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Abstract

Oxbows are common elements of fluvial landscapes in Hungary. The aim of this paper is to introduce their origin, development and future perspectives. Oxbows have been formed either naturally or artificially. Natural oxbows, or rather paleo-channels have silted up by now, but have got a key importance in the reconstruction of Late Pleistocene and Holocene landscape evolution and natural floodplain aggradation. Man made oxbows, resulted by cutoffs during the regulation works of the 19th century, are on the other hand experience recent environmental and land use changes, threatening their future sustainability. Problems and processes affecting them highly depend on their location with respect to the post-regulation active floodplain and artificial levees. Main issues are water recharge and retention, increasing sedimentation, spread of invasive species, improper landscape management and conflicting utilization interests. The exemplary Mártély Lake, an oxbow of the Tisza River, is on of the largest such forms in Hungary. Being on the active floodplain it has a great ecological potential, but meanwhile it is seriously affected by silting up and also has a diverse utilisation with conflicting interests. In order to sustain or even improve its status a complex management strategy has to be implemented in the future. This is true for other oxbows as well, being highly sensitive but at the same time extremely valuable elements of the Hungarian landscape.

Keywords (separated by '-') Floodplain - River engineering - Oxbow lakes - Sedimentation - Land-use management - Tisza river

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Mártély Lake: An Oxbow of the Lower Tisza River

31

Tímea Kiss and György Sipos

Abstract

Oxbows are common elements of fluvial landscapes in Hungary. The aim of this paper is to introduce their origin, development and future perspectives. Oxbows have been formed either naturally or artificially. Natural oxbows, or rather paleo-channels have silted up by now, but have got a key importance in the reconstruction of Late Pleistocene and Holocene landscape evolution and natural floodplain aggradation. Man made oxbows, resulted by cutoffs during the regulation works of the 19th century, are on the other hand experience recent environmental and land use changes, threatening their future sustainability. Problems and processes affecting them highly depend on their location with respect to the post-regulation active floodplain and artificial levees. Main issues are water recharge and retention, increasing sedimentation, spread of invasive species, improper landscape management and conflicting utilization interests. The exemplary Mártély Lake, an oxbow of the Tisza River, is on of the largest such forms in Hungary. Being on the active floodplain it has a great ecological potential, but meanwhile it is seriously affected by silting up and also has a diverse utilisation with conflicting interests. In order to sustain or even improve its status a complex management strategy has to be implemented in the future. This is true for other oxbows as well, being highly sensitive but at the same time extremely valuable elements of the Hungarian landscape.

Keywords

Floodplain • River engineering • Oxbow lakes • Sedimentation • Land-use management • Tisza river

31.1 Introduction

As the lowlands of Hungary have been primarily formed by rivers both in the past and present, oxbow lakes are common elements of the landscape. Numerous meanders and palaeochannels have been left behind by the actively migrating alluvial rivers, such as the Tisza, Danube or Hernád (according to Blanka 2010, for instance, 10 natural cutoffs occurred on the Hernád in the past decades). In the 19th and 20th centuries human interventions leading to artificial cutoffs have become the key processes behind oxbow formation. Let they be naturally or artificially developed, oxbows are very important landmarks of the alluvial landscape. Most of them are situated along the highly engineered Tisza and Körös Rivers, but practically they can be found anywhere on the plains. Their total number is estimated to be around 500 (Molnár 2013).

Unfortunately even those formed recently have silted up in the past centuries and started to disappear. Consequently, most of these lakes and marshlands are under strict protection and not just because of their geomorphological and hydrological importance, but also because they provide high-diversity refuges and important corridors for the

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continuously shrinking natural flora and fauna. As the area of wetlands in the Carpathian Basin decreased dramatically as a result of intensive river regulation and drainage works during the 19th to 20th centuries (from 57 to 2 %, Gábris et al. 2004), oxbows are almost the only still existing witnesses of the once flourishing floodplain ecosystems. Oxbows are very sensitive to climate change and intensified human impact, thus the area of their open water surfaces is decreasing, and at the same time their water quality is also deteriorating. In order to preserve these landforms for the future several problems need to be tackled to maintain their hydrology and water quality and to prevent further siltation and disturbance (for instance, through the spreading of invasive species). A well-designed management would also serve economic interests, since oxbows are significant water reservoirs, and can be used for water retention, irrigation or, in special cases, to extract drinking water. Their use for angling, fishing and summer tourism is also increasing.

