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MORPHOLOGICAL ALTERATIONS DUE TO CHANNELIZATION ALONG THE LOWER TISZA AND MAROS RIVERS (HUNGARY)

ABSTRACT: SIPOS GY., KISS T. & FIALA K., *Morphological alterations due to channelization along the lower Tisza and Maros rivers (Hungary).* (IT ISSN 1724-4757, 2007).

The effects of the the 19th century river channelization were studied on approximately 20 km long sections of the Tisza and Maros Rivers. Large scale human impact on their morphology was almost simultaneous. Regulations of the 19th century followed uniform plans, but the response of the rivers was different. This can partly be explained by their different hydrological characteristics (slope, discharge, sediment) and partly by the differences in further human interventions of the 20th century. Engineering works were almost continuous in case of the Tisza, but the studied Maros reach became a border river at the end of World War I and it has remained untrained since then.

Human impact and its morphological results were divided into three phases along the Tisza (natural phase, post cutoff phase, post bank stabilisation phase) whereas in case of the Maros two phases were identified (natural phase, post cutoff phase). The different responses were also evaluated from the point of view of morphological stability. Based on the rates and direction of changes we found that subsequent to 19th century human impact the Tisza started to give a robust answer, however, by further interventions these answers have been blocked in the long run. In case of the Maros human impact induced a sensitive answer in the short run, which might gradually turn into a robust answer in the long run.

KEY WORDS: River channelization, River response, Channel morphometry, Tisza and Maros Rivers (Southeast-Hungary).

INTRODUCTION

The horizontal and vertical parameters of channels affected by several factors are broadly discussed in different geomorphological and hydrological texts (Schumm, 1977; Knighton, 1998; Bridge, 2003; Richard, 2005). The impact of various human activities on channel morphology is less widely investigated. However, the results must be incorporated into the process of river management as it is emphasized by several authors (Newson, 1997; Hey, 1997; Gilvear, 1999; Downs & Gregory, 2004; Chin & Gregory, 2005). Furthermore, some researchers have drawn attention to the fact that engineering works designed to stabilize the channel and to control river regime often increased flood hazard (Tiegs & Pohl, 2005; Pinter & Heine, 2005).

Human activities affecting channel morphology and fluvial processes can be quite varied. Indirect influences, including changes of land-use and management on the catchment, urbanisation and land drainage, can modify runoff and sediment yield. A wide range of direct impacts influence the channel itself: e.g. dams, reservoirs and grade-control structures, channelization, artificial cutoffs and rectification, dredging, installation of groynes, artificial bank stabilisation etc. (Newson & *alii*, 1997; Knighton, 1998; Uribelarrea & *alii*, 2003; Antonelli & *alii*, 2004).

Land management and urbanisation usually change basin hydrology and lead to increased flood hazard (Stover & Montgomery, 2001; Kondolf & *alii*, 2002). Indirect human impact is often combined with local channel transformations, as in the case of Italian and Alpine rivers, where catchment scale and local impacts were superimposed and led to incision. The first phase of incision (at the end of the 19th century) was induced by land-use and land-management changes, while the second phase (1945-60) was the result of gravel quarrying and upstream dam construction (Rinaldi & Simon, 1998).

Direct anthropogenic interventions on lowland alluvial rivers primarily aim at ensuring navigation and enhancing flood control. However, measures may involve long profile degradation, channel narrowing (Liébault & Piégay, 2001) or to incision (Rinaldi & Simon, 1998; Arnaud-Fassetta, 2003; Surian & Rinaldi, 2003). Channelization effects were studied by Brookes (1985) and Yates & *alii* (2003), who that it resulted in an increase in slope and a decrease in roughness. Investigations show that cutoffs lead to increased stream power (Laczay, 1977) and bed-load trans-

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port (Biedenharn & *alii*, 2000), modifying channel geometry (Smith & Winkley, 1996). Processes are very similar to those acting in the case of a natural cutoff (rapid widening, accelerated bank erosion, formation of bars and riffles etc.), and in most cases, following the rapid changes of the first 2-3 years, the channel needs an additional few years to relax and to become stable (Hooke, 1995).

The present paper aims to evaluate the morphological (planform and cross-section) changes caused by different types of river regulation works on selected lowland sections of River Tisza and Maros in order to find evidence for the assumption that rivers are self-supporting morphological systems, which adjust themselves to modified conditions.

STUDY AREA

The Tisza River is the second largest river in Hungary, draining the water of the eastern Carpathian Basin (157,200 km^2). Its total length is 962 km, of which 596 km is in Hungary (Lászlóffy, 1982). A 25 km long reach was chosen as a study area on the Lower Tisza River (fig. 1). The Maros River is the most significant tributary of River Tisza, with a catchment of 30,000 km^2 and a length of 750 km. In this case a 22 km long section along the border between Hungary and Romania was investigated (fig. 1).

