Doctoral School of Earth Sciences

Department of Natural Geography and Geological Information Sciences

Mária Bezdán

Characteristics of the Water Regime of Regulated Tisza in the River Section below Tiszafüred

Arguments of Doctoral (Ph.D) Thesis

Supervisor:

Dr. István Zsuffa (1933–2004), Professor, BME

&

Dr. János Rakonczai, Associate Professor, SZTE

2011

Introduction

The regulation planned by Pál Vásárhelyi and implemented under the management of Károly Herrich rearranged the downflow conditions of River Tisza and its affluent rivers. It considerably raised the level of its floods (by 3 to 4 metres) and in the same time it lowered the level of its low waters substantially (by 2 to 3 m). Furthermore the regulation shortened the length of the river in the ratio of 1.6:1 and increased the average slope of the Tisza river bed in the same proportion, thus increasing the average mean-stage flow speed of the river $\sqrt{1,6} = 1,26$ times. It also changed the temporality and extent of the interaction of the main river and the affluent rivers *(Vágás 2007)*.

Due to the water discharge accelerated by the regulation of Tisza river (by roughly 26%) and to the elimination of the water storage function of swamps *(Vázsonyi 1973*) the flood waves of spring and early summer subside more quickly and the summers of poor in precipitation advanced the long low water period. After no or only very little precipitation fell for ca. 20 to 40 days the water flowing in the channel mostly leaks trough the ground water *(Szalay 2000)*. Human water consumption leads to the further reduction of the water reserves stored in the soil *(Csatári et al 2001, Völgyesi 2005, 2009)* which result in the sinking of the ground water *(Rakonczai 2006)*.

As a result of the intervention, they started hydrologic processes which contradicted the formerly believed regularities and laws and to the explanation of which no actual reason or reasons could be revealed in every case according to the rigid attitude till then. It includes ***the sinking of low-water water levels*** *(Iványi 1948, Dunka – Fejér – Vágás 1996, Konecsny 2010…)**, the changes of the ground water, the flow regime of rivers** (Rónai 1956, 1958, Tóth 1995, Szalay 2000, Rakonczai 2001, Bozán –*

Környezet... Körösparti 2005, Völgyesi 2005, 2009, Pálfai 2005, 2010, Szalai – Lakatos 2007, Marton 2010,...), ***the elevation of high-water water levels and the effects of the barrages****(Koncz 1999, Stegăroiu 1999, Schmutz – Mader – Unfer 1995, Hausenstein et al 1999, Giesecke – Mosonyi 2005...)****.*** The researches of the recent period have seen the answer to the raised problem in the status changes of the floodplain (accretion, the proliferation of vegetation) and in the changes of the channel cross sections *(Nagy et al 2001, Schweitzer 2001, Gábris et al 2002, Sándor – Kiss 2006)*. Their significance may be quite considerable however the hydrological conditions I outlined (changes of water level reductions, effect of barrages and the prevailing hydrological conditions of the receiving and affluent rivers as well as the ground water) may overwrite the effects of them that are considered substantial on the merits.

It has been known for a long time that the flood waves starting form the Upper Tisza often join before reaching Middle Tisza. It became known later that some flood waves joining before Middle Tisza may disjoin again at Lower Tisza, which can be explained by the damming and sinking impact of the affluent rivers or the receiving waters *(Vágás 1982)*. The flood waves generated by the affluent rivers (Maros and Hármas-Körös) can appear in the subsiding or flooding branch of Tisza river and cause peaking. In the same way Danube can also start a flood wave peaking in bottom up direction. The flood waves generated by the affluent rivers (Maros and Hármas-Körös) appear as stray flood waves in the subsiding or flooding branch of Tisza and cause peaking. Similarly the Danube can also start flood waves peaking from bottom up. ***The appearance of these stray flood waves may become capable of indication due to the flat slope of Tisza and very important in changing the flow regime.*** Flow rate measurement that had become frequent in the past decades highlighted that the slope of the water surface must be taken into consideration during the calculation of the water yield *(Dombrádi 2004)*.

