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HYDROLOGICAL AND MORPHOLOGICAL CHANGES OF THE LOWER DANUBE NEAR MOHÁCS, HUNGARY

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Abstract

Various direct human impacts changed the hydro-morphology of the Danube during the last centuries. The aims of the present study are (1) to analyze the water regime of the Danube River using the data of Mohács gauging station (1900-2013), and (2) to study the channel development (1952-2014) in connection with water regime changes and human impacts at a section near Bogyiszló (upstream of Mohács). According to the results the height of low water stages decreased by approx. 136 cm (1.2 cm/year), and new, high record flood stages were measured too. The discharge values appertaining to the same low water stages doubled, thus nowadays almost twice as much water flows through the cross-section of the channel at a given stage as at the beginning of the studied period. As the duration of low stages increased, the sandbar development intensified, thus the channel became narrower (by 48% at some places) and deeper thalweg evolved. Therefore, a smaller cross-section for flood-waves evolved, affecting the height of flood. These changes affect shipping, as due to riverbed incision and decrease of low water stages, the lowest shipping water level has to be set repeatedly at lower stages. Besides water extraction from the channel will have difficulties, thus irrigation and industrial cooling water supply will be limited in the future.

Keywords: Danube, hydrological water regime, low water stages, riverbed incision, bar development

INTRODUCTION

Direct human impacts on rivers, such as cut-offs of meanders, building of revetments and groynes, constructions of dams, water retention or in-channel gravel mining could cause significant alterations in river hydrology (Blanka, 2010; Kiss and Andrási, 2011; Cheng et al., 2012) and morphology too (Bonacci and Oskoruš, 2008; Williams and Wolman, 1984; Kiss and Blanka, 2012; Kiss and Andrási, 2015).

For the society the most important changes are the frequency increase of floods and the decreasing level and increasing durability of low water stages. As a result of lower water stages, the water extraction (for drinking, irrigation or industrial cooling) will be more and more difficult, and the shallow riverbed deteriorates shipping and the incision might cause damages for floodplain ecosystems (Kiss and Andrási, 2015). In the Carpathian Basin several rivers are affected by similar hydrological changes. For example on the Dráva River the level of low stages decreased by 118 cm in connection with dam constructions during the last century, resulting in channel pattern changes (Kiss and Andrási, 2011; Kiss and Balogh, 2015). On the Maros River water stages decreased by 50 cm in the past 20-30 years (Sipos, 2006), whilst on the Hernád by 60 cm in the last 50 years (Blanka, 2010), both resulting in channel narrowing.

The Danube is one of the most important commercial waterways in Central Europe. However, shipping requires significant regulation works, such as construction of revetments and groynes, which alter natural processes in river morphology. The changing hydrology (characteristically decreasing stages) is also the result of cut-offs of meanders in the 19th c., and gravel mining started in the 1970's (VITUKI, 2007). One of their consequences is that meander development terminates (Somogyi, 2001) and the low water stages start to decrease gradually, while the frequency of record-high floods increases (VITUKI, 2007). Besides several dams trap sediment and affect the hydrology (IDCPR, 2014). The second largest Danubian dam located at Bős–Gabcikovo (its hydropower plant operates since 1992) is responsible for higher durability of low stages and incision by ca. 1.5 m on the downstream sections of the river (Rákóczi, 2000; VITUKI, 2007). Due to the incision, the lowest navigable water level had to be set at lower and lower water stages, thus it was decreased by 0.9 m between 1970 and 2004. As a result, on the Hungarian–Croatian section riffles and fords inhibit shipping during low-stage periods.

Nowadays, a current topic in the Hungarian news is the planned expansion of the Paks Nuclear Power Plant, which needs increased cooling water supply, which could only be provided by damming the river downstream of Paks [1]. No preliminary impact study has been made on the possible consequences on river morphology, water regime or sediment-transport yet, nor is the present channel processes known in detail.

