PERIODICA POLYTECHNICA SER. CIV. ENG. VOL. 45, NO. 1, PP. 121–140 (2001)

# TYPICAL FLOOD PATTERNS ON THE FEKETE KÖRÖS AND FEHÉR KÖRÖS RIVERS AND THE POTENTIAL FLOOD CONTROL DEVELOPMENTS

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Received: Sept. 5, 2000

## Abstract

Owing to the physico-geographical situation of the country, important and steadily growing public interests have been attached to flood and inundation control for centuries in Hungary. The vast lowlands of the Hungarian Plains form the deepest part of the Carpathian Basin. The flood waves emerging from their steep mountain catchments in the Carpathians and the Alps tend to overtake each other causing often emergency situations.

The *flood embankments* – main line levees – along the rivers form the backbone of the *flood control scheme* developed in Hungary from the middle of the past century to these days. At the same time, the flood control experiences gained over the recent 30 years have demonstrated that along with the development, strengthening to the prescribed dimensions of the embankments along the river, new engineering solutions and methods must also be applied. These include – among others – **local flood control schemes**. The method of emergency flood storage has been introduced as part of the latter on some rivers, involving the establishment of **lowland emergency flood reservoirs**.

The aim of emergency storage is to detain temporarily part of the flood volume and to lower thereby the peak level of the flood wave. The method of emergency storage has been applied repeatedly on the Körös rivers during the past decades. The flood levels on the Körös rivers have been observed to rise steeply over the recent decades. The analyses and assessments of the Körös floods of the past decades have contributed a wealth of data and information for development planning. The flood travel pattern on the Fekete Körös and Fehér Körös rivers have changed significantly. The peak flood levels and the peak flood discharges and water volumes have risen; the flood surface profiles have changed. Flood control in the Körös Valley has commanded and will continue to command also in the future special attention. On the Körös rivers – yet also on some other Hungarian streams – the 'conventional' constructional methods of providing a higher level of flood safety, by raising the crest and increasing the cross sectional dimensions of the embankments are alone inadequate and that resort must be made to active flood control solutions, i.e., emergency flood storage.

*Keywords:* flood fighting, emergency reservoirs, emergency storage, flood peak reduction.

## 1. Introduction

Owing to the physico-geographical situation of the country, important and steadily growing public interests have been attached to flood and inundation control for centuries in Hungary. Each major flood has revived the demand and arguments for flood control development. This was the case also in the XX. century, when the floods of 1916, 1830 and 1845 have provided the final impetus triggering the comprehensive reclamation project in the Tisza Valley, while the floods of 1855, 1867–68, 1879, 1881 and 1888, each of disastrous proportions, have redirected public attention to the importance of continuing and improving the defences (FEJÉR 1997; SZLÁVIK 1992).

In the past century such periods of intensive development were prompted in response to the major floods in the Tisza and Danube valleys: 1919, 1925, 1932, 1939, 1940–41, 1947–48, 1956, 1965 and 1970 (SZLÁVIK 1989; SZLÁVIK–FEJÉR 1988). Recent events have again focused public attention on flood safety in the country. A major flood has travelled down the Körös rivers in winter 1995–96 (SZLÁVIK–VARGA–VÁRADI 1996; SZLÁVIK–VÁRADI, 1996), between June 15 and August 8, 1997, disastrous floods devastated several regions in Central and East Europe claiming human lives and causing enormous losses to property. From ten regions in eight countries of Central and East Europe 147 casualties and losses amounting to several billion dollars have been reported. A major summer flood was recorded also on the Danube in 1997 (BÁLINT 1997; HARKÁNYI–BÁLINT 1997, SZLÁVIK–BÁLINT 1997). The most recent flood occurred in November, 1998 on the Upstream-Tisza and Bodrog rivers, with disastrous consequences in the catchment beyond the national boundary.

Although several of the floods on the streams in Hungary rose to record stages, the defences along them have withstood these flood waves without failure virtually for the last two decades. The last flood to claim lives was the ice-jam flood in winter 1955-56. And this not attributable to luck, to any fortunate situation, but rather to carefully planned, methodical development and organising efforts.

The most comprehensive national flood control R+D programme during the past decades was launched in the wake of the unprecedented flood in the Tisza Valley in 1970 (BENCSIK 1970). The design flood levels prescribed earlier (VITUKI 1964) for the defences were revised, the concept of the design flood wave was introduced and estimated for all Hungarian rivers (VITUKI 1976), all polders were identified, demarcated and confinement studies were made on them (VITUKI 1977). These studies laid the foundations of the long- term flood control development policy of Hungary (OVH 1981). The development principles set forth therein are still basically valid. The policy was updated and refined in 1985 (KHVM 1995, SZLÁVIK–VÁRADI 1996, SZLÁVIK–VARGA–VÁRADI 1996).

The flood events in the most recent years appear to justify some parts of the defence development plans. The experiences gained on the Fehér (White) and Fekete (Black) branches of the Körös Valley river system are published with the intent of contributing to this effort.

## 2. Flood Exposure and Defences in Hungary

The vast lowlands of the Hungarian Plains form the deepest part of the Carpathian Basin. The flood waves emerging from their steep mountain catchments in the Carpathians and the Alps tend to overtake each other causing often emergency situations. Owing to the climate and the physico-geographical situation, floods are liable to develop on any river in any season of the year.

Of the total, 93 000 $km^2$ area of the country, 21 248 $km^2$ (22.8%) are flood plains along the streams exposed to inundation. Of these flood plains 97% has already been reclaimed by embankments flanking the streams. In this respect the only country in Europe which can be compared with Hungary is the Netherlands, where 20% of the territory is situated below the flood and tide level. The remaining 3% of the flood plains (700 $km^2$) is situated in the arrow valleys of the Rába, Répce, Ipoly, Sajó, Hernád and Bodrog streams, where no flood control development was and still is economically viable. Exceptions to this are some 125 $km^2$ at communities situated on the perimeter of the flood plains, to which control can be extended for development purposes.

The flood plains along the rivers are subdivided into 151 polders. A polder is a flood plain section bounded by natural contour features and/or structures, the inundation of which does not jeopardise the neighbouring ones. Of these polders 55 (5 590 $km^2$ total area) are situated along the Danube and 96 (15 610 $km^2$ total area) along the Tisza river.

From the cumulated flood statistics of the various rivers and regional units of Hungary it is concluded that the recurrence frequency of minor to medium floods is 2–3, that of major floods 5–6 years, while exceptional floods are liable to occur on some rivers at 10-12 year intervals of time. The duration of the major flood waves is 5–10 days on the Hungarian upstream sections, while 50–120 days along the flat middle and downstream reaches. Duration of this length is rare on other European rivers. The flow regime along the headwater reaches of the tributaries is a flashy one, in that the flood waves triggered by rapid snowmelt or a violent storm arrive 1–2 days later at the Hungarian boundary, raising the water-level by several metres sometimes within a few hours only. In this respect the Hungarian Upstream Tisza and her tributaries, further the Körös river represent an especially grave risk, in that the water level in the boundary cross section may rise 8-10 metres within 28–36 hours following a storm. On some rivers the possibility of dangerous ice jam floods must also be taken into account.

