Paleo discharge of Mureş River in the lowland area

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Abstract. Mureş River left behind many traces on its alluvial fan located in the south-eastern part of the Pannonian Basin. The analysed sector (Lipova-Nădlac) is one of the most dynamic sectors in the lowland section of this river. Mapping 2D shape of these micro-scale landforms, the bankfull discharge of the channel during the given time periods was calculated. The amount of paleo discharge constantly increased from the older meanders generation (557 $m^3 s^{-1}$) to the XXth century (1018 $m^3 s^{-1}$). The results of the discharge values obtained for the last century by applying the local equations are quite close to the amount of present-day bankfull discharge (850 $m^3 s^{-1}$).

Key Words: paleo meanders, bankfull discharge, alluvial fan, Mureş River.

Introduction. The fluvial system is one of the most dynamic geomorphic systems (Charlton 2007). The flowing waters left behind many macro and micro landforms especially in the lowland sections of the rivers. Analysing fluvial landforms, it could be found not only present-day characteristics of discharge but reconstruction of past enivronmental conditions can be assesed as well. Paleo meanders and meander scars are the best evidence of the river presence in a given area, and they are very good indicators for changing (Charlton 2007). Many of those bends are hardly detectable in the field because of the flat relief characterising the floodplain areas.

The river channels are shaped by bankfull discharge also known as channel forming discharge (Wolman & Miller 1960). The river capability to transport higher amount of sediments and discharge is greater than the mean annual values of average discharge. The only condition for this is the recurrence of the same high water level at least two times per year.

Paleo hydrology can be simple defined as the study of flowing waters before any records or direct measurements (Jarrett 1991). This field used some methods for historical reconstruction based on documentation, regime-based reconstruction using the channel characteristics or tree rings analysis of buried trees and different absolute dating techniques (e.g., optical stimulated luminescence, C14 etc.) (Loaiciga et al 1993; Carson & Munroe 2005).

There are many methods to calculate the river discharge based on measurements, but a great challenge is to calculate the amount of paleo discharges. Williams (1984) has summarized the paleo hydrologic equations used by different authors for calculating not only the bankfull discharge but also for other parameters (e.g. channel width, channel cross-sectional area, channel slope or energy gradient, Manning resistance coefficient etc.).

Determining the paleo discharge amount, and making comparisons with nowadays values, some others controlling factors, such as climatic (especially precipitation quantities) or runoff conditions can be estimated using morphometric parameters of the paleo channels (Leopold & Wolman 1957; Alford & Holmes 1985; Scheurle et al 2005).

The main goal of this study is to assess recent paleo discharges based on accurate mapping of the recent paleo channels of the Mureş River between Lipova and Nădlac and by morphometric analysis of the paleo meander characteristics. Even if some recent studies (Sümeghy & Kiss 2011; Sipos et al 2012) have approached this topic for a part or for the entire alluvial fan of the Mureş River, we suppose that for the last thousands years the accuracy could be increased. Further, the different equations for bankfull discharge can be tested and the results compared. The provided results can be integrated in future works for reconstructing the past discharge of floods and predicting the future threats.

Study area. The Mureş River is the longest internal river in Romania (766 km). It springs from Hăşmaşu-Mare Mountains (850 m altitude) and outlets in Tisa at Szeged (Ujvari 1972). Its catchment area covers ~ 30,000 km^2 (Sümeghy & Kiss 2011), mostly within the Romanian territory (94%). The study area is assigned to the western side of Romania, on the alluvial fan, located in the south-eastern part of the Pannonian Basin from Lipova (123 m; 46°05' N, 21°41' E) to Nădac (88 m; 46°09' N, 20°42' E) (Figure 1).

