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EFFECTS OF CHANNELIZATION ON THE SEDIMENT QUALITY OF THE DANUBE AND TISZA RIVERS, HUNGARY

ABSTRACT: SZALAI Z.: *Effects of channelization on the sediment quality of the Danube and Tisza rivers, Hungary.* (IT ISSN 1724-4757, 2007).

The present paper focuses on channelization-induced sediment quality changes in active floodplains. Five transects were established along the River Danube. Samples were taken from active banks, from natural levees (or the line of willow grove) and from the active floodplains and from abandoned channels. Grain size composition and five heavy metals (Cd, Co, Cu, Pb, Zn) were determined from the samples. The samples were physically fractionated into five sediment fractions (<5 µm, 5-10 µm, 10-20 µm, 20-50 µm, >50 µm). The studied elements were also determined from each fraction. Results show that the bank profile and the bank alignment exert an influence on the fractionation of surface deposits. Presence (or absence) of natural levees and crevasses causes variation in the distribution of heavy metals along transects and in the proportions of the grain-size fractions of individual samples.

During the early 20th century the flood control measures of the Danube completely transformed river channel pattern. The braided pattern disappeared and small channels were abandoned. Only the highest floods inundate the floodplain, while typical floods, as a consequence of channelisation-induced incision, remain within the channel. Parallel to this, the grain-size composition of suspended sediment and profiles of heavy metal concentration also changed. This change is manifested both in the surface sediments and the deeper layers. Surface accumulation of heavy metals in the internal parts of floodplains derives from wet and dry deposition of airborne particles. This phenomenon is caused by the filtering function of riparian groves. Heavy metal accumulation on the natural levees is most often associated with the increased heavy metal content of suspended load, while in sediment records it is of two kinds of origin: from old pollution events or a result of natural processes.

KEY WORDS: Heavy metals, Physical speciation, Floodplain, Riverbank, Danube, Tisza (Hungary).

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INTRODUCTION

Flood control and water regulation measures started along the Tisza and Danube rivers in the mid-19th century and were extended subsequently to their tributaries. These activities have continued until the present day and can be classified into three groups:

- 1 - dyke system construction and cut-offs,
- 2 - bank protection measures and
- 3 - construction of hydropower plant systems (Fejér, 2001; Somogyi, 2001).

The dyke system had been completed along the most important rivers by the early of 20th century parallel with cutting off meanders. The construction of new dykes continued in the late 20th century, but by now the strengthening and rising of the already existing embankments had become the most important activity in the field of flood control. The constricted active floodplains have accelerated alluvial processes (e.g. sedimentation in sensitive areas) and changed riverbank evolution. The present paper focuses on sediment quality changes in active floodplains induced by flood control measures.

MATERIALS AND METHODS

Five transects were established along the River Danube and River Tisza (fig. 1). Samples were taken from active banks, from natural levees (or the line of willow groves) and from the active floodplains and from abandoned channels. The present study however primarily focuses on surface sediment characteristics. Sampling covered the whole sequence of cover sediments in the Danubian sampling sites.

During dredging channel sediments are usually deposited on the bank. This is the reason why when travers-

