic data.

With the aid of the code numbers 0 and 1, Table 2 shows the frequencies of pears of the vaious floodinb types during the past century.

Table 2. *Periodic floodings compared to the 600 cm water-level from 1876 to 1975*

	Vásárosnamény	Tokaj	Szolnok	Szeged
000	33	28	33	38
100	27	33	25	19
010	3	5	4	6
001	6	4	4	3
110	15	18	24	25
101	6	6	2	1
011	1	2	2	2
111	9	4	6	6
	100	100	100	100

The most frequently-occurring type of year is the dry one, i.e. the 000 case. This is found with a frequency of 30% on the upper three water-gauges, and with a frequency of 40% on the Szeged gauge. This shows that flooding of the Tisza may sometimes not occur for several years on end. (Such dry periods, for example, are to be found in 1896—1901, 1903—1906, 1909—1911, 1926—1931, 1936—1939 1943—1947, 1969—1961 and 1971—1974.) If the level 700—750 cm is taken as criterion, there are two periods of almost 20 years (1896—1911 and 1943—1961) during which the Tisza did not rise above the given level in its middle and lower sections. There are no such long dry periods in the upper section, and an otherwise extensive period of calm is disturbed more frequently by individual, suddenly-occuring flooding.

Next in frequency after the 000 years follow the years of 100 and 110 types. The former are more common for the upper-Tisza than for the lower-Tisza, but the situation is the opposite for the latter type. The cause of this may be that the spring floodwaters more often reach the middle- and lower-Tisza only in May. Years with a spring floodwater alone (100 type) have a frequency of about 30% for the upper sections of the river, and of about 20% for the lower section. Years with floodwater in both spring and summer (110 type) have a frequency of below 20% for the upper sections, but a frequency above 20% for the lower section. All this shows that it is necessary to reckon with spring floodwaters and also with spring-summer floodwaters in the Tisza, as regards frequency and importance. Individually, the frequencies of the years of other types are fairly insignificant, but when considered together they comprise about 20% of the total. Perhaps only the markedly wet years (111 type) deserve special attention. Such years were 1876, 1879, 1882, 1884, 1885, 1893, 1912, 1919 and 1941 at Vásárosnamény, 1876, 1919, 1941 and 1965 at Tokaj, 1915, 1919, 1922, 1941, 1952 and 1965 at Szolnok, and 1876, 1878, 1912, 1915, 1919 and 1941 at Szeged. It is interesting that years of 111 type occurred simultaneously for all four water-gauges only in 1919 and 1941, while three water-gauges indicated the 111 type simultaneously only in 1876. It may be stated, therefore, that the given years were not nesessarily years of a floodwater nature on both the upper and lower sections of the Tisza. There are years when the upper-Tisza floods violently in all three periods, but the strength of the floodwaves is expended in the upper section. On the other hand, there are also years when a large number of smaller floodwaves descend, unite with floodwaves arriving simultaneously from the tributaries, and give rise to a considerable build-up of water and protracted flooding in the lower section of the river (Table 3).

Table 3. *Periodic highwaters on the Tisza from 1876 to 1975*

	Vásárosnamény			Tokaj			Szolnok			Szeged		
	I—IV	V—VIII	IX—XII	I—IV	V—VII	IX—XII	I—IV	V—VIII	IX—XII	I—IV	V—VIII	IX—XII
600	43	72	78	39	71	84	43	64	86	50	60	89
601—700	27	17	11	33	20	13	28	25	12	18	16	8
701—800	21	8	9	20	6	1	17	7	—	21	19	3
801—900	9	2	2	8	3	2	12	3	2	10	3	—
901—	—	1	—	—	—	—	—	1	—	1	2	—
Total	100	100	100	100	100	100	100	100	100	100	100	100
>600	57	28	22	61	29	16	57	36	14	50	40	11

Compared to Table 2, Table 3 is more detailed. The Table shows not only whether or not the 600 cm water-level was exceeded, but also the frequencies of water-levels in excess of the "flood"-level of 600 cm, in intervals of 100 cm.

Let us consider first the lowest row of Table 3. This shows that, as regards the one hundred years, spring flooding was recorded in roughly 60 years on the upper three water-gauges, and in 50 at Szeged. A water-level above 600 cm in summer occurred in about 30 years for the upper two gauges, and in about 40 for the lower 2. In the autumn period the frequency of flooding decreases from 20 to 10 years on progressing downstream from the uppermost gauge. It follows from these data that:

a) Spring floodwater is very common in the Tisza. During the past one hundred years it occurred in around 60% at the three upper gauges and in 50% at Szeged.

b) Summer flooding is also appreciable throughout the entire length of the Tisza, with an occurence of 30—40%. Most summer floodwaters were recorded at Szeged. The highest floodwaters in 1919, 1941 and 1970 were summer ones, in the first two cases in May, and in 1970 in May and June.

c) The number of autumn floodwaters is not too large for the upper-Tisza, but substantially less for the lower-Tisza.

