Carpathian Journal of Earth and Environmental Sciences, September 2011, Vol. 6, No. 2, p. 101 - 108

EFFECT OF DIFFERENT WATER STAGES ON BANK EROSION, CASE STUDY ON RIVER HERNÁD, HUNGARY

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Abstract: The aim of the paper is to analyse the rate of bank erosion of meanders along a short reach of the Hungarian section of the meandering River Hernád and to assess the relationship between the water stage and the rate of erosion. The active bank erosion within a 1.5-year period was analysed by field measurements and aerial photos were used to evaluate the process during the last 50 years. Hydrograph characteristics and extreme hydrological events were also evaluated in relation with bank erosion.
The research shows that a great flood has considerable channel-forming effect (3.7-9.8 m/half year), however significant erosion also occurs during the medium- and low-stage period following the flood (1.2-3.2 m/half year). Erosion rates of this low-stage period (1.2-3.2 m/half year) exceeded the average value (0.85-2.25 m/half year) of the former 30 years on each studied sites. However the rate of bank erosion can differ significantly even in nearby bends, which shows that local boundary conditions (e.g. bank material and height) and the stage of meander development have different effect in bend scale.

Keywords: bank erosion, meander development, River Hernád, effect of different stages (flood, medium water stage)

1. INTRODUCTION

Accurate rates and patterns of channel changes are fundamental in river engineering, since they influence the lifetime of different engineering works, such as dams, bridges, revetments or levees. Bank erosion has an enhanced importance, because it is a relatively rapid process and extensive changes can happen in the bank line within a short time (Wolman 1959, Schumm & Lichty 1963). However bank erosion is a complex process and interaction of several factors controls the changes in the bank line. It is an episodic process and the rate of changes is affected by the mechanical properties of the bank material (Thorne 1982, Hasegawa 1989, Couper 2003) and the hydrograph characteristics (Hooke 1979, 1980, Lawler 1992, Carroll et al. 2004). The hydrograph characteristics define the temporal changes of shear stress of the bank, thus the rate, time, duration and the frequency of bank erosion. The erosion of the riverbank is significantly affected during the period between peak flows (Hooke 1979, Lawler 2008). Hughes (1977) recognised that the major bank erosion events and extensive channel pattern changes are linked to flood peaks with a return period of 1.5 years. Although slower rate of sediment removal and bank retreat occur during moderate flows, which have a monthly return period. Moreover, the resistance of river bank material to fluvial entrainment changes through time with moisture condition, freeze-thaw activity (Hooke 1979, Lawler 1992, 2008) and vegetation growth (Smith 1976, Kirkby & Morgan 1980, Murgatroyd & Ternan 1983, Simon & Collison 2002, Wynn & Mostaghimi 2006). Hooke (1979) observed that fluvial entrainment and slumping of the bank are also associated with the influence of the antecedent precipitation conditions. The most critical conditions to strength reduction appear during heavy and prolong precipitation events, snowmelt and rapid drawdown following a high flow stage, because cohesive materials become more erodible when wet, while increasing of the degree of saturation causes decreasing in strength and increasing in unit weight (Lawler 1992).

Aims of the paper are (1) to analyse the short and long-term rate of bank erosion in adjacent bends on a short reach of the Hungarian section of the meandering River Hernád and (2) to assess the relationship between the water stage and the rate of erosion. The relevance of this research is arisen from the fact that significant changes were detected in hydrological parameters since the late 1950s on the Hungarian section of the River Hernád: the duration of medium stages decreased, but that of the low stage increased; water stages dropped in average, but extremities increased. These hydrological changes can be explained by changes in precipitation condition, intensive urbanisation processes, increased water extraction and reservoir impoundment on the Slovakian part of the catchment (Kiss et al. 2009). In addition the River Hernád is characterized by relatively rapid meander development and channel changes, thus the meander shape and the location of the channel might change extensively within few years or decades, therefore more exact data of the rate of bank erosion can be important.

The recent bank erosion over a 1.5-year period was observed by field measurements, and aerial photos were used to evaluate the process during the last 50 years. The observed rates of erosion and the hydrograph characteristic of the studied period were compared in order to assess the effect of hydrograph characteristics and extreme hydrological events on bank erosion.