A survey completed in 1994 and a complex economic analysis have shown some 2.5 million people to be exposed to flood hazards in 700 communities in the protected parts of the plains, which comprise 1.8 million hectares of farmland, or one-third of the arable lands of Hungary, over 2000 industrial plants, 32% of the railway and 15% of the road network. About 25% of the GDP originates from these reclaimed flood plains and the assets accumulated there have been estimated at 2 400 thousand million Ft (price level of 1994). A single inundation of a flood plain polder would cause a loss ranging from 5-6 up to 50 thousand million Ft, as for instance Szeged town, or the Algyő oil field. (SZLÁVIK-VÁRADI 1996, SZLÁVIK–VARGA–VÁRADI 1996).

The present network of flood defences has been built gradually from the middle of the last century and comprises the following components:

- The main flood defences of 4 327 km total length along the rivers, including 4 011 km earth embankments, 30 km flood walls and 286 km high banks. The state water agency is responsible for 4 128 km of main defences, the rest – 199 km – is owned and maintained by the municipalities.
- Floodways on the Lajta, Rábca and Répce rivers to split and transfer into another catchment the flood discharge. (Their length and conveying capacity is 13 km and 50 $m^3/s$, 2.5 km and 54 $m^3/s$, 10 km and 120 $m^3/s$, respectively.)
- Low-land emergency reservoirs on relatively small, flashy streams to retain the flood peaks (two in the Danube Valley, eight (pus one under construction) in the Tisza Valley). With 220 $km^2$ total area their capacity is 383 million $m^3$.
- Confinement dikes to prevent the flow through any failed defence from spreading, or to route such flow. These secondary defences were established using suitable terrain features or structures serving other purposes (road and railway embankments).

The defences are required to withstand safely the design flood, the magnitude of which depends on the actual socio-economic value of the polder protected, further on the funds which can be mobilised from central (or local beneficiary) resources. Floods higher and/or of longer duration may occur any time but their probability is too low to adopt them as design criteria. In such situations emergency measures must be adopted to avert or moderate the disastrous consequences.

*The long-term development plan of the flood defences* was adopted by the government in June, 1995 (Government Resolution 2182/1995.(VI.27.), declaring the once in 100 years flood which the defences are required to withstand safely. The safety freeboard above the estimated 100 year flood must be at least 1.0 m. *The minimal cross sectional area of the embankments* – the flood levees – with due regard to the requirements of stability, traffic in emergency conditions and maintenance with mechanical equipment. In the light thereof, the level of development and safety of the defences can be characterised as follows: As a result of improvement projects implemented so far, the length of the defences which meet these safety requirements is 2288 km, or 57.5% of the total. Over the remaining close to 2000 km length, the defences are capable of withstanding floods of 60-80 years recurrence period – often in combination with major emergency efforts. It must be noted also that even along the defences classified safe there are (may be) short sections differing from their environment, which fail to meet the safety criteria. Methodical surveillance work has revealed several hundred sections, the stability of which is jeopardised by poor subsoil conditions (e.g. crossing of ancient meanders), or cracks. The total length of these sections is about 560 km.

A number of structures (1801 sluices, culverts, etc.) penetrate the embankments. Some of these are 80-100 years old and are in a very poor condition. Special attention must be devoted to the crossing structures, in particular to the old ones,


*Fig. 1.* Levee failures and emergency storage on the Körös rivers (1925-1956)

which are *potential sources of hazard.* At the present 85 structures are considered unsafe.

The cost of improvements needed to attain the aforementioned goal of attaining the required level of safety has been estimated at 60 thousand million Ft at the 1994 price level, or at over 100 thousand million Ft at 1998 prices. Of the development needs 24% arises in the Danube Valley and 76% in the Tisza Valley. The development projects have been ranked and scheduled according to priority. The cost of these projects, which improves considerably the safety in the high-value, large polders amounts to about 25–30 thousand million Ft at current prices.

## 3. Emergency Storage as an Alternative to Flood Control Improvement on Some Rivers

The *flood embankments* – main line levees – along the rivers form the backbone of the flood control scheme developed in Hungary from the middle of the past century to these days. These have become organic parts of the infrastructural assets, the maintenance and improvement of which must be given priority. At the same time, the flood control experiences gained over the recent 30 years have demonstrated that along with the development, strengthening to the prescribed dimensions of the embankments along the river, new engineering solutions and methods must also be applied. These include – among others – local flood control schemes. The method of emergency flood storage has been introduced as part of the latter on some rivers, involving the establishment of lowland emergency flood reservoirs.

An emergency flood reservoir is understood as an area improved by means of hydraulic structures for temporary storage under abnormal conditions alone, critical state of the mainline levee, to avert major losses and a flood disaster, while normally it serves its original purpose (farmland, forest, etc.).

The aim of emergency storage is to detain temporarily part of the flood volume and to lower thereby the peak level of the flood wave.

The reasons underlying the terminology 'temporary, emergency reservoir', rather than a normal one are mainly economic ones. The area selected for the reservoir is not acquired, it is designated legally for this purpose. As a consequence thereof the uses of the area are restricted (e.g. building ban). The decision on impounding the emergency reservoir is invariably the outcome of careful, comprehensive deliberations, during which the economic consequences are also taken into account along with the flood situation. Opening an emergency reservoir is necessarily associated with major costs and losses, for which the state is obliged to damages to the owner. In the case of a normal reservoir no such compensation obligations would arise, on the other hand, the costs of acquiring the area would be several times as high and in view of the infrequent use hardly justifiable. As implied also by the term adopted for the facility and the activity alike, the reservoir is used under emergency conditions alone.

The method of emergency storage has been applied repeatedly on the Körös rivers during the past decades. Notwithstanding continuous defence improvements and enormous flood fighting efforts, the major floods from 1925 to 1955 could not be contained between the levees (*Fig. 1* and *Table 1*). In the Körös Valley, over the section upstream of the confluence of the Kettős- and Sebes-Körös streams, on Hungarian territory and on the Romanian side of the boundary, but endangering Hungarian areas, 21 levee failures and emergency storage events occurred between 1925 and 1980 (10 in Hungary, 11 in Romania). Between 1981 and 1995 further 9 failures or emergency storage events occurred (3 emergency reservoirs were opened in Hungary, 4 in Romania, where also two failures occurred). The experiences gained from a total of 31 flood events are thus available to assess the merits and drawbacks of emergency storage.