The aim of the present research is to reveal the long-term changes in hydrology of the Danube, and in connection with them to analyze the morphological changes of the riverbed, focusing on the development of mid-channel bars and islands

STUDY AREA

On the Danube regulation works started at the end of 19th century. Their main objective was to shorten flood-waves and increase their velocity, therefore several meanders were cut-off downstream of Budapest. One of the sharpest and thus most dangerous bend located near Bogyiszló, which played an important role in ice damming, for example during the devastating icy flood in 1838. Between Dunaföldvár and the Hungarian–Croatian border altogether 32 meanders were cut off, and the channel was almost straightened. The final step of regulation works was the construction of groynes to support shipping (Ihrig, 1973). In the 1970's in-channel gravel mining started causing intensive incision and low stages decrease, thus shipping became more difficult. The incision made the water withdrawal complicated, especially for the Paks Nuclear Power Plant, therefore the rate of dredging was reduced. However, the increasing duration of low water stages is still a problem, in connection with the Bős–Gabcikovo Dam (VITUKI, 2007).

In the present study the water stages measured at Mohács gauging station (1446.9 fkm) were analyzed and the morphological changes of a downstream section of the Danube near Bogyiszló (1493–1502 fkm) (Fig. 1). In this section the river has 4-5 cm/km gradient, and the channel width varies between 450 m and 600 m. The transported sediment is very fine-grained, especially made up of fine silt and sand (VITUKI, 2007). The studied nearly straight section was formed when the meander at Bogyiszló was cut off in 1856 to avoid the development of ice-jams (Ihrig, 1973). Along the studied section the channel development is mainly affected by groynes built since 1935 (Ihrig, 1973), though the main period of groynes construction was in the beginning of the 1950's.

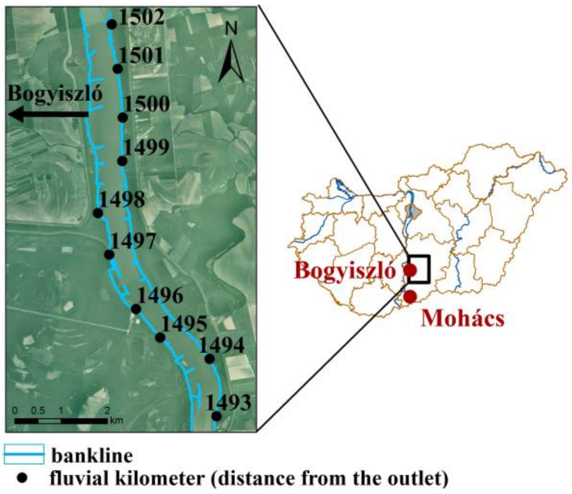

Fig. 1 Hydrological data are from Mohács gauging station, whilst the studied channel section of the Danube is located north of Mohács. (source: Google Earth)

METHODS

Daily water stages (1890–2013) and discharge values (1900–2013) measured at Mohács gauging station were analyzed (data source: ADUVIZIG). This huge dataset has been divided into ten-year periods (1900-1909, 1910-1919 etc.) to facilitate analysis. In each period we calculated the duration of different stages, the number of days when low stages (≤315 cm, occurred with a frequency of 90% in the first decade) were present, and we analyzed the water stage – discharge relationship.

We analyzed the development of the river channel near Bogyiszló using maps and aerial photographs representing the period between 1952 and 2014. The maps and aerial photos were geo-referenced, and we digitized the banklines, and bars with and without woody vegetation using ArcGIS.

RESULTS

Hydrological changes of the Danube River at Mohács

The stage duration curves of the decades show obvious decrease of water stages lower than 700 cm (Fig. 2). In the first decade (1900-1909), for instance water stages were above 315 cm during 90 % of the period, though in the last ten years (2000-2009) they were above 179 cm in accordingly, referring to a decrease of 136 cm at 90 % frequency stages.

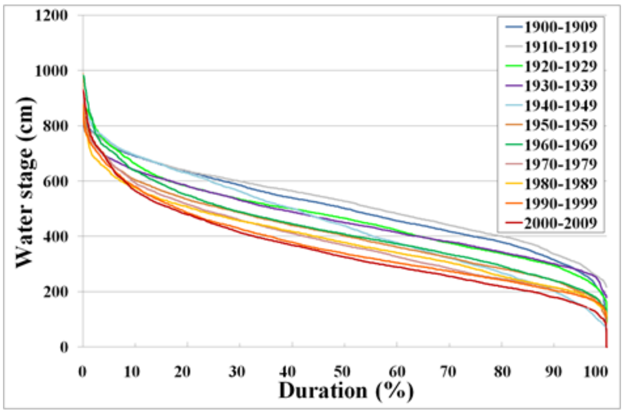

Fig. 2 Changes in the duration of water stages

Obvious change in the duration of flood stages cannot be proved, however their extremity (scattering) decreased, thus record-high flood stages (>900 cm) became more frequent since the mid-20th century (Fig. 3). Between 1900 and 1946 annual highest stages were more or less similar characterized by some fluctuations. In this period characteristically the annual flood stages were between 700 cm and 850 cm, and flood level exceeded 900 cm only once (in 1938). However, in the second half of the 20th c. and especially in the 21st c. quite high flood stages occurred, when flood stages exceeded 900 cm more often (in 1954, 1956, 1965, 1975, 2002, 2006, 2010 and 2013). This does not obviously mean that the height of flood stages continuously rises, just their frequency increases.

