MORPHOLOGICAL ALTERATION OF THE DRÁVA AS THE RESULT OF HUMAN IMPACT

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Abstract
The Croatian-Hungarian border section of the Dráva River has been undisturbed for almost a century, and it is characterised by unique fluvial morphology (braided pattern and islands) supporting rich habitats and wildlife. However, during the last decades human impact became more and more intensive. Between 1975 and 1989 three water reservoirs were built on the Croatian section of the river, just 16 km from the beginning of the border-section, altering the hydrology and the sediment characteristics of the river. On a local scale cut-offs, revetments and groynes were built. The aim of the study was to evaluate the effect of these human interventions. As the result of the alteration of the hydrology the channel pattern of the Dráva has been changing from braided to meandering, though on the upstream meandering part the territory and number of islands increased due to the drop of water stages. A cut-off and a groyne influenced only the morphology of a short section. As the result of the cut-off braided pattern became more pronounced, and the groyne caused intensive channel aggradation and gave way to lateral island development.

Keywords: human impact, cross-section, channel pattern, island, aggradation

1. Introduction

The effects of different river engineering works on channels and floodplains are rarely investigated, though on some rivers there are evidences on rapid changes (Liébault and Piégay, 2001; Brooks, 2003; Pinter and Heine, 2005; Kiss and Sipos, 2007; Mecser et al. 2009). The regulation works, especially flood control structures alter not only the fluvial system (Kiss and Sándor, 2009), but also the soils (Arnaud-Fassetta, 2003, Szabó et al. 2008), the riparian vegetation (Tóth et al. 2009) and the micro-climate of the floodplains (Antal 2000). The in-channel constructions (dams, grade-control structures, groynes, revetments etc.) mostly alter the channel (Laczay, 1977; Surian, 1999; Surian and Rinaldi, 2003), however they also have an affect on floodplains.

In Hungary, river regulations started in the 18th century, though the lowland rivers were regulated following uniform plans in the 19-20th centuries (Ihrig, 1973). The greatest number of cut-offs were made on the Tisza River and its tributaries. Here the first cross-sections were surveyed in 1842 to monitor the channel changes after the river regulation works. The same cross-sections were repeatedly surveyed enabling the engineers and researchers to evaluate the channel development (Fekete, 1911; Félegyházi, 1929; Károlyi, 1960; Kiss et al. 2008). These studies recorded intensive incision and widening soon after the creation of cut-offs, thus the area of cross-sections increased. However, local revetment and groyne constructions reversed this tendency, and the channel of the Tisza started to became narrower, thus the flood hazard has increased (Nagy et al. 2001; Kiss et al. 2008).

The regulation works were so drastic in case of some rivers, that river metamorphosis occurred. For example the original anastomosing/meandering pattern of the Maros River turned into braided (Kiss and Sipos, 2007). In this process the artificially increased slope and the naturally high bed-load resulted in bar formation, especially in the wide braid sections. As these bars were colonised by vegetation they developed into downstream migrating islands (Sipos and Kiss, 2006). The rate of island development and migration depends on the hydrological factors and the type of vegetation (Osterkamp, 1998).

The aim of this paper is to quantify river bed changes and to connect them to human or natural processes on the Dráva River. Though the border section of the river (between Hungary and Croatia) was undisturbed for almost a century, human impact became more and more pronounced on the upstream sections and in some local points. Between 1975 and 1989 three storage lakes and hydro-power plants were built on the Croatian section of the river, just 16 km from the beginning of the border-section. These constructions drastically altered the hydrology and the sediment characteristics of the river (Kiss and Andrási, 2011). On a local scale cut-offs, revetments and groynes alter the morphology of the Dráva. The downstream effects of these human impacts are not known, though they endanger the wildlife of the Duna Dráva National Park.

The above mentioned human interventions have different and superimposing effects, therefore the morphological characteristics of the Dráva were analysed from different approaches and at different scales. The effects of the dams are long-lasting but the rate of change is slow. To evaluate them the pattern of the Dráva was studied, calculating the vertical and horizontal channel parameter changes along a 40 km long section (between 154 and 195 fluvial km). The local engineering works have mostly local consequences, thus the aim was to evaluate the effects of a cut-off and a groyne-construction on the channel and its forms. To evaluate the effects of the local works, the channel changes of a section between Bélavár and Heresznye (185-195 fkm) were studied, where a cut-off was made in 1979-82, while near Vízvár the effect of a groyne (1982) on channel and island formation was also measured.

2. Study area

The Dráva is the greatest west-side tributary of the Danube in Hungary. Its catchment area (40,095 km^2) is located in the Eastern Alps. On its upper section (upstream of Őrtilos) its slope is 0.00080-0.00130, while between Őrtilos and Eszék (Osiak) it decreases to 0.00013-0.00035. The medium discharge near Maribor (Slovenia) is 300 m^3/s, and at the inlet it is 653 m^3/s (Mantuáno, 1974). The sediment load of the Dráva is dominated by bed-load. In the reservoirs 95 % of the transported sediment is deposited, thus before their construction the yearly sediment discharge was 1.08 million t (1967-1975), then after 1989 it decreased to 0.66 million t[1].