2. STUDY AREA

The River Hernád is the main tributary of the River Sajó and belongs to the drainage system of the Tisza River. The catchment of the river (5440 km^2) is situated in the Northern Carpathians, shared between Slovakia (4427 km^2) and Hungary (1013 km^2). The total length of the river is 294 km, of which 186 km is in Slovakia and 108 km is in Hungary. The elevation of the catchment varies between 100 and 1943 m a.s.l. (Hanusin et al. 2006). The characteristics of the hydrograph of the Hungarian section of the river is basically determined by the Slovakian sub-catchment, as no significant tributary joins the Hernád on its Hungarian section (Csoma 1973). The average mean discharge of the river between 1971 and 2000 was 27.3 m^3/s (stage: -27 cm), but the fluctuation of it was high, as the minimum discharge was 4.6 m^3/s (stage: -94 cm) and the maximum was 653 m^3/s (stage: 445 cm), based on Hydrographic Yearbook 2003. The oscillation of the water level is high. The difference between the highest and the lowest water-level at the oldest-established gauge-station (operating since 1901) is 562 cm, as the minimum water level was -128 cm (05.10.2009.) and the maximum was 434 cm (05.06.2006.) (www.vizadat.hu). The average duration of floods between 1950 and 1995 was 59.2 hours/flood (less then 2.5 days) (Reimann et al. 2001). The duration of floods changes slightly downstream. At the downstream Gesztely gauge-station the floods are slightly longer with smaller maximum water-level compared to the Hidasnémeti gauge station upstream (Csoma 1973).

The River Hernád transports large amount of suspended sediment (at Hidasnémeti 820,000 t/y), its maximum concentrations can be as high as 29,000 g/m^3. At the same time, the bed-load transport (6000 t/y) is also considerable (Bogárdi 1971). Due to the large amount of sediment and the changing water stages the channel is highly sinuous, but shallow (Laczay 1973) and natural channel diversions frequently occur especially during great floods (Bendefy 1973).

The water and the sediment regimes of the river are under considerable human impact. , Mostly dams and water storage lakes influence them (the total capacity of the 3 largest is 73 million m^3 and 3 smaller dams were also built on the Hungarian section), and urbanisation (water output and input) on the Slovakian section. Locally the channel is directly modified by some revetments, cut-offs and flood-protection levees.

The studied section of the river is situated north of Alsódobsza (36.0-42.5 rkm) (Fig. 1). The mean grain size of the bed-load is 11-16 mm, while the bank material is 0.04-0.09 mm (Csoma 1973). The average slope of the section is 0.00047. The development of the meanders shifting eastward is fairly controlled by an escarpment running along the river, as the meanders encounter with the escarpment at several sections. On these sections, the height of the escarpment is 10-15 m, while the average bank height on the river is 2-3 m. The studied reach can be considered unregulated as engineering works were not constructed on it.

3. METHODS

The rate and pattern of the active bank erosion over 1.5-year period were observed by field surveys with Sokkia SET310 total station and geodesic GPS. The main advantage of the survey was that it does not require installation of any instruments, thus any damage or losses in the instruments can not affect the results and the survey is repeatable at any time.

The location of the outer bank line of the meanders was survey 3 times within the 1.5 years (28-29.03.2008; 20-21.08.2008 and 26-27.08.2009).