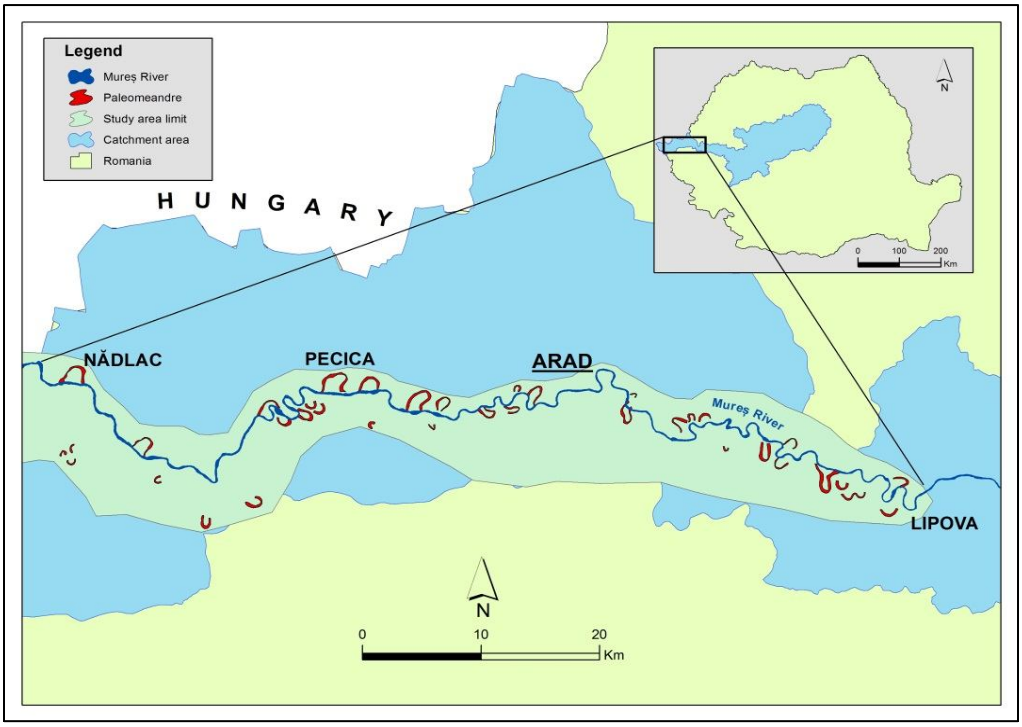

Figure 1. Location of the study area in the western part of Romania.

The eastern part of the study area is the apex of the alluvial fan, the whole study area overlapping on it. This great accumulation area covers around 10,000 km^2 (Sipos et al 2012). Its evolution started in Quaternary (late Pliocene or early Pleistocene) but the youngest part has been configured starting with late Pleistocene or early Holocene period (Ando 1976). The channel patterns and flow direction for each period was delineated by Sümeghy & Kiss (2011, 2012) and Sipos et al (2012). The authors also calculated the paleo discharge values for all the paths of the river in the alluvial fan area, but for the recent evolution, some paleo meanders are missing.

The climatic changes during the last 20,000 years and an intense tectonic activity, especially the presence of subsidence areas (Nádor et al 2007) affected the development of the alluvial fan. The channel migrated in the first evolution period to the north, nearing Crişul Alb channel, then flowing to the south draining the actual catchment of Aranca. The whole network of paleo channels areas can be set out according to various types of channel patterns and different slope gradient. The present flow direction of the Mureş River (Lipova-Arad-Pecica-Nădac-Mako-Szeged) was followed by the river in the middle or last Holocene (Nádor et al 2007).

The study area was delineated based on configuration of alluvial fan suggested by Sipos et al (2012). The authors used Optically Stimulated Luminescence (OSL) for dating each of the 12 channel main flow directions. According to Sipos et al (2012), this channel generation is the last one and its age is around 1500-2000 years. The average value of the nearest distance from the main channel to the left side of the polygon area is 5387 m and for the right side the distance is 2246 m.

Looking on mean value of the maximum multiannual discharge presented by Zaharie (2010), the mean amount (between 1964-2003) at Arad station was 903 $m^3 s^{-1}$. If the highest discharge peaks (from flooded years 1970 and 1975), are removed the average discharge could decrease to 828 $m^3 s^{-1}$. According to Fiala et al (2007) the present-day bankfull discharge of the Mureş River is around 850 $m^3 s^{-1}$.

Material and Method. The main data source for the paleo meanders mapping has been the orthophoto acquired in 2005. In addition temporal images from Google Earth were used for a better detection of the ancient paths of the river. Drawing the shapes of the bends was a real challenge. It was chosen the developed and mature loops but frequently, only the upside part of meanders could be identified. Difficulties were encountered when mapping the paleo meanders within the Lunca Mureşului sector (downstream of Arad) because of the very developed riparian forest. Some of the paleo meanders were active a few decades ago, but for some the ages are older than 250 years, according to Hapsburg topographic maps (XVIIIth century). For a relative dating of each paloemeander and in order to group them, historical maps were used (e.g. Habsburg and Austro-Hungarian military surveys and Romanian topographic maps).

