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AN ANALYSIS OF FLOW REGIME AND CHANNEL DYNAMICS ON THE CROATIAN-HUNGARIAN SECTION OF THE DRAVA RIVER

Thesis of Dissertation

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1. Introduction and objectives

Rivers have always played an important role in society even if their water level and channel have constantly been evolving. **However, the more developed a civilization became, the more powerful they intervened into the life of rivers, and nowadays, as a result, most of the rivers have changed a lot, and they lost their once characteristics natural forms.** *River and flood controls were primarily carried out for economic purposes* (Szabó, 2006), *the latter of which was mainly for arable land expansion.* In addition, *protecting the settlements against floods* was also a major factor as floods often caused significant destruction. River regulation includes economic interests related to *ship transport* as well as *hydroelectric power plants* that completely change rivers. In addition, the hydrological and morphological characteristics of a river are also influenced by *surface water extraction and gravel mining.* In my opinion, *the most significant anthropogenic-induced changes are those caused by hydroelectric power plants.* They are serious obstacles forming a sharp break in the river, so they alter the hydrology of a river to a great extent, and they also disconnect the river system (Brierley and Fryirs, 2005).

The hydro-morphological characteristics of our large rivers are the result of channel regulation and flood control works. From the early 20th century on, river engineering took a new turn, the building of in-channel constructions (revetments and groynes) as well as of hydroelectric power plants and dams marked this period. Rivers were shortened due to the regulation works, so their decline changed resulting in the transformed morphology of the river bed and even the pattern of the river bed (Surian and Rinaldi, 2003). *After the HPPs began working, flow regime underwent drastic alteration, while sediment characteristics also changed* completely as most of the sediment got trapped in reservoirs. *Clean water erosion caused by the lack of sediment induced the intense incision on the lower section of the power plants* (Knighton, 1998). Cutting off meanders on the Drava River has already begun at the end of the 1700s, but *the regulation work (mainly cut-offs)* reached its peak in the 19th century (Ihrig, 1973) when a great number of meanders (62) were cut off between the confluence of the Mura and the Danubian confluence, in which process the length of the river was shortened significantly (György and Burián, 2005). Further regulation occurred in the 20th century, but it was characterised by in-channel construction, and the instalment of hydroelectric power plants in the upper section of the river since the early 1900s.

Islands were common in Hungarian rivers before the 19th century river regulation works, but most of them disappeared after the regulations. However, anthropogenic effects may not only destroy islands, they may also cause them to appear again in the channel. A good example of this effect is the islands which have appeared as a result of in-channel constructions, such as groynes, but these islands are more short-lived formations than real islands, for example, not only because they develop more dynamically due to the groynes, but also because they merge with the river bank faster.

There are few in-channel constructions in the section between Őrtilos and Barcs of the Drava. As a result, there are also such processes (such as island and point bar formation) present which are less characteristic of our other rivers of the similar size (the Danube and the Tisza) due to the greater extent of their regulation.

The main aim of my research is to determine how the Drava reacted to hydro-morphological changes (induced mainly by anthropogenic activities) in 19th and 20th centuries.

The *aims* of my research are as follows:

1. ***How did the flow regime of the Drava change in the past 114 years?***

   In order to understand (partly) the factors governing the morphological transformation of rivers, it is essential *to study the river regime and its changes.* As the Drava was substantially regulated and numerous hydroelectric power plants were built along it in the past 100 years, its river regime have changed a lot. Therefore, I intend to explore how these facilities have changed the flow regime. In particular, I wish to focus on how floods, minimum and mean water levels and discharges as well as the daily flow regime have changed, which factors are important to analyse hydrological consequences of HPPs built earlier.