The regulation works on the river started by levee constructions in the 1750's (Remenyik, 2005), followed by cut-offs in the 1780's (Majdán, 2008). The hydrologic and hydraulic data collection began in 1886. As the result of 19th century regulations the original length of the lowland section of the Dráva River was reduced to 60 %, thus the river became navigable from its conjunction up to Barcs (Ihrig, 1973). The last major engineering work was made in 1993-94, when two overdeveloped meanders were cut off near Zaláta and Drávasztára. On the upper section of the river 22 dams were built, the last was completed at Donja Dubrava (Croatia) in 1989. In contrast, the middle – border – section of the Dráva is close to its natural condition (Ihrig, 1973). According to the Trianon Treaty (1920) the thalweg of the Dráva was declared as the state border-line. However, the Dráva has a high energy and very active lateral erosion, thus its course changes rapidly. Nevertheless the border-line was not corrected, therefore nowadays the channel is located partly in Croatia and partly in Hungary. The special political location of the area enabled the survival of natural riparian conditions: the unique fluvial morphology (braided pattern and islands) support extremely rich habitats and wildlife, which is under the protection of the Danube Dráva National Park.

The study was made along this almost undisturbed border section of the Dráva applying different scales. The longer term (1972–2006) research on channel changes was made between the Bélavár and Barcs section (154-195 fluvial km) evaluating cross-sections, while between Bélavár and Heresznye (185–195 fkm) island formation was studied in detail (Fig 1). In the summer of 2008 a side-channel and an island was studied in detail near Vízvár.

[1] http://www.kvvm.hu/cimg/documents/elozetes_kornyezeti_hatastanulmany.pdf

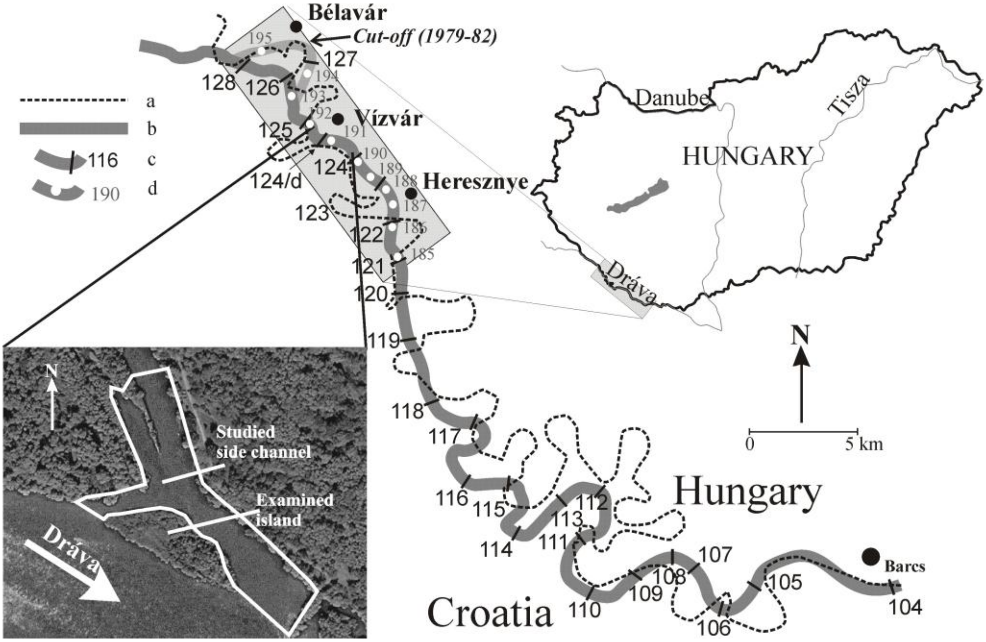

Fig.1. The studied 40 km long Dráva reach is located along the Hungarian-Croatian border. On the upper quarter of the reach the islands were studied in detail. The aggradation of a side-channel and the accumulation of an island were analysed near Vízvár. *a: course in 1920; b: course in 2006; c: location of cross-section; d: fluvial km*

On the studied section the slope of the Dráva is 0.00025-0.00030. The mean discharge at Barcs is about 510 m^3/s, during low stages it is approximately 150 m^3/s and during floods it is over 2000 m^3/s, the ratio between the lowest and highest discharge is 13.1 (Mantuáno, 1974). The upper section of the study area can be characterised by mostly gravel bed-load transport (Kiss and Andrási, 2011), where the greatest grain-size is 55.6 mm, but towards Barcs it is getting progressively finer (greatest grain-size: 38.7 mm). This section of the river was not systematically regulated, though some groynes and revetments influence the course of the river, and near Vízvár a cut-off was made in 1979-82.

3. Methods

To evaluate the effects of engineering works cross-sections and islands were studied. The cross-sections were surveyed in 1972 and 2006 by the DDKÖVIZIG[2]. For each cross-section the bankfull water-level was determined (a.s.l), and from this line the depth data were measured in 10 m intervals. The average depth was

[2] DDKÖVIZIG: South Transdanubian Environmental Protection and Water Management Directorate

defined as the arithmetic mean of the depth data, the cross-sectional area was calculated by the sum of depth data multiplied by their interval distance. The width/depth ratio refers to the pattern of the channel, if its value is over 50, the channel is considered to be braided (Fergusson, 1987).

The changes in the number and area of islands were measured on maps surveyed in 1972 and 2006 (DDKÖVIZIG). Their geo-correction was made under Erdas Imagine 8.4. Islands were digitalised and their area and shape were analysed using ArcView 3.2. The elongation ratio (width/length) refers to the energy conditions of the river around an island (Sipos and Kiss, 2004). The elongated and narrow islands indicate higher energy conditions in their surroundings, than the oval shaped or rounded islands.

The development stage of the braids was determined following the definitions of Sipos and Kiss (2003). In the first, juvenile stage mid-channel bars develop into mid-channel islands. These are getting larger and they shift towards one bank in the mature stage. Finally, in the senile stage the large islands get close to the river-bank, and the side-channel between them aggrades, thus the island submerges into the floodplain.