*Table 1*. Time sequence of failures and emergency storage on the Körös rivers (1925-1955)

| Year | River | Levee | Romania: Levee failure | Romania: Storage | Hungary: Levee failure | Storage |
|---|---|---|---|---|---|---|
| 1925 | Fehér Körös | Right bank | **X** | | | |
| | Tőz | Left bank | **X** | | | |
| 1932 | Fehér Körös | Left bank | **X** | | | |
| | Tőz | Left bank | **X** | | | |
| 1939 | Fehér Körös | Right bank | **X** | | | |
| 1966 | Fehér Körös | Right bank | **X** | | | |
| 1970 | Fehér Körös | Right bank | **X** | | | |
| | Fekete Körös | Right bank | **X** | | | |
| 1974 | Fekete Körös | Right bank | **X** | | | |
| | Fehér Körös | Right bank | | | | **O** |
| | Fekete Körös | Left bank | | | | **O** |
| 1980 | Tőz | Left bank | **X** | | | |
| | Fekete Körös | Left bank | | | | **O** |
| | Kettős Körös | Right bank | | | **X** | |
| | Kettős Körös | Right bank | | | | **O** |
| 1981 | Fekete Körös | Right bank | | **O** | | |
| | Tőz | Right bank | **X** | | | |
| | Fekete Körös | Left bank | | | **X** | **O** |
| | Fekete Körös | Left bank | | | | |
| 1995 | Fekete Körös | Right bank | | **O** | | |
| | Fehér Körös | Left bank | **X** | | | |
| | Fehér Körös | Right bank | | **O** | | |
| | Fekete Körös | Left bank | | | | **O** |
| | Kettős Körös | Right bank | | | | **O** |

The *'inland delta' between the Fehér Körös and Fekete Körös* rivers was inundated totally or partly on 9 occasions during the past 70 years owing to levee failures, or emergency storage (1925, 1932, 1939, 1966, 1970, 1974, 1980, 1981, 1995). The area inundated ranged from 10 to 161 km$^2$, while the inundating water volume from 8 to 200 million m$^3$ (*Table 2*).

Besides the Körös rivers similar emergency storage-flood detention measures became necessary in April, 1965 on the River Rába, in October 1974 on the Tarján and Gyöngyös Streams, further on three occasions on the Lajta (1965, 1975, 1997). An analytical study of these flood events has revealed that – regardless of the different hydrologic situations, topographic and flood control conditions – the emergency storage events displayed a number of features accessible to generalisation. In total 14 events could be considered (*Table 3*), which create the data and information sources for the way of thinking of the application of emergency storage.

*Table 2*. Areas inundated and inundating water volumes on occasions of levee failures and emergency storage on the Körös rivers

| Year | No. of failures and storage events | Inundated area km$^2$ | Inundating volume $10^6$m$^3$ |
|---|---|---|---|
| 1925 | 4 | 160 | 200 |
| 1932 | 2 | 36 | 30 |
| 1939 | 1 | 64 | 39 |
| 1966 | 2 | 200 | 188 |
| 1970 | 3 | 155 | 115 |
| 1974 | 3 | 71 | 118 |
| 1980 | 5 | 175 | 320 |
| 1981 | 3 | 33 | 75 |
| 1995 | 5 | 30 | 46 |

## 4. Flood Trends on the Fekete Körös and Fehér Körös Rivers

The flood levels on the Körös rivers have been observed to rise steeply over the recent decades. Any detailed analysis of the causes thereof would exceed the scope of the present study. Without any claim at completeness, no more is intended here than to point to the phenomenon and to illustrate it by some typical data of the Körös floods.

The analyses and assessments of the Körös floods of the past decades have contributed a wealth of data and information for development planning. The most important flood waves occurred in the following years:

1966 (AMBRUS 1966; PAPP 1966, 1996),

1970 (NÉMETHY–BELEZNAI 1970; PAPP 1971, 1997; TAKÁCS 1971),

1974 (NAGY 1975; SZLÁVIK 1976),

1980-81 (LITAUSZKI 1980; SZLÁVIK 1981/a, 1982/a, 1982/b, 1982/d),

1995 (KHVM 1996, PÁLINKÁS 1996; SZLÁVIK–GALBÁTS–KISS 1996;

VITUKI 1996).

The hydrological characteristics of the floods examined on the Fehér Körös and Fekete Körös rivers will include the rising peak flood levels, the changes in the flood surface profile (slope), the growing peak discharges and water volumes conveyed by flood waves, the changes in the time pattern of flood travel on the two rivers, further the impacts of levee failures and emergency reservoir operation on flood wave travel.

### *4.1. Rising Peak Flood Levels*

The data illustrating the rising peak flood levels are summarised in *Table 4*. Most of the peak levels recorded will be seen to be influenced and to represent the resultant impact of levee failures and emergency reservoir operation.

The peak flood level registered on the Fekete Körös River at the Ant gauging station rose by 172 cm between 1966 and 1981 (*Table 4*), or by 16 % of the widest fluctuation range (the difference between the highest and lowest stages on record). The corresponding figures on the Remete station between 1966 and 1974 are 128 cm (13 %), on the Fehér Körös at the Gyula station between 1962 and 1974 111 cm (11 %), on the Kettős Körös at Békés between 1966 and 1974 131 cm (12 %). Over the aforementioned periods record peak stages were observed on the Fekete Körös River during five successive flood waves on the Ant gauging station and during three on the Remete gauge, while during three such floods on the Fehér Körös River on the Gyula river gauge (in spite of the fact that the levee failures and the diversions to emergency storage have modified – lowered – the natural water levels in some instances significantly). The dynamics, frequency and extent of water level rise are unparalleled on the Hungarian rivers. The floods on the Körös rivers continue to present a threat of unchanged magnitude, in that the peak stages observed in 1988 and 1989 would have been 'unprecedented' before 1970 (*Fig.* 2).

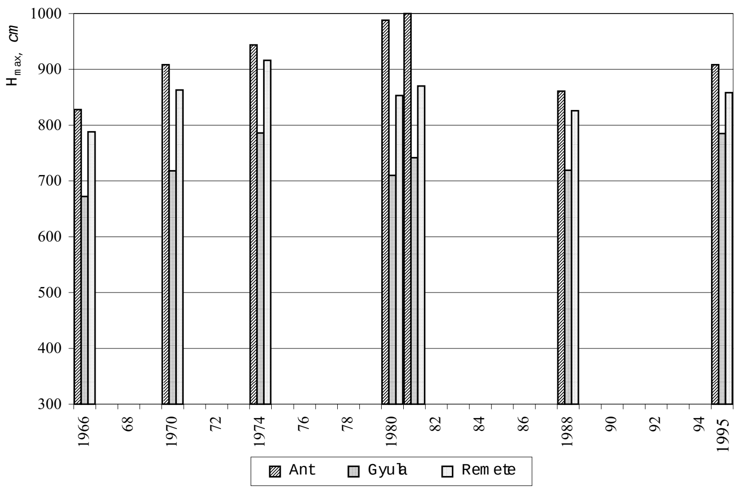


*Fig. 2.* Major floods on the Fekete Körös and Fehér Körös (1966-1995)