River regulation along Hungarian lowland rivers can be divided into two periods. Extensive works of uniform plans and design (Ihrig, 1973) started in the late 19th century and aimed at the protection of land from inundations and the decrease of the duration of floods. During the interventions 4,220 km of artificial levees were constructed, which meant the protection of 21,200 km^2 of land, almost one fourth of the present territory of Hungary (Dunka & *alii*, 1996; Szlávik 2000). Simultaneously, 102 and 33 cutoffs were made on the lowland sections of the Tisza and the Maros, respectively. On the affected reaches the slope was approximately doubled in case of both rivers (Dunka & *alii*, 1996). During the 20th century, especially between 1930 and 1960 mostly revetments and groynes were constructed. The aims of these works were (1) to stop lateral erosion, (2) to facilitate navigation and (3) to to allow the rapid passage of floods. Along the Tisza reach studied 3 cutoffs were made and along 37 per cent of the reach one or both banks were protected. In the meantime the studied section of the Maros was almost completely straightened by 7 cutoffs. Later, however, hardly any engineering works were implemented.

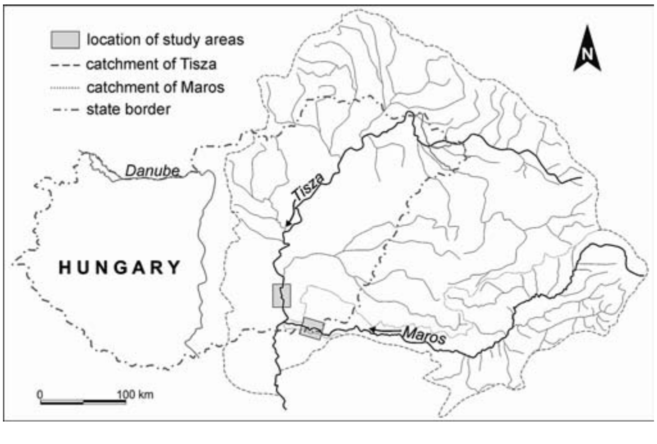

FIG 1 - Location of the studied river reaches, and the catchment of the Tisza and the Maros.

The Tisza and Maros Rivers and their tributaries are mostly fed by overland flow. The first, and normally the largest flood of the year is due to snowmelt in early spring, while the second is caused by early summer rainfall. The period between late summer and early spring is characterized by low stages on both rivers (tab. 1). Note that the ratio of mean annual peak flow to low flow is 21.9 in case of the Tisza and 8.8 in case of the Maros. Nevertheless, along the Tisza average inundation of the floodplain lasts for 2-3 months, while only for 2-3 weeks along the Maros (Török, 1977). Along the Tisza peak flood levels increased by 350-150 cm over the past century, while peak discharges hardly changed. On the Maros an approximately 50 cm increase was accompanied by higher discharges too.

TABLE 1 - Discharge and sediment data of the Tisza and the Maros at the study areas (data source: Bogárdi, 1974 and http://www.vizadat.hu)

		Tisza	**Maros**
Discharge (m^3/s)	maximum	3820	2420
	mean	930	161
	minimum	63	34
	mean annual peak	2514	842
	mean annual low	115	95
	bankfull	2020	850
Load (t/y)	suspended load	18,700,000	8,300,000
	bed load	9000	28,000

As a result of cutoffs, the slope of the studied Tisza reach is 0.000029 at present while mean velocity during mean discharge is 0.3 m/s (Károlyi, 1960). On the other hand the slope of the straightened Maros reach is almost ten times greater (0.00028) and the mean velocity is 0.7 m/s (Török, 1977). The volume of the annual suspended load is twice higher for the Tisza but the Maros transports three times more bedload. If we consider mean discharge data as well, then the specific sediment transport of River Maros is significantly higher.

METHODS

Planform change was detected from detailed and precise hydrological survey maps for the Tisza. Since regulation the floodplain and the channel were mapped 6 times

(1842, 1890-91, 1929-31, 1957-61, 1976 and 1999). No hydrological survey maps were prepared for the Maros, thus a regulation map series (1829), military survey maps (1865) and aerial photographs (1950, 1973, 2000) were used for the analysis.

Maps of different projection systems and aerial photographs were geocorrected by AutoDesk Land Desktop 2004 and Erdas 8.4 softwares, and transformed into the Unified Hungarian Projection System (EOV). Subsequently, the centre-line and inflection points of the studied reach were determined by measuring and halving the distance between bank-lines at every 100 m. Based on these planform parameters, such as length of centreline (L), sinuosity (S) and mean channel width (w_{mean}) were evaluated.

Measuring cross-sectional parameters was alleviated by a reference-point system established by the Hungarian Hydrological Institute along the Tisza River in the late 1890's. These fixed survey points were installed within 100 m distance from the banks and on the levees, with a spacing of 0.5-1.0 km along the river. They make the precise re-survey of cross-sections possible. First channel depth was determined along a steel wire, now ultrasonic sonar is used. The cross-sections were mapped 6 times (1890, 1929, 1957, 1976, 1999 and 2001), depth data were acquired at every 2 m along a section.