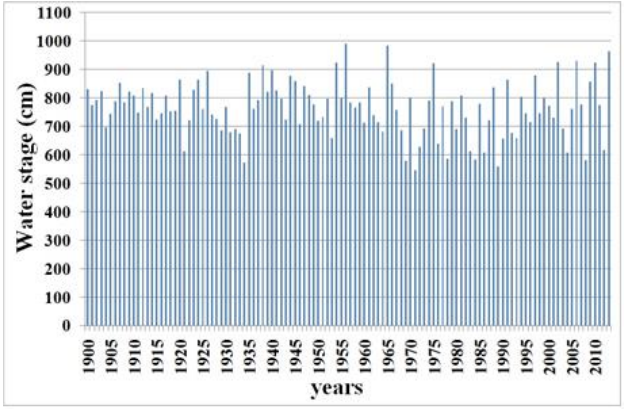

Fig. 3 Changes in the annual flood stages (1900–2013) at Mohács gauging station

Annual low water stages decreased significantly during the studied period (Fig. 4). In the first half of the 20th century (1900-1945) the level of the annual lowest stages exceeded 200 cm, their average height was 245 cm. Extremely high stages occurred in 1910–1916 and 1936–1941 when most of the water stages were above 315 cm. In the second half of the studied period (1946-2013) the level of annual low water stages decreased, thus between 1946 and 2002 their average height dropped by 84 cm to 170 cm, and since 2003 their average height decreased further to 125 cm. These results show an obvious decrease of low water stages, which could be explained by (i) more extreme water regime or (ii) by incision of the riverbed.

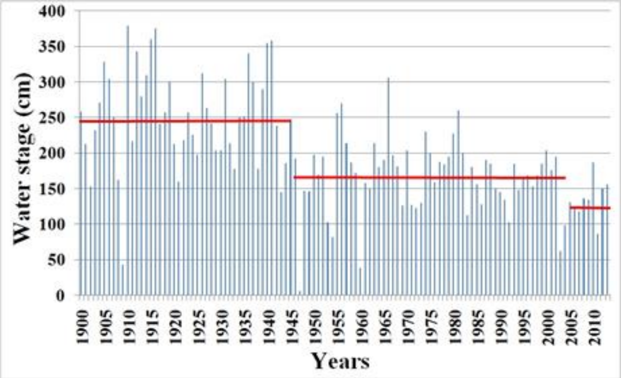

Fig.4 Level of the annual lowest water stages (1900–2013) at Mohács. The red lines represent average values of different periods

The extremity of water regime could be proved by changes in the number of days when low water stages (≤315 cm) occurred. The duration of low stages within the decades increased considerably (Fig. 5). In the first decades of the 20th century low stages occurred in 7-15 % of the decades, however from 1990 until 2013 it increased to 43-47 %, thus the duration of low stages increased by five times (by 20 day/year). This process is in connection with the operation of Bős–Gabcikovo Hydroelectric Power Plant, which started to function in 1992, or it could also be connected to the incision of the riverbed due to groynes built in the river.

Riverbed incision could be indicated by the changes of water stage – discharge (H–Q) relationship: discharge appertaining to a given water level increases in the case of incision, while it decreases in the case of aggradation. However, if the height of flood stages increase while discharges stay stable or decrease, it means that flood channel becomes narrower (Vágás, 2004). The H–Q point-clouds gradually shift upwards (Fig. 6), i.e. discharges appertaining to given water stages increase considerably. It obviously refers to the incision of the riverbed. Discharges appertaining to low water stages are gradually increasing, for example, discharges belonging to 250-300 cm water stages increased from 900-950 m^3/s to 1700 m^3/s in the last almost 110 years. This obviously proves the incision of the riverbed, as the channel transports almost twice as much water at the same water stage.