2. ***How did channel parameters change in the Croatian-Hungarian section of the Drava?***

   The analysed section of the river Drava reveals that river channel development is indirectly influenced by HPPs, while it is directly influenced by the river regulation works. However, there are several sections which still develop free, without any direct impacts even today. Therefore, I evaluate the morphometric parameters of the river channel in the total length of the river (extent of water surface, channel width, braiding (index) and sinuosity) in order to reveal the effects of anthropogenic activities. At the same time, I study the development of the meanders on smaller study areas, because the dynamic changes of the point bars and the eroding banks are closely related to flow regime. The study of these factors enables me to reveal the spatial and temporal characteristics of the morphological changes of the river, both of which I study together with the changes that happened to the island.

3. ***How were the different island types modified: how did their number and area change as a result of various anthropogenic effects occurring in the Drava?***

   The spatial and temporal changes of the islands are fundamentally determined by anthropogenic influences affecting the river, so they can be closely related to the hydro-morphology modifications. As islands are integral parts of a river system, they react sensitively and fairly quickly to changes in the river, so they can give information on the processes taking place in the river channel. My aim is to investigate the changes occurring in the islands that can be found in the Drava section after the Mura confluence and their morphometric parameters, from which I infer the extent of the influences affecting the river. I study the building and development of the islands on a larger scale, and to do so I chose islands which are directly affected by anthropogenic effects. This procedure enables me to investigate directly human-induced island development not only on the river Drava but in general too.

2. Study area and methodology

During my research, my aim was to understand the hydro-morphological changes that happened on that section of the Drava River that is downstream of the HPPs from the end of the 19th century on. In order to do so, I applied several methods, among which there were some which had been successfully used in earlier research, however, there were some which had to be modified to fit the conditions of the Drava.

2.1. Analysis of hydrological parameters

In order to analyse the changes having occurred in the morphology of the Drava, it is essential to understand its hydrology, since changes occurring in the flow regime also cause the floodplain, the river channel and the formations in the channel to change. For analysing the temporal changes of hydrology, I used the data of the measuring station of Barcs (154.1 river km): the data series used were daily water levels (form 1901 to 2014) and discharge (from 1960 to 2014). For analysing the spatial changes of water level, I compared the data of the Őrtilos measuring station (235.9 river km) with those of the Barcs measuring station.

I determined the annual minimum (MRR), mean (MeRR) and the maximum (MaRR) water levels as well as the typical annual minimum (MD), medium (MeD) and the maximum (MaD) discharges. I classified the data series on the basis of major changes in water level (HPPs). By comparing water level and discharge values, the extent of incision can be inferred too. Therefore, I also established what kind of discharge characterized the water levels in each year. In addition, I assessed the numbers of flood days and flood waves as well as flood frequency. I also prepared water level and discharge durability curves which enabled to determine for how long the water levels and the discharges exceeded the given water level and water flow for each period. The annual and monthly water level data conceal the daily "mini floods" originating from the peak-running of the HPPs, so I analysed the daily flow regime too. I not only analysed these data measured at the Barcs water measuring station, but I also compared the Őrtilos and Barcs sections, because the measuring stations are situated 82 river km from each other, which may cause the flood waves to attenuate.

2.2. Long-term analysis of the changes affecting the channel, the islands and the meanders

In order to determine the long-term changes occurring in the river channel and the islands, I used the 3rd Military Survey (S = 1: 25,000) (1878-1882), **the Hydrographic Atlas of the Drava** (S = 1: 25,000) (1966-1968), **Croatian topographic maps** (1977-1979, S = 1: 25000; 1980-1982, S = 1: 5,000; 2003-2006, S = 1: 25,000), **Google Earth satellite images** (2006-2007) and **a 2011 Croatian aerial photograph** (S = 1: 5,000). **I divided the Drava section between the Mura and the Danube into 20 separate, 10-km-long units** based on the river valley. I divided them into further sub-sections: an **upstream** sub-section (units 20-15) and **downstream** sub-section (units 14-1).