For the Maros no reference point system exists, therefore typical pre-regulation cross-sections from 1816 hydrological maps were compared with present-day ones, surveyed by ourselves. In addition, short-term changes were reconstructed from our 5 surveys, made in 2004, 2005 and 2006 at different water levels (2 low stages, 2 falling limb and 1 high flow measurement) and at fixed points of ca 100 m spacing along the channel. An ultrasonic sonar (Garmin) was applied, data were acquired at every 2 m with 10 cm accuracy. Both for the Tisza and the Maros the following parameters were measured: width (w), mean depth (d_{mean}), maximum depth (d_{max}), width/mean depth ratio (w/d) and cross-sectional area (A). Values were adjusted to the reference water level of bankfull discharge.

RESULTS

Before channelization *planform* was very different from that of today. The 1842 survey shows a highly sinuous meandering pattern and a wide bed with large mid-channel bars for the Tisza (fig. 2). In its natural state the sinuosity of the studied reach was 1.84, the length of the centre-line was 37.9 km. As a result of cutoffs the reach shortened by 35 per cent to 24.6 km and sinuosity also dropped to 1.26. Subsequently, length increased by 0.35 km (1.4 per cent) by 1999 but unevenly. Until the banks were stabilized it reached 6 m/y, but afterwards the process slowed down (between 1976 and 1999 only 0.8 m/y). The slow but continuous growth of length and sinuosity was due to meander development and the initiation of two new bends (fig. 2 and fig. 3).

Meander formation can already be detected on the 1890 survey maps. The lateral shift of banks has varied between 25 and 347 m since 1842 (0.16-2.4 m/y). However, this migration was uniform neither in space nor in time. As a result of 19th century cutoffs the slope doubled and with the lack of artificial bank protection the rate of migration between 1842 and 1890 was 0.7 m/y. The most intensive migration rate (2.4 m/y) was measured at sharp meander bends with sandy bank material (fig. 3B). As a result of 20th century bank protection works bank shift slowed down, even for non-stabilized meanders (0.6 m/y). However, the process has continued and has not stopped even at protected meanders where concave, stabilized banks remained unchanged but convex banks have advanced towards the centre-line (at a rate of 0.4 m/y) in the form of point-bars (fig. 3C). The length of straight sections within the study reach increased due to cutoffs (their proportion was 4 per cent in 1842 and 24 per cent in 1999), but since then these sections have developed without direct human impact. Bank-line migration here is small (0.3 m/y), as thalweg shifts are insignificant.

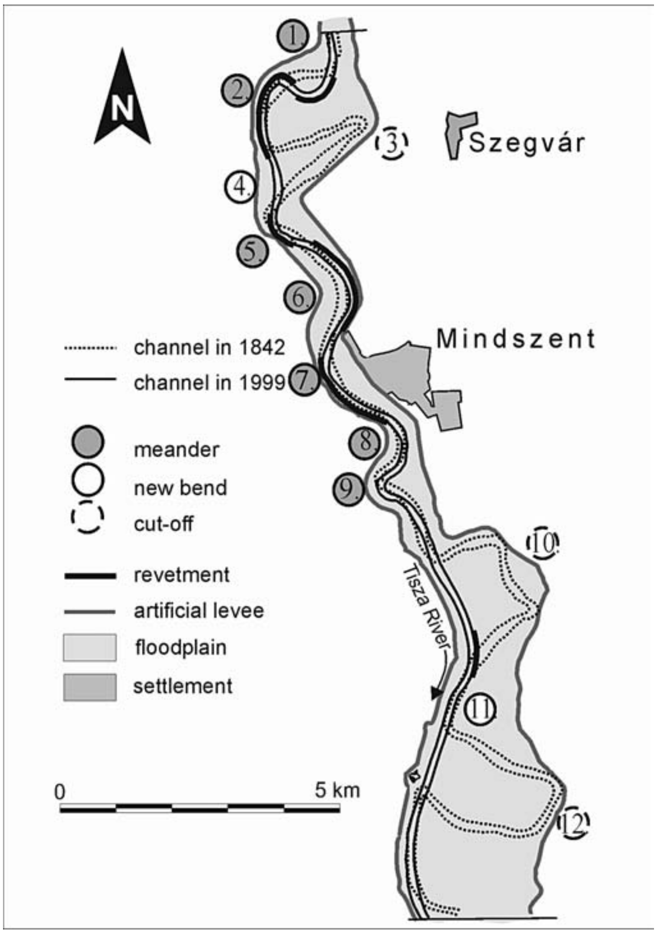

FIG. 2 - The course of the studied Tisza reach in 1842 and in 1999. The location of cutoffs, meanders and revetments. Note that banks were stabilized in order to protect the levees.