*Table 3.* Emergency reservoirs built or designated and their uses

| No | Reservoir | River | Distr. Water Authority | Area ($km^2$) | Volume ($10^6$ $m^3$) | State of reservoir | Time inundated | Remark |
|---|---|---|---|---|---|---|---|---|
| 1. | Mályvád | Fekete Körös | Körös Region | 34.70 | 75.0 | Completed | Aug.1,1980<br>March 13, 1981<br>Dec. 29, 1995 | All or part inundated owing to levee failure:1925, 1932, 1939,1966, 1970, 1974 |
| 2. | Kisdelta | Fehér Körös | Körös Region | 5.50 | 26.0 | Under construction | – | All or part inundated owing to levee failure:1925, 1932, 1939,1966, 1970, 1974 |
| 3. | Mérges | Kettős and Sebes Körös | Körös Region | 18.20 | 87.2 | Completed | July 28, 1980<br>Dec. 30, 1995 | |
| 4. | Kutas | Berettyó | Trans-Tisza | 38.96 | 36.5 | Designated | Febr. 9, 1966<br>June 15, 1970 | |
| 5. | Halaspusztai | Sebes Körös and Berettyó | Trans-Tisza | 21.75 | 35.0 | Designated | July 26, 1980 | |
| 6. | Érmenti | Ér and Berettyó | Trans-Tisza | 13.52 | 12.2 | Designated | – | |
| 7. | Jászteleki | Zagyva | Middle-Tisza | 20.00 | 24.0 | Completed | – | |
| 8. | Viszneki | Gyöngyös and Tarna streams | North-Hungary | 5.56 | 4.51 | Designated | Oct. 21, 1974 | |
| 9. | Rába jobbparti | Rába | North-Transdanube | 57.30 | 78.0 | Designated | – | Inundated owing to levee failure: 1965 |
| 10. | Lajta I. | Lajta and Lajta left-hand canal | North-Transdanube | 2.35 | 3.0 | Designated | Apr. 24, 1965<br>July 5, 1975 | Inundated owing to levee failure: 1965; levee failure and inflow from Austria: 1975 |
| 11. | Lajta II. | Lajta and Lajta left-hand canal | North-Transdanube | 2.07 | 1.5 | Designated | Apr. 27, 1965<br>July 5, 1975<br>July 11, 1997 | Inundated owing to levee failure: 1965; levee failure and inflow from Austria: 1975 |

*Table 4.* Rising peak flood levels on the Körös rivers
(Actually observed peak stages influenced by levee failures, outlet to emergency reservoirs)

| River | Gauging station | Warning stage I | Warning stage II | Peak stage of flood waves 1919 | 1925 | 1932 | 1939 | 1940 | 1962 | 1966 | 1970 | 1974 | 1980 | 1981 | 1988 | 1989 | 1995 | 1997 | $H_{max}$ Rise |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fekete Körös | Ant | 500 | 700 | 8.59 | 8.00 | 7.74 | 8.48 | 8.02 | 8.28 | 8.28 | 9.08 | 9.44 | 9.88 | 10.00 | 8.61 | 8.56 | 9.08 | 6.03 | +1.41 |
| Fekete Körös | Remete | 500 | 750 | 7.86 | 7.15 | 7.77 | 7.28 | 7.70 | 7.53 | 7.88 | 8.63 | 9.16 | 8.53 | 8.70 | 8.26 | 6.97 | 8.58 | 7.22 | +1.30 |
| Fehér Körös | Gyula | 400 | 600 | 6.72 | 6.13 | 6.46 | 6.53 | 6.63 | 6.75 | 6.72 | 7.18 | 7.86 | 7.10 | 7.42 | 7.19 | 5.74 | 7.85 | 6.53 | +1.14 |
| Kettős Körös | Békés | 550 | 800 | 8.62 | 7.76 | 8.41 | 8.27 | 8.60 | 8.32 | 8.41 | 9.38 | 9.72 | 9.63 | 9.44 | 8.91 | 7.64 | 9.50 | 7.87 | +1.10 |
| Berettyó | Szeghalom | 300 | 500 | 5.66 | 4.88 | 5.61 | 4.68 | 5.82 | 5.44 | 5.48 * | 6.78 | 5.89 | 6.66 | 6.32 | 5.14 | 5.08 | 4.90 | 4.24 | +1.12 |
| Sebes Körös | Körösladány | 400 | 600 | 7.14 | 6.18 | 6.99 | 6.17 | 7.26 | 6.79 | 6.67 | 8.15 | 7.36 | 7.98 | 7.67 | 6.55 | 6.34 | 6.39 | 4.99 | +1.01 |
| Hármas Körös | Gyoma | 550 | 750 | 8.73 | 7.56 | 8.38 | 7.36 | 8.64 | 7.94 | 7.92 | 9.18 | 8.07 | 8.81 | 8.35 | 8.01 | 7.11 | 7.56 | 6.29 | +0.45 |

*Legend:*

9.38 – highest ($H_{max}$) till the next maximum
**9.72** – highest on record so far ($H_{max}$)
* – ice-jam flood!
7.10 – Stage influenced by levee failure and emergancy storage!

*Table 5.* The rise of peak stages on the Körös rivers

| River | Gauge | First year of period studied | $H_{max}$, increment, m |
|---|---|---|---|
| Fekete Körös | Ant | 1919 | **1.41** |
| | Sarkad | 1932 | **1.39** |
| | Remete | 1919 | **1.30** |
| Fehér Körös | Gyula | 1919 | **1.14** |
| Kettős Körös | Doboz | 1919 | **1.32** |
| | Békés | 1919 | **1.10** |
| | Köröstarcsa | 1919 | **0.57** |
| Sebes Körös | Fokihíd | 1919 | **1.00** |
| | Körösladány | 1919 | **1.01** |
| Berettyó | Berettyóújfalu | 1919 | **0.78** |
| | Szeghalom | 1919 | **1.12** |
| Hármas Körös | Gyoma | 1919 | **0.45** |
| | Szarvas | 1919 | **0.60** |
| | Békésszentandrás | 1962 | **1.35** |
| | Kunszentmárton | 1924 | **0.85** |
| | Bökényi duzzasztó | 1966 | **0.98** |

To gain an impression about the magnitude of the last, the *1995 Christmas flood*, it is of interest to note that the 785 cm peak stage observed on the *Fehér Körös River* at Gyula was the highest on record, yet also the 929 cm peak on the Doboz gauge of the *Kettős Körös* was the second on the historical record (19 cm lower than the HHW of 1974). The 950 cm peak at Békés was the third highest (22 cm below the HHW of 1974 and 13 cm below the HW of 1980). We are thus justified in claiming that the 1995 flood has travelled down these sections with peak stages that were above, or close to those on record.

*Tables 4* and *5* illustrate clearly the rise of the highest water levels ($H_{max}$ – the highest on record – HHW) on the Körös rivers over the recent decades. Over the past 80 years the peak stages rose by over one m on each tributary, the rise (1.1–1.4 m) on the Fekete Körös, Fehér Körös and Kettős Körös rivers being especially conspicuous.