31.2 Environmental Background

31.2.1 Natural Cutoffs

It is a well-known feature of meandering rivers that they continuously develop their channels and leave behind overmatured bends. A natural cutoff will occur when sinuosity exceeds a threshold value where at the given slope and stream power conditions the river cannot maintain its meander further (Hooke 2004). A natural cutoff can develop in two ways. If the river finds its shorter track along point bars or on the floodplain, a chute cutoff, the more common type according to Knighton (1998), occurs. However, on the Tisza River and its tributaries neck cutoffs are more characteristic. In this case two downstream migrating meanders in the same phase get so close to each other that during an erosive, high-energy event (flood) the neck of the enclosed bend is broken through, and its limbs are blocked by the sediments of the rapidly developing natural levee.

31.2.2 Artificial Cutoffs—Regulation Works on the Tisza River

Prior to the 19th century regulations the rivers of the Hungarian Great Plain were highly sinuous and their channel slopes were very low. Therefore, floods inundated vast, potentially arable lands for 5–6 months in almost every year. Rivers also functioned as the main routes of commerce, since boats provided practically the only means of transportation in the lowland, covered by extensive swamps and marshlands. Therefore, the need for flood control and safe navigation facilitated the elaboration of regulation plans in the beginning of the 19th century, and by the end of the century river training works were more or less completed.

One of the most important aims of these regulations was to increase slope and the rate at which flood waves pass. This was achieved through making numerous artificial cutoffs (Fig. 31.1). Cutoffs were actually narrow conductor channels made usually at the neck of meanders, while the excavated material was deposited 8–10 m away from the new banks. When the river was captured by the cutoff