The effect of a groyne on channel aggradation and island development was studied at Vízvár, mostly based on field measurements (June 29, 2008, water stage: 51 cm, discharge: 585 m^3/s). The depth conditions of the side-channel were determined by radar (accuracy: ±5 cm). The depth was measured along cross-sections in the length of a 450 m section of the side-channel. Based on the results a bathymetric map of the side-channel was drawn, and the data-set was compared to the cross-section No. 124/d made in 1972 by the DDKÖVIZIG.

The periods of island formation were defined by dendrology. Poplar and willow species occupy the bars higher than the mean water-level (Sipos and Kiss, 2003), thus they indicate the beginning of the colonisation of the bar surface, which is the date of the island initiation or growth. Sampling was made with tree-borer, the trees (68) were sampled along transverse and longitudinal sections. The tree-rings were counted under a stereo-microscope. Based on the data an isochrone map was drawn.

4. Results and discussion

4.1. Hydrological changes caused by dam constructions

The three Croatian storage lakes and hydro-power plants built in 1975-1989 influenced the hydrology of the river considerably (Fig 2). The Őrtilos gauging station (235.9 fkm) is located upstream of the studied reach, and based on its daily water-stage measurement the changes could be documented. The water stages dropped, especially after the dam constructions were completed. The level of the annual low water level was dropped from –18 cm to –100 cm during the studied period of 1958 and 2009. The annual mean water level decreased from 103 cm to 36 cm. Flood stages were also influenced, as autumn floods triggered by the Mediterranean climate effect disappeared, and spring flood stages decreased. Before the construction of the dams the average cumulative length of floods totalled 15 days, while after the construction of the last dam at Donja Dubrava it decreased to 3 days.

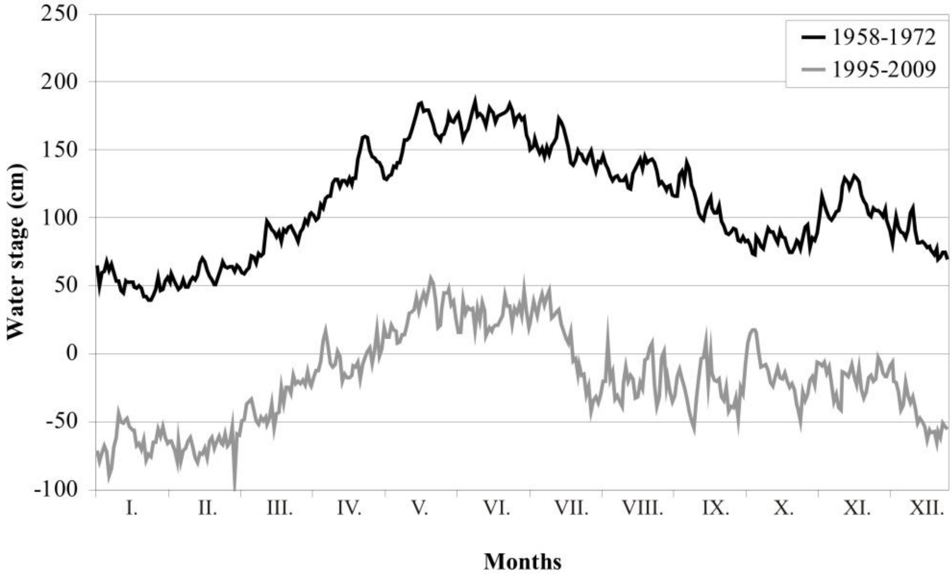

Fig. 2. Mean water stages (cm) of 15 year long periods before (1958-1972) and after (1995-2009) of the dam constructions (1975-1989)

The duration curves of the water-stages also reflect this decreasing tendency (Fig 3). Before the construction of the dams water level bellow 0 cm occurred only in 1-2 % of the year. In the period of 1991-1999 it increased to 58 %, and in the last 10 years it became 70 %. Simultaneously the duration of high water level decreased.

The drop in water-level could be explained by water storage of the reservoirs, and also by degradation of the channel bed (2.8 cm/y) below the dams (Szekeres, 2003).

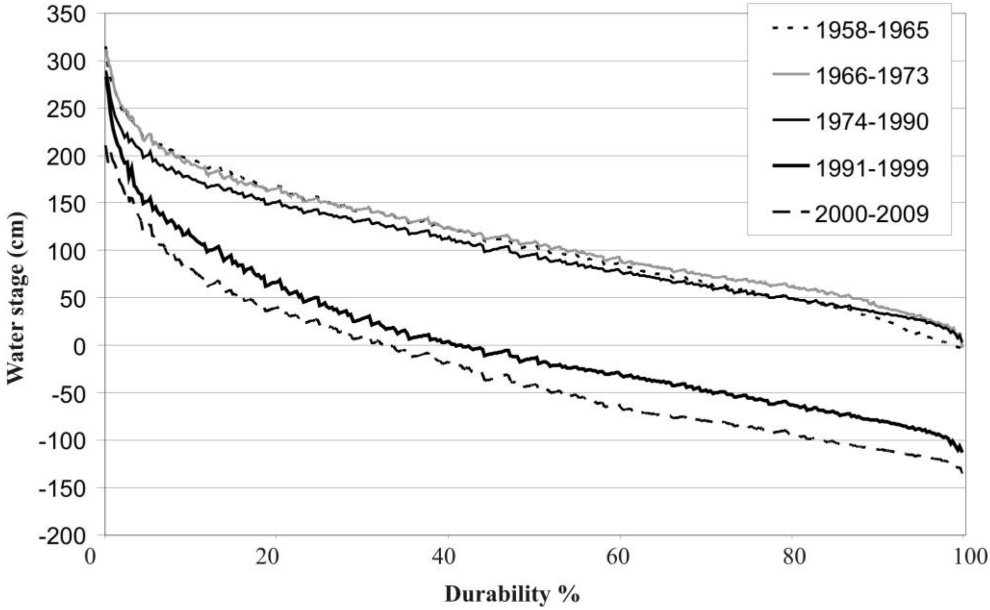

Fig. 3. Changes in durability (%) of water stages as the result of dam constructions (1975-1989)

4.2. Changes in cross-sectional parameters of a 40 km long reach of the Dráva River influenced by hydrological alterations

Along the studied 40 km long Dráva reach (from Bélavár to Barcs) 24 cross-sections were analysed (Fig 1). The repeated surveys (1972 and 2006) enabled us to evaluate their spatial and temporal changes.