Morphometric parameters of the channel. The relation between discharge and morphometry of the channel and meanders was very well described by Dury (1961). He asserted that these elements are strong related each other. The further step after the precisely mapping of all the scars left behind by the river in the study area was to extract the meander features (Figure 2). The task was completed in ArcGIS 10.2 software, some processes were manually made and some were drawn semi-automatically.

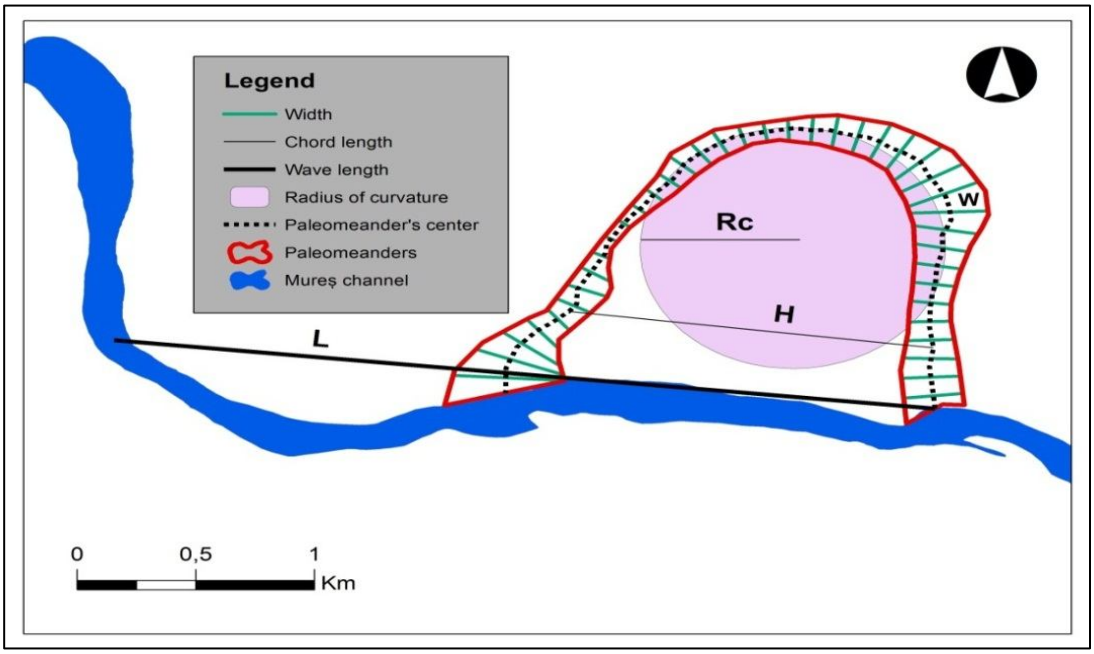

Figure 2. The morphometry of Mureş channel in the Nădlac area.

Bankfull discharge calculation. Some local equations were generated by Sümeghy & Kiss (2011) in order to rectify the former equations of other authors (e.g. Leopold & Wolman 1957; Mackey 1993). Both these authors have developed equations for bankfull discharge (Q_b) only based on half of wave length (L): $L = 65.2Q_b^{0.5}$ (Leopold & Wolman 1957) and $L = 72.16Q_b^{0.49}$ (Mackey 1993). Applying these formulas, the differences of results are not as significant.

For determining the equations, Sümeghy & Kiss (2011) have chosen 18 stations from Tisa catchment. The authors have correlated discharge values from 1930's with every meander parameter (Table 1). The correlation coefficient for each index was between 0.69 and 0.78.

Table 1

Correlation between discharge and channel parameter (after Sümeghy & Kiss 2011)

Channel parameter	*Equation and correlation coefficient*	*Applicability range*
Width (W)	$Q = 0.0001*W^{3.2111} R^2 = 0.76$	55–185 m
Radius of curvature (Rc)	$Q = 0.0008*Rc^2+4.1692*Rc - 226.13 R^2 = 0.69$	29–509 m
Half-wavelength (L)	$Q = 0.0003*L^2+ 0.344*L - 81.329 R^2 = 0.72$	472–2538 m
Chord-length (H)	$Q = 0.0015*H^2+ 0.0647*H - 31.762 R^2 = 0.78$	307–1197 m

Results and Discussion

Paleo meanders characteristics. By visual inspection of available spatial data sources 37 meander scars have been detected within the investigation area (Table 2). Almost all of them were active before the Mureş River to be affected by regulation work (second part of the XIXth century). Some of them seem to appear only on the ortophotos and that means these are older than 300 years. According to results presented by Kiss et al (2014), some younger meander generations overwrote the older ones. The paleo meanders in the southern part of Nădlac could be from 1600-1900 years ago while the bends near Periam could be much older (~ 6000 years ago) (Sipos et al 2012). The parameters in Table 2 are the average values of each age and flow direction.