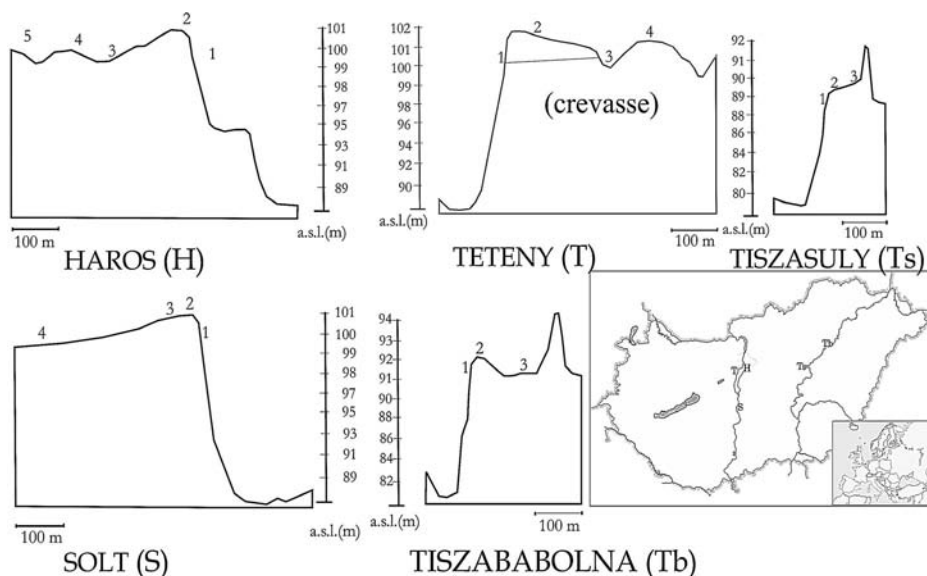


FIG. 1 - The river sections and transects studied.

ing the transects the sections to be selected must not be disturbed by such activities since the latest flood. Sampling was carried out during low water stage so it could be extended to the riverbank as well. Alluvia were sampled from the uppermost 10 cm layers. Bank sediments were sampled at the same height along a five-metre long line by one metre. In other sites 2.5 times 2.5 m squares were identified and samples were taken from the corners and geometric centres. Individual sampling sites are characterized by averaged values.

Grain size properties were analysed by Fraunhofer laser diffraction method (Fritsch Analysette Microtech 22). To study riverbank-induced physical speciation of heavy metals, sediment samples were fractionated into five sediment fractions (<5 μm , 5-10 μm , 10-20 μm , 20-50 μm , >50 μm) by a Retsch AS 200 sieving machine. The elements studied were determined in sediment samples and also determined from each sediment fraction. Both sediment samples and fractionated sediment fractions were digested by the $\text{cc.HNO}_3\text{-H}_2\text{O}_2$ method. Digested samples were analysed by a Zeiss AS30 gf atomic absorption spectrometer for the following elements: Cd, Co, Cu, Pb and Zn.

RESULTS

The heights of natural levees range from a few decimetres to several metres and their width from a few metres to 3-4 channel width (Bridge, 2003). The studied Danube and Tisza levees fall into the province of lower values. Although Brierley & alii (1997) suggest that «there is no preference of levees along different sections of channels», in our case there seems to be no correspondence between levee development and the width of active floodplains.

Studied transects show different widths. The narrowest active floodplain is less than 100 m wide, while the broadest one is more than 1 km. It seems that natural levees cannot develop in the narrowest floodplains. If the floodplain is wider than 100-150 m, natural levees occur. There are correlations between levee height and active floodplain width as well as between levee height and width. Along some river sections levees were strengthened and heightened to protect active floodplains against smaller floods. These are some differences in height-width ratio between the different kinds of levees as well (fig. 2).

Changes in textural properties in bank (levee) profiles indicate natural bank evolution and construction processes. The increased proportion of coarser fractions (particularly sands along the Hungarian section of the Danube) points to incipient levee development. Natural and artificially raised levees show different textural properties. Sediment texture is usually more homogenous in the profile of constructed levees than natural levees (fig. 3). The grain size distribution along the artificial levee profile shows similarities with sediments of their flood basins. In this way textural homogeneity and grain size distribution is a characteristic feature of the raised part of levee. Moreover the depth and quality of inhomogeneous deposits above the homogenous layers refers to altered sedimentation processes.

Independent of the vegetation cover both kinds of levees play a decisive part in physical speciation and serve as a sediment sorter. The percentage of the sand and coarse silt fractions are decreasing dramatically in «back levee areas». This phenomenon is manifested in the distribution of the dominant fraction (*max*) and of the grain size category represented to a minimum extent (*min*) along transects (table 1). Proportions of dominant grain size category values decrease gradually along the Tiszasüly transect. In other profiles *max* values show a down-

FIG. 2 - Correspondence between levee width and height above flood basin.