Let us now look at the whole of Table 3. Here we still find significant frequencies in the 601—700 cm interval, but less than for the water-levels up to 600 cm. Appreciable values are also observed for the 701—800 cm interval, but the frequencies are generally less than for the preceding interval (interestingly, this is not the case for Szeged). It is surprising, however, that the occurrence of maximum water-levels above 800 cm, resulting from regulation of the river, is relatively not too frequent. About two-thirds of the HW values in the interval 801—900 cm for the 4-monthly periods occurred in the spring period, whereas the bulk of the few cases higher than 900 cm took place after May 1. All this means that we cannot say that the likelihood of floodwater in the Tisza is higher as the year proceeds, but *an outstandingly high floodwater is the more to be expected, the more progressed the first half of the year.* The explanation for this is that one or two large floodwaves in themselves are never maximum, but if several floodwaves catch up with one another and meet in a peak together with the floodwaves of the larger tributaries, the case of maximum water can enswe in the Tisza. Much time is required for this to develop, however, and as a rule the first four months of the year is not enough: the winter-spring waters must unite with the late spring-early summer waters.

Let us mention here those years in which the water-level of the Tisza exceeded 800 cm, all the more so since the present embankment system in general demands a more advanced state of defence preparedness (usually grade III) at this level.

At Vásárosnamény the water-level peaked above 800 cm in the spring period in 1876, 1881, 1888, 1895, 1932, 1940, 1948, 1962 and 1964; in summer in 1884, 1970 and 1974; and in autumn in 1915 and 1947. The 900 cm was reached only once, on 23 March 1888, and exceeded only once, on 15 May 1970.

At Tokaj the water-level peaked in the 801—900 cm interval in spring in 1888, 1895, 1924, 1932, 1940, 1941, 1964 and 1967; in summer in 1919; 1970 and 1974; and in autumn in 1915 and 1925. The water-level has so far not exceeded 900 cm at Tokaj: the maximum high-water was 872 cm on 27 March 1888.

At Szolnok the water-level peaked above 800 cm in spring in 1888, 1895, 1924, 1932, 1940, 1941, 1953, 1962, 1964, 1966, 1967 and 1970; in summer in 1919, 1941, 1970 and 1974; and in autumn in 1915 and 1974. The 900 cm level has been exceeded (909 cm) only once, on 30 May 1970.

At Szeged the water-level peaked above 800 cm in spring in 1879, 1881, 1888, 1889, 1895, 1924, 1940, 1941, 1962 and 1970; and in summer in 1913, 1941, 1970 and 1974. A water-level higher than 800 cm has not yet occurred in autumn at Szeged. Peaking above 900 cm was the most frequent at Szeged: 916 cm on 12 May 1919, 923 cm on 15 April 1932, 961 cm on 2 June 1970, and 924 cm on 18 June 1970.

The data for the four selected water-gauges also indicate those years which, with their especially high water-levels, resulted in memorable floodwaters in the Tisza for the Water-Board experts. Such years were primarily 1888, 1895, 1919, 1932, 1940, 1941, 1970 and 1974. Of these, 1888, 1895, 1932 and 1940 had winter-spring floodwaters; 1919, 1941 and 1970 had late spring floodwaters (although there was also early spring flooding in 1970); and 1974 had a markedly summer floodwater. The 1879 floodwater, which destroyed Szeged with a water-level os 806 cm, did not attain 800 cm on the gauges above Szeged.

Waters in excess of 800 cm occurred in 15 years at Vásárosnamény, 13 years at Tokaj, 15 years at Szolnok, and 14 years at Szeged. On average, this is a frequency of 1 year in 7. On the other hand, compared to the average levels, and even to the floodwater level of 600 cm, these water-levels above 800 cm were very high, exceeding the level for ovespill onto the bank edges by even 300—360 cm. It can be regarded as significant that in every seventh year on average (and, with a certain probability, on more than one ocassion in some years) the water-levels exceed 800 cm on all four of the main water-gauges of the Tisza.

Next, it must be decided how the data comprising the elements of statistical multiplicity can be generalized with regard to examinations for the future, e.g. findings relating to the expectation of highwaters in the Tisza during the following one hundred years. An answer may be given to this with methods of mathematical statistics.

Tables 2 and 3 gave the relative frequencies of the water-levels during the past one hundred years, for the three 4-monthly periods. The relative frequency (p) of each event follows binomial distribution, with an expected value $k = n.p$ and with a scatter $S = \sqrt{n.p.(1-p)} = 10\sqrt{p.(1-p)}$ (where n is the number of total cases, here 100, and p is the quotient k/n formed from the tabulated k values). The two values arising from the square root of the scatter express the interval which, including the expectable value as the arithmetical mean, contains about 68,3% of the cases occurring. It is reasonable to select an interval characterized by two scattering values which contains 95,4% of the occurring values; i.e. for chance reasons only about 4,6% of the cases do not lie in the given scattering interval. Thus, the equation for the confidence interval at the 95,4% level is

$$K = \pm 20 \sqrt{p(1-p)}$$

If $k = 50$ and $p = 0,5$, therefore, K is maximum, with a value of 10. Thus, in every case where the frequency value is 50, i.e. when some event occurred 50 times during the one hundred years considered, it must be understood that, as a consequence of the chance causes resulting from the behaviour of the water, it can be stated with 95,4% certainty that in later periods the number of occurrences of the event will lie in the interval between 40 (i.e. $50-10$) and 60 (i.e. $50+10$).