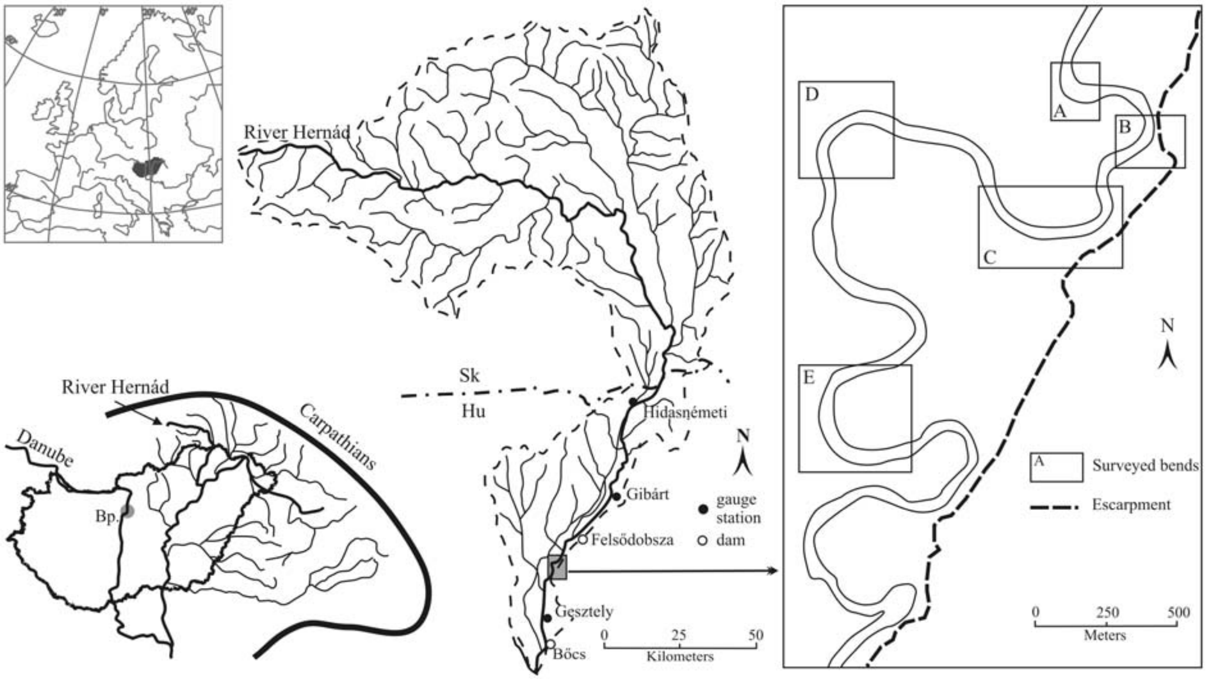


Figure 1. The location of the studied meanders

The bank line was measured at every 5 m. The total station measures the location of the point in a local coordinate-system, therefore geographical coordinate in EOV (Hungarian National Grid) was also measured by geodesic GPS on 3 of the measured points. The errors of the GPS coordinates were about 10 cm. The points, measured by total station were transformed into EOV coordinate system using GPS data. The average rate of bank erosion between surveys was calculated in m/half year. (This unit gives more exact data on the short first period and can be compared with the twice as long second period.)

To evaluate the rate and pattern of the bank erosion over the 50-year period aerial photos (1953, 1975 and 2007) were applied. The photos were geo-corrected using ErdasImagine 8.6 software. Bank lines were digitised and the extent of bank erosion was calculated under ArcGis 9.3. The average rate of bank erosion was calculated in m/y for the periods between the aerial photos.

The observed rates of erosion and the hydrograph characteristic of the studied period were compared to assess the effect of different stages and extreme hydrological events on bank erosion. Data of two gauge-stations (Gibárt & Gesztely) were used to analyse the hydrology of the studied periods. The investigated meanders are between these stations, downstream of the dam at Felsődobsza which is located between the gauge-stations and which can alter the hydrology of the studied section. The Gesztely gauge station is located upstream of the dam at Bőcs, therefore the swelling might affect the stage data of Gesztely. The data of the two gauge-stations were compared, using daily data (www.vizadat.hu) to reveal the alteration of the hydrology.

4. RESULTS

4.1.Hydrography of the period of the direct bank erosion measurements (2008-09)

On the Gibárt-Gesztely reach minor changes in the hydrographs were detected, i.e. at Gesztely in August 2008 the flood stage was lower and delayed flood peak was observed, but the human impact on the hydrology was negligible (Fig. 2). Accordingly the data of both gauge stations could be applicable, hereafter the water stage data is referred to the Gesztely gauge-station.

The hydrography of the two periods between the field surveys differ fundamentally. The basic feature of the first period (between 28.03.2008. and 21.08.2008.) was a great flood (386 cm) at the end of the period (29.07.2008.). The second survey was completed 3 weeks after the flood at about 50 cm water-level, thus the survey shows the effect of the flood on bank erosion. Flood did not occur in the second period, the water remained in the channel (maximum water stage was 228 cm on 09.03.2009.), however intensive fluctuations were detected, thus significant channel forming could take place.

The variability of water stage was greater conversely, than in the first period, which is important in the removal of the failed material and keeping up the instability of the bank.