In the case of higher water stages, there is no significant increase or decrease in the relationship between water stages and discharges. However, the frequency of record-high flood stages shows an increasing trend. The increasing water stages at same discharges can be caused by the narrower flood channel.

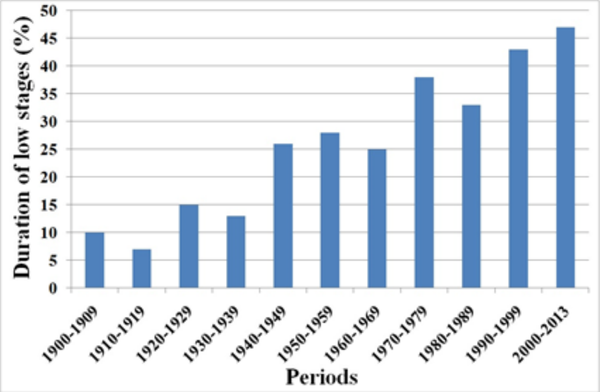

Fig. 5 Duration of low water stages (≤315 cm) at Mohács gauging station

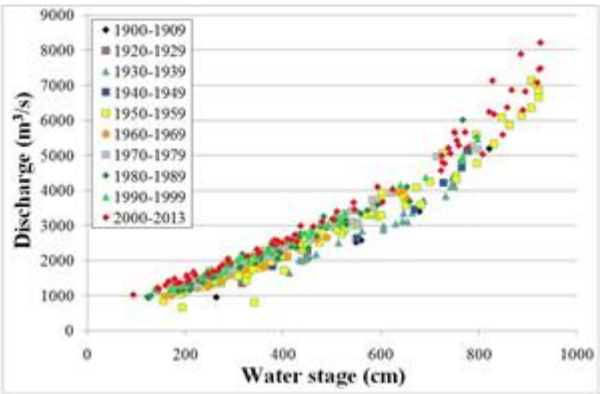

Fig. 6 Relationship between water stages and discharges measured at Mohács

Horizontal changes in the channel of the Danube near Bogyiszló

In the first analysed year (1952) there were only two bars (area: 0.046 km^2) which developed behind groynes, downstream of the mouth of a tributary (Sió River, at 1496 fkm; Fig. 7). In the following year (1953) more bars formed behind the newly built groynes. At the 1500 fkm

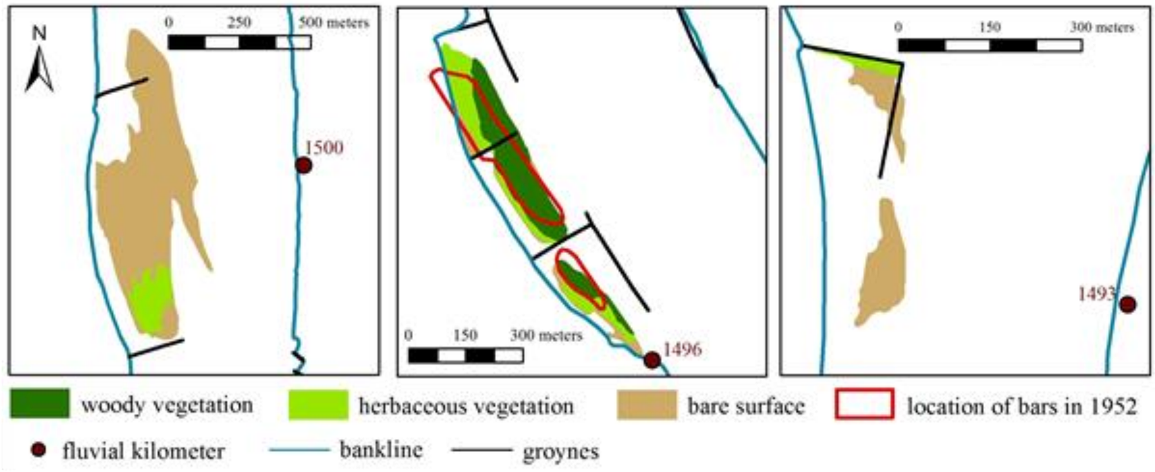

Fig.7 Location of bars (1953) in the studied section of the Danube near Bogyiszló

a large bar evolved (area: 0.22 km^2) with some herbaceous vegetation. The area of already existing bars increased (to 0.88 km^2), and by now their surface was covered by woody vegetation. In the bend, in the southernmost part of the study area (1493 fkm) new sand bars formed without vegetation.