The flow regime and flood history data of River Tisza for the last 133 years has revealed that the flow speed and the direction of the flowing water differ outstandingly from the speed and direction of the summit of the flood waves *(Vágás – Simády 1983)*. The flow rate is determined by the stream flow, bed and surface slope conditions of the river in accordance with the common laws of hydraulics, whereas the run-off speed of the flood waves depend highly on the damming and surface sloping impacts caused by the affluent rivers and the receiving water (the Danube). The flowing direction of the flood peak of the water stage may become opposite to the flowing direction of the water on long river sections: it may often occur that the flood wave starting on the upper section of River Tisza does not end at the river mouth of the Danube but rather at the middle or lower section. The correlation of the mentioned phenomena seems obvious however intensive researches regarding the issue started only recently.

The general opinion of *Huszár M. (1985), Bogdánfy Ö. (1906), Erdős F. (1920), Tellyesniczky J. (1923), Korbély J. (1909), Iványi B. (1948), Lászlóffy W. (1982), Vágás I. és Simády B. (1983)* was that not all of the flood waves progressing along River Tisza but only part of them peaked earlier at the upper gauging stations rather than the lower ones, and ended “regularly” at the river mouth at the Danube. The majority of the flood waves of Tisza is exposed to damming impact on one of the sections of Middle or Lower Tisza (not necessarily the same in every case) in case of the flood of the Danube or some of the affluent rivers of Tisza - especially River Maros or the Körös Rivers or to sinking impact in case of their recession, and it peaks at the lower gauging station earlier than at the upper ones.

The known hydrological features of River Tisza include ***hysterese function*** (a line displaying the water yield of the flood wave together with the corresponding water stage in the form of a loop) *(Péch – Hajós 1898, Bogdánffy 1906, Schocklitsch 1930, Schaffernak 1935, Korbély 1937, Németh 1954…)* and its substantial feature is the ***invariance*** of ***peaking water stages*** in the same section for a longer period (for several days). As the consequence of all these, the unanimity and unanimous applicability of curves correlated with permanent condition of velocities and unvaried surface slope as well as displaying the water yields in the function of the water stage are ***restricted***.

Objectives

I dealt with the disclosure as well as the theoretical and practical solution of the unsolved issues arising in the section of Tisza under Tiszafüred. By using six hundred thousand daily figures selected from the available more than six million (!) registered water levels and the data of the ground water wells (between Tiszafüred and Törökbecse stations) I tried to work out further statements to be applied by the theoretical, designing and flood protection practice in the present problems of researches of technical and geographical sciences, that facilitate the organisation of flood protection as well as scientific researches and hydrological activities.

As an objective I set the detailed disclosure of the ***downflow and the progress of the flood wave***, the analysis of their relations of ***layout and time***, their ***statistical characterisation*** and the definition of the ***hydrological and geographical reasons*** leading to their occurrence in ***the sections of Tisza under Tiszafüred*** considering that these characteristics that may be considered extraordinary in comparison with other rivers mostly occur in the river section mentioned above.

I tried to put the areas of scientific issues in new light that had not been elaborated in detail before but the improvement of which was more and more required by the flood protection demands of recent decades and made possible by latest conditions computerised analysis. The evolvement of water surface slopes may be considered such a factor. I considered the analysis of the impact of the affluent rivers and the receiving water (Danube) on Tisza the most crucial issue on which recent researches had paid little attention. The problem required the highlighting of the differences between the downflow velocity of the water and the velocity of the flood waves on Tisza, and therefore the description of the occurrence possibly unique in the hydrology of Tisza on a global scale that explains the direction of peaking opposite to the flow direction.

Due to the changed water drainage of the period flowing the regulation of greater Tisza I intended to cast light on fact of ***water reserve reduction*** occurring in the Tisza section under Tiszafüred in the periods of low precipitation based on the data of ground water level detection that had started in the beginning of 1930's.

During the analysis of the ***water barrages*** I expatiated upon their impacts modifying ***ground water level, water stage and flow regime***.