Mean width has decreased since 1842 by 16 per cent (tab. 2) but not at a uniform rate. Narrowing was greatly

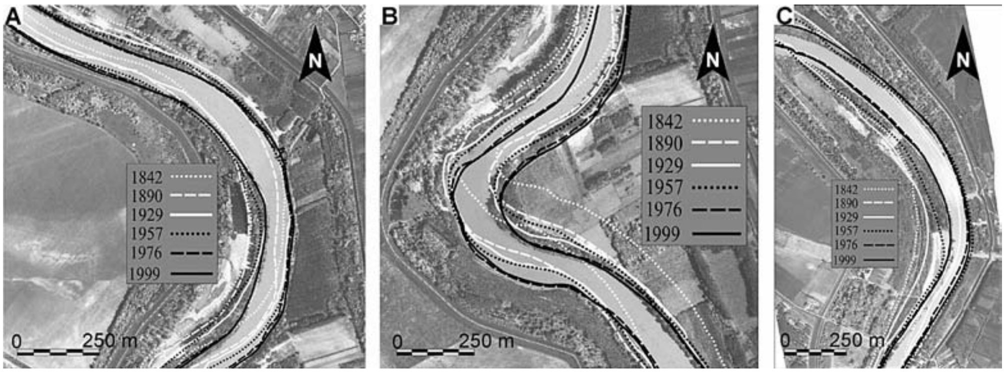

FIG. 3 - Meander development at sections under different human impact. A) and B) - bend 8 and 9 - no bank stabilisation, lateral and longitudinal evolution is obvious. C) - bend 6 - revetment construction stopped bank retreat, Note the intensive narrowing of the channel (location of cross-sections can be seen on fig. 2).

TABLE 2 - Change of planform parameters on the studied Tisza reach

date	L (km)	S	w_{mean} (m)
1842	37.9	1.84	182
1890	24.6	1.26	169
1929	24.7	1.27	174
1957	24.9	1,28	154
1976	24.9	1,28	156
1999	25.0	1,28	152

influenced by the place and time of cutoffs (fig. 2), as the technique of 19th century engineers was to create only a small, 8-11 m wide and 5-6 m deep lead ditches occupied and further shaped by the river itself after blocking the meander (Lászlóffy, 1982). The outcomes are shown on hydrological maps. The 8 per cent width decrease measured between 1842 and 1890 results from undeveloped artificial lead ditches. By 1929 the width of the reach was almost the same prior to cutoffs (tab. 2). Following artificial bank stabilisation the channel started to narrow down intensively, and by 1957 its width was just 154 m, 12 per cent (0.7 m/y) reduction since 1929. These changes were related to the advance of convex banks toward the centre of the river. Since 1957 widths are considered stable as in 1999 the average width decreased only by 2 m (tab. 2). A reach-scale narrowing is much greater along stabilised sections than along naturally developing sections (see tab. 4).

Before the regulations the pattern of the studied Maros reach was compound: slightly meandering along the upper, while anastomosing along the lower section (according to Fergusson 1987), where large islands (three times wider than the total width of the channels surrounding them) dissected from the floodplain (chute cutoffs) and sub-channels (fig. 4). Pre-regulation river dynamics can be evaluated on the basis of 1829 and 1865 map series. Absolute measurements on the 1829 maps were not possible, thus the 1865 length of the centreline was determined (40.6 km). The sinuosity of the main channel was 1.78 and 1.82 in 1829 and 1865, resp. (tab. 3). This refers to the lengthening of the centreline through the formation of compound meanders between the two dates, with an approximate value of 25 m/y.

During channelization the upper, meandering part of the reach was left intact, the lower anastomosing section, however, was almost entirely straightened. As bank stabilization did not follow cutoffs, the natural reaction of the river could be evaluated. The intact upper reach lengthened by 670 m from 1865 to 1953 (7.6 m/y rate). Between 1953 and 2000 length increased by 2.3 m/y. The difference may arise from errors in geocorrection, thus the later data (derived from aerial photographs) seems more adequate

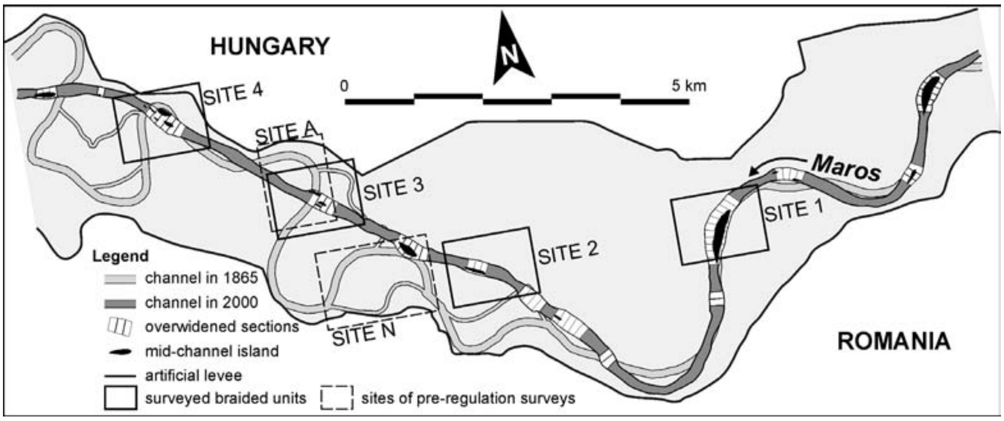

FIG. 4 - The course of the studied Tisza reach in 1865 and 2000, overwidened sections and the location of surveyed sites.