Equation (1) is suitable for determination of the relevant confidence intervals in the cases of the other numerical frequency values. Some values may be given: for $k = 20$ and thus $p = 0,2$. $K = \pm 8$; for $k = 10$ and thus $p = 0,1$, $K = \pm 6$; for $k = 4$ and thus $p = 0,04$, $K = \pm 3,92$. The scatter values obtained are comparatively large. However, this is not a deficiency of the calculation producere, but stems from the peculiarities of the nature of the river. It would be incorrect to create the appearance of "engineering accuracy" and to introduce neglections which would be destined to "improve" the reported values.

Consideration of the floodwater periods for the Tisza shows that there are somewhat more 4-monthly periods involving flooding in the upper-Tisza than in the lower-Tisza. The difference is mainly accounted for by the autumn period. It might be said that the behaviour of the river is more violent in the upper section, and more quiet in the lower section. Because of the tributaries (Körös and Maros), however this rule is not of absolute validity. The effect of levelling-out begins from Tokaj and lasts until the mouth of the Körös. It may be manifested in Szeged too, but this can be disturbed by the back-swelling of the Körös and the Maros. The maximum peakings at Szeged, including those for the longer river sections below and above Szeged, are influnced decisively by floodwaves on the Maros and the Körös, simultaneously with those on the Tisza. No matter how large a floodwave may be on the upper section of the Tisza, if this cannot unite with a floodwave of the Maros at the same time in Szeged, there is a high probability that the Tisza floodwave will flatten out by Szeged. In the opposite case, however, floodwaves not beginning as maximum ones may become maximum in the lower section, and such floodwaters are the really high ones (1919, 1932, 1970). The Körös and particularly the Maros often peak before the floodwave of the Tisza arrives, and consequently it has happened on a number of occasions that the tisza has peaked several days or even a week earlier at Szeged than at Szolnok. As regards Szeged, otherwise it is most frequent for the Maros peaking to precede that of the Tisza by 3 days, but this is accurate only to ± 3 days with the scattering interval of 68,3%.

In generality, the following additional remarks may be made as a result of examination of the one hundred years' data:

a) The extent or lack of precipitation in given periods does not influence the floodwater conditions of the subseqent periods. It has often happened that a dry autumn has been followed by a spring with much precipitation and floodwater, but also that a summer with extremely high precipitation has followed a dry winter and spring. There is virtually no significance as to the extent of precipitation in the autumn and its effect on the winter, or as to whether a spring is associated with snow-melting or high precipitation.

b) In the history of the Tisza it is not ununsal to find periods of a decade or so free from floods, and periods of several years which are especially wet and thus prone to floodings. From all this it is not necessary and not possible to draw conclusions on the changing of the climate, and nor is there sufficient reason for us to talk of alleged deepening of filling-up of the bed of the river-course. The maximum highwater levels rise because they are rewritten if an elevation occurred, but these still fit into the probability series characterizing the behaviour of the river.

Let us assume finally that in the future the climate will not change, that the runoff conditions too will remain the same, and that there will be no significant technical intervention in the valley of the Tisza. If it happens merely that the precipitation coincides better than hitherto with the order of meeting of the floodwaves, it is still possible that the maximum highwater values now valid (primarily in the lower sections) may be exceeded by even half a metre. The "reserves" of the mutual effects of the water yields, as regard the floodwave meetings, have by no means been exhausted in the one hundred year period. Even in 1970 the flooding did not utilize these to the maximum extent: for example, if the two floodwaves of the Maros had reached Szeged in the opposite order, i.e. if the smaller floodwave had preceded the larger one, a water-level of 1000 or even 1020 cm would not have been impossible in place of the observed level of 961 cm.

Uniformity and extreme values of the highwaters

The concept of the "behaviour of the water", just like that of the "climate", is a collective concept. The fundamental definitions of Aujeszky for the climate may be taken over for the water behaviour, and thus it may be said that the behaviour of the water is the resultant of the hydrological (water-level, water-yield) possibilities for some river, i.e. a framework within which the hydrological events of the river in question must take place. The numerical values characterizing the "framework" may be determined by means of mathematical statistics. Data on the Tisza over one hundred years serve as the basis of our investigations.