Spatial changes

In 1972 the average bankfull channel width of the reach was 261 m (Fig. 4A). The upper, A-section of the studied Dráva reach (cross-section No. 121-128) was the widest, as here the width varied between 120 m and 470 m (average 327 m). The width of the B-section (cross-section No. 109-120) decreased to 140-260 m (average 216 m). The smaller width of the B-section can be explained by the existence of revetments, as they prevent lateral erosion, though the possibility of point-bar formation exists. On the lowest, C-section of the reach (cross-section No. 104-108) the average channel width increased (266 m), but its sinuosity became greater as well, indicating meandering channel pattern.

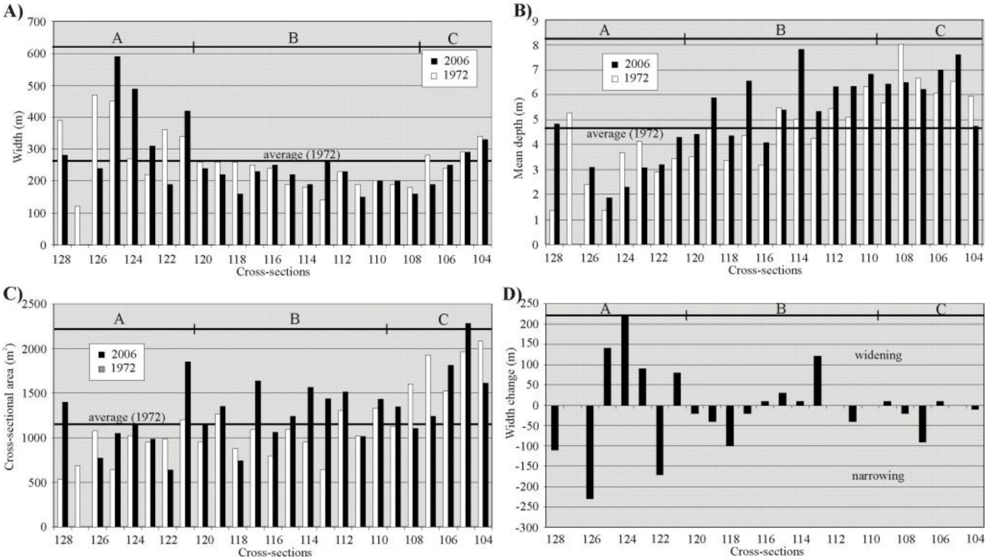

Fig. 4. Changes in bankfull width (A), mean depth (B), cross-sectional area (C) of the studied Dráva reach between 1972 and 2006. The width changes (D) reflect the widening or narrowing of the reach

The average depth of the studied reach was 4.6 m. The mean depth of the cross-sections increased downstream (from 3.0 m to 6.6 m). In the upper A-section the mean depth varied between 1.3 m and 5.2 m (Fig. 4B). Here the average width/depth ratio is 148.2 indicating braided pattern. It is also represented by the large number of bars and islands diverting the thalweg. In the B-section the average depth of the cross-sections was 3.1-6.3 m, and this parameter increased further in the C-section (5.9-8.0 m). Simultaneously the width-depth ratio decreased downstream (B-section: 48.9 and C-section: 41.1), indicating intensifying meandering pattern.

The maximum depth of the cross-sections varied between 4.4 and 14.8 m showing a similar pattern as the mean depth variations. The differences between the maximum and average depth values increased towards downstream (from 3 m to 3.7 m), reflecting a more pronounced thalweg.

The area of a cross-section determines the water conductivity capacity of the channel (Fig. 4C). Its average is 1147 m^2, varying within a wide range (536-2081 m^2). This parameter was doubled towards downstream (from 890 m^2 to 1820 m^2).

Temporal changes

The average bankfull-channel width of the reach has not changed considerably (+ 1 m) between 1972 and 2006 (Fig. 4D). In case of the studied three cross-sections (No. 105, 110 and 112) no width changes could be measured, however, ten cross-sections became wider due to human impact. On the upstream A-section a meander cut-off was made in 1979-82 (Fig. 1). The dimension of the new channel was designed for smaller slope, as it was supposed to be on a section impounded by a never built dam at Barcs-Gyurgyevác (Remenyik, 2005). Due to the straightened channel the slope increased, the width decreased, partly because a groyne was built simultaneously to close a side-channel. In case of the cross-sections No. 124 and 125 the channel became considerably wider (490 m and 590 m), as their bankfull width increased by 81 % and 31 % respectively. As the result of the upstream regulation processes, the lower part of the A-section became wider due to the very intensive lateral erosion and the development of braids. The material of the eroding, newly developing channel was transported downstream, and it deposited in the form of bars and islands, decreasing the depth (1.8-2.3 m), and increasing its width/depth ratio (213-315). In B-section (cross-section No. 109-120) the cannel became narrower but not everywhere. It can be explained by the newly built revetments, which prohibit bank erosion, but enable point-bar formation on the opposite bank. The smaller width changes of the C-section (cross section No. 104-108) reflect that this unit is in the most stable condition, the channel pattern is stable and the meandering pattern is not stunted considerably. In contrary, the narrowing tendency in part of the A- and B-sections predicts channel pattern shift from braided to meandering, though in the area of a cut-off the channel is getting more and more braided.