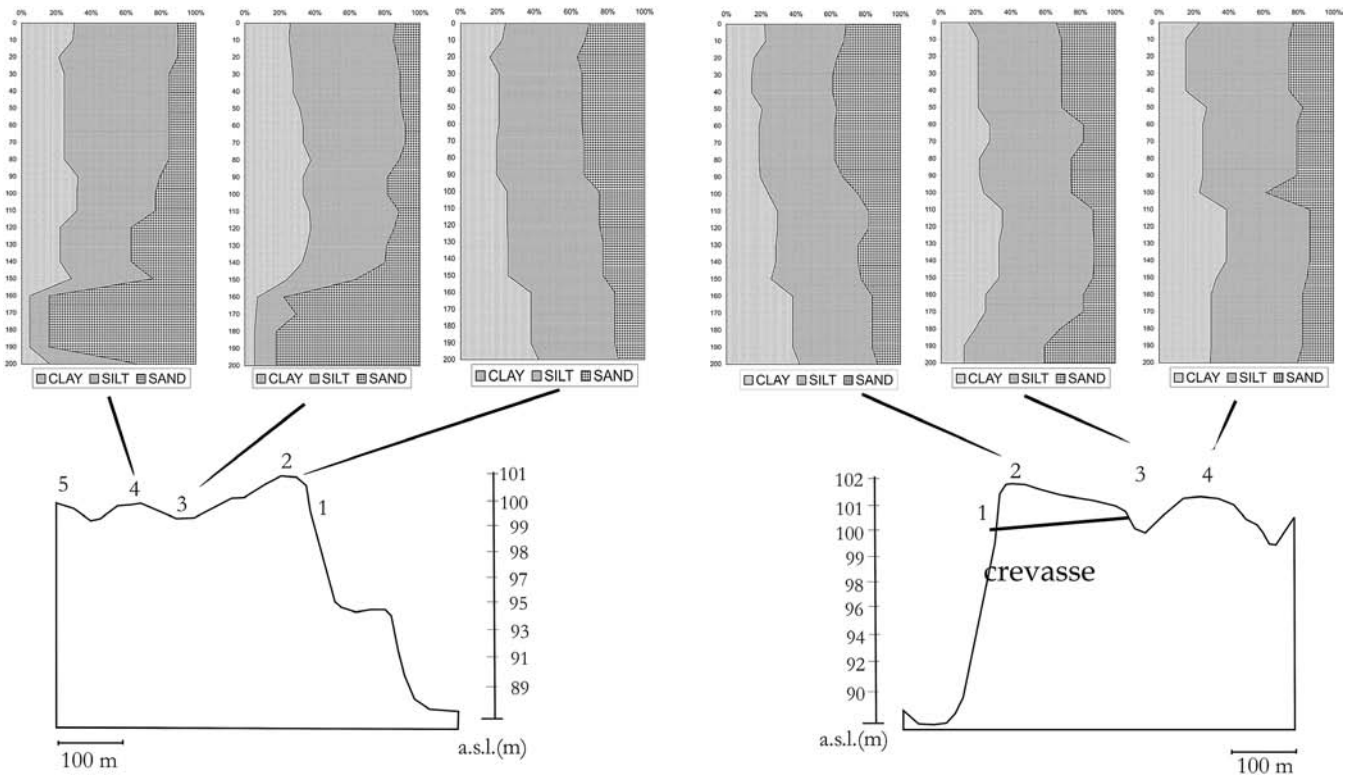
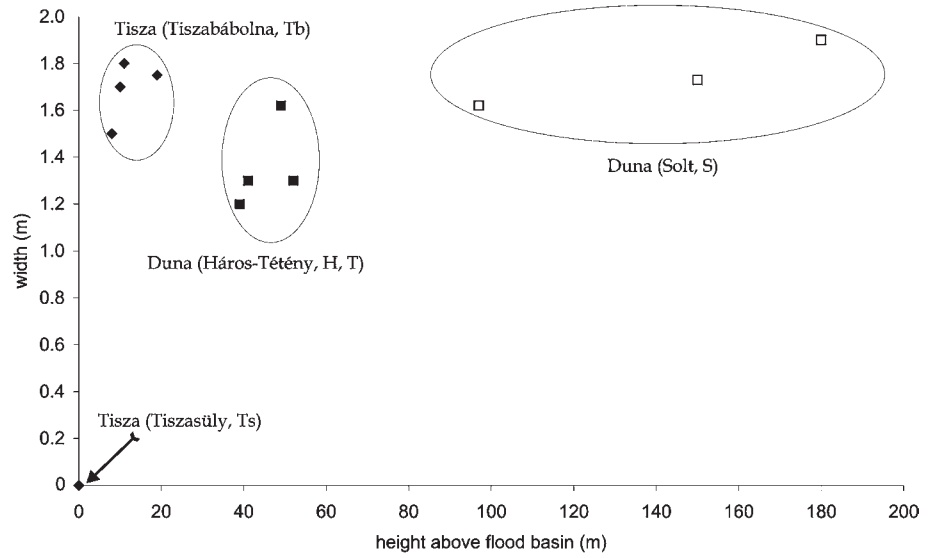


FIG. 3 - Changes in textural properties along different bank profiles.

ward trend reaching ca 30 per cent in the end. Minimum values display an upward trend up to ca 10 per cent. *Min* values recorded along the Tiszastűly transect are close to similar index values measured on natural levees in the other localities.