Answers must primarily be given to the questions fo whether the same Tisza (highwater Tisza) flowed in the one hundred year period, or whether water-behaviour periods can be dinstinguished in the life of the highwater Tisza during this time. The second question is closely connected to the first: was there a change in the nature of the behaviour of the water of the Tisza after 1876, compared to that in the preceding period?

The answers the both questions can be given concretely from examination of the numerical multiplicity arising from the annual maxima (annual HW) in the water-levels, by means of the Smirnov-Kolmogorov method, the Student t-method, and the F-method, well-known in mathematical statistics. For application of these methods, the distributions of the HW data series for Vásárosnamény, Tokaj, Szolnok and Szeged are analyzed separately for two fifty-year periods, 1876—1925 adn 1926—1975 (Fig. 5). Only a single HW data series was available for before 1876, for Szeged, and even this only for an interval of forty years (1835—1875, with the exception of one of the intervening years). This latter HW distribution is shown in Fig. 5.

The essence of the Smirnov-Kolmogorov method is that the empirical distribution functions are plotted separately for the HW data series broken down into two parts; next, we seek the greatest difference between them in a vertical sence, i.e. on the probability scale, and this is compared from case to case, in accordance with the number of elements of the multiplicity and the proportion of the separation, with the threshold value determined according to the selected level of reliability. In a sample of one hundred elements divided into two, the threshold value relating to the 95% reliability level, for instance, is 0,272. In a comparison of samples with numbers of elemets $n=50$ and $1=40$, the 95% reliability level is associated with a threshold value of 0,29; the exceeding of this, occurring by the greatest probability difference interpretable between the two empirical distribution factors, points to the lack of uniformity of the two distribution functions and to the fact of non-exceeding.

With regard to the distribution functions in Fig. 5, it may be stated that the periods 1876—1925 and 1926—1975 confirmed the uniformity of the behaviour of the water in the life of the Tisza according to the four main water-gauges examined, for the differences observed in the highwater levels did not attain the threshold value indicative of lack of uniformity. However, comparison of the period 1835—1875 with either the imediately subseqent period, 1876—1925, or the later period, 1926—1975, points to the lack of uniformity of the highwater behaviour, as in this case the relevant probability differences exceeded the threshold value of 0,29. The result of application of the Smirnov-Kolmogorov method in effect expresses that, if we were to take the pre-1876 Tisza to be of the same nature as the Tisza in the subsequent

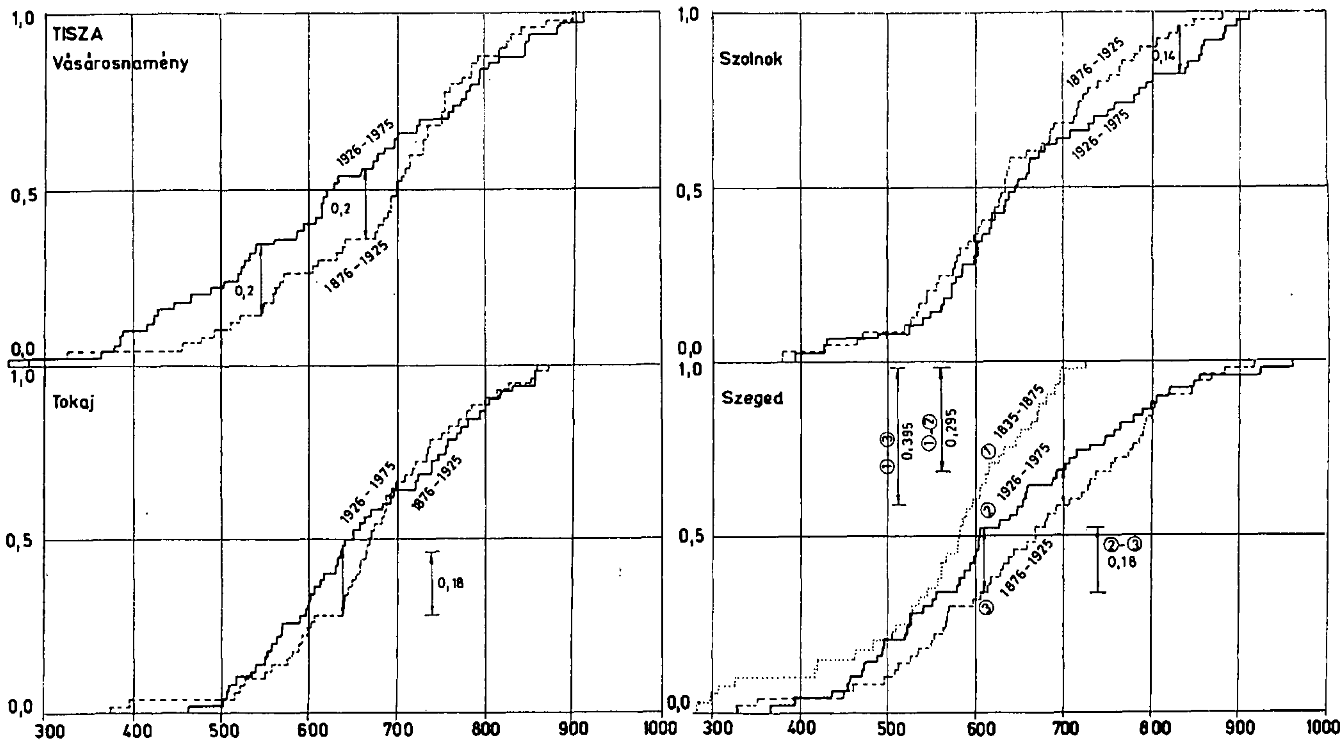

Fig. 5. Annual HW distributions for the part-periods.