I geo-corrected the maps and satellite images into the EOV system by using ArcGIS 10.1, then I drew the bank line of the river channel, the islands, and the sandbars. I defined an island as the form which is surrounded by water and covered with trees and bushes. However, some of these forms transform over time, and the channel beside them becomes narrower and narrower until slowly the island partially or completely melts into the river bank. Since the process is not always obvious, I included (former) islands now linked to the mainland into the research, because they also reflect the dynamics of the river.

Even during the research period, the types and location of the islands have changed. In order to follow this process, I classified the islands several different ways. **I distinguished two island types based on their origin**. *Real islands* were most likely to have evolved of bars and are smaller in size. *Floodplain islands* are larger, and they often evolved from artificial and natural meander cut-offs (the latter of which may also be called avulsion) as well as amalgamation of smaller islands/forms. **I also classified the islands on the basis of their state of further evolution**, in other words, their location compared to the thalweg. *Islands in the thalweg* divide and divert the thalweg. *Osculating islands* gradually lose their island character by growing close to the bank or another island, and sooner or later they cease to exist as separate islands. *Partially amalgamated islands* are either connected to the river bank or to a bigger island. *Completely amalgamated islands* are almost completely part of the floodplain. I also studied the **frequency** of the islands by applying a modified version of

Wyrck and Klingeman's classification system (2011). *Overlapping islands* refer to the state when two or more islands are present in the cross-section of a single river channel. *Densely located islands* refer to the state of having no more than two islands in the cross-section of the river channel or the distance between the islands situated in the thalweg downstream is less than 10% of the river width. Finally, *infrequent islands* refer to the state when there is only one island in a certain cross-section of a river, and the distance between the islands situated in the thalweg downstream is greater than 10% of the river width. I also calculated the **elongation ratio** of the islands present in the river channel, which is the ratio of maximum length (L) and maximum width (W), and which refers to the energy conditions of the river surrounding the island.

2.3. Detailed analysis of the island and meander development in the study areas

I investigated **the development of the islands and the meanders** in a total of **six study areas** in detail. For the analysis, I used the cartographic data and satellite images mentioned above, and I also carried out an RTK-GPS survey, a geomorphological mapping, and dendrochronological measurements to corroborate the data. In order to carry out a short-term analysis of the eroding river banks on the outer arc of the meanders, I examined the river banks by using a Topcon HiPer Pro RTK GPS between October, 2011, and January, 2015. I determined amount of eroded beach material (m^3/year) in the different periods as well. Moreover, I prepared cross-sections of several point bar surfaces (also with the Topcon HiPer Pro RTK GPS) perpendicular to their longitudinal axis to determine the development of the elevation characteristics of the surface. I analysed the spatial and temporal evolution of the inner arc of the bends and those of the meanders on the basis of a dendrological survey when I investigated the poplars and willows being present there. The method allows determining the minimum age of a specific surface which enables the researcher to specify the meander development and the rate of island development as well as its spatiality (Everitt, 1968). Tree-boring took place along specified sections. I marked the locations of the trees and the sections with a 60CSx Garmin handheld GPS. I sampled the thickest, therefore probably the oldest trees with an increment borer (at 1 m height each tree) on a given formation, which means a total of 403 trees. I counted the tree-rings by using a LEICA S4E stereo microscope with 6.3 to 30 times magnification. Based on the GPS measurements and the age of the trees, I drew isochrone maps, then I determined the development periods of each surface.