The changes in the mean depth are more uniform. In 1972 the mean depth of the reach was 4.6 m, and until 2006 it increased by 0.6 m. Downstream of the cut-off (cross-sections No. 123 and 124) the channel became shallower due to aggradation, indicating more well-defined braided pattern. However, on the lower B-section (cross-section No. 109-120) the depth increased by 1.1 m, the thalweg became more pronounced, indicating profound incision. Since the incision and narrowing took place simultaneously, they indicating continuous pattern shift from braided to meandering, and the process is developing upstream. The narrowing of the channel was over-balanced by the simultaneous incision, therefore the cross-sectional area increased considerably (from 1147 m^2 to 1310 m^2).

The cross-sectional parameters reflect that the studied reach of the Dráva could be considered as a transitional zone between the lowland meandering and upstream braided sections. The spatial and temporal comparison of the parameters indicates that the meandering pattern proceeds upstream. The metamorphosis of the channel can be explained by the dropping water stages and waning floods caused by the reservoir constructions. However, local engineering works (e.g. cut-off) surpass these changes, and alter the pattern of a shorter section.

4.3. Island development on a 10 km long transitional zone influenced by dam constructions and a cut-off

As it was represented above, the A-section of the studied Dráva reach remained braided even in 2006 (width-depth ratio: 131). As islands and bars are good indicators of the braided pattern, their changes were studied in detail.

In 1972 only 12 islands (total area: 51 ha) were located on the A-section of the studied reach (Fig 5A), and almost a dozen of bars. These islands were mostly elongated (average elongation ratio 4.7) all along the studied section, suggesting, that at this time the Dráva had high energy and the change of the islands was quick and dynamic. By 2006 (Fig 5B) the number of islands almost doubled (23), their territory tripled (175.5 ha). On the upper part of the section their number increased considerably, though downstream their number remained constant (Fig 6AB). The elongation ratio decreased (average elongation ratio 4.3), wider islands became dominant, indicating lower energy conditions.

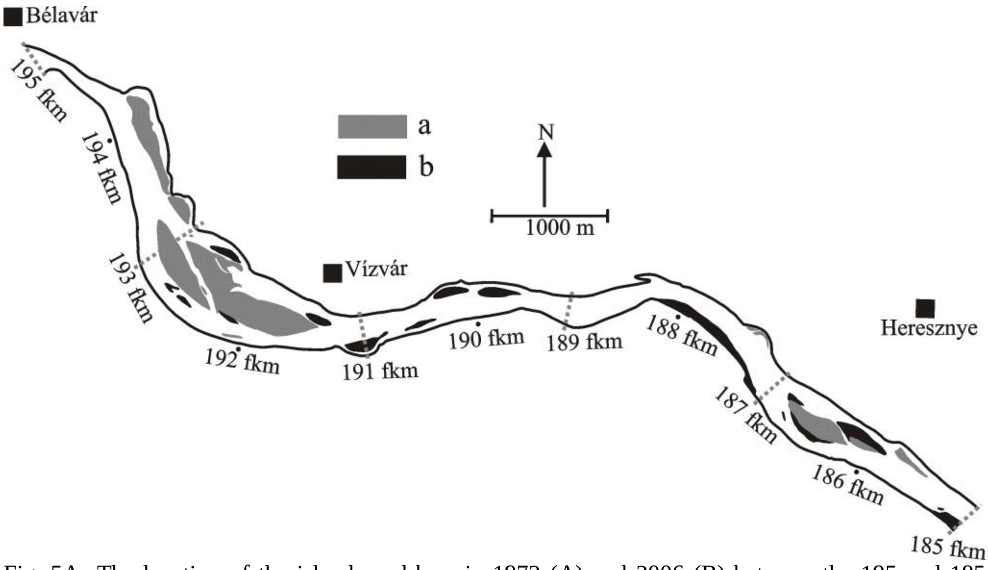

Fig. 5A. The location of the islands and bars in 1972 (A) and 2006 (B) between the 195 and 185 fluvial km of the Dráva River. *a: island; b: bar*

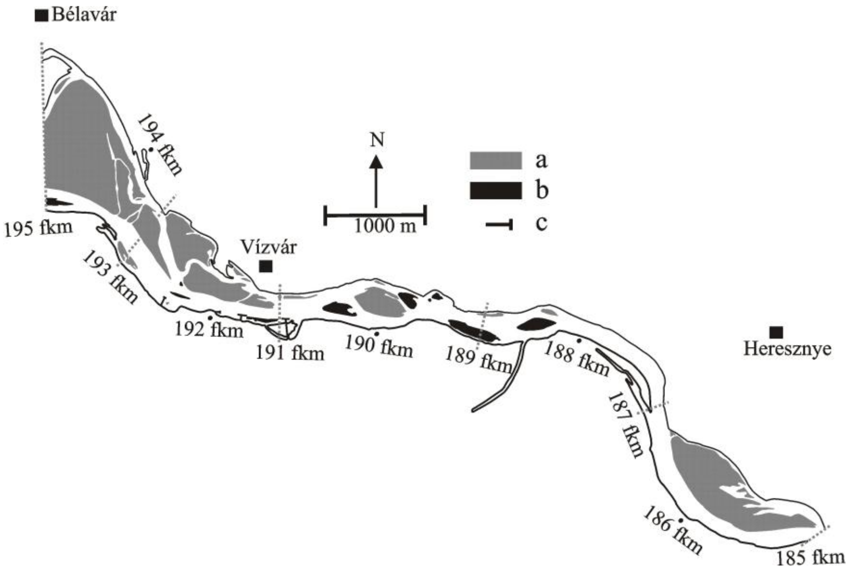

Fig. 5B The location of the islands and bars in 1972 (A) and 2006 (B) between the 195 and 185 fluvial km of the Dráva River. *a: island; b: bar; c: groyne*