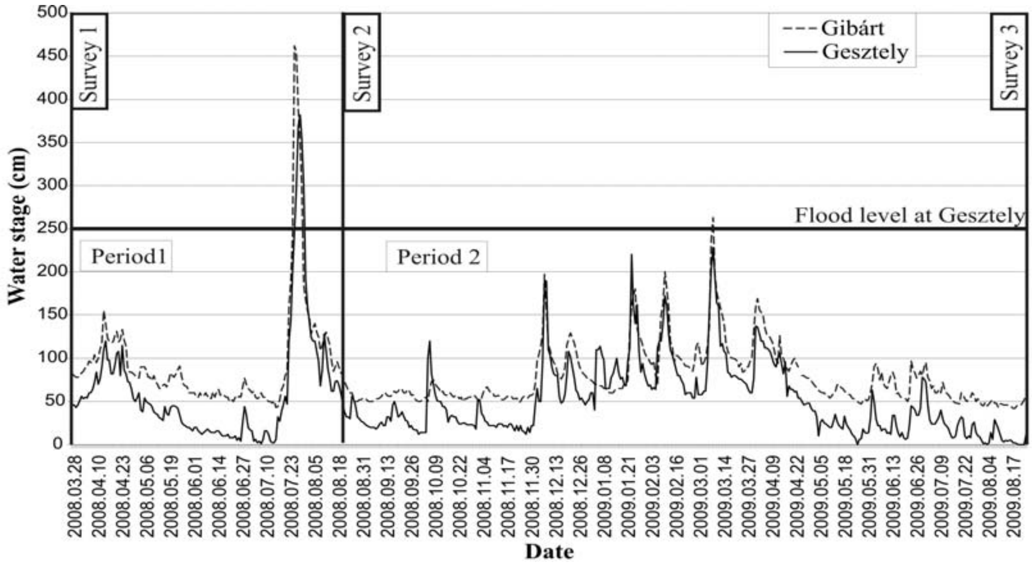


Figure 2. Water stage changes in the period of the direct measurements (28.03.2008.-30.08.2009.) at the gauge-stations of Gibárt & Gesztely. On the indicated survey days the bank line of the river was mapped

The duration of middle- and low water was however almost the same in both periods. The dominant water stage was 0-100 cm in both periods. Moreover the water stage did not exceed the long term (1971-2000) average (52 cm) in the 58 % of the first period and in the 61 % of the second period.

4.2. Short-term active bank erosion (2008-2009)

The rate of bank erosion was considerably different in the studied meanders. During the whole studied period (from March 2008 to August 2009) the maximum rate of bank erosion varied between 2 and 13 m. The largest bank erosion was observed at meander ***A*** (13.8 m). The maximum bank erosion was 6.5 m at meander ***B*,** 4.7 m at ***C***, 2.5 m at ***D*** and 2 m at meander ***E*** (Fig 1.). As the largest bank erosion was measured at ***A***-***B***-***C*** meanders, therefore these meanders will be shown hereafter. Difference between the meanders is the degree of freedom, as meander ***A*** and ***C*** can migrate entirely free, however the development of meander ***B*** is limited, because the meander encounters with the escarpment at the valley-side and the bank height (8-10 m) at the apex of the meander is much higher than the regular.

The location of the maximum bank erosion within a meander was different between the studied meanders. The maximum bank erosion at meander ***A*** was measured at its apex and downstream from the apex (Fig. 3). At meander ***C***, notable bank erosion took place only at the downstream section of the meander (Fig. 5). At meander ***B*** on the section where the river encounter with the escarpment, the bank height is 6-7 m higher than on the downstream sections of the meander (Fig. 4). Here no field survey was carried out because of the active bank failures and dense vegetation. Though, Hickin & Nanson (1975) recognised that the rate of bank erosion is generally decreasing with the increase of bank height. The greatest bank erosion rate was measured where the meander leaves the escarpment.

The rate of bank erosion was the highest in meander ***A*** during the whole 1.5 year. In the first period the rate of bank erosion (total 7.8 m, means 9.8 m/half y) was more intensive than in the longer second period (total 6 m means 3.2 m/half y). In the meander ***C***, the bank erosion was 3 m (3.8 m/half y) in the first period, but it did not exceed the 1.2 m/half y in the second period. In case of both meanders the rate of bank erosion was more than three times larger in the first period than it was in the second one. In meander ***B*** the rate of erosion was similar to meander ***C*** (3.6 m/half y in the first period and 1.6 m/half y in the second one), but smaller difference was detected between the periods.