Some of natural and constructed levees are cut across by crevasses. In the Nagytétény site an abandoned chan-

nel has a direct connection with the river through a natural crevasse. While all of the studied abandoned channels are fed by rising groundwater during smaller floods, this channel is filled with floodwater even during minor flood events. The influence of crevasses on sediment quality is indicated by the presence of sediments of the crevasse-splay deposit (Bridge, 2003). This is charac-

TABLE 1 - Minimum, maximum and T-values of particle size distribution curves

	MIN	MAX	Proportion of clay fractions (a)	T
Ts 1	0.8	77.4	0.010	96.8
Ts 2	6.9	43.1	0.160	6.2
Ts 3	9.7	35.4	0.325	3.6
Tb 1	1.1	78.3	0.014	71.2
Tb 2	9.9	29	0.669	2.9
Tb 3	12.2	29.3	0.812	2.4
H 1	2.1	51	0.041	24.3
H 2	7.9	30	0.813	3.8
H 3	12.8	28.2	0.918	2.2
H 4	10.4	30.3	1.000	2.9
T 1	1.3	62.7	0.021	48.2
T 2	7.9	31.1	0.707	3.9
T 3	9.2	33.9	0.457	3.7
T 4	9.7	30	0.767	3.1
T 5	10.7	29.9	0.809	2.8
S 1	2.6	56.8	0.046	21.8
S 2	7.1	33.6	0.655	4.7
S 3	8.7	29	1.000	3.3
S 4	8.4	29.3	1.000	3.5

terized by a higher ratio of coarser fractions compared to its surroundings. The presence of crevasses is the reason why coarser sediments are still predominant at longer distances from the channel (150 m and more) (fig. 4).

Compared to other rivers the Hungarian section of the Danube and the Tisza do not belong to the polluted watercourses as far as their heavy metal concentrations are concerned (Ciszewski, 2001, Kabata-Pendias, 2001). In non-fractionated average samples these concentrations remain below the reference level. Similar to other elements heavy metals do not display a uniform distribution in sediments over the floodplain. The zones of accumulation are controlled by topography and vegetation pattern. In convex floodplains most intense accumulation occur on the

sides of natural levees and willow groves facing the river. In the case when there is a gradual uninterrupted elevation from the bank up to the embankment this zone is confined to willow groves.

Riverbank profile and vegetation pattern affect both total extractable concentrations and their distribution among the different grain size categories. Along floodplain sections without levees physical fractionation of heavy metals in suspended sediments is not a relevant process. In this case the highest heavy metal concentrations are associated with the same grain size fraction along whole transect (fig. 5). Compared with extremely narrow floodplains, levees always fractionate heavy metals within sediments. In straight river sections the concentration maxima is moving parallel with distance from the coarser fractions towards finer fractions. Crevasses also have an influence on the physical fractionation of heavy metals. In contrast with other Danubian sites the highest Cu, Cd, Zn and Pb concentrations are confined to the sand fraction along the whole Nagytétény transect. This phenomenon can be explained by a process similar to the one that produces a coarser texture for crevasse-splay sediments.

DISCUSSION

There is correspondence between active floodplain width and levee/floodplain development. The presence and nature of natural levees correlates most spectacularly with floodplain width. Accordingly the constricted floodplain simultaneously has an influence on the morphological evolution of riverbanks and on the physical parameters of alluvial sediments. If levees are present, the proportion of finer sediment fractions in flood basin sediments increases. Levee development usually prolongs the lifetime of abandoned channels in active floodplains along regulated river sections. This process can be also enforced by human activities. A continuous raised levee enhances the