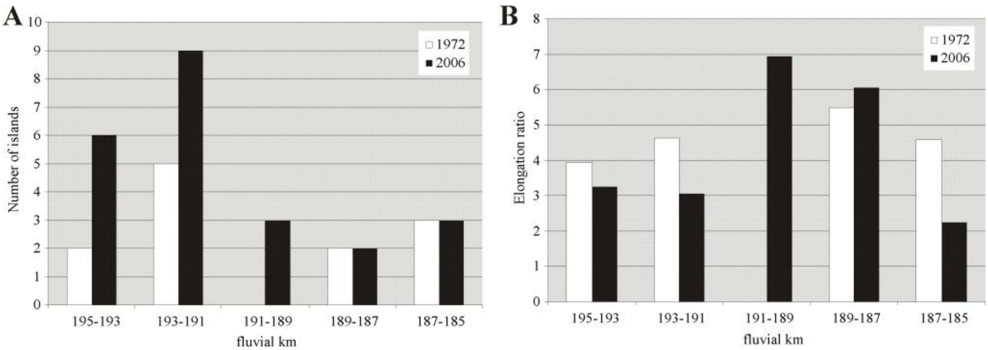

Fig. 6. The number of islands (A) along the studied reach in 1972 and 2006 and their elongation ratio (B).

To analyse these changes in detail, the studied section was divided into 2 km long parts (following the fluvial km division of the river). Between the 193 and 195 fluvial kms two islands existed in 1972. These islands have merged to the banks, thus the development phase of this braid could be considered as senile (Table 1). By 2006 these islands merged to the banks. The huge island appeared by 2006 between the 194 and 195 fluvial km is the result of a cut-off (made in 1979-82). Probably this great island and the four nearby will disappear, as the side-channel separating them will aggrade. Due to the cut-off the development phase of the braid quickly reached the senile stage. The small elongation indices, especially in 2006, also indicate this process and the energy reduction of the Dráva.

Table 1. Changes in the number and type of islands along the studied section, and the development phase of their braids

Section (f km)	1972 Type of island	Braid development phase	2006 Type of island	Braid development phase
195-193	submerging	senile	submerging and mid-channel	senile
193-191	submerging and mid-channel	mature	submerging and mid-channel (behind groins)	mature/senile
191-189	bars	juvenile	submerging and mid-channel	mature
189-187	submerging	no braid exists	submerging and mid-channel	juvenile
187-185	submerging and mid-channel	mature	submerging	senile
Total number of islands		12	23	
Total area of islands (ha)		51	175.5	

In 1972 there were 5 islands between the 191 and 193 fluvial km, most of them were located in the middle of the channel. By 2006 their number increased (9), their elongation ratio increased and their location changed. Some appeared in the middle of the Dráva, others merged to the bank, but islands also developed behind the groynes. Based on their characteristics, the braid could be divided into upstream senile and downstream mature part.

On the next section (189-191 f km) only bars appeared in 1972, most of them along the banks, and some in the middle of the channel. The existence of these side- and mid-channel bars shows a juvenile stage of the section. By 2006 the bars were developed into islands, and the braid turned to a mature stage.

Two islands were surveyed in 1972 on the next section (187-189 f km), reflecting a senile braid development stage. However, by 2006 two mid-channel islands and a mid-channel bar appeared in the braid, which became juvenile again.

On the lowest section (187-185 f km) three islands were formed in 1972, two of them in the middle of the channel, and the third have merged to the bank. The number of the islands has not changed by 2006, but their area increased considerably, their elongation ratio decreased. The braid remained in its mature/senile stage. Here the changes are in connection with the metamorphosis of the river: a meandering pattern is developing, the cannel is getting more sinuous, and the islands were developed on the point-bar surfaces.

As it was shown above the number of islands was doubled between 1972 and 2006, and their territory increased by 3.5-fold. The braid development stages of the section suggest that the braids are reviving. It can be partly explained by the cut-off which supplies more sediment for the formation of bars and islands, especially in the upper part of the section. Besides, the increase in their area can be explained by the drop of water stages, as it provided new bar surfaces for island development.
The similarity in elongation indices along the reach in 1972 can be described the equilibrium conditions between the morphology and the hydrology of the river. By 2006 this has changed, as the elongation ratio became different in the sections, referring to threshold conditions, where the equilibrium of the river was disrupted, and the re-arranging of the hydro-morphology of the river had started.

4.4. Effect of a local engineering work: aggradation caused by a groyne

Aggradation of a side-channel

The effects of local engineering works are superimposed by additional human impact. The consequences of a groyne on channel aggradation were studied near Vízvár (Fig 1 and 7AB). In 1972 the studied side-channel was almost as large as the main channel. Based on the data of an upstream cross-section (No. 124/d) the width of the side-channel was 140 m (main channel: 120 m), while its average depth was only 2.3 m (main channel: 5.8 m), and its maximum depth 3.0 m. The cross-sectional area of the side-channel was 360 m^2, indicating considerable contribution in water conductivity. Then, in 1982 a groyne was built at the confluence of the side channel, in order to support the development of the upstream cut-off by closing this important side-channel. The same cross-section was not surveyed in 2006 by the DDKÖVIZIG, so we made measurements along the former cross-section, and within the side-channel to demonstrate the effect of groyne construction.