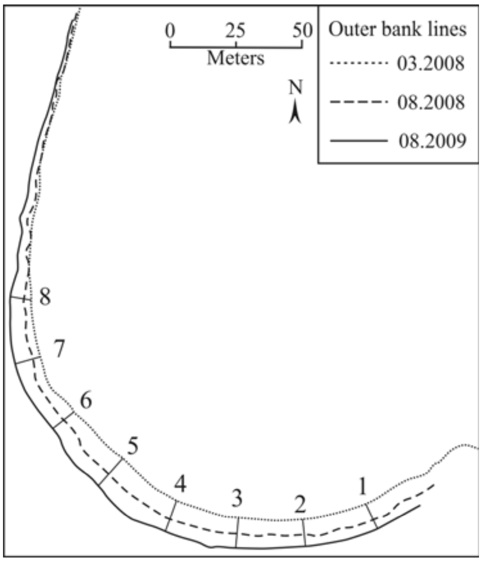
The comparison of the hydrography and the rate of bank erosion in the periods reveal that in the first period, when a great flood was occurred, the rate of erosion was 2.4-3.2 times higher than in the second period, when medium- and low stages were dominant.

4.3. Longer-term bank erosion (1953-2007)

Longer-term bank erosion was calculated using aerial photos. The studied 50 years were split into two periods according to the date of the aerial photographs (1953-1975 and 1975-2007).

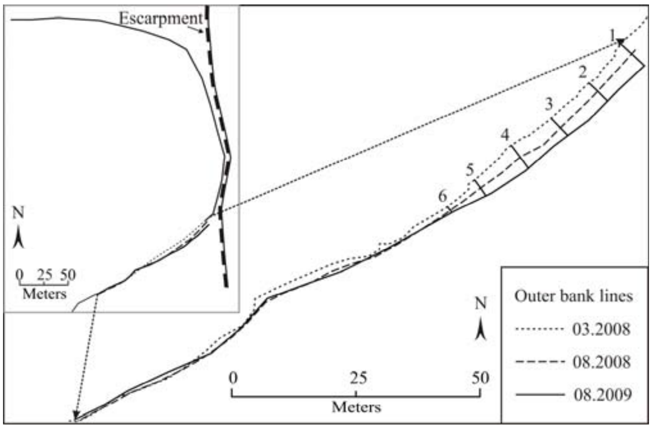
The frequency of floods in the periods was also calculated. Between 1953 and 1975, the return interval of great floods (above 350 cm) was 7 years, whilst in the second period it increased to 5 years.

The rate of bank erosion was markedly different at the studied meanders in longer-term, just like in the short-term. In meander ***A*** the rate of bank erosion was 2.5 m/y on the most intensively developing section of the meander in the period of 1953-1975 (Fig. 6), while in the next period (1975-2007) it increased almost to the double of the previous period (4.5 m/y).



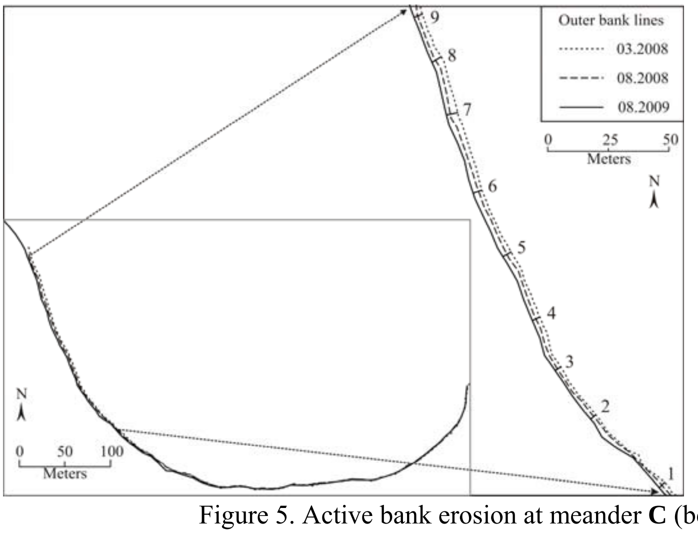
	1. period		**2. period**	
	Total bank erosion (m)	**Rate of bank erosion (m/half y)**	**Total bank erosion (m)**	**Rate of bank erosion (m/half y)**
1	6.6	8.3	3.6	1.8
2	6.0	7.6	4.1	2.1
3	6.2	7.8	5.6	2.8
4	7.0	8.8	5.3	2.6
5	7.9	**9.8**	6.0	3.0
6	4.9	6.2	5.0	2.5
7	3.3	4.2	6.4	**3.2**
8	2.4	3.0	5.3	2.7