period as regards the annual highwater behaviour, the possibility that we were right for chance reasons (here 0,2%) would be substantially less than 5%.

It seems reassuring, however, that lack of uniformity of the highwater behaviour for the overall period 1876—1975 could not be detected for any of the four water-gauges. This means that the differences between the behaviours of the water for the two fifty-year periods fit into the "framework" interpreted by identical water behaviour, and the chance causes involved in the behaviour may give rise to the differences just as easily as (if not more so than) some constantly acting factor (e.g. bed-deepening or bed-filling). Otherwise, it is advisable to be careful by stressing these latter two possible reasons, for at Vásárosnamény the first fifty years provide higher water-levels for the same step of the sequence in the low and moderate HW values.

At Tokaj the difference already extends to lower ranges, with smaller numerical values. At Szolnok the process is reversed, the second fifty years giving the relatively higher HW values. At Szeged, however, the first fifty years again do so. Is it possible to believe that the Tisza has deepened its bed in places, and become shallower in others? Perhaps yes, but 1—2 dm fifty years differences occurring as regards the averages of the HW values are scarcely convincing evidence of this. The behaviour of the water of the Tisza changed considerably during the 1870's- This is understandable because of the regulation. However, it would be difficult to explain (over and above the natural fluctuations in the behaviour, i.e. by causes other than chance) why the river flooded irregularly to a lesser extent in certain places in the second fifty years after the large elevations following the regulation. All the same, we considered it advisable to evaluate the annual HW data by other methods too.

The essence of the Student t-test is that, from the HW data series broken down into the two fifty-year periods, the expectable values of these are determined, i.e. their arithmetical mean values, the periodic mean highwaters (MHW), followed by the scatters of the HW data series. If the difference of the MHW values for the two fifty-year periods is compared to the "resultant" scatter characterizing the whole of the data series, it can be established whether the difference between the MHW values fits ot not into the numerical interval here one-sidedly expressing 95% of normal distribution. The condition for this is that the value of

$$t = \frac{MHW_1 \cdot MHW_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} \tag{2}$$

should not exceed 1.96, the threshold value relating to this condition. (Notations: n_1 and n_2 are the numbers of elements involved in the examination, in this case both 50, while σ is the empirical scatter of the relevant HW distribution.)

Our calculations (Table 4) showed that comparison of the data for the periods 1876—1925 and 1926—1975 for the four Tisza water-gauges nowhere refuted the hypothesis that the differences to be found in the data series for the two fifty-year periods are not significant. Consequently, it may be stated that their originating from identical statistical distribution, i.e. from the same water behaviour, has been confirmed. The largest MHW difference between the two fifty years is observed at Vásárosnamény: 42 cm. However, this is not significantly high within the t-test. The smallest difference is that at Tokaj: only 6 cm. The differences at Szolnok and Szeged are -26 cm and 31 cm, respectively. The fact that the higher MHW value occurred

Table 4. *Mean highwaters and scatters for the part-periods*

Water-gauge	MHW		S		t	F
	1876—1925	1926—1975	1876—1925	1926—1975		
Vásárosnamény	671	629	131	162	1,66	1,55
Tokaj	670	664	106	107	0,28	1,03
Szolnok	644	670	111	129	1,08	1,34
Szeged	663	632	135	138	1,14	1,03

for the second period at Szolnok, and for the first period on the other three gauges, would perhaps only be worthy of mention if the differences between the MHW values had been significant and sufficiently large to overthrow the homogeneity hypothesis. Under such conditions, however, remaining within the framework of chance fluctuation, all other explanations of the reasons for the differences observed would be incorrect.

Naturally, the result is different when the HW values for the period 1835—1875 at Szeged are compared with those for either of the two subsequent fifty-year periods. The t values now appreciably exceed the threshold value of 1,96 everywhere, and maintenance of our hypothesis on homogeneous water behaviour might be correct with a probability less than 0,001 in comparison with the immediately following fifty years, and with a probability less than 0,01 in comparison with the later fifty years. It is obvious from the calculations, therefore, that the behaviour of the highwaters in the period preceding the regulation differs significantly from that in the subsequent period.