(tab. 3). Length increase is the outcome of the natural bend evolution (fig. 5A), also involving lateral and downstream shifts. The average rate of lateral migration from the regulation till 1953 was 2.1 m/y (approximate data), while over the last 50 years 1.3 m/y.

Due to cutoffs the entire lower section became virtually straight, its length decreased by 56 per cent (from 32 km to 14 km, sinuosity: 1.02). A major response of the river was pattern change. Between 1856 and 1953 the channel widened out around small mid-channel islands at several locations (braided pattern to absorb the additional energy from the doubled channel slope). Braided pattern is also reinforced by present bar forms and cross-sectional parameters (see later). Prior to the regulations two mid-channel islands were identified, with a total area of 1.6 ha. By 1953 number 36 developed (total area: 11.5 ha). The total area of coalescing islands (21 in number) increased to 26.6 ha by 2000 as a result of vegetation and hydrological processes which enabled the colonisation of bar surfaces (cf. Kiss & Sipos, 2006). Meanwhile, the centreline showed significant (in certain cases 60-70 m) lateral shifts (fig. 5B). The reason for this is mainly the continuous birth and decline (merging into the banks) of islands, since this way the thalweg is diverted, and thus banks can be eroded (Sipos & Kiss, 2003). The process is cyclic with the thalweg swapping between both banks (Sipos & Kiss, 2004). Centreline displacement is also expressed in the variation of reach length but sinuosity hardly changed over the past 50 years (tab. 3). Thus no direct morphological evidence has been found yet for bend initiation, and the reach still shows a braided pattern.

The river reach significantly widened parallel with the development of braided sections. The difference between the natural and the 1953 state is 18 per cent (tab. 3). However, from 1953 till 2000 an average 0,4 m/y tightening resulted a 13 per cent decrease. Channel narrowing has been temporally and spatially uneven (tab. 3). Taking temporal changes the most significant decrease occurred during low water stages in the 1990's, when vegetation conquered extensive point bar surfaces. Spatially the greatest decrease has been experienced in terms of over-widened sections, where the rate of narrowing was 0.8 m/y in average. This refers to the slow but continuous decline of braids.

Based on the degree of human impact, *cross-sections* were classified into the following groups: (1) those without direct interventions, in straight reaches (1a) or in meanders (1b); and (2) those affected by artificial cutoffs (straight reaches, 2a) and by revetment constructions (meanders, 2b).

(1a) At cross-sections along unaffected straight reaches width has decreased since the channelization by 15-19 per cent on average and locally even by 35 per cent (tab. 4). Maximum depth increased by 3-5 m (45 per cent growth), suggesting intensive incision. Altogether, the simultaneous narrowing and deepening caused only minor (3-4 per cent) reduction in cross section (tab. 4). These changes on the other hand the channel shape, however, were significantly affected: w/d ratios decreased by 45 per cent on average and the originally trapezoid cross-sections were deformed.

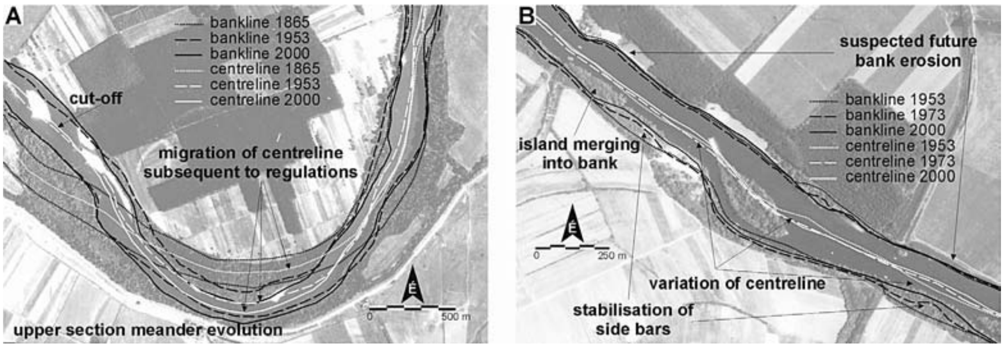

FIG. 5 - Changes in the course of bank line and centre line on A) the upper intact section, and on B) the lower straightened section of the studied Maros reach.