The location and area of bars changed considerably until 2000 (Fig. 8). Along the uppermost section (1498–1502 fkm) islands developed behind each groynes, and they were already completely colonized by forests. In the bend along the southern section of the study area, the inlet of an oxbow lake became closed by a sediment plug and a small island became connected to the riverbank. Besides three more bars were formed, one of them was covered by herbaceous. In this year the total area of the bars and island was 0.4 km^2.

By 2011 the area of bars and islands doubled (0.85 km^2) and they became common along the whole studied reach. It could be explained by the increasing duration of

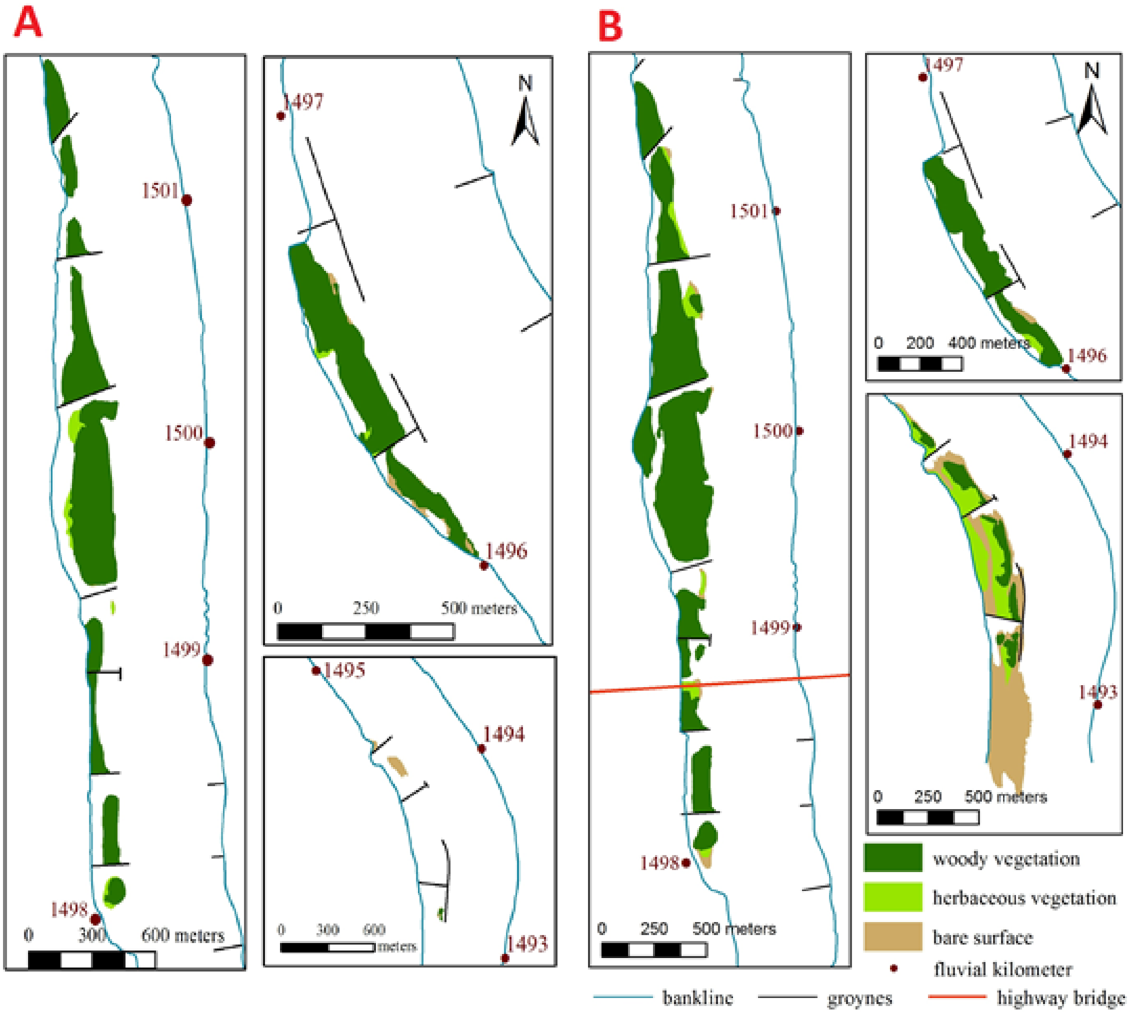

Fig.8 Location of bars and islands in the study area in 2000 (A) and in 2014 (B)

low stages, the drop of their level, and the lack of significant flood which could have eroded the material of the islands and bars. The most intensive aggradation was typical in the bend at the downstream section of the study area, as here the area of islands and bars increased from 0.13 km^2 to 0.29 km^2 within one year.