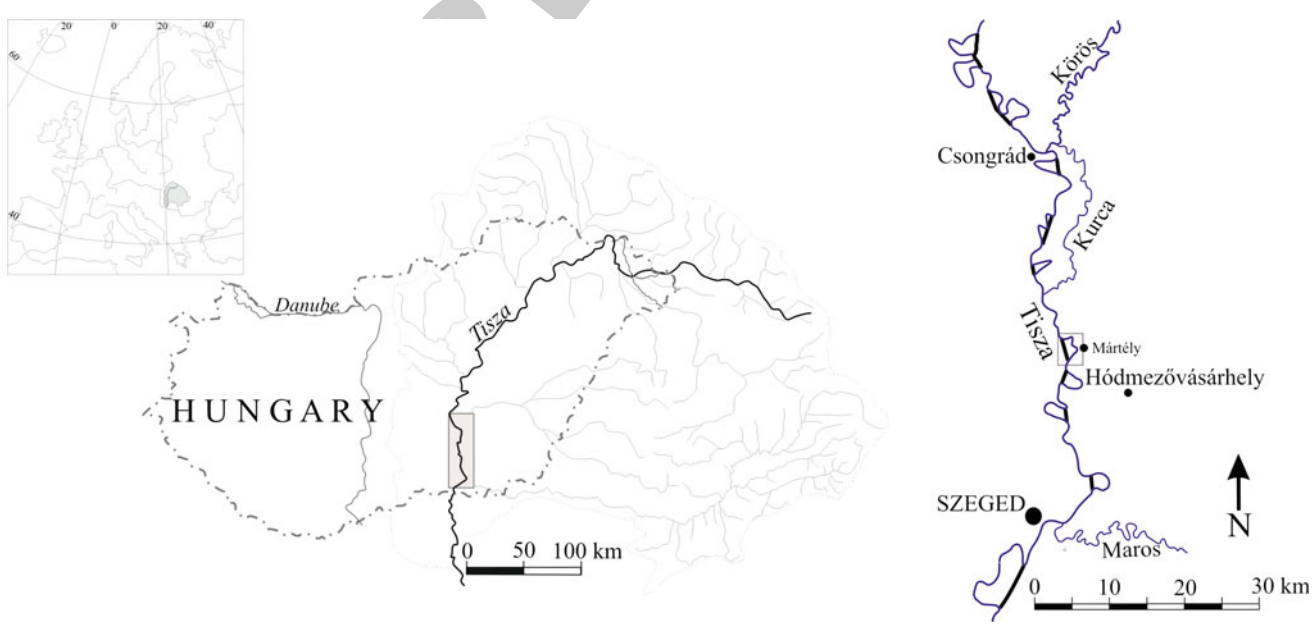

Fig. 31.1 Location of the Tisza catchment and the exemplary Mártély Oxbow Lake

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channel, it could develop its new cross-sectional geometry in accordance with its increased slope and energy (Ihrig 1973). This way the cutoff channel could naturally turn into the main channel of the river, saving a considerable amount of effort for engineers. However, the procedure was sometimes more complicated, especially at longer cutoffs and on the lower sections of rivers (Fig. 31.1), where the main channel was embedded in clayey-silty sediments. In these cases cutoff channels had to be deepened and widened, and had to be dredged from time to time to make the river finally occupy its new course (Károlyi and Nemes 1975; Lászlóffy 1982).

The first cutoff, ending with successful diversion and fixation of the main channel, was finished in 1846. The excavation of cutoff channels was usually completed quickly, e.g. on the Middle Tisza in less than 20 years, however, it took a much longer time to capture the thalweg of the river. It has to be emphasized though that all works were made by using only human power, no machines being available at that time (Dunka et al. 1996).

Along the Tisza River 114 meanders were cut off, shortening the river course from 1,419 to 966 km, and increasing its slope from 3.7 cm km^{-1} (0.000037) to 6 cm km^{-1} (0.000060). In total approximately 1,000 cutoffs were implemented on Hungarian rivers (Somogyi 2000).

In general the slope of rivers doubled, which initiated a series of geomorphic processes, though responses were different. Energy and slope increase usually resulted in incision, channel widening, increased sediment production and in certain cases pattern change. For example, in case of the meandering and anastomosing Maros River, the largest tributary of the Tisza, the whole process could be identified, and the river turned to be braided (Kiss and Sipos 2007). In the meantime the Tisza experienced a 3–5 m incision (Kiss et al. 2008), which resulted a 300–400 cm decrease in the absolute level of low waters (Rakonczai 2000) and the sinking of groundwater level along the river. Consequently, oxbows became relatively elevated, and only the greatest floods could recharge their water naturally, thus open water surfaces can only be preserved by human intervention.

Enhanced floodplain aggradation was another direct and also indirect outcome of cutoffs, which necessarily lead to the silting-up of oxbows as well. During the capturing of thalwegs by cutoff channels extra sediment entered the river systems directly. Subsequent incision and related bank failures and slides still supply further material to the channels from time to time (Kiss et al. 2008). These processes also lead to intensive sedimentation (1.5–2.0 m) on the narrow, artificial floodplain bordered by levees constructed for flood control purposes in the 19th century. The process is unfavourable not just for oxbows and geomorphological diversity but also from the aspect of increasing flood levels and flood risk (Lóczy and Kiss 2009).

31.3 Research History

The investigation of oxbows and palaeochannels is an important field of Hungarian geomorphological research. During the geomorphological mapping of the Tisza-Körös confluence zone, with numerous oxbow lakes, Schweitzer (2006) has identified several types based on the degree of sedimentation. A similar mapping was prepared along the Middle Tisza (near Vezseny) at 1:10,000 scale by Balogh et al. (2005), however actively developing forms (e.g. present-day point bars) were not indicated. For the Middle Tisza Region Tóth et al. (2001) had shown the possibility of mapping and classification of oxbows, also emphasizing the necessity of landscape rehabilitation and water retention.