Methods and area of analysis

I processed the water stages measured ***on River Tisza*** by gauging stations between Tiszafüred and Törökbecse in the period between 1876 and 2009. I defined the water surface slope from the data of two neighbouring gauging stations measured in the same period. I completed statistical evaluations from the surface slope variations. I analysed the following sections: Tiszafüred, Taskony, Tiszabő, Szolnok, Martfű, Tiszaug, Mindszent, Csongrád, Algyő, Szeged, Törökkanizsa (Novi Kneževac), Zenta (Senta), Törökbecse (Novi Bečej). By integrating the water stages to one metre pitches I analysed the water surface slopes of the various water stage ranges separately. I sectioned the analysed period in terms of period as well.

I formulated the longitudinal sections of water stage on the basis of daily density. I collected the annual low water, middle water and high water levels. I drew conclusions on the temporal changes of these water stages taking the events and interventions in the history of the river into consideration that had or could have impact on the changes of the flow regime.

Furthermore I defined the annual residence period of the water stages below "0" and above 600 cm together with the residence period of larger flood waves above 600 cm.

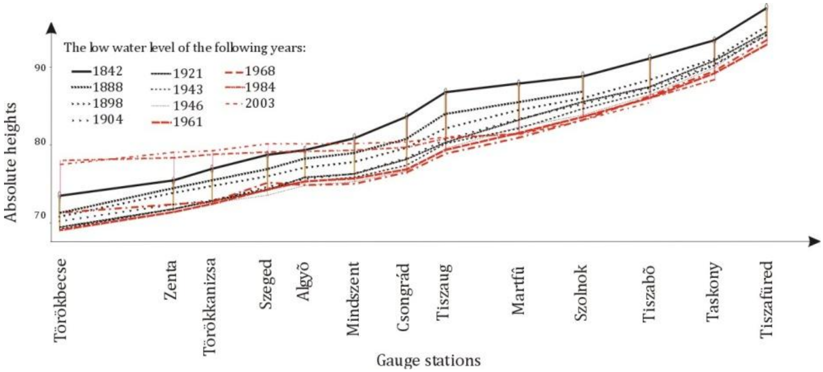
I analysed the number of flood waves subsiding on Tisza that had peaked at each station and those which subsided regularly, where there was no detectable backwater effect at peaking.

I analysed the temporal changes of the annual low water levels of the ground water wells and compared them to the changes of the low water stages of the rivers.

I formulated flood loop curves based upon the water stages and the few instances of water yield measurements. For the same cases I prepared the gauge correlation history curves as well.

Summary of the results

1. ***The larger extent of low water surface drop resulted from the strong reduction of the water yield and water reserves of the catchment area of the Körös rivers in the Tisza section between Martfű and Mindszent.***



1.figure: Evolution of the lowest water levels in the specified years

The strong sinking consisted of two parts: the water yield of Hármas-Körös fed the involved section of Tisza sufficiently in the low water period of 1841–42 taken into account for the establishment of the "0" point of the watermark posts, thus its level was recorded at a higher value. Secondly the water supply of Tisza by Körös dropped strongly due to the reduction of water reserve in the low water periods due to the regulation of the Körös rivers. The reduction of the low water yield of Hármas-Körös led to the process of the smoothing of the water level curve drawn by low water surface drops on the above mentioned section of Tisza (1. figure). The reduction of the low water yield of Hármas-Körös is justified by the absence of the former peak of the river mouth of Körös in the drawn longitudinal sections of Tisza during low water [10, 14, 15].

2. ***The low water surface drops react sensitively to the changes of the water yield of the affluent rivers.*** *The water yield reduction of Hármas-*

Körös led to the reduction of the low water yield of Tisza in the sections under Csongrád. As a result the backwater effect of Maros could predominate more strongly leading to the water surface drops on its surface in the section above the river mouth up to Csongrád. However the increase of water surface drops can be observed in the section above the river mouth of Hármas-Körös as the consequence of the absence of heading-up of Tisza as a result of the water shortage of the affluent river.

The area could obtain extra water supply by the construction of the Tiszalök barrage and the Eastern Main Canal, thus the water supply of analysed section at low water improved. After the construction of the Kisköre barrage and Nagykunság Main Canal the situation improved due to the new water supply. Törökbecse barrage smoothed the surface curves of the low water stages further by the heading-up of Törökbecse barrage *[8, 9, 10]*.