Figure 3. Active bank erosion at meander **A** (between 03. 2008 and 08. 2009)



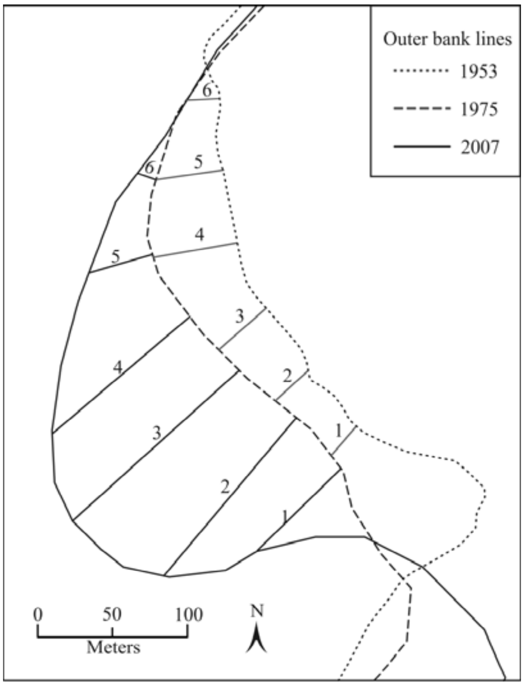
	Period 1		**Period 2**	
	Total bank erosion (m)	**Rate of bank erosion (m/half y)**	**Total bank erosion (m)**	**Rate of bank erosion (m/half y)**
1	2.9	**3.7**	3.3	**1.6**
2	2.4	3.0	2.8	1.4
3	2.1	2.7	2.7	1.4
4	2.8	3.6	3.0	1.5
5	2.0	2.5	1.9	1.0
6	0.6	0.7	0.9	0.5

Figure. 4. Active bank erosion at meander **B** (between 03. 2008 and 08. 2009)



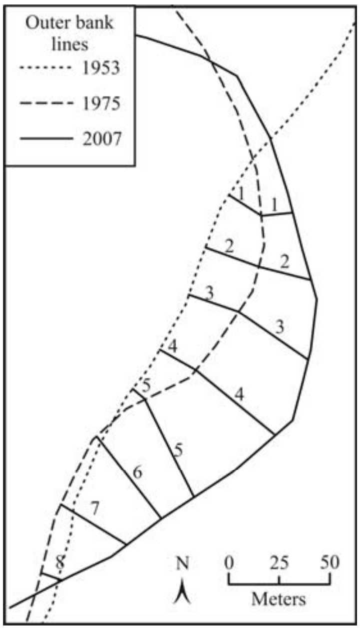
	Period 1		**Period 2**	
	Total bank erosion (m)	**Rate of bank erosion (m/half y)**	**Total bank erosion (m)**	**Rate of bank erosion (m/half y)**
1	1.6	2.0	1.5	0.8
2	1.1	1.4	1.7	0.8
3	1.6	2.0	1.2	0.6
4	1.8	2.2	1.6	0.8
5	2.0	2.5	1.9	1.0
6	1.4	1.7	2.4	**1.2**
7	3.0	**3.8**	1.7	0.9
8	2.8	3.5	1.7	0.8
9	2.0	2.6	1.7	0.8

Figure 5. Active bank erosion at meander **C** (between 03. 2008 and 08. 2009)



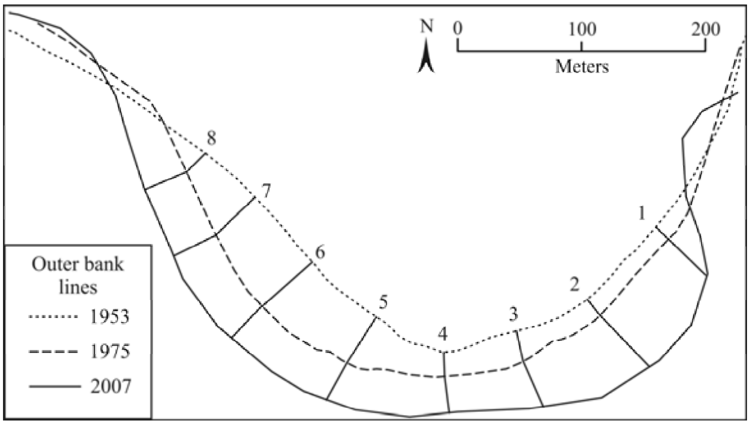
Section	Bank erosion rate (m/y)	
	1953-1975	**1975-2007**
1	1.2	2.4
2	1.3	4.2
3	1.9	**4.5**
4	**2.5**	3.7
5	2.0	1.4
6	1.0	0.4