By 2008 the average width of the side-channel decreased to 47 m, indicating considerable (65 %) narrowing. The average depth along the former cross-section decreased to 1.2 m (by 48 %). The depth of the thalweg (the deepest point) was 3 m in 1972, but it also decreased to 2.1 m (by 30 %). The most obvious change was measured in the cross-sectional area, which was reduced to 70 m^2, indicating 80 % channel-capacity loss in 26 years. Considering these data, the rate of channel aggradation was 5 cm/y (channel capacity loss: 2 %/y). Calculating with this rate, the side-channel will loose its function within 25 years. However, as it will be shallower the amount of transported bed-load will also decrease, thus this final stage of its development might last longer.

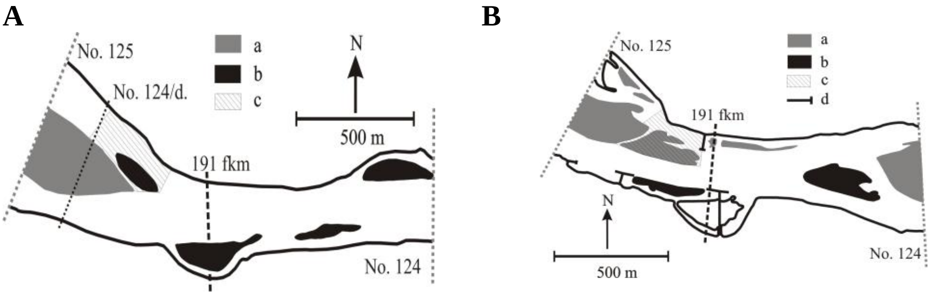

Fig. 7. The effect of a groyne on channel and island development was studied near Vízvár. In 1972 (A) islands (*a*) and bars (*b*) appeared in the study site (*c*). In 2006 (B) the morphology of the river was altered by groynes (*d*).

The depth conditions of the studied side-channel show, that the river was shallower than 1.0 m over large areas of the river-bed (Fig. 8). Therefore, at very low stages the two bordering islands would join, and their areas would increase significantly. Behind the groyne a large mid-channel bar was formed exceeding the water level most of the year. The thalweg within the side-channel was deeper (over 1.5 m), it had a meandering pattern, which was especially obvious during lower stages. The meandering thalweg moved close to the banks, initiating bank erosion. The outlet of the thalweg was narrow and deep as it confined to the groyne and joint to the main channel. Besides, the very end of the groyne diverted the current of the main channel, thus during higher stages these currents erode the outlet section of the side-channel.

These measurements show that after an engineering work the channel change considerably: even a wide side-channel could loose its function by aggradation. At the same time its originally braided pattern (width/depth ratio: 52.1) altered towards meandering, as it is indicated by the meandering thalweg and the smaller width/depth ratio (39.1).

Island development

In order to determinate the exact age, thus the hydro-morphological change of the Dráva River, one island was studied in detail (191-192 f km). In 1972 this island did not exist, but upstream of its present location a large gravel-bar was surveyed (Fig. 7AB). On the 2006 map the island already developed. If the side-channel aggradation is quick, this island will submerge to the large island upstream within years.

The island could be classified as mid-channel island when it was formed and the side-channel was almost as wide as the main one. Its elongation ration is small (2.96), thus now lateral erosion is superseded by lateral aggradation. The island itself consists of two submerged islands, the chute between them is continuously aggrading. The erosional marks on its surface indicate the direction of flood-currents, and they were probably formed when the vegetation was not very dense on the island. The horizontal accumulation is greater on northern part of the island, as this part is bordered by the dying side-channel, where the erosional activity is weak.