3. Results

3.1. Long-term changes of hydrology

3.1.1. **The flow regime of the Croatian-Hungarian part of the Drava**, which greatly influences the evolution of the morphology of the river channel, **has changed dramatically over the past 114 years, since water levels have decreased significantly.** *The changes can be closely associated with the modifying effects of the hydroelectric power plants* built along the upper section of the river as they influence water retention and water levels to a great extent (Kiss and Andrási, 2011). Even after the first hydroelectric power plant started to work (1918-1941), flow regime changed as a result: the characteristic water levels (62-69 cm) decreased. The durability of the water levels also changed: before 1918, water levels of 263 cm and above were characteristic in the half of the period, from 1918 to 1941, water level sank under 199 cm. In addition, the durability of high water levels lessened, and their levels also declined steadily, becoming more extreme at the same time. After the construction of the most downstream and, at the same time, the last hydroelectric power plant (Donja Dubrava), minimum water levels decreased with 268 cm, mean water levels decreased with 250 cm, and maximum water levels decreased with 199 cm compared to the "HPP-free" times before 1918. The change is clearly visible in data: there was only one year before 1918 (1919: 97 cm) when minimum water level was lower than 100 cm, and mean water level has never exceeded even this rate after 1990 (max. MeWL: 87 cm, 2014).

3.1.2. **The impact of the hydroelectric power plants could be well examined in the modification of the floods too**, because while there was 349 flooding days (20,5 days/year) in Barcs between 1901 and 1917 according to the water level data, the number of flooding days dropped to a total 307 days between 1918 to 2014 (3,2 days/year). In addition, before the first Drava hydroelectric power plant started to operate (1918), there used to be 39-day-long flood-waves on the Drava, and flooding also used to occur about every five months, but after the lowest HPP started to work (1989), the length of flood waves significantly reduced (4 days), their occurrence became extremely rare as there is an average of one flood per every 8th year. This change is definitely beneficial in terms of flood risk. However, it also means that the river channel as well as the banks and the in-channel formations (bars, islands) are mainly shaped by the minimum and medium waters. The fact that the floodplain is flooded for shorter and shorter periods, if at all predicts that the floodplain and its biozoenoses are surely going to change because they have to adjust to other life conditions.

3.1.3. Prior to the construction of the Croatian hydroelectric power plants (1970), the average daily range of water level fluctuation was only 10-11cm, which could have been caused by the HPPs that had been operating already on the upper section of the Drava. **After the HPPs in Varaždin and Čakovec started to work (in 1975 and 1982 respectively), "mini-floods" appeared.** The daily maximum of the range of water level fluctuation was 51 cm in Őrtilos, and 29 cm in Barcs in 1977, which increased to 73 cm and 63 cm respectively in 1984, which was due to the fact that the Čakovec HPP was built 24 km closer to the water level measuring stations than the Varaždin HPP. The most significant differences in daily water levels have occurred after the start of the lowest HPP in Donja Dubrava started to work. Indeed, the average daily range of water level fluctuation in Őrtilos was 62 cm in 1991, while the maximum was 139 cm. In the same period, the average daily range of water level fluctuation in Barcs situated 82 km further downstream was 30 cm, while the maximum was only 104 cm. The evening flood wave measured by the Őrtilos water level measuring station occurs next morning in Barcs, the flood wave attenuates to the half of its original size (an average of 0.24 cm/km), but it is still a significant daily water level fluctuation. These "mini-floods" originating from the peak-running of the HPPs can also modify the sediment transport of the river, and they can also intensify the development of the river banks and the in-channel formations (bars, islands).

3.1.4. **The descending water levels are not only the result of water retention, but also of the incision that occurs at the same time**, which is shown by the increase of discharge belonging to a certain water level. However, the annual water level trend clearly shows that the water retention effect of hydroelectric power plants was the most significant factor in water level decrease. At the same time, the increased permanence of low water levels caused incision to intensify, which means that descending water levels intensify incision further.