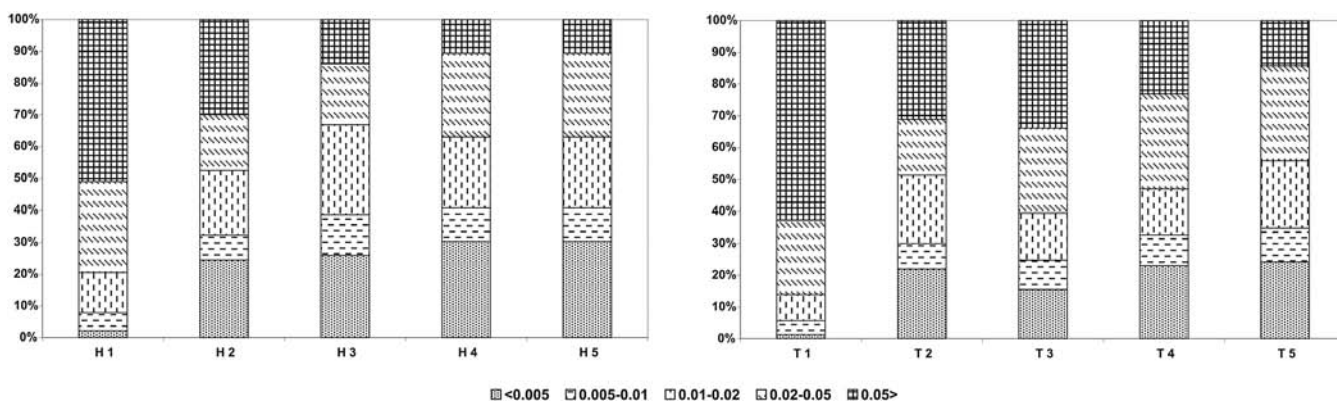


FIG. 4 - Grain size distribution in surface sediments along Háros transect and along Nagytétény transect (crevasse affected floodbasin). 1 - riverbank, 2 - natural levee, 3 - abandoned channel, 4 - flood basin.