TABLE 3 - Change of planform parameters on the intact and straightened sections of the studied Maros reach

date	entire reach			upper intact section			lower straightened section		
	L (km)	S	w_{mean} (m)	L (km)	S	w_{mean} (m)	L (km)	S	w_{mean} (m)
1829	–	1.78	–	–	1.32	–	–	2.23	–
1865	40.59	1.82	150	8.54	1.46	163	32.05	2.17	137
1953	23.57	1.20	177	9.21	1.38	184	14.36	1.02	169
1973	23.62	1.21	171	9.29	1.39	183	14.33	1.02	158
2000	23.65	1.21	156	9.31	1.39	163	14.34	1.02	149

TABLE 4 - Change of average cross-sectional parameters at reaches under different human influence

	no direct human impact										direct human impact				
	meander					straight					meander				
date	w (m)	d_{mean} (m)	d_{max} (m)	w/d	A (m^2)	w (m)	d_{mean} (m)	d_{max} (m)	w/d	A (m^2)	w (m)	d_{mean} (m)	d_{max} (m)	w/d	A (m^2)
1890	110	9.8	11.0	11	1741	196	6.8	7.0	29	1674	124	6.7	7.5	19	1474
1929	103	9.1	11.1	11	1667	164	9.1	10.0	18	1752	100	8.5	9.8	12	1566
1957	107	9.2	9.9	12	1568	145	9.0	9.5	16	1763	97	9.1	10.1	11	1360
1976	119	9.8	9.9	12	1651	144	9.4	10.8	15	1743	102	10.1	11.0	10	1370
1999	111	10.4	10.6	11	1767	140	8.9	10.0	16	1710	103	9.8	11.1	11	1321

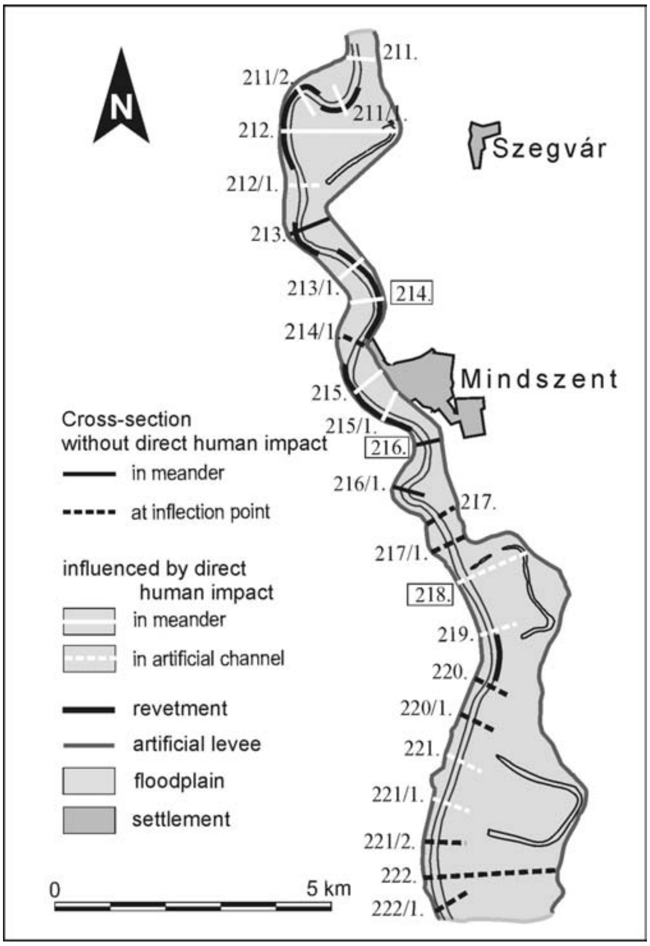

FIG. 6 - Location and type of investigated cross-sections on the studied Tisza reach.

(1b) In case of cross-sections of unstabilized meanders, width has decreased by 16-17 per cent since 1890 as the convex banks migrated 50-60 m towards the concave banks (tab. 4 and fig. 7A). Meanwhile maximum depth changed slightly (0.3 m on average). However, mean depth grew by 22.1 per cent. The direction of change denotes a continuous deformation, even though w/d ratios have stayed almost the same (fig. 7A and tab. 4). Cross-sectional area remained almost unchanged (2-3 per cent growth).

(2a) Subsequent to channelization the cross-sections of straight reaches first became wider and deeper (fig. 7B). By 1957 incision was replaced by channel accumulation, making it 14-16 per cent shallower (fig. 7B). Cross-sections have been continuously broadening (since 1957 by 7 per cent), although at a lower rate than before. Cross-sectional areas reduced only slightly (1-2 per cent).

(2b) Last-century river management mainly concentrated on hindering bank retreat at meanders. The bank stabilisation structures applied permanently fixed the concave banks. Following the establishment of revetments (1932) the width of these cross-sections decreased due to point-bar formation at the convex banks (tab. 4 and fig. 7C). As bank protection prevented lateral erosion, an intensive incision started (3-3.5 m, i.e. 30 per cent increase of maximum depth and a striking decrease of average w/d ratios - tab. 4). The thalweg moved ever closer to the protected bank, channel shape deformed and cross-sectional area dropped extremely (by 25 per cent on average). The most distorted shapes were observed at this group of cross-sections (fig. 7C).