3.2. Changes of channel parameters

3.2.1. **The drastic fall of water levels foreshadows the transformation of riverbed morphology too**. The river channel of the Drava section between the Mura confluence and the Danube confluence was altered significantly, as both the water surface area and the river channel width greatly decreased in the past almost 130 years (Andrási and Kiss, 2013). In the period between 1882 and 2007, the surface water area of the entire study area shrank nearly to the half (from about 9,389 acres to 5,010 acres). Although the shrinkage of the surface water was continuous during the study period, its speed rate was different between the various surveys. While between 1882 and 1968 the rate of water surface area decline was an average of 35 acres/year, its speed doubled for a short period between 1968 and 1979 (63 acres/year). Then it declined a little bit after 1979, but the water surface of the Drava got smaller 24 acres per each year on the section between the Mura and the Danube. Parallel to this, the average width of the river channel also decreased constantly, the Drava channel narrowed to more than the half of its original width between 1882 and 2007. The rate of channel narrowing of the entire length of the study section of the Drava was the lowest in 1882-1968 (an average of 1.8 m/year). The most dynamic narrowing, similarly to the reduction of the surface water area, marked the years 1968-1979 (3.6 m/year), then it slowed down after 1979 (2.3 m/year), although it still exceeded the rate characterising the first half of the 20th century. These parameters, however, have not only changed in time but also in space, and, as a result, the upper and the lower sections of the river have become more and more uniform.

3.2.2. **Between 1888 and 1968, open water surface shrank due to the fact that islands formed by meanders cut-offs amalgamated into the river bank in a great amount**. Then, after 1968, open water surface shrinkage and river channel narrowing not only continued, but it even accelerated, which is closely related to the operating hydroelectric power plants and their impact on the descending water levels. Changing flow regime caused the morphology of the river channel to change too, the channel of the Drava significantly narrowed down in the study area by 2007, compared to 1882 state (with 50%), a similar case was also documented by Wilcock et al. (1996) who reported that a dam built on the Trinity River, California, resulted in decreasing discharge and a 20 to 60% narrowing of the river channel, which may also intensify the erosion of the river banks and the river channel forms.

3.2.3. **The braiding index decreased continuously after 1968**, and the upper section of the river changed the most significantly until 2007, as a narrower and more uniform channel was formed. The lower section did not experience so significant changes as it had always been a narrower channel consisting mainly of one main branch. **The most significant changes of sinuosity occurred after the 1882 survey**. Indeed, the upper section was characterised by high values in the 1882 survey, because there had been numerous cut-offs on the lower section which straightened the river channel, so that part is characterised by lower values. As the river lost its balance, it sought to restore its previous state. In addition, water level descended which intensified the change of riverbed morphology resulting in the further disturbance of the balance. From the 1965 survey on, numerous units of the lower section were characterised by sinuosity. It is in line with the characteristics of the surface water area, the width of the river channel and the islands since the upper section is wider, and the river channel is divided by lots of islands, while the lower one is characterized by a more typical main channel. The Drava can be defined as a river with wandering pattern on the bases of the braiding and sinuosity indices in the past nearly 130 years.

3.2.4. **The slope and the energy of the river increased after the river channel had been straightened by artificial meander cut-offs, and,**

as a result, the river channel began widening, which simultaneously meant an excess of sediment. The excess sediment was deposited in the widened channel forming bars and islands. Sipos (2006) described the same process characterising the lower section of the Maros after the 19th century cut-offs. The channel of these shorter sections was divided into several branches causing the braiding index to increase. But after 1968, due to the continuously descending water levels, the islands began to "drift" toward each other and the river banks, so, in addition to average decrease of the braiding index, the more pronounced and single-channel thalweg caused the river to start meandering in those units where river engineering did not occur.

3.3. Long- and short-term changes of the islands

3.3.1. **The number of real islands in the Drava has increased by 26.8% in the past nearly 130 years, while their total area has decreased by 29.5% though not gradually**. Most of the islands (21-25 islands/unit) were situated on the upper section of the Drava (units 20-15) each time the upper sections of the Drava (Kiss et al., 2012). The number of real islands located on the lower section (units 14-1) and their total area increased (real islands by 54%, total area by 35%; 5 pieces/unit in1882, 10 pieces/unit on average in 2007), and they reached their maximum during the 1979 survey. The reason why the area of more islands increased compared to the 1968 situation is due to the fact that the islands merged together because of the sinking water levels, thus, the forms were of greater area. By the 2007 survey, the total area was reduced because the bigger forms merged with the river banks due to river engineering and water level decrease mainly. But, at the same time, new islands also developed from the bars which process is due to the further sinking water levels and the shadow effect of in-channel constructions as well.