The examination of the annual highest water levels revealed a similar trend. The changes in the annual highest stage at the Gyula gauging station on the Fehér Körös River over the 1901 to 1996 period have been plotted in *Fig.3*. Beyond the actual steepness of the rise, the clear demonstration of the rising trend is of interest here (KÖVIZIG 1997; RÁTKY 1997).

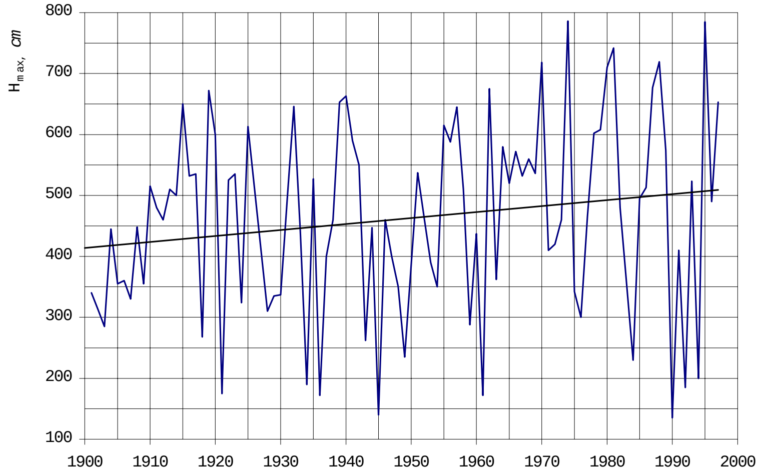


*Fig. 3*. The annual highest stages between 1901 and 1997 in the Gyula gauging cross section on the Fehér Körös river

### *4.2. Changes in the Flood Surface Profile*

An examination of the surface slopes estimated from the stage records during the 1995 Christmas flood has revealed that the antecedent flood wave travelled down the *Fekete Körös* with a rise rate resembling that of a typical summer flood, in that the 508 cm maximum water level difference between the Ant-Remete gauges was surpassed during the 1980 flood alone (557 cm). The main flood wave was an appreciably milder one, in that the widest, 426 cm water level difference 20 hours before the peak on the Ant gauge resembled mostly that of the summer floods in 1970 and 1974. (In 1970 the widest water level difference was 348 cm 36 hours before the peak, whose corresponding figures for the 1974 flood were 394 cm and 56 hours. The steepest rise rate of 8 cm/h during the main flood wave was not an abnormal one. True, it should be remembered that the original water level was already a very high one (720 cm). The highest rise rate at Gyula on the Fehér Körös River was 12 cm/h, which reflected unambiguously the predominance of the Fehér Körös River in this flood wave. The typical surface slopes and rise rates of the five major floods since 1970 are summarised in *Table 6*.

### *4.3. Peak Flood Discharges and Water Volumes*

The peak flood discharges reveal similarly a rising trend. In *Fig.4* the annual highest streamflows ($Q_{g,a}$) observed between the years 1919 and 1995 on the Gyula and Remete gauges were ordered according to magnitude to determine the changes

*Table 6.* Typical flood surface slopes and rise rates on the Körös rivers

| Flood year | Max. diff. level elevation between Ant and Remete (cm) | Time between max diff. elevation and peaking at Ant (hours) | Highest rise rate at Ant (cm/h) |
|---|---|---|---|
| 1970 | 348 | 36 | 14 |
| 1974 | 394 | 56 | 16 |
| 1980 | 557 | 13 | 44 |
| 1981 | 456 | 7 | 34 |
| 1995 | 426 | 20 | 8 |

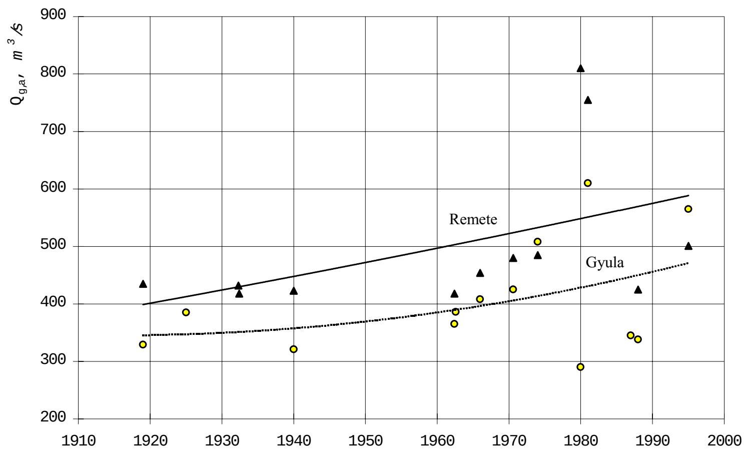


*Fig. 4.* The trend of high flows on the Fekete Körös and Fehér Körös rivers

over time of those above 200 $m^3/s$ (RÁTKY 1997). Evidently, the trend is not a statistically significant one, but remembering the fact that in the artificial, virtually straight bed of the lower section of the Fehér Körös the growing flood waves travel down at successively high velocities, it will be realised that these effects are already strong enough to cause substantial changes along the Fehér Körös, yet even the Kettős Körös rivers as well.

The water volume conveyed by isolated flood waves was also found to grow steadily, owing presumably to human activities in the upstream catchment. The water volumes which have flown past the gauging stations Gyula and Remete between 1919 and 1995 with stages higher than Flood Alert Level I are presented in *Table 7*. The discharge and flood volume figures have been estimated under the assumption of no levee failure, or diversion to an emergency reservoir (SZLÁVIK–GALBÁTS–KISS 1996).

The water volume conveyed by the flood wave was estimated according to previous practice from the discharges passing at stages above the Flood Alert Level I. The water volumes estimated for the Remete Gauging station were used to describe and qualify the earlier major floods. In terms thereof the 144 $Mm^3$ conveyed by the 1995 flood was the fifth on the historical record and was smaller than the volumes of the 1980 and 1981 great floods. The water volume carried past the Gyula gauging station in the 1995 flood was virtually equal in magnitude to that at Remete. The figure estimated for this gauge – 133 $Mm^3$ – is also the fifth highest on the record.

The ratio of the water volumes estimated at the Remete and Gyula gauges for the 1995 flood wave reflects the predominance of the Fehér Körös River, in that virtually the same water volume was conveyed in a considerably narrower bed at Gyula. The figures estimated for the Gyula and Remete gauging stations were found to agree fairly, in that volume estimated for Békés was 217 $Mm^3$. The parameters of the greatest flood on the Fekete Körös and Fehér Körös rivers between 1915 and 1995 have also been entered into *Table 7*.