In lack of data, some pre-regulation cross-sections from the lower part were compared roughly to those surveyed recently. Such cross-sections are slightly wider and narrower (tab. 5). From the present surveys cross-sections of similar width and morphological situation were chosen (tab. 5). Concerning channel depth a significant difference can be detected in terms of the ratio of d_{max} and d_{mean} values. Prior to channelization the ratio was 1.8, while at present it is 1.3 on average (a 38 per cent difference), meaning that the bed floor is more even now. The reason is that in the original meandering-anastomosing channel the thalweg was more pronounced near the convex banks. Nevertheless, if pre-regulation and present-day width/depth ratios are compared the mean difference is only 9 per cent, and there is also a great similarity in terms of cross-sectional areas (tab. 5). Some parameters may have changed in the long run (mostly d_{max}), but those reflecting channel pattern (d_{mean}, w/d, A) returned to their initial values, the river readjusted itself.

At present the average width/depth ratio along widened reaches is 64, while along narrow reaches only 27. This reflects a high longitudinal variation in accordance with the riffle-pool system (braided and non-braided sections) typical of the reach (fig. 4). According to Fergusson (1987) width/depth ratios above 50 indicate braiding, while those below show meandering. The studied reach is transitional between both pattern types.

FIG. 7 - The development of characteristic cross-sections representing A) non-stabilised meander reaches, B) artificial straight reaches and C) meanders with bank stabilisation structures (location of cross-sections can be seen on fig. 6).

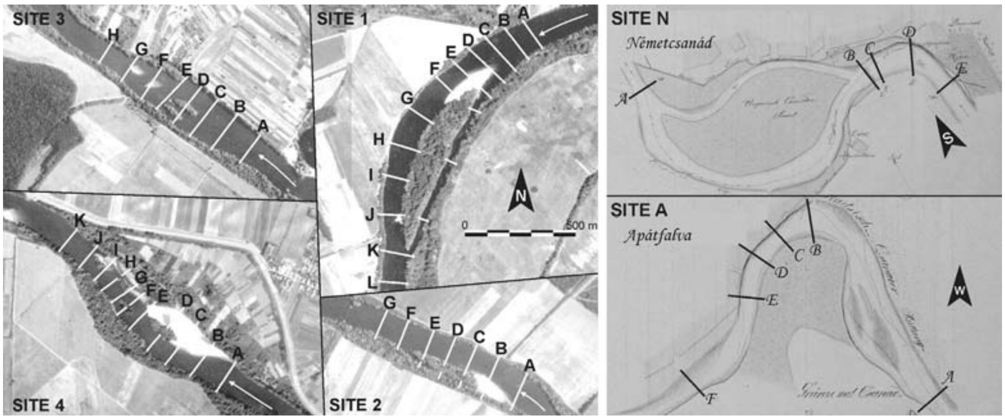

TABLE 5 - Parameters of pre-regulation and present day cross-sections (morphological situation of cross-sections can be seen on fig. 8)

	1816 cross-sections					location*		2004 cross-sections				
ID	w (m)	d_{mean} (m)	d_{max} (m)	w/d	A (m^2)		ID	w (m)	d_{mean} (m)	d_{max} (m)	w/d	A (m^2)
N/A	119	3.65	5.2	33	427	U	2/A	129	3.5	4.1	37	452
N/B	163	3.7	5.0	44	606	U	3/A	151	3.4	4.7	45	513
N/C	199	3.4	5.8	58	686	U	3/B	185	3.0	4.0	61	555
N/D	205	3.9	6.5	53	795	O	4/B	206	3.1	4.4	66	639
N/E	145	4.2	6.9	34	615	D	2/I	134	3.8	5.7	35	509
A/A	144	3.3	4.8	44	472	U	4/A	164	3.2	3.7	51	525
A/B	219	3.0	8.3	73	655	O	4/B	206	3.1	4.4	66	639
A/C	112	4.1	8.8	27	460	D	4/P	114	3.8	4.6	30	433
A/D	138	4.3	6.6	32	595	D	2/I	134	3.8	5.7	35	509
A/E	123	3.8	6.5	32	471	D	2/J	129	3.7	5.1	35	477
A/F	150	2.5	7.3	60	375	O	–	–	–	–	–	–

* O: overwidened; U: upstream of overwidened, D: downstream of overwidened

Very intensive variations were observed in terms of cross-sections both spatially and temporally in the short run. Changes can be related to different hydrological and morphological situations. Temporal changes showed that the mean depth of cross-sections during low flow was 31 per cent greater than during high flow, and 19 per cent greater than on the falling limb (tab. 6). This means a 0.8-0.9 m overall aggradation of the bed by increased bedload transport along bars during floods. At low stages sediment is washed out by lateral erosion and cross-sectional area increases by 150-200 m^2 on average.

TABLE 6 - Change of cross-sectional d_{mean} in relation with different hydrological situations at the surveyed sites (values are the mean of all depth data at a given site)

	Site 1	Site 2	Site 3	Site 4
2003 low stage (60 m^3/s)	3.47	–	–	3.56
2004 falling limb (217 m^3/s)	3.23	3.07	3.12	3.33
2004 low stage (94 m^3/s)	3.42	3.20	3.17	3.54
2005 high flow (404 m^3/s)	2.51	2.59	2.58	3.09
2005 falling limb (259 m^3/s)	3.04	2.82	2.79	3.13

The degree of aggradation and erosion shows a spatial variation, too. The greatest mean depth changes were observed in terms of cross-sections at overwidened units (the mean aggradation after floods was 0.9-1.0 m in wide cross-section). Concerning narrow reaches differences were smaller, and mean depth changed between the survey dates only 0.2-0.3 m on average.