3.3.2. **The Drava was characterised with a decreasing number of floodplain islands, most of which (32 pieces) was to be found during the 1882 survey**. These islands were mainly formed by artificial meander cut-offs when the pilot cut had been made, but, of course, there were natural cut-offs as well. After a while, the side channels surrounding the cut-off islands were filled up with sediment, thus these islands gradually amalgamated into the floodplain further narrowing the river channel.

3.3.3. **The number of islands in the thalweg gradually decreased**. During the first recording (1882), their number was 65 pieces, which lessened to 41 pieces by 2007. The reduction in the number of islands in the thalweg was due to their growing closer either to each other or to the river bank, then they amalgamated into them which was also enabled by the more and more sinking water level (Kiss and Andrási, 2014). As a result, the number of osculating islands continuously increased (1882: 118 pieces; 2007: 173 pieces). Such islands characterised the upper section mainly, their number was greater here in general, because they could evolve more dynamically in the wider, more divided channel. By being located closer to the hydroelectric power plants, the water level decrease caused by the HPPs was more likely to cause the final inactivity of the side channels on the upper section and the development of osculating islands, therefore the river channel became more unified and morphologically poorer. The number of partially amalgamated islands (1882: 30 pieces; 2007: 52 pcs) also grew during the whole research period. So more and more islands lost their separate island character, and they merged with other forms, which process is closely related to the anthropogenic influences affecting the Drava. It is proven by the last survey the most obviously since it was the period when partially amalgamated island appeared in the greatest number. Unlike any the other island types, completely amalgamated islands characterised the lower section of the Drava River mostly. It can be explained by the fact that this island type consisted of the large forms of earlier cut-offs that had been amalgamated into the river bank by the 1882 survey. Later river engineering works on the lower section of the Drava (groynes and rock piles blocking side channels) a greater number of former islands was connected into the floodplain. It means that the isolated nature of the islands disappears, moreover, the river channel becomes narrower and more unified, the thalweg is more pronounced, and incision increases. Thus, the changes of the islands, and thus that of the channels reflect the transformation of the pattern, which indicates the change of the whole hydro-morphology of the river. This process foreshadows the islands as ecologically valuable habitats become endangered, because while the larger forms amalgamated into the river bank, more and more smaller islands appeared and are likely to appear in the Drava which islands are less resistant to the eroding work of the river.

3.3.4. **The formation of islands growing closer to the banks that develop due to the presence of in-channel constructions foreshadows the aggradation of side-channels beside these forms, which also means the further narrowing of the Drava channel**. The narrow main channel makes it even more difficult for islands to develop.

3.3.5. Comparing the development of the Drava islands examined in detail to that of the Maros islands (Sipos and Kiss, 2001), it can be concluded that **the downstream lower end of the Drava islands is mostly eroded, and their upstream end is built, which is completely the opposite of the Maros islands.** No doubt that groynes must play an important role in this process. However, the fundamental reason for the different island development might be that the Drava transports large amounts of gravel bed-load, and when the flowing water reaches the higher bars and islands, it deposits its coarse sediment here (Kiss et al., 2011). The lower section of the Maros is characterised by sand bars, where sand is deposited in the lower end of the islands' downstream side. The sediment is deposited on the upstream part of the islands on the Drava, the energy of the river increases, and the resulting clean water erosion destroys the lower end of the islands. This is supported by field experience, since the sediment deposited on the upper end of the islands is much coarser that that of their lower ends which forms the bars that are merged to them. In addition, the lower downstream part of the forms is older, and vegetation appeared later on their upper parts. The islands I investigated in detail exhibit a periodic evolution, which evolutional periods are closely related to the maximum and minimum water periods of the Drava.