Because of the intensive agriculture in the study area, the shape of older paleo meanders is not complete. The river loops in the XIXth and the XXth centuries are very well outlined and the parameter values are a little bit greater than previous rates.

Table 2

The age, surface and planform parameters of the paleo meanders

Age	*Number of paleo meanders*	*Total surface (km^2)*	*Rc (m)*	*L/2 (m)*	*H (m)*	*W (m)*
Before XVIIIth century	11	2.32	261	994	597	142
XVIIIth century	5	1.74	307	956	736	176
XIXth century	18	8.96	355	1266	920	150
XX^{h} century	3	0.8	353	1425	865	128

Paleo discharge calculation. The equations presented in Table 1 can be applied only for meandering channels. If previous studies have chosen to determine the discharge only based on wavelength (Leopold & Wolman 1957; Mackey 1993) or to use besides radius of curvature and chord length (Sipos et al 2012), in this work the mean values of width channels was also integrated.

The discharges calculated for the abandoned paleo meanders before the XVIIIth century have quite similar values both for results derived from all planform parameters (Table 3) and the results based on wavelength alone. It is more likely that the loops included in this category to be part of different flow direction and different generation, but to answer this problem it is required an absolute dating for each meander. Applying the equations of Leopold & Wolman (1957) and the equation of Mackey (1993), the results are less than half of the values calculated using the local equations developed by Sümeghy & Kiss (2011). Similar results were obtained by Katona et al (2012) using the same equations for Mureş paleo channel in Oroshaza area.

The river channel was affected by regulation works in the second part of the XIXth century (Kiss et al 2014) and the channel morphology and parameters were affected. Around 20 meanders were cut off between Lipova and Nădlac, and meanders configuration is still in changing (Timofte et al 2016).

Table 3

Bankfull discharge ($m^3 s^{-1}$) calculated from planform parameters

Equation	*Before XVIIIth century*	*XVIIIth century*	*XIXth century*	*XX^{h} century*
Sümeghy & Kiss (2011) (Rc, L/2.H.W)	499±120	544±120	673±170	693±180
Sümeghy & Kiss (2011) (L/2)	557±150	522±140	835±180	1018±200
Leopold & Wolman (1957)	232±70	215±70	377±90	478±110
Mackey (1993)	190±50	176±40	308±80	390±90

The accuracy of the results is much better for that time period because almost half of meanders are dated in the XIXth century. The discharge amount is greater than the previous values (and is for sure that the flow regime changed starting with the second part of the XIXth century). The increasing tendency is shown also by the values from the XXth century, even if there are only 3 meanders dated in that period. The obtained values for last two periods (using universal equations of Leopold & Wolman (1957) and Mackey (1993)) are less than half of the multiannual maximum discharge quantity. On the other hand, applying the equation developed by Sümeghy & Kiss (2011), the estimated paleo discharges are very close to the value of bankfull discharge proposed by Fiala et al (2007).

The future flow behavior of Mureş river will be strongly influenced by nowadays air temperature rising and precipitations income. Some prediction based on climatic evolution models reveal the fact that the precipitations will decrease in the next decades (Sipos et al 2012). These shifting will probably lead to alterations in bed and suspended load volume.

Conclusions. The aim of this study was to extract the recent meander scars from the orthophotos and historical maps and then to calculate the bankfull discharge of those channels based on planform parameters (radius of curvature, wavelength, chord length and channel mean width).

Each meander bend was assigned to a time period and according to each period, the paleo discharge was determined. The values are increasing from the first generation (232 $m^3 s^{-1}$, before the XVIIIth century) to the last one (478 $m^3 s^{-1}$), based on Leopold & Wolman's equation respectively from 673 $m^3 s^{-1}$to 693 $m^3 s^{-1}$ based on Sümeghy & Kiss's formulas.

Comparing the results of the applied equations, it can be concluded that the local formulas are more suitable for bankfull discharge than the universal ones. Surprisingly, using the universal equations, the results are quite close to multiannual mean discharge, while, the results from applied local equations are very close to multiannual maximum discharge of the Mureş River and to bankfull discharge values obtained for the Hungarian part of the river.

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