The F-test compares the quotient of the squares of the scatters of the compared data series with the threshold value to be taken from the F Table. Our calculations showed that these quotients nowhere exceeded the threshold value of 1.60 generally established for this case, or of 1,64 in comparison with the pre-regulation HW values at Szeged. This can probably be attributed to the fact that the nature of the HW distribution of the river did not change as a consequence of regulation, since the weather did not vary, but the water-levels rose because of the high embankments.

Following confirmation of the uniform nature of the HW distribution for the post-regulation period, 1876—1975, therefore, we may now plot epmirical distribution functions for the complete period (Fig. 6). The curfe for normal distribution fits these distribution functions well. The largest difference between the step-like diagram and the curve is 0,08, while the threshold value for the lack of fitting in the given case is 0,136. The more important water-levels obtained from the normal distribution are listed in Table 5.

Our general findings are as follows:

a) The O points of the four main Tisza water-gauges (as regards the highwaters) are practically in agreement, since the MHW values vary only between 648 and 667 cm on the individual gauges, and thus this variation is less than the MHW fluctuations observed on the same gauge in the comparison of the two fifty years.

b) The empirical scatters are also fairly close to one another. The extent of the scatter is the largest at Vásárosnamény, ±148 cm; the values for Szeged, Szolnok and Tokaj are ±137 cm, ±120 cm, and ±106 cm, respectively.

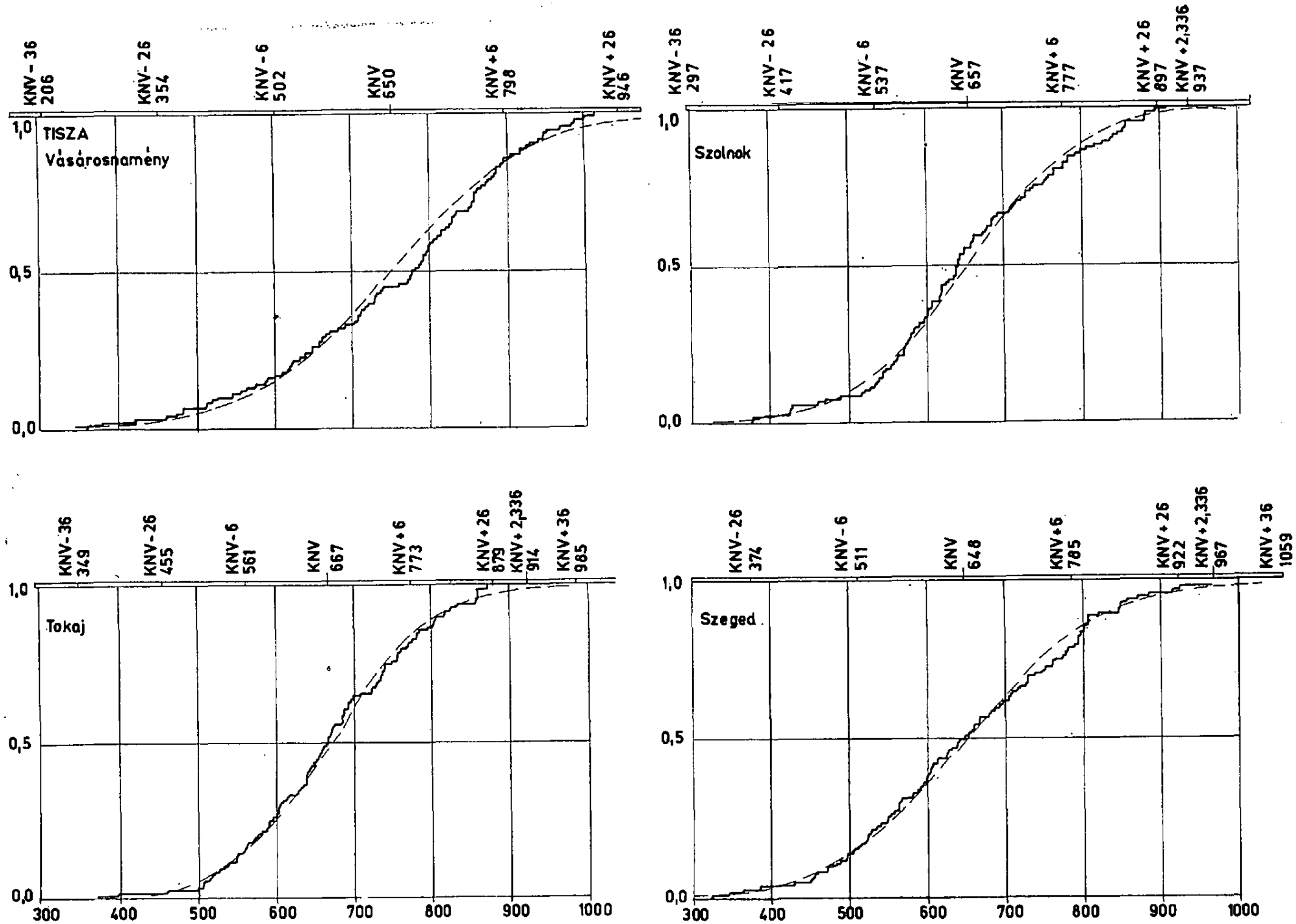

Fig. 6. Empirical HW distribution function for the Hungarian section of the Tisza.