3. **The river drains the flood waves with different water surface drops case by case.** The average surface drops calculated for the sections are derived from data sets of quite high dispersion. The changes of water surface drops are quite significant in percentage, which are highly important in the changes of water stages. Taking the local distribution of precipitation into account is a similarly important factor in forecasting *[8, 9, 10]*.

4. **The water surface drop increases as the water depth increases except for the channel sections swelled during low water period as well.** The water surface drop decreases in the mid-water channel in comparison with the low water surface drops. The reason for this phenomenon is that the water yield of the affluent river is added to the water yield of Tisza as we proceed downwards on Tisza from the mouth of the affluent rivers and the water level increases together with strong

surface drop, however swelled state comes about on the Tisza section above the river mouth: the water surface increases and the surface drop decreases (sometimes even showing a negative figure). Peaking is delayed on this section and reversed flood loop curve is generated. ***Reversed loop curves are generated in the mileage(s) above heading-up.*** Loop curves of traditional direction of rotation are expected to generate directly under the mouth of the affluent rivers. If the impact of the recipient or the affluent river or the barrage is detected above the mouth of the affluent river, the reversing of the direction of the loop curve below the river mouth depends on the current water yield of the affluent river *[2, 3, 5, 7, 8, 9, 10]*.

5. ***More than 70 percent*** of the flood waves of Tisza ***were submerged*** by one of the affluent rivers or by the Danube ***in the period between 1876 and 1975***. ***It is more than 90 percent for the flood waves peaking above 600 cm. In the period after 1976*** and since the operation of the Törökbecse barrage ***80 percent of the flood waves have been submerged*** whereas ***95 percent of the flood waves leaving the main channel have been swelled.*** In case of high water flood waves flood discharge is also deteriorated by the fact that the joint impact of two or more anabranches and the receiving water has been detected together with heading-up effect of the Törökbecse barrage since 1976. **The most frequently swelled** channel sections ***in the high water range are located between Tiszaug and Algyő.*** Flood waves have been in swelled status several times in these sections since the commissioning of the barrages. ***In case of the flood waves peaking in the main channel the backwater effect of Danube made an upward impact up to Szeged in 25 percent of the cases in the period without barrages whereas this rate have increased to 48 percent since Törökbecse barrage was put into operation. The rate of heading with impact above Szeged was 25***

percent before 1976 which decreased to 20 percent later on. This piece of information is highly important with regard to forecasting and flood protection. The number of flood waves peaking in "reversed" manner decrease in the function of their distance measured from the river causing the flood wave. The number of peaks attributed to the backwater effect of Danube decreased by the increase of the distance from the river mouth of Tisza but due to the superpositions of Maros and Körös that could not be separated from the impacts of Danube the connection is more complex than simple exponential correlations. In the same way the unbalanced distribution of the number of occurrences of "reversed" flood waves is also influenced by the possibility of similar superpositions between various watermark posts [4, 7, 10].

6. The flood waves do not always peak at the river mouth for the last time; this phenomenon happens due to the backwater effects. ***Forty percent of the flood waves subsiding since 1876 and peaking at every station have finished above Zenta. It is 54 percent for the flood waves peaking above 600 cm. In the period after 1976 when the Törökbecse barrage was also put into operation peaking terminated at one of the mileages above Zenta in case of 58 percent of the flood waves whereas it had been 28 in the previous period***. In case of flood waves peaking over 600 cm Tisza had peaked at the ***Martfű*** and ***Szolnok*** stations for the last time in the period between 1876 and 1975; most of the flood waves have peaked in the region of ***Martfű, Tiszaug and Mindszent*** since 1976. The apparent *"packing"* of the flood waves of Tisza (as described by several authors) correlate with the hydrologic conditions of the drainage area changing from case to case and it is not associated with the development or regulation abnormalities of the river channel. This piece of information is important with regard to strengthening the dams *[4, 6, 7, 10]*.

7. Low water surface drops decreased on the Tisza sections influenced by the barrages in the period between 1976 and 2009 whereas their statistical dispersion increased however the increase of high water surface drops goes hand in hand with the reduction of their statistical dispersion *[8, 9, 10, 11, 12]*.