The geomorphological mapping and absolute dating of channels on the now inactive floodplain also provides an opportunity to reconstruct the evolution of alluvial rivers. Analyses of this kind have already been made on the Sajó-Hernád (Nagy and Félegyházi 2001), Hortobágy (Félegyházi and Tóth 2003) and Maros (Katona et al. 2012; Kiss et al. 2014) alluvial fans, and along the Körös (Nádor et al. 2011) and the Middle Tisza Rivers (Gábris et al. 2001).

In the Upper Tisza Region detailed analyses of Pleistocene and Holocene palaeochannels revealed not only the pattern of landform evolution, but also the rate and timing of floodplain and oxbow sedimentation. For instance, near the Tisza-Bodrog confluence channels are silting up significantly faster (1 mm year^{-1}) than general floodplain aggradation (Borsy et al. 1989). However, there was a significant variation in the rate of sedimentation, being quite low during the Late Glacial and Preboreal Phase (0.2–0.3 mm year^{-1}), getting faster during the Atlantic Phase (1–2 mm year^{-1}) and lower again during the Subboreal Phase (0.8 mm year^{-1}) (Csongor et al. 1982). Based on palynological and radiocarbon data the palaeochannels on the Hernád floodplain silted up at a similar rate (0.4–0.5 mm year^{-1}) in the Subboreal Phase. However, during the past 2,000 years sedimentation increased (to 1 mm year^{-1}) and accelerated further in the past 300 years (8 mm year^{-1}) (Szabó 1996).

Depending on their location, the oxbow lakes which resulted from regulation works developed individually. Somogyi (2000) described those beyond levees as living water lakes of different status, while those situated between levees as forms completely silted up by the sediments of post-regulation floods. Although the later remark is not generally applicable, there are spectacular examples, for instance, along the Maros River, which transports a

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considerable amount of suspended load and has filled up all oxbows along its course by now (Kiss et al. 2011).

The sedimentation rate of Tisza River oxbows was investigated by Braun et al. (2000, 2003), using ^{137}Cs and heavy metal markers. They found a 2–6 cm year^{-1} accumulation on the average, though for instance in the case of a representative Upper Tisza oxbow, experiencing a 400 cm accumulation (ca 3 cm year^{-1}) since its cutoff in 1860, the rate of silting up was decreasing from 5 cm year^{-1} (from the 1920s till the 1970s) to 2 cm year^{-1} through time (Braun et al. 2000).

The pollen of adventive species (e.g. ragweed, *Ambrosia artemisiifolia*) were applied by Kiss et al. (2011) to study the sedimentation rate of Maros River oxbows. The oxbows located on the artificial floodplain silted up rapidly, at a rate of 1.3–2.6 cm year^{-1}, and water vanished from them within 50–70 years following cutoff. The analysis of several forms indicated that the rate of sedimentation was uneven in time and it was affected by several factors (Kiss et al. 2011). For instance, an increasing accumulation rate (from 2.5 between 1842 and 1960 to 3.5 cm year^{-1}) was detected in a representative oxbow as a consequence of longer inundation in the 1970s. The sedimentation rates in oxbows were primarily controlled by their location relative to the alluvial fan and their distance from the active river channel.

31.4 Classification

Based on the above, oxbows can be classified in four ways: by origin, location, degree of degradation and utilisation. As we have seen above, oxbows can either result from natural or artificial cutoff. From the aspect of water management and conservation, however, more recent artificial oxbows are more important, as many of them still have a permanent open water surface (Molnár 2013). Concerning their location the most important types are those located on the active floodplain and those beyond the flood-control levees.