3.4. Characteristics of meander development

3.4.1. **The spatiality of the meander development is indicated by the cross-flows in the inner arch and swales, while its temporality is indicated by the age of the trees taking root on the bars.** There were years when arborescent vegetation was dominant on each point par surface, for example, after 19889, which can be connected to the water-decreasing effect of the Donja Dubrava power plant, but there were other point bar surfaces of considerable area that stabilised during 1994-1998 and 2002-2004. The latter period was also an important phase of island development. In my opinion, before the Čakovec power plant started to operate (1982), the frequent floods and higher mean waters could raise the surface of the point bars, which could also result in meander development. However, after the Čakovec and Donja Dubrava power plants started to work, water level decreased, the dominant process of inner arch evolution and meander development was the stabilisation of the bar surfaces that were not covered by water any more.

3.4.2. **The dominant forms of point-bar surfaces were the islands which evolved from the highest points of the bar-heads, then they gradually melted into the point-bar surfaces.** It is a typical process of island evolution, as islands can only evolve there in a continuously narrowing river channel, where the velocity of the water is lower, so they are farther away from the thalweg.

3.4.3. **The amount of eroded material originating from the outer arches of the river changed not only from meander to meander but also from time to time in the same meander**. The latter of these was partly due to the amount of the deposited sediment in front of that particular river bank as well as the missing floods and flood protection facilities on the outer arch. The erosion of the outer arch of the upper two meanders investigated only partially are not affected directly by any in-channel river engineering constructions, however, such influences are already present in the meanders of Heresznye and Bolhó affecting bank retreat, and the direction of meander development. Bank erosion was especially intense in 1979-1982, as floods were more frequent these years, and mean and minimum water levels were also higher. It is the minimum and mean water levels as well as the floods caused by the daily HPP-induced water level fluctuation that take part in river bank development nowadays.

3.4.4. On the basis of my results, **bank retreat on the Drava is basically determined by the height of the river bank** (Kiss and Andrási, 2015). It is well-identifiable in the Heresznye study area as a a 520-meter long and 20-22-meter high high-bank runs along the upper downstream part of the outer arch, while a significantly shorter, 850-meter long bank is eroded by the Drava on the lower part of the meander. The evolution of the latter one is more dynamic, because while the high-bank retreated 0.4-1.9 m/year between 1979 and 2014, the erosion of the lower bank section was 1.3-12.9 m/year. The maximum bank retreat also supports this process, because in 2013-2014 the high-bank retreated a maximum of 10.5 meters, while the lower section of the outer arch retreated almost 70 meters. In my opinion, this could be related to the fact that the higher banks are more solid, and their underwashing needs more time, since their erosion is characterised by large blocks falling down, which temporarily stabilise the upper part of the river bank, and bank erosion can only continue when these blocks are transported away (Kiss et al., 2013).

3.4.5. Based on the cross-sections of the point bar surfaces it can be concluded **that there are significant height differences between the former bank of the Drava and the currently active youngest point bar head.** As these banks were still active in 1979, the slope of the point bar surface indicates an incision process, which is further intensified by the more and more frequent and durable minimum waters caused by water retention.

3.4.6. **The uppermost three meanders that I investigated are elongated and bent in downstream direction.** It is because the thalweg reaches the lower part of the outer arches in a bigger and bigger angle, moreover, the slower bank retreat in the Heresznye meander intensifies this spatial pattern. **However, the Bolhó meander is elongated more upstream, therefore more laterally due to the revetment located in the middle section of the outer arch.** Thus, the upper section of outer arch retreats, the meanders becomes more pointed, and if the current development trend goes on, it may even evolve into a complex meander modified by anthropogenic effects.

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