Figure 6. Long-term (1953-2007) bank erosion at meander **A**



Section	Bank erosion rate (m/y)	
	1953-1975	**1975-2007**
1	1.1	0.5
2	**1.6**	0.8
3	1.4	1.3
4	1.1	1.6
5	0.5	**1.7**
6	-	1.6
7	-	1.2
8	-	0.3

Figure 7. Long-term (1953-2007) bank erosion at meander **B**



Section	Bank erosion rate (m/y)	
	1953-1975	**1975-2007**
1	0.9	1.2
2	1.1	**1.7**
3	1.7	1.2
4	1.3	1.0
5	2.9	1.0
6	**3.6**	1.1
7	2.9	1.2
8	1.4	1.2

Figure 8. Long-term (1953-2007) bank erosion at meander **C**

Different rate of erosion of the outer bank-line was measured at meander ***C***. Between 1953 and 1975 its rate was 3.6 m/y, but in the next period, − in contrast with meander ***A*** − it decreased to 1.7 m/y (Fig 8). The rate of bank erosion in meander ***B*** was the smallest among the studied meanders (Fig. 7), and similar rate of erosion was measured in both periods (1953-1975: 1.6 m/y and 1975-2007: 1.7 m/y). The slower rate of bank erosion could be the consequence of the increased bank height.

In the studied periods the location of the maximum bank erosion within the meander was different between the meanders and it was also changed with time within a single meander. The maximum bank erosion at meander ***A*** occurred at the apex of the meander in both periods, however the apex shifted downstream due to the asymmetric meander development. At meander ***B*** the maximum bank erosion was also took place at the apex of the meander in the first period, but then it was shifted to the downstream section of the meander, simultaneously the apex of meander ***B*** also shifted downstream as the result of the growth of the meander. The downstream section of the meander ***C*** presented the fastest development (3.6 m/y) between1953 and 1975, while it was shifted to the upstream section of the meander.

The comparison of the recent and the long-term measurements shows that the recent bank erosion in both periods exceeded the average of the long-term rates. This result corresponds with the results of our research on the Lower Tisza, where the bank erosion between 2007-09 was much higher (3.3 m/y) than between 1980-2007 (2.15 m/y), due to different occurrence interval of channel forming events.

5. CONCLUSIONS

Overbank floods have considerable channel-forming effect. High rate of bank erosion was measured at all of the studied meanders in 2008 when an extreme flood occurred. However significant erosion also occurs during medium- and low-stage periods following the flood. The rate of bank erosion even in these low stage periods exceeded the average rate of erosion of the previous 30 years at all study sites, probably because a short period after a flood was studied, and the return interval of the floods is higher, therefore this short period did not represent the average regime on Hernád River. During flood events the outer bank of a meander eroded several meters, therefore changes in hydrology of a river (e.g. changes in the stage or in the frequency of floods due to environmental changes) can alter the long-term tendencies in channel migration significantly.

The investigation shows that the rate of bank erosion differs significantly even on a short section of a river. Considerably different bank erosion was observed in neighbouring meanders either in short- or long-term. This suggests that the local boundary conditions in meander-scale (e.g. bank material, bank height) and the stage of meander development controls the rate of meander development in different ways in each meander. The stage of meander development can affect the rate of bank erosion significantly, as in a single meander parallel to the changes of the rate of bank erosion, the location of the maximum bank erosion was also changed within wide range (downstream or even upstream of the apex).

Acknowledgement

The research was founded by the Hungarian Research Foundation (OTKA 62200 and 68897).

REFERENCES

Bendefy, L. 1973. *Geomorphology of the River Hernád* (in Hungarian).In. Vízrajzi Atlasz sorozat 16. A Hernád Budapest: VITUKI.16-19.