The river barrage of Kisköre has been operating since 1973 ***the lowest level of the waters decreased by more than 100 cm at Taskony, 50 cm at Tiszabő, 20 cm at Szolnok and 10 cm at Marfű until 2009.***

The barrage at Törökbecse was put into operation in 1976 and its impact can be detected roughly up to Csongrád (or up to Tiszaug at the lowest water levels). ***The lowest water levels have increased on average due to barraging: by 55 cm at Tiszaugnál; by 105 cm at Csongrád; by 150 cm at Mindszent; by 170 cm at Algyő; by 200 cm at Szeged; by 270 cm at Törökkanizsa; by 300 cm at Zenta and by 385 cm at Törökbecse.*** It means that the lowest waters show the following values: (-240 cm) at Tiszaug, (-135 cm) at Csongrád, (-25 cm) at Mindszent, 50 cm at Algyő, 70 cm at Szeged, 140 cm at Törökkanizsa, 205 cm at Zenta and 270 cm at Törökbecse. That means we may not talk about water stages of low water at the upper channel sections near the barrage any more. Beneath the barraged water levels the flow-through rate of the channel is low; it is almost excluded from water conveyance.

8. ***The drainage of the low and middle waters is fully regulated by the barrage.*** It also means that the channel sections behind have no impact on the water stage and operate like an inland water system: they store the water until it is discharged by the barrage in its own pace *[1, 11, 12]*.

9. ***The minimal barrage level has increased by more than one metre at the Kisköre barrage since the nineties.*** The lowest barrage levels at the Törökbecse barrage have also increased by 30 to 50 cm. High waters are characterised by higher water levels due to the heading impact of the waters of the barrages and affluent rivers. Kisköre barrage influences flow regime by its stored water. Due to the water body stored at the Kisköre reservoir the arriving flood waves run onto higher water level instead of low water level which means the change of the initial condition. It may increase the flood levels considerably especially in the section above the southern border of Hungary together with the nearly concurrent flood waves of the two large affluent rivers (Maros and Hármas-Körös) mentioned earlier *[11, 12]*.

10. ***In case of larger flood waves the impact of the heading of the Törökbecse barrage locks up the historical gauge correlation curves together even up to Tiszaug.*** It is difficult even for the high flood waves of Maros that it overwrites the extent of heading and opens the historical gauge correlation curves. It also means that the Törökbecse barrage regulates water discharge at high water period as well because it can forward the water yields brought by the river only in accordance with the water discharge capability of the mileage built up by structure. As a result the arriving water quantities are forced to wait behind the barrage, while the water level is increased due to the restricted reservoir capacity (high water river channel forced by dams is closed by the Kisköre barrage). ***The pace of water discharge at the river mouth is not necessarily determined by the pace of the original afflux but rather by the water discharge capacity of the channel built up with barrage depending upon current hydrological condition of the receiving water.*** At the times before the construction of the barrage the historical gauge correlation curves well demonstrated backwater thus substituting the loop curves describing the connection between water yield and water stage. By this a

shortage characterising the comparatively rare applicability of water yield measurements could be eliminated [1, 11, 12].

11. ***The barrage does not only submerge the water of the river but the ground water as well. This impact is especially significant in case of the Törökbecse barrage due to the topographical conditions. Thus the level of the ground water at low water level may not sink below a certain level.*** The large extent of the elevation of low water levels for large areas ***have decreased the volume of the further receptible water quantity*** in comparison with the former years without any influence. Reservoirs have been built on the upper part of the water catchment area, the low water level elevation impact of which changes the flow regime similarly. ***The permanence of low waters will decrease whereas permanence of middle and consequently high waters will increase.*** The minimum water levels sustained as the result of barrages are also higher in comparison with the low water conditions before the construction of the barrages, therefore the ground water may not sink below a certain level even in periods of poor precipitation. The flood waves starting from the upper section of the rivers will face ***changed initial conditions*** in the Hunagrian river sections because ***the basic water level of the rivers is higher due to heading but nevertheless it is not sure that their water yield is higher*** and that ***barrages regulate water discharge [11, 12, 13, 14, 15].***