On the last aerial photo (2014) the morphology of the reach remained the same as it was in 2011 (Fig. 9). The total area of bars and island increased by 0.04 km^2 and the area of woody vegetation increased on the islands north of 1498 fkm. The number of bars decreased though their total area increased, probably because the bars coalesced and the water level decreased at the time of the shots of the aerial photographs (2011: 72 cm, 2014: 36 cm).

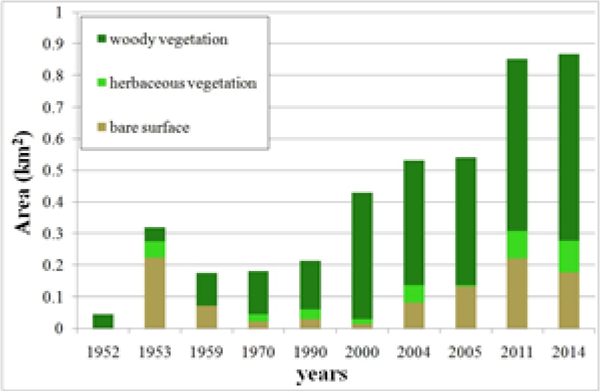

Fig. 9 Changes in total area and vegetation cover of the studied section of the Danube between 1952 and 2014

Reviewing the processes it could be stated that in the northern section of the study area (upstream of 1498 fkm) bars and islands are spatially permanent features, and they have not changed significantly since their formation. In contrary, in the southern, downstream section they are more changeable, as their material could be eroded and transported away easily during floods, and they could coalesce during low water stages. The more dynamic formation and development of these forms could be the resulted of the closeness of the thalweg.

Between 1990 and 2000 the number of bars doubled (from 4 to 10), due to the increased duration and frequency of low water stages and the descending water level. In the first decade of the 21st c. the number and size of wooded islands increased, while the area of bare and herb vegetated bar surfaces fluctuated (Fig. 9). This could only be explained by the changes in water stages, as due to descending water stages the higher surfaces of bars become watertight, thus vegetation could colonize them, while lower bars still have bare surfaces, as they are in the zone of fluctuating water level, thus they develop more dynamically as their material could be transported away by smaller flood waves.

As a result of bar formation the width of the channel decreased considerably. While in the 1950's the average channel width was 600 m, in 2014 it became 480 m. The most significant narrowing took place at 1500 fkm, where the width of the channel decreased from 780 m to 445 m.

CONCLUSIONS

At the lower section of the Hungarian Danube the height of low stages decreased by 136 cm (1.2 cm/y) during the analyzed period (1900–2013). The duration and frequency of low stages increased, and their level decreased, thus for example between 1900 and 1909 water stages exceeded 315 cm in 90 % of the decade, whilst between 2000 and 2013 they only exceeded 179 cm accordingly. On the other hand, the height of yearly highest (flood) stages became more scattered, and the frequency of record-high flood stages increased. The analysis of the relationship between water level and discharge values refers to significant changes in water regime and in river channel.

Simultaneously with the water level drop, the number of bars quadrupled in the analyzed section of the Danube between 1952 and 2000. This process became accelerated in the 1990's, when low water stages (≤315 cm) were measured almost in half (43 %) of the decade, while in the 1980's they occurred only in 33 % of the decade. As a result, sediment accumulation began behind the groynes, and woody vegetation could colonize the surface stabilizing the material of bars. The duration of low stages continued to increase (48%) in the 2000's, thus the number and area of bars continued to raise and woody vegetation could spread on their surface.

Development of bars has feedback on water stages and on the development of the river channel, as due to bars the river channel becomes narrower, which affects the height of flood stages and results in intensive riverbed incision. In the study area the average width of the channel decreased from 600 m to 480 m, though at some places it became narrower by 330 m (by 45%).

These changes affect shipping, as due to riverbed incision and decrease of low water stages, lowest shipping water levels have to be stated at lower and lower water stages. On the other hand, drop of characteristic water stages affect water management, as water extraction will face difficulties, thus irrigation and industrial cooling water supply will be limited in the future.

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