Bogárdi, J. 1971. *Sediment transport of streams* (in Hungarian). Budapest: Akadémiai Kiadó. 755.

Carroll, R.W.H., Warwick, J.J. James, A.I. & Miller, J.R. 2004. *Modeling erosion and overbank deposition during extreme flood conditions on the Carson River, Nevada.* Journal of Hydrology 297, 1–21.

Couper, P. 2003. *Effects of silt–clay content on the susceptibility of river banks to subaerial erosion*. Geomorphology 56, 95–108.

Csoma, J. 1973. *Hydrology of the River Hernád* (in Hungarian). In: Vízrajzi Atlasz sorozat 16. A Hernád. Budapest: VITUKI. 7-15.

Hanusin, J., Kunikova, E., Petur, F., Rácz, M., Jansen, H., Haverkamp, S. & Vennekes, W. 2006. *River Basin Management Plan for the Hornad-Hernád Basin. Hungary and Slovakia: Implementation of the Water Framework Directive* in *a transboundary context. (Project PPA03/HUSK/9/1)*

Hasegawa, K. 1989. *Universal bank erosion coefficient for meandering rivers*. J. Hydraul. Eng. 115, 744–765.

Hickin, E.J., & Nanson, G.C. 1975. *The Character of Channel Migration ont he Beatton River, Northeast British Columbia, Canada*. Geological Soc. of Am. Bulletin 86, 487-494.

Hooke, J.M. 1979. *An analysis of the processes of river bank erosion*. Journal of Hydrology 42, 39-62.

Hooke, J.M. 1980. *Magnitude and distribution of rates of river bank erosion.* Earth Surface Processes and Landforms 5, 143-157.

Hughes, D.J. 1977. *Rates of erosion on meander arcs*. In: Gregory K.J. (ed.) River Channel Changes. Chichester: Wiley. 193-205.

Kirkby, M.J. & Morgan, R.P.C. 1980. *Soil Erosion.* Chichester: Wiley. 312.

Kiss, T. Blanka, V. & Sipos, Gy. 2009. *Morphometric change due to altered hydrological conditions in relation with human impact, River Hernád, Hungary*. Zeitschrift für Geomorphologie 53, Suppl. 2, 197-213.

Laczay, I. 1973. *Meander conditions of the Hernád River* (in Hungarian). In: Vízrajzi Atlasz sorozat 16. A Hernád. Budapest: VITUKI. 23-29.

Lawler, D.M 1992. *Process dominance in bank erosion system*. In: Carling P.A. – Petts G.E. (eds.) Lowland Floodplain Rivers. Chichester: Wiley. 117-141.

Lawler, D.M 2008. *Advances in the continuous monitoring of erosion and deposition dynamics: Developments and applications of the new PEEP-3T system*. Geomorphology 93, 17–39.

Murgatroyd, A.L. & Ternan, J.L. 1983. *The impact of afforestation on stream bank erosion and channel form*. Earth Surface Processes and Landforms 8: 357-369.

Reimann, J., Fehér, J. & Gáspár, J 2001. *Statistical analyis of the floods of the River Hernád* (in Hungarian).. Vízügyi Közlemények 83/4, 581-600.

Schumm, S.A., & Lichty, R.W. 1963. *Channel widening and floodplain construction along Cimarron River, in south-western Kansas.* U.S. Geological Survey Prof. Paper 352-D.

Simon, A. & Collison, A.J.C. 2002. *Quantifying the mechanical and hydrologic effects of vegetation on streambank stability.* Earth Surface Processes and Landforms 27, 527–546.

Smith, D.G. 1976. *Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river.* Geological Soc. Of Am. Bulletin 87, 857-860.

Thorne, C.R. 1982. *Processes and mechanisms of river bank erosion.,* In: Thomas C.R. – Bathurst J.C. – Hey R.D. (eds): Gravel Bed Rivers. Chichester: Wiley. 227-271.

Wolman, M.G. 1959. *Factors influencing erosion and cohesive river bank.* American Journal of Science 257, 204-216.

Wynn, T.M. & Mostaghimi, S. 2006. *Effects of riparian vegetation on stream bank subaerial processes in southwestern Virginia, USA.* Earth Surface Processes and Landforms 31, 399–413.

Received at: 24. 11. 2010
Accepted for publication at: 29.03.2011
Published online at: 02. 04. 2011