Table 5. *Mean highwaters, Scatters and Extreme values*

Water-gauge	MHW	6	MHW —26	MHW +25	MHW +2,336	MHW +35	Max. HW
			95,4% interval		1% HW	0,13%HW	
Vásárosnamény	650	148	354	946	995	1094	912
Tokaj	667	106	455	879	914	985	872
Szolnok	657	120	417	897	937	1017	909
Szeged	648	137	374	922	967	1059	961
Szeged 1835—1875	644	144	256	832	880	976	722

c) The HW level interval with a scatter of ± 2, which embraces 95,4% of the cases occurring, includes the highest maximum HW levels at Vásárosnamény and Tokaj. At Szolnok and Szeged the maximum HW was in excess of this interval (by a 39 cm at Szeged).

d) If we examine what the HW value is which occurs once on average per one hundred years as regards the series of annul aHW values (assuming normal distribution), then the MHW must be increased by $2{,}33\sigma$. The value thus calculated exceeds the maximum HW by 83 cm at Vásárosnamény, by 42 cm at Tokaj, by 28 cm at Szolnok, and by only 6 cm at Szeged. Does this mean that the Tisza has not yet taken full advantage of its statistical possibilities at the upper gauges, and that increases of the maximum HW are primarily to be expected there? A clear-cut answer can not be given, all the more so since it is perhaps precisely at Vásárosnamény that the HW istribution differs most considerably from the normal. There can be no doubt, however, that these high values have never been left out of consideration in the construction and maintenance of the embankments.

e) It is also interesting to consider the MHW +36 values, which are theoretically the number of waters occurring 1,3 times per 1000 years on average. Such values are not impossibly high, and it must be noted that even today the tops of the embankments are close to these values in many places. The water-level of 1059 cm at Szeged (as the "1000-year value") does not appear unattainbale in an extreme case. This is barely 1 m higher than the maximum HW which occurred in 1970. The heightening of the defence wall now going on at Szeged is therefore really justified, from the present defence-level of 1040 cm to 1090 cm.

The HW data series for the interim period, 1835—1875, no longer characterizes the behaviour of the old, unaffacted Tisza, but as a result of the lack of observations there is no mass of utilizable data from prior to 1846.

The transitional state of the period 1835—1875 is confirmed by the fact that the empirical distribution function differs significantly from the normal. Hence, the theoretical results calculated from normal distribution can not be used in this case. The level of the floodwater troying Szeged in 1879 (806 cm) was 84 cm higher than the maximum HW of 722 cm for the interim period. The levels of 786 cm at Szeged in 1876, 795 cm in and 720 cm in 1878 should have been sufficient warning, and indeed they were (but only for the experts). However, no-one could have predicted the HW changes due to the regulation in the 1870's.

Finally, let us examine what can be expected of the Tisza in the future, particularly in the fifty or one hundred years following 1976. It is obvious that the conditions causing changes in the behaviour of the water (artificial climatic changes, radical changes in the catchment area, bed changes, mass highland and plain reservoir construction, etc.) can not be forecast. Let us make some conclusions, however, as to the maximum HW value and the individual extreme HW values. The indicator of the unchanged nature of the behaviour of the water at the reliability level 95,4% is if the difference of the MHW value for the next one hundred years, i.e. the period 1976—2075, does not exceed the value $2\sigma_n = \pm 2\sigma/\sqrt{100} = \pm\sigma/5$. At Vásárosnamény this is ± 30 cm, at Tokaj ± 21 cm, at Szolnok ± 24 cm, and at Szeged ± 27 cm (Table 4). The numerical data of Table 3 and 4 may otherwise be used to establish the condition of uniformity for the following fifty years or for other periods, applying the well-known correlation $\sigma_n = \sigma/\sqrt{n}$.

Thus, it is possible to state what the conditions are for characterization of the behaviour of the water in the future, but not whether the nature of the behaviour in the future will be the same as that at present or not.

For the expected maxima too, preliminary conclusions can be made only in the event of the maintenance of the condition of water behaviour of an unchanged nature. Attention is drawn here to two characteristic data in Table 5. The MHW +2,35 value is indicative of the HW to be expected on one occasion on average in one hundre value is indicative of the HW to be expected on one occasion on average in one hundred years. But this does not mean that the given water-level unconditionally occurs once in some one hundred year period. The probability that it will not occur is fairly high: 0,3679. The probability that it will occur once or more times is therefore 0.6321. The probability of a single occurence is again only 0,3679, which means that a probability of 0,2642 still remains for occurrence on more than one occasion. Of this, 0,1840 is the value for double occurrence, a fairly high value. The total probability for more than two occurences is 0,0802, of which 0,0613 is the probability for three occurrences. The total probability for four or more occurrences, 0,0153, is rather small, but with regard to the severity of such cases the probability should nevertheless be taken into consideration.