DISCUSSION AND CONCLUSIONS

Human interventions and geomorphological responses along the studied meandering reaches of the Tisza can be divided into three phases, whereas in the case of the Maros two phases can be identified. The first and common period is the natural development of the two rivers. In case of the Tisza this stage is represented by only one survey (1842), which shows a meandering river. For the Maros two surveys refer to this era, and indicate a partly meandering, partly anastomosing pattern. The sinuosity of the main channel of the two river reaches was almost identical at this time (1.84 and 1.80), the Maros, however, had a significantly steeper channel and valley slope. According to

Schumm & Khan (1972), steeper slope leads to higher sinuosity, since this is the way how the river consumes additional stream power. On the other hand increasing discharge and decreasing sediment load result in similar processes (e.g. Knighton, 1998).The observed planimetric similarity between the two rivers is caused by differences in the later two variables: sediment load and discharge. In case of the Maros significantly higher specific sediment load transport and lower discharge are suspected to equalize morphological parameters. Higher bedload transport along the Maros is also reflected in different channel form. Pre-channelization w/d ratios were approximately twice as high as for the Tisza, i.e. mean width difference between the two rivers was only ca 17 per cent.

The second phase of development can be related to very intensive engineering measures (primarily cutoffs). The direct effect of this technique can be studied on the basis of 1890 and 1929 Tisza surveys. As a result of cutoffs, the length considerably decreased and due to the existence of artificially created lead ditches the average width of the reach also decreased. However, meandering pattern remained, and by 1929 all cross-sectional parameters reached almost the same value as before (just a slight incision and cross-sectional area increase was detected). For the Maros no precise surveys were made right after channelization. However, 1953 aerial photographs suggest that following the artificial narrowing and incision due to lead ditches the river significantly widened, similarly to the model described by Schumm (1977) or Simon & *alii* (1999). Meanwhile the meandering-anastomosing pattern of the studied reach abruptly changed and became straight along the lower sections, then locally braided. Another key difference between the responses of the two rivers was that along the straightened sections of Tisza bend initiation was observed. Along the Maros this process has still not started, even though uncut bends have shown a higher rate of lateral shift than those of the Tisza. Nevertheless, if summarizing all the changes in centre-line increase and lateral shift, the studied Tisza reach shows a more intensive planform adjustment after channelization.

The reaction of management for the above processes along the Tisza was the implementation of further regulation structures (revetments and groynes). These measures and the morphological responses represent the third stage of development (from 1957 up to the present). As more than one third of the reach length was artificially stabilized, this type of intervention had a major impact on the channel. While lateral migration was prevented, the total length of the centre-line increased, meaning that meanders became sharper. Furthermore, point-bar formation on the convex banks continued. Therefore, the channel became narrower, cross-sectional area decreased; the shape of the cross-sections was distorted. These changes have implications not just in terms of morphological stability but also on flood hazard and flood level (the same discharge passes with a higher water level).

Meanwhile, in the lack of further human impact (due to historical reasons) the Maros remains in the second stage. Namely, processes of the present and the near past are responses to the cutoff type intervention. In the past 50 years the lateral movement of unstabilized bends along the upper section continued. Concerning the lower section morphological processes referred to the slow decline of braided units and future possibility of bend initiation. This is reflected in the size, number and position of islands and the intensive narrowing of widened reaches. Thus, compared to the Tisza, here tightening is mainly driven by seminatural processes. Present day cross-sectional analysis proved that the shape of the Maros channel is very similar to its pre-channelization state, i.e. the morphological rearrangement on the level of w/d ratios has been completed, and flood hazard is not increased morphologically (same discharge, same water level). In addition, it must be also emphasized that in case of a sand-bedded, high bedload waterflow the precise detection of long-term changes is viable only if cross-sections made at similar hydrological situations are compared.

If morphological responses are evaluated in the system of Werrity & Leys (2001), then we may claim that following the 19th century human impact the Tisza started to give a robust (rearranging) answer with most of its morphological parameters in the short run. However, by further interventions these answers have been blocked in the long run. In case of the Maros human impact induced a sensitive (pattern change) answer in the short run, which might gradually turn into a robust answer in the long run. The difference in the intensity of responses may be explained by the fact that the investigated Maros reach experienced a more severe impact in terms of cutoffs. The highly mobile sand bed (dunes and bars) and significant specific bedload transport (suggested to consume a significant proportion of stream power) of the Maros might be a further reason for the different rate of rearrangement.

Based on the morphological and hydrological outcomes of different human interventions along the two studied river reaches (Tisza: flood hazard morphologically increased accompanied by pattern stability; Maros: flood hazard morphologically not increased, but pattern instability emerged) we claim that any kind of management strategy has to strike a balance between managing flood hazard and morphological stability.

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