As it was shown earlier, location primarily affects the degree of sedimentation and degradation. Water managers and conservation specialists identify three types of oxbows in this respect (Pálfai 2001). So-called "sanctuary" oxbows are resembling natural ecosystems. They are not under human use and have not silted up. These are usually under strict protection and managed by national parks. Oxbows of "wise utilization" are lakes with a certain economic use, slightly degraded, but their different uses can be harmonized. The third group consists of highly degraded oxbows, usually of minor natural value or silted up almost completely.

In general there are four main types of human use, which are the following according to Pálfai (2001). Use for water management purposes includes flood or excess water storage, drinking, irrigation and industrial water storage, or water quality improvement. Production-related uses are fishing, fowl breeding and reed growing. Recreational uses include bathing, tourism, water sports and angling. Finally, the fourth type of utilisation is in relation with nature and landscape conservation. Most of the lakes are naturally under a mixed use, which generates several land-use conflicts between different stakeholders.

31.5 The Oxbow of Mártély

The Mártély Oxbow was cut off from the main channel of the Tisza River between 1889 and 1892 (Fig. 31.2). The length of the Mártély Oxbow is 4.6 km, its average width is 100 m, its area is 46 hectares, from which 33.5 hectares are open water (Fig. 31.2). Average depth is 2 m, though at places it can be as deep as 6.5 m (Fig. 31.2). The oxbow is connected to the Tisza at its downstream end with a feeder canal and a lock (Pálfai 2001). Nevertheless, due to the incision of the Tisza, natural water supply is limited to flood periods. At lower stages water can only be recharged by pumping. The water of the lake is partly used for irrigation, the outlet is situated near the midpoint of the oxbow. Artificial pumping and simultaneous draining ensures at least some water circulation, though affecting only the southern limb of the oxbow, the northern limb lacks oxygen and has gradually turned into a swamp (Fig. 31.3). Due to dredging in 2003, however, water quality has improved considerably (Molnár 2013).

Although during the regulation works a localisation dam was constructed along the bank of the oxbow, the final levees were built on a different track, resulting in a fairly wide active floodplain (Fig. 31.2). Riparian forests and meadows are under nature conservation (protected landscape) and the oxbow itself is a Ramsar site (Fig. 31.4). The lake therefore has a mixed use. The main conflict is related to recreational use, since for over 100 years a bathing place is situated on the eastern shore of the oxbow, and an 18-hectare resort village has been growing around it (Molnár 2013). At present ecotourism is facilitated by a new visitor centre and several hiking and educational trails.