### *4.4. Changes in the Flood Travel Pattern on the Fehér and Fekete Körös Rivers*

The flood waves on the Fehér Körös and Fekete Körös rivers have travelled down for decades following the same pattern, which was believed attributable to the shape and stream network of the catchment, further to the impact of the flood control structures built. This pattern was characterised by the sequence of the flood waves, the ratio of the slopes, the peak discharges and water volumes. It was concluded therefrom that it was the Fekete Körös, which had a controlling influence on the flood regime in this part of the Körös Valley (SZLÁVIK 1982/b). The active component of flood control development on the two rivers, the Mályvád emergency reservoir was established with due regard to this pattern (SZLÁVIK 1978, 1983).

From a review of the hydrological features of the 1995 Christmas flood it has become apparent, however, that as regards peak stages and slopes the greatest flood observed on the Fehér Körös has changed also the normal interactions between the flood waves on the two rivers. In December, 1995, the flood wave on the Fehér Körös arrived some 24 hours ahead of the normal flood-travel schedule, changing the slope conditions and creating a new situation not experienced so far, in that the runoff conditions of the Fehér Körös have 'controlled' this flood wave (SZLÁVIK–GALBÁTS–KISS 1996). The causes thereof could not be traced back to the rainfall pattern, to the hydrometeorological-hydrological situation triggering the flood, so that the change must probably be attributed to water control measures implemented in the catchment. This should be interpreted also as a warning of the urgent revision of the state and effectiveness of the existing flood control scheme (KÖVIZIG 1997).

*Table 7.* Dates and parameters of large floods on Rivers Fehér Körös and Fekete Körös (1925–1955)

| Flood crests | | Peak flow | | Volume of flow above I. level of alert | | Volume of flow above II. level of alert | | Duration of water levels above I. level of alert | |
|---|---|---|---|---|---|---|---|---|---|
| stage, m | Date | $m^3s^{-1}$ | Date of peak | $10^6$ $m^3$ | Date of peak | $10^6m^3$ | Date of peak | Day | Date of peak |
| FEHÉR KÖRÖS Gyula | | | | | | | | | |
| (8.25) | 13. 03. 1981 | (610) | 29. 12. 1995 | (262.5) | 14. 06. 1970 | (122.6) | 13. 03. 1981 | 17.4 | 14. 06. 1970 |
| (8.20) | 15. 06. 1974 | 565 | 13. 03. 1981 | (218.1) | 13. 03. 1981 | (92.3) | 29. 12. 1995 | 12.8 | 11. 02. 1966 |
| (7.94) | 29. 12. 1995 | (508) | 15. 06. 1974 | (166.1) | 11. 02. 1966 | (86.6) | 14. 06. 1970 | 12.4 | 26. 07. 1980 |
| (7.40) | 14. 06. 1970 | (425) | 14. 06. 1970 | 152.0 | 26. 07. 1980 | 84.0 | 26. 07. 1980 | 12.3 | 04. 04. 1932 |
| (7.37) | 23. 11. 1925 | (408) | 11. 02. 1966 | (133.0) | 29. 12. 1995 | 64.7 | 25. 03. 1988 | 11.5 | 13. 03. 1981 |
| 7.19 | 25. 03. 1988 | 386 | 03. 04. 1962 | (128.7) | 15. 06. 1974 | (52.6) | 15. 06. 1974 | 10.7 | 15. 06. 1974 |
| 7.10 | 26. 07. 1980 | (385) | 23. 11. 1925 | 116.6 | 13. 02. 1970 | 48.6 | 08. 06. 1987 | 9.8 | 13. 02. 1970 |
| (7.00) | 11. 02. 1966 | 365 | 03. 04. 1962 | 111.6 | 25. 03. 1988 | (48.4) | 11. 02. 1966 | 9.0 | 22. 03. 1915 |
| 6.76 | 08. 06. 1987 | 345 | 08. 06. 1987 | 102.9 | 04. 04. 1932 | (23.8) | 23. 11. 1925 | 8.1 | 04. 05. 1919 |
| 6.75 | 03. 04. 1962 | 338 | 25. 03. 1988 | 81.7 | 08. 06. 1987 | 21.8 | 03. 04. 1962 | 6.7 | 03. 04. 1962 |
| 6.72 | 04. 05. 1919 | 329 | 04. 05. 1919 | 80.4 | 03. 04. 1962 | 19.7 | 13. 02. 1970 | 6.1 | 25. 03. 1988 |
| 6.63 | 16. 03. 1940 | 321 | 16. 03. 1940 | 79.8 | 04. 05. 1919 | 14.9 | 03. 04. 1962 | 5.1 | 29. 12. 1995 |
| 6.53 | 01. 11. 1939 | 290 | 26. 07. 1980 | (49.4) | 23. 11. 1925 | 11.0 | 04. 05. 1919 | 4.0 | 08. 06. 1987 |
| FEKETE KÖRÖS Remete | | | | | | | | | |
| (9.54) | 13. 03. 1981 | 810 | 26. 07. 1980 | 276.0 | 26. 07. 1980 | 182.0 | 26. 07. 1980 | 15.7 | 14. 06. 1970 |
| (9.50) | 15. 06. 1974 | 755 | 13. 03. 1981 | (237.9) | 13. 03. 1981 | (103.7) | 13. 03. 1981 | 12.6 | 26. 07. 1980 |
| (8.85) | 14. 06. 1970 | (501) | 29. 12. 1995 | (255.8) | 14. 06. 1970 | 64.9 | 25. 03. 1988 | 11.2 | 11. 02. 1966 |
| (8.74) | 29. 12. 1995 | (485) | 15. 06. 1974 | 156.2 | 25. 03. 1988 | (62.7) | 29. 12. 1995 | 10.7 | 03. 04. 1932 |
| 8.53 | 26. 07. 1980 | (480) | 14. 06. 1970 | (144.0) | 29. 12. 1995 | (51.3) | 14. 06. 1970 | 10.5 | 13. 03. 1981 |
| 8.26 | 25. 03. 1988 | (454) | 11. 02. 1966 | (134.1) | 11. 02. 1966 | (30.4) | 15. 06. 1974 | 9.7 | 22. 03. 1915 |
| (7.95) | 11. 02. 1966 | 435 | 04. 05. 1919 | 116.2 | 13. 02. 1970 | (23.7) | 11. 02. 1966 | 9.6 | 04. 05. 1919 |
| 7.86 | 04. 05. 1919 | 432 | 21. 03. 1932 | 110.3 | 04. 05. 1919 | 16.4 | 04. 05. 1919 | 9.6 | 13. 02. 1970 |
| 7.77 | 21. 03. 1932 | 425 | 25. 03. 1988 | (101.9) | 15. 06. 1974 | 13.6 | 16. 03. 1940 | 7.3 | 03. 04. 1962 |
| 7.70 | 16. 03. 1940 | 423 | 16. 03. 1940 | 95.2 | 03. 04. 1932 | 10.1 | 03. 04. 1962 | 7.2 | 21. 03. 1932 |
| 7.66 | 03. 04. 1932 | 418 | 03. 04. 1932 | 90.1 | 03. 04. 1962 | 9.8 | 21. 03. 1932 | 6.9 | 25. 03. 1988 |
| 7.53 | 03. 04. 1962 | 418 | 03. 04. 1962 | 74.4 | 16. 03. 1940 | 9.8 | 13. 02. 1970 | 6.5 | 29. 12. 1995 |

In brackets calculated/reconstructed values referring to conditions without levee failures of the use of emergency storages.
Floods are listed in ascending order according to their peak flows, dates of peaks serve to identify the events.