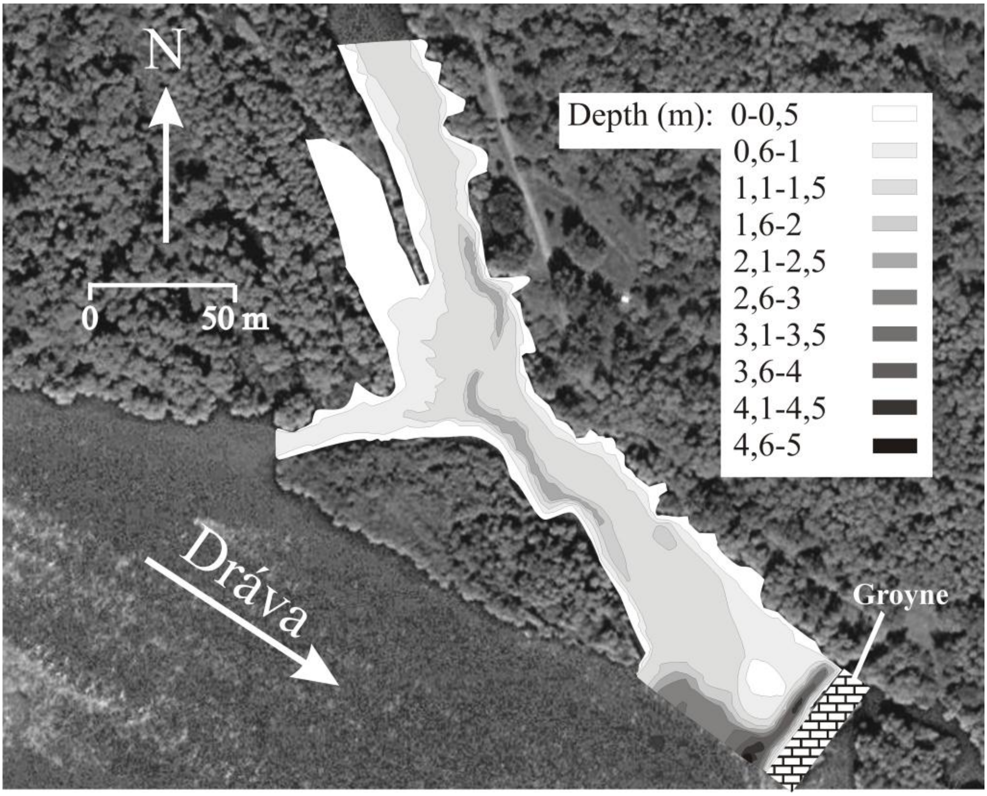

Fig. 8. Depth conditions of the studied side-channel in 2008 (water-level stage at Barcs station was 51 cm)

The accumulation periods of the island were determined by dendrology: the age of the trees indicate the minimum age of the island’s surface, before the surface was just a gravel-bar, inundated by high and medium water stages. Nowadays flood-waves higher than 300 cm (frequency: 5 %) inundate the island.

Based on the ages of the tree an isochrone map was created (Fig. 9), and the periods of island accumulation were compared to the yearly highest water levels.

The oldest tree on the island started to grow in 1992. Thus, the gravel bar, which is the core of the island, was probably formed during the 1989 flood. The next three years were flood-free, providing excellent conditions for the colonisation of the riparian vegetation. This process was repeated, thus during flood new bar surface was connected to the island and its surface was heightened by overbank floods, and in the following low-water periods riparian vegetation invaded the surface of the bar. The largest bar surface joint to the island during the floods of 1998-99, and it was colonised between 2000 and 2002.

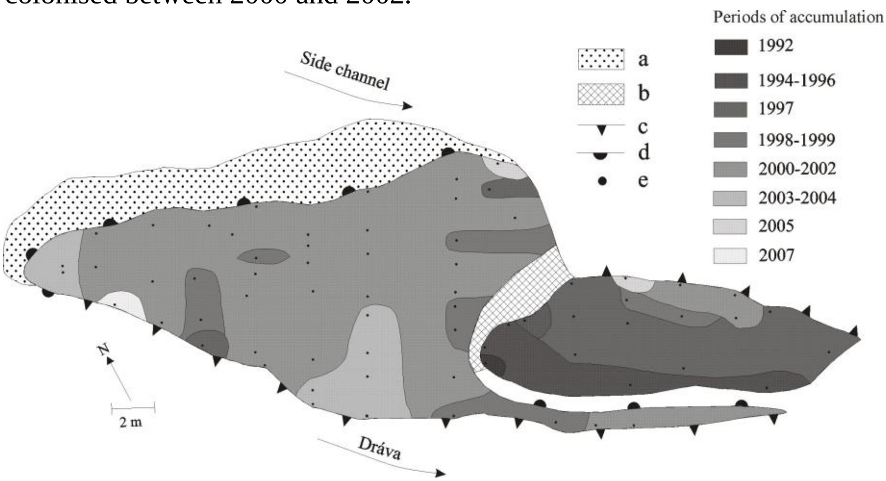

Fig. 9. Isochrone map of island development near Vízvár. *a: submerged side-bar; b: aggrading chute; c: erosion; d: accumulation; e: sampled tree*

Comparing the spatial development of the island to others studied islands on the Maros (Sipos and Kiss 2003) it is worth to note, that the location of erosion and accumulation differs. On the Maros River the front of the island (facing upstream) erodes and their downstream end accumulates. Here the situation is the opposite: the upstream end of the islands is the scene of accumulation, while the downstream part is eroding. It can be explained by the different bed-load, as the Dráva transports mostly gravels, while the bed-load of the Maros is sandy. The gravels aggrade easier, as soon as the stream power decreases, which is the case in front of the islands, where the current is dissected. Besides, the studied island is situated in a very special location, behind a larger island and in front of a groyne, which might provide an irregular sedimentary environment.

5. Conclusions

On the studied section of the Dráva River distant (reservoir construction) and local (cut-off and groyne) human impact influence the hydro-morphology of the river. As the result of dam constructions the hydrology was altered, the water stages dropped, lower stages became more frequent and the floods almost disappeared.

These hydrological changes produced the morphological alteration of the river. The upper part of the studied Dráva reach was braided and the lower section meandering before the construction of the Croatian dams and reservoirs. As they reduced the water level, meandering pattern shifted upstream and became more pronounced. It was indicated by the narrowing channel and incising thalweg. As bar surfaces were exposed due to the lower stages, the vegetation colonised their surfaces and new islands were formed on the upper section (in the transitional zone between the braided and meandering parts). The number of islands was doubled between 1972 and 2002 on the section between Bélavár and Heresznye, their territory increased from 51 ha to 174.5 ha. They shape became more rounded, indicating the decreasing erosional activity of the Dráva. The braids got to their mature and senile development phase, indicating the decline of the braided pattern.

However, local engineering works also influenced the upper part of the studied reach, where a cut-off and groyne were built. The cut-off resulted intensive lateral and vertical scour, thus the produced large amount of bed-load. Downstream of the cut-off a short section became wider and shallower, as the cut-off increased the slope and the sediment discharge. On this section the braided pattern became dominant, despite of the above described river-metamorphosis.

The effect of groyne is manifested in side-channel aggradation and intensive island formation. The blocked side-channel looses ca. 2 % of its water conductivity capacity each year. The intensive narrowing of the side channel gives way to lateral growth of the islands. Applying this rate to the side-channel accumulation, its remaining life-time is approximately 25 years.

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