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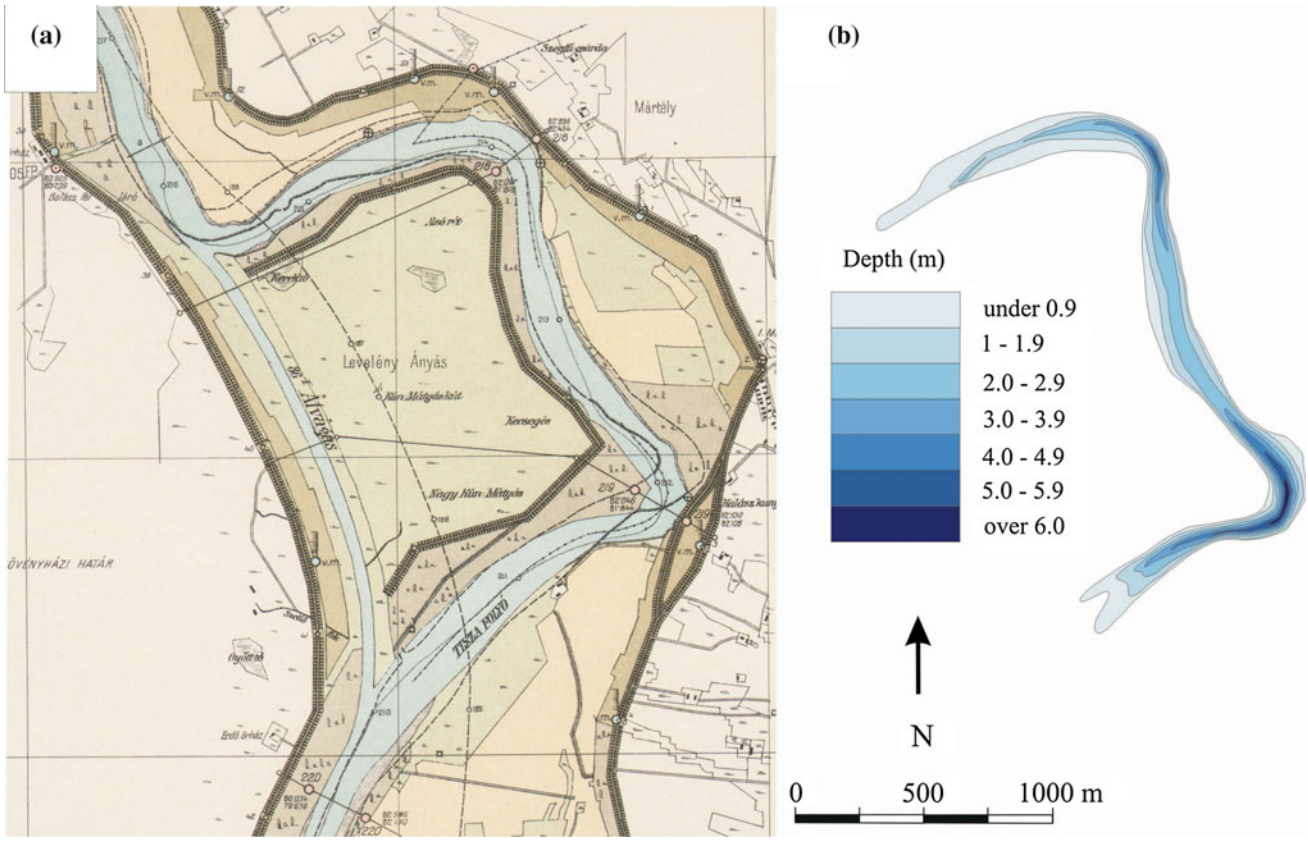

Fig. 31.2 **a** The Mártély Oxbow Lake during the regulation works. The cutoff is completed, however the conductor canal has not been captured by the main channel (*source* Tisza Regulation Map Series). **b** Bathymetric map of the Mártély Oxbow Lake (*source* Bártfai 2011)

Fig. 31.3 Both ends of the Mártély Oxbow Lake are filled up by now

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Fig. 31.4 A newly built board trail over the swamp

31.6 Conclusions

The oxbows of the Great Hungarian Plain, and especially those of the Tisza River, have exceptional natural and geomorphological values. They preserve something from the pre-regulation character of the floodplain both in terms of ecology and geomorphological processes. Their conservation is a difficult task, as they are seriously affected either by climate change, sedimentation and/or human use.

Future research should focus on factors determining the sustainability of these lacustrine and wetland systems. A key question in this respect is water recharge or water retention, which is most problematic for oxbows beyond the levees. The preservation of oxbows would also increase the resistance of landscape to climate change. Retention, however, also imposes water quality issues, becoming critical in the future.

The long-term dynamics of sedimentation varies with time and space and mostly affects oxbows on the active floodplain. To reconstruct the general pattern of changes further research is necessary, along with monitoring of present-day sedimentation. These investigations are of key importance for rehabilitation and conservation, and to determine, for example, the necessary extent of dredging.

Another very important sphere where earth sciences can address the management of oxbows is land-use mapping and related conflict and risk assessment. Over the past century *land use* around oxbows and in the floodplain has changed considerably. Main issues on the active floodplain are the lack of land management and the disappearance of traditional land-use techniques, which lead to the advance of adventive species and alteration of biogeomorphological processes. Meanwhile, oxbows beyond the levees have to face the effects of intensive agriculture, manifested in increased pollution and modified ecology. Conflicts, as seen in the case of the Mártély Oxbow Lake, are more profound if there are several interests of utilization, motivated by recreation, nature conservation or water management.

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