### *4.5. The Impacts of Levee Failures and Emergency Storage on Flood Wave Travel*

From *Tables 1* and *2* it will be perceived that levee failures and diversions to emergency reservoirs have resulted in storage on a growing number of occasions since 1996. It is of considerable interest to note further that these have shifted gradually to Hungarian territory over the recent 20 years (KÖVIZIG 1997). Whereas during the first half of the period studied (some 35 years) no levee failure has occurred, nor has any emergency storage become necessary on Hungarian territory, during the second half (roughly the same number of years) their number was 13. The likelihood of this trend continuing is high. Moreover, the revival of economy, intensifying measures in the catchments and stream beds in Romania – not confined to the main streams but involving also the minor tributaries – are liable to result in deteriorating further the runoff conditions over the Hungarian section of the Körös rivers.

From the foregoing it will be perceived that under the particular physico-geographical and hydrological conditions of the Körös Valley, the problems encountered in providing the prescribed level of flood safety are without exaggeration extremely difficult ones. The remark of Joseph Korbély that any coincidence of the adverse phenomena observed in the past is liable to raise the flood levels further in this river system remains valid to these days (KORBÉLY 1915, 1916-17). To quote from his study of 1916: '...Recent experiences show the present standard of flood safety along the Körös rivers to be unsatisfactory and also the need of further improvements. Once the tributaries are regulated, the recipient Körös forks will be required to carry higher flows. Although abnormal rainfalls have occurred and precarious situations have developed in the past, the possibility of even heavier rainfalls and more adverse superimposement of flood waves must not be excluded.' (KORBÉLY 1916–17). The decades elapsed since have underlined the validity of this statement and have produced no evidence to question the validity thereof in the future. On the contrary, the facts and statistics presented in the foregoing appear to confirm so far the continuation of the adverse trends.

The notorious recurrence of critical flood situations on the Körös rivers during the past seven decades – despite the continuous improvements – is noted with special concern. The flood control problems on the Fehér Körös and Fekete Körös rivers have 'travelled downstream' during the past 20 years and shifted to Hungarian territory. The obvious cause thereof is that embankments are built successively along the mountain and foothill river reaches and even in the relatively narrower valleys of the tributaries. The prognosis of Joseph Korbély quoted above proved correct to the extent that the continued dynamics and rate of the process have become by now impossible to predict. However, the flood flow conditions along the Hungarian Körös sections must be expected to change adversely, but any quantitative estimation of these changes would require detailed studies on flood genetics, co-ordinating the efforts of Romanian and Hungarian hydrologists and hydraulic engineers.

## 5. Flood Control Development in the Körös Valley

Owing to the hydrometeorological situation described in the foregoing, flood control in the Körös Valley has commanded and will continue to command also in the future special attention. In the aftermath of the 1915 flood a detailed analysis of the flood control situation in the Körös valley was prepared by Samuel Hajós (HAJÓS 1915). The flood problems in the Körös Valley were studied also by Joseph Korbély (KORBÉLY 1915, 1916–17). The steep and steady rise of the peak flood levels on the Fekete Körös and Fehér Körös rivers has prompted repeated in-depth studies on the actual tasks of flood control development (KÖVIZIG 1981, 1987; PÁLINKÁS–SZLÁVIK 1980, 1982; SZLÁVIK 1981/b, 1983/a). The experiences gained over the past three decades have made it clear that on the Körös rivers – yet also on some other Hungarian streams – the 'conventional' constructional methods of providing a higher level of flood safety, by raising the crest and increasing the cross sectional dimensions of the embankments are alone inadequate and that resort must be made to active flood control solutions, i.e., emergency flood storage.

From the trends derived from the past data a strong likelihood of major floods on the Körös rivers is inferred, which will be impossible to confine to the flood bed between the defences, so that repeated operation of the emergency reservoirs will become inevitable. We are therefore fully justified in claiming that special attention must be devoted to improving both the flood control scheme and the flood fighting organisation in the Körös Region. Any decision to open an emergency reservoir must be preceded by careful deliberations involving a number of complex factors and ramified consequences.

Starting from a hydrologic analysis of the 1995 December flood in the Körös Valley and the emergency storage operations implemented a proposal has been formulated for expanding the flood control scheme on the Körös rivers and for improving the organisation of emergency measures.

In the interest of diverting and detaining the flood waves on the Fehér Körös, the establishment of a Minor-Delta emergency reservoir was proposed (KÖVIZIG 1981), as a realistic alternative to strengthening the right-hand defences along the Fehér Körös and to raising the bridges crossing it. Construction work is under way on the reservoir of 5.5 $km^2$ area and 26 million $m^3$ volume (VÁRKONYI 1998).

It was proposed also to revise and update the management and operating instructions of the emergency reservoirs in the light of the experiences gained during the 1996 December flood (KÖVIZIG 1977). For the potential cases of emergency storage scenarios taking account of the various possible circumstances must be developed. Work thereon has been started (RÁTKY 1977; RÁTKY 1998-99; RÁTKY–SZLÁVIK 1999).