The reasonably assumable upper limit of the maximum water-level is given in statistical practice by the value MHW — 36. This is the 0,13% average return value, and thus is not exactly zero. Here we have already reached the limit of problems sluble by means of mathematical statistics; this branch of science is capable of solving only those questions which follow directly from the series of basic data, and since the data for the past contain the future not deterministically, but stochastically, the uncertainties of occurrence can not be dispelled unambignously be ond a certain limit.

Summary

The study evaluates the highwaters of the Tisza which occurred in the period 1876—1975. It proves that in this examined period the annual highwaters originate from water behaviour of the same nature, and that the river did not change its highwater character over and above chance fluctuations. However, this is not the case for several decades prior to 1876, the period of regulation of the Tisza.

The one hundred year study confirmed that about one-third of the years were floodwater-free, i.e. the water-level did not exceed 600 cm on the main water-gauges in spring, summer or autumn. Apart from these, the most frequent years were those

when there was floodwater only in the spring, or in both spring and summer. Years with floodwaters of other types were rare individually, together comprising 20—25% of the total number of years. The greatest general Tisza-valley floodwaters occurred in 1888, 1895, 1919, 1932 and 1970. Water-levels higher than 80 cm were observed on average 13 times on the main water-gauges, i.e. roughly in every seventh year, mainly in the first four months of the year. For the development of outstandingly high floodwater, particularly in the middle and lower river sections, it is necessary for the floodwaves of the main river to build up on one another, and for the tributaries to flood simultaneously; accordingly, such floodwaters usually occur only in the later stages of the first half of the year (im May or June). The water-level attained or exceeded 900 cm at Vásárosnamény in 1888 and 1970, at Szolnok in 1970, and at Szeged in 1919, 1932 and 1970.

The empirical distribution function for the annual highwaters for the period 1876—1975 is close to normal distribution. Thus, besides the expectable mean highwater value, the scatters too are characteristic. For all four water-gauges examined (at Vásárosnamény, Tokaj, Szolnok and Szeged) the water-levels which can occur once on average in one hundred years were higher than the previous highest water-levels, to a greater extent for the upper than for the lower gauges. This, together with the highwater falue of 1,3 per thousand, indicates that high floodwaters in excess of the current maximum water-levels can not be excluded in the future.

REFERENCES

M. Andó (1971): A Tiszai vízrendszer árvízhelyzetének főbb természeti földrajzi összetevői (Main natural geographical components of the floodwater state of the Tisza water system). Water-Board Documentation and Information Office, Budapest,

L. Aijenszky—D. Berényi—B. Béll (1951): Mezőgazdasági meteorológia (Agricultural meteorology). Akadémiai Kiadó, Budapest.

Ö. Bogdánfy (1906): A természetes vízfolyások hidraulikája (Hydraulics of natural flowing-waters). Franklin Society, Budapest, II, pp. 228—250.

I. Botár—Zs. Károlyi (1971): A Tisza szabályozása (Regulation of the Tisza). Water-Board Documentation and Information Office, Budapest, I, p. 60; II, p. 30.

B. Iványi (1948): A Tisza kisvízi szabályozása (Low-water regulation of the Tisza). Vízügyi Közlemények, 4, p. 418.

I. Kardos (ed) (1975): Szeged árvízvédelmi rendszere (Floodwater defence system of Szeged). Water-Board Documentation and Information Office, Budapest, p. 21.

J. Korbély (1937); A Tisza szabályozása (Regulation of the Tisza). Debrecen, p. 41.

Gy. Péczely (1971): A felszíni vízbevétel rendszere a Duna felső és középső vízgyűjtőjén (Surface water-intake system on the upper and central catchments of the Danube). Publication of the National Meteoroligical Service, Budapest.

T. Moriariu—A. Savu (1954): Densitatea retelei hidrografice din Transilvania, Banat, Crisana si Maramures. Editura Academiei Republicii Populare Romane. Vol. 1.

I. Vágás (1972): Az Alsó-Tiszán és mellékfolyóin 1970 májusában és júniusában kialakult árhullámok hidrológiai jellemzése (Hydrological characterization of the flood-waves developing on the lower-Tisza and its tributaries in May and June 1970). Publication "Az Alsó-Tiszavidéki nagy árvízvédekezés, 1970 (High floodwater defence in the lower-Tisza region, 1970)" of the Water-Board Documentation and Information Office, Budapest, p. 61.

I. Vágás (1974): Hidrológiai statisztika (Hydrologic statistics). Notes for specialist engineers. Technical University, Budapest (Note M. 275).

Water-Board Yearbooks (1892—1975) and various publications dealing with previous water-levels (1876—1891).

I. V. Nagy (1965): Hidrológia. Budapest.