12. During the statistical processing of the water stages of Tisza and considering the researches on sediment transport and river channel into account, it must be taken into account that barrages cause changes in both the hydrological processes and the sediment transport. This is why ***we do not treat the data of the period before and after putting the barrages into operation uniformly [8, 9, 10, 11, 12, 15].***

13. The planned river barrage at Csongrád is an important chain-link of the series of barrages in close connection. The river channel erosion and the accumulation above the river barrage is of much lower extent at the barrages built up on one another than in the case of barrages in loose connection. However the river strives to balanced condition and therefore the extensive transport of sediment slows down after some time. According to the experiences regarding the constructed barrages the river barrage would change the flow regime in its impact area: it would elevate low, middle and high water levels. The flow rate would decrease and accumulation would increase *[10, 11, 12]*.

14. ***Frequent and sometime quite strong natural and artificial headings in the Tisza sections below the Kisköre barrage (Hármas-Körös, Maros, Törökbecse barrage and Danube) are disadvantageous regarding the efficiency of emergency water storage. It might be more efficient to increase the height and width of the dams sufficiently for the protection against flood levels and flood durations.***

Published or approved publications in the subject of the thesis

1. ***Bezdán, M. 1994:*** Capacity analysis illustrated by the Algyő Land Drainage Development. *Hidrológiai Közlöny,* 74 (6), pp. 381–383.
2. ***Bezdán, M. 1997:*** Special Stage-Discharge Relationnships in the Flow Regime of the Tisza River. *Hidrológiai Közlöny,* 77 (3–4), pp. 197–202.
3. ***Bezdán, M. 1998:*** Interactions in the flow regime of the Tisza River. *Hidrológiai Közlöny,* 78 (4), pp. 247–249.
4. ***Bezdán, M. 1999:*** Flood waves on the Middle- and Lower-Tisza. Publications of the Regional Meeting Hungarian Hydrological Society (Miskolc). pp. 14–21.

5. ***Bezdán, M. 1999:*** The impacts of the left-hand Tisza tributaries on the flood waves. *Hidrológiai Közlöny,* 79 (2), pp. 89–99.
6. ***Bezdán, M. 2002:*** End of the peak flood level on the Middle-and Lower Tisza. *Hidrológiai Közlöny,* 82 (2), pp. 123–126.
7. ***Bezdán, M. 2008:*** Natural backwater and drawdown phenomena on the middle and lower reaches of the Tisza River. *Hidrológiai Közlöny,* 88 (1), pp. 9–26.
8. ***Bezdán, M. 2008:*** Slope of water surface on the Lower Tisza. *Hidrológiai Közlöny,* 90 (5), pp. 29–36.
9. ***Bezdán, M. 2010:*** Slope of water surface in the Tisza sections between Szolnok and Szeged. *Hydrological Brochure.* pp. 65–66.
10. ***Bezdán, M.:*** Resultants of statistical investigations on the river Tisza under Tiszafüred. *Hidrológiai Közlöny,* Approved: 11. 10. 2010. 2 p.
11. ***Bezdán, M. 2011:*** The effect of the barrages on to the water district of River Tisza. *Hidrológiai Közlöny,* 91 (2) pp. 18–20.
12. ***Bezdán, M. 2011:*** Change of flow regime in the Tisza sections South-Alföld. In: Rakonczai J. (ed.): Environmental changes and the Alföld. *Bocks the Foundations Grandalföld. Volume 7*. pp. 199–210.
13. ***Bezdán, M. 2011:*** Connections between aridites, undrained runoffs, and ground waters in the lowland basin of River Tisza. *Hidrológiai Közlöny,* 91 (4) pp. 57–59.
14. ***Bezdán, M. 2011:*** Connections between low water of River Tisza and ground water. *Hydrological Brochure.* pp. 98–102.
15. ***Bezdán, M. 2011:*** Incomprehensible phenomena in the formation of water-levels on the River Tisza near Martfű (Hungary). *Hidrológiai Közlöny,* 91 (5) pp. 45–48.