## References

[1] AMBRUS, L., Flood on the Körös Rivers. *Vízgazdálkodás*, 1967, No. 1.
[2] BÁLINT, G., The Hydrometeorological History and Predictability of the Flood Disaster in Central Europe. *Víztükör*, 1997, No. 5.
[3] BENCSIK, B., Flood Control Improvements in the Tisza Valley. *Vízügyi Közlemények,* 1971, No. 3.
[4] FEJÉR, L., Floods and Undrained Runoff... *Vízügyi Történeti Füzetek*, **15** Bp. 1997
[5] HAJÓS, S., The Present Flood Control Situation in the Körös Valley, Manuscript, In Országos Környezetvédelmi és Vízügyi Könyvtár, A-74.
[6] HARKÁNYI, K.–BÁLINT, G., Analysis of an Assumed Flood Triggered by Extreme Precipitation. *Vízügyi Közlemények*, 1997, No. 4.
[7] KHVM: Hydrology of the 1995 December Flood in the Körös Valley and Emergency Etorage (SZLÁVIK, L. – DOMAHIDY, L. – GALBÁTS, Z.,– KISS, A.) Manuscript, Budapest, 1996.
[8] KORBÉLY, J. On floods. *Vízügyi Közlemények*, 1915, Nos. 1-2.
[9] KORBÉLY, J., Regulation of the Körös and the Berettyó Rivers. *Vízügyi Közlemények*, 1916, No. 6, 1917, No. 1.
[10] KÖVÍZIG, Management and Operating Instructions of the Emergency Flood Reservoirs in the Körös Valley, Manuscript. (SZLÁVIK L. GALBÁTS Z.) Körös vidéki Vízügyi Igazgatóság, Gyula, 1977.
[11] KÖVÍZIG, Report on the Flood Ccontrol Development of the Delta between the Fehér Körös and Fekete Körös rivers, Manuscript. Körös vidéki Vízügyi Igazgatóság, Gyula, 1981 (SZLÁVIK, L.)
[12] KÖVÍZIG: Report on the Flood Control Improvement Alternatives for the Upstream Region of the Fehér, Fekete and Kettős Körös Rivers, Manuscript. Körös vidéki Vízügyi Igazgatóság, Gyula, June 1997.
[13] LITAUSZKI, I., The 1980 July-August Flood in the Tisza Valley. *Magyar Vízgazdálkodás*, 1980, No. 9.
[14] NAGY GY., Changing Runoff Conditions in the Körös Region. *Vízügyi Közlemények*, 1975, No. 3.
[15] NÉMETHY, L.–BELEZNAY, T., Impoundment of the Emergency Reservoir, the Experiences Gained and Flood Fighting on the Embankments of the Emergency Reservoir. Tájékoztatás a Tiszántúl vízgazdálkodásáról. 1970, Nos. 1-2, Debrecen
[16] OVH: Long-term Development Policy of Flood Control in Hungary. 1981.
[17] PAPP, F., The 1966 Ice-jam Flood on the Berettyó River. *Vízgazdálkodás*, 1966, No. 6.
[18] PAPP, F., Flood Fighting on the Sebes Körös and Berettyó Rivers. *Vízügyi Közlemények*, 1971. No. 3.
[19] PAPP, F., Review of the Körös Floods between 1966 and 1995. *Hidrológiai Közlöny*, 1996.
[20] PÁLINKÁS, L., Organisation of Emergency oOerations during the 1995 winter and 1996 January Flood Waves on the Körös Rivers. *Vízügyi Közlemények*, No. 1, 1996.
[21] PÁLINKÁS L.–SZLÁVIK, L., Water Management Development Policy for Békés County. *Hidrológiai Tájékoztató* 1980. október.
[22] PÁLINKÁS L.–SZLÁVIK, L., Design and Construction of Flood Control Improvements on the Fehér and Fekete Körös Rivers. Magyar Hidrológiai Társaság III. Országos Vándorgyűlés (Debrecen), 1982, Vol. II (Vízépítés).
[23] RÁTKY, I., Development of the management and operation of the emergency flood reservoirs in the körös Valley. Technical Report. Budapest, 1997.
[24] RÁTKY, I., A Körös-völgyi árvízi szükségtározókkal kapcsolatos hidraulikai vizsgálatok I.-IV. (2001) Műszaki tanulmányok. Manuscript, 1998-99.
[25] RÁTKY, I.–SZLÁVIK, L., Perfection of Operation Control for the Emergency Reservoirs in the Körös Valley. *Periodica Polytechnica. Civil Engineering.* **44** pp. 93–119.
[26] SZLÁVIK L.: Hydrology of the 1974 flood in the Körös Valley. *Vízügyi Közlemények* 1976, No. 1.

[27] SZLÁVIK L., Hydrologic Aspects of the Mályvád Emergency Flood Reservoir. Vízügyi Közlemények, 1978 No. 1..
[28] SZLÁVIK L., Design, Construction and Operation of Emergency Reservoirs. *Vízügyi Műszaki Gazdasági Tájékoztató (VMGT)* **118**, 1980.
[29] SZLÁVIK L., Hydrologic Features of the 1980 and 1981 Floods in the Körös Valley. *Magyar Hidrológiai Társaság II. Országos Vándorgyűlés (Pécs)*, 1981/a, I. (Hidrológia).
[30] SZLÁVIK L., Water Management Development Policy for Békés County. Alföldi Tanulmányok, Békéscsaba, V, 1981/b.
[31] SZLÁVIK L., Hydrology of the 1981 Körös Valley Flood and the Mályvád Emergency Reservoir. *Hidrológiai Tájékoztató*, 1982/a.
[32] SZLÁVIK L., Hydrological Features of the Körös Floods and the 1980 Flood. Alföldi Tanulmányok, Békéscsaba, VI. 1982/b.
[33] SZLÁVIK L., Hydrology of the Körös Floods in 1980-81. *Vízügyi Közlemények* 1982/c, No. 2.
[34] SZLÁVIK L., Flood Control Improvement Objectives at the Körös Valley District Water Authority. *Magyar Hidrológiai Társaság IV. Országos Vándorgyűlés (Győr)*, 1983/a, I. (Árvízvédelem).
[35] SZLÁVIK L., Design and Operation of Emergency Flood Reservoirs. *Vízügyi Közlemények*, 1983/b, No. 2,.
[36] SZLÁVIK L., Regulation and Flood Characteristics of the Tisza River. in A "Mérlegen a Tiszaszabályozás", MHT-OVF, Budapest, 1992.
[37] SZLÁVIK L., Emergency Flood Storage. *Vízügyi Közlemények*, No. 1, 1998.
[38] SZLÁVIK L.–BÁLINT, G.: Development of the 1997 Spring-summer Floods and Inundations by Undrained Runoff. Emergency Measures. *Vízügyi Közlemények*, 1997, No. 4.
[39] SZLÁVIK, L.–KISS, A.–GALBÁTS, Z., Hydrologic Study and Assessment of the 1995 December Körös Flood and Emergency Storage. *Vízügyi Közlemények*, 1996, No. 1.
[40] SZLÁVIK, L.–FEJÉR, L., Levee Failures on the Upstream Tisza on New Years eve in 1947. *Vízügyi Közlemények*, 1998
[41] SZLÁVIK, L.–VARGA, M.–VÁRADI, J.: Experiences with National Organisation of Emergency Measures between December, 1995 and June, 1996. *Vízügyi Közlemények*, No. 1, 1996.
[42] SZLÁVIK L.–VÁRADI J., Flood Control in Hungary. The 1995 Floods on the Upstream Tisza and the Körös Rivers. *Polgári Védelmi Szemle*, No. 1, 1996.
[43] SZŰK, T., Flood Fighting in the Trans-Tisza Water Authority District. ’A Tisza völgyi árvíz 1970.
[44] TAKÁCS L., Flood fighting on the Körös rivers. Vízügyi Közlemények, 1971, No. 3.
[45] VÁRKONYI, K., Construction work on the Minor-Delta emergency reservoir. *Víztükör*,No. 1, 1998.
[46] VITUKI, Design floods in Hungary. (Csoma János). VITUKI, Budapest, 1976.
[47] VITUKI, Flood Polders in Hungary. VITUKI, Budapest, 1977.
[48] VITUKI, Study on the Peak Flood Levels in the 1995 December Flood on the Fehér Körös. (SZEKERES János) February, 1996. február.