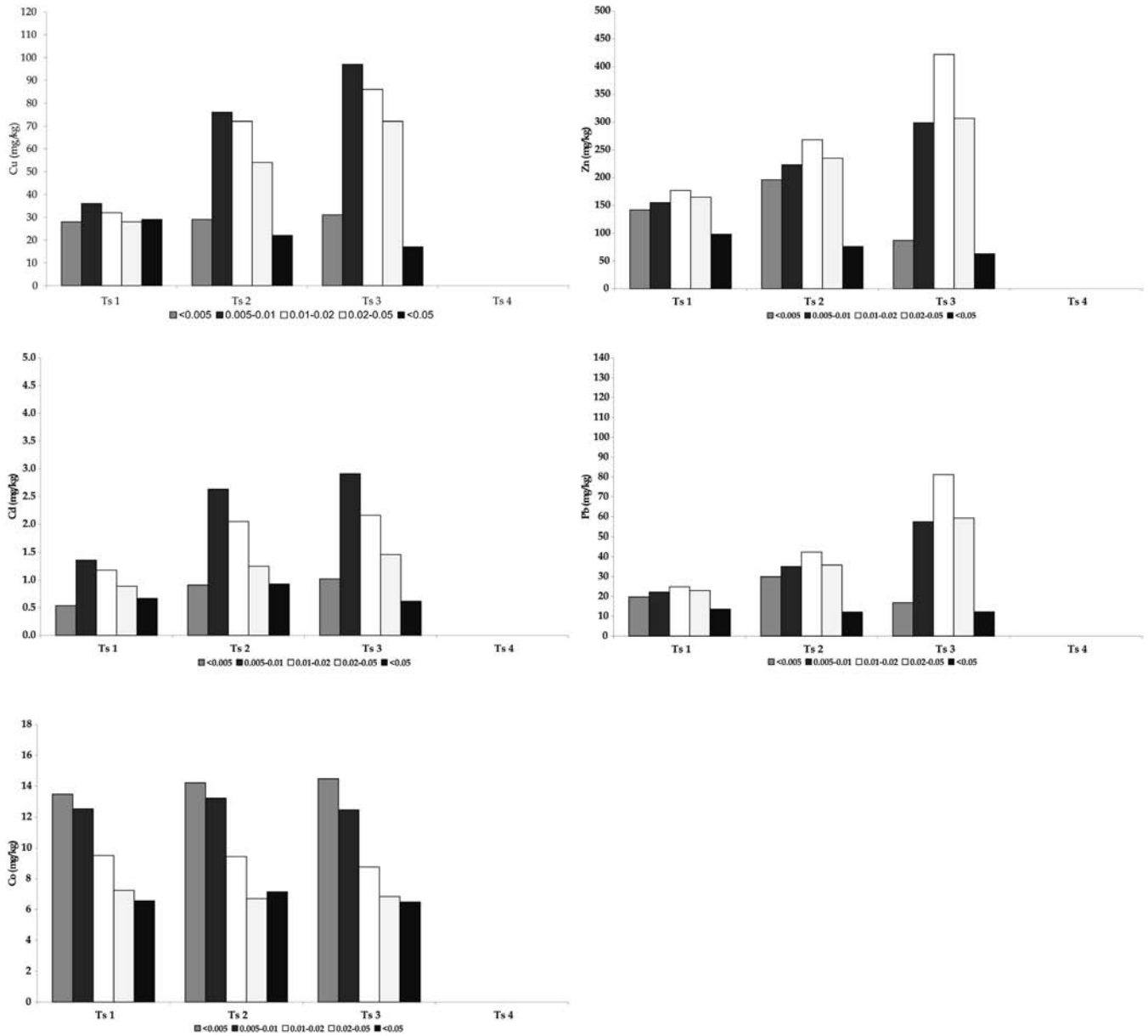


FIG. 5 - Distributions of heavy metals among various particle size categories along a continuously rising riparian transect (Tiszasily transect).

proportion of finer ($d < 10\ \mu\text{m}$) sediment fractions, because it blocks floodwater inundation of abandoned channels during smaller floods and increase physical speciation during higher floods.

Crevasse on levees serve as a natural feedback of levee raising and strengthening. They usually reduce the intensity of physical speciation, but this phenomenon is more pronounced during lower flood events. Bank profile plays a substantial part in the spatial distribution of pollutants associated with suspended load (eg. heavy metals), which is deposited in floodplains (Krauss and Aslan, 1999). Moreover, the spatial distribution and accumulation of

such elements depends on actual floodplain morphology, vegetation pattern as well as geochemical conditions. Since the above-mentioned parameters essentially control their bioavailability, there are direct and indirect interactions between flood control and pollutants-induced environmental hazards in floodplains.

Some literary sources testify to minor variations in heavy metal contents of sediments with distance from channel (Martin, 1997, 2000). Other sources report the highest concentrations from a narrow strip behind the natural levee along the Hungarian section of River Maros (Kiss and Sipos, 2002). Distribution of heavy metals in

channel and floodplain deposits was described by other authors using examples of watercourses of distinct character (Hudson-Edwards & *alii*, 2001). Our experience with sediments of two rivers, Danube and Tisza, of different discharge and origin of sediment load concerning heavy metal distribution is different. A common feature for various floodplains, described by Brinkmann (1989), Miller (1997) and Macklin (1996), is the occurrence of highest heavy metal concentrations on natural levees, which is most often associated with the increased heavy metal content of suspended load. Bank profile driven physical speciation also affects the susceptibility of floodplains for various kinds of pollutants, because this process exerts an influence on their bioavailability and solubility. Levees have an essential role in physical speciation. Both of the modus of the grain size distribution curve and the modus of heavy metal distribution move towards finer fractions.

CONCLUSION

According to previous findings published in literature (Bird & *alii*, 2003; Macklin & Dowsett, 1989, Dowsett & Macklin, 1998) there is an enrichment of heavy metals in finer fractions downstream whereas higher concentrations are confined to coarser sediments upstream along the Tisza River. It somewhat contradicts to Kiss & Sipos (2002), who assume that finer sediment fractions show higher heavy metal concentrations. The latter statement, however, could not be corroborated either in the Danube or in the Tisza floodplain, in spite of the completely different origin of heavy metals in suspended, then deposited, load of both rivers. In case of the Danube sections studied, heavy metals are much less physical fractionated along sinuous than straight river sections. In addition, it applies to both of these transects that the concentration maxima are observed from the natural levee towards the floodplain rather in the 20-50 μm fraction instead of that $>50 \mu\text{m}$. Along a transect 80 km downstream concentration maxima, in the riverbank sediments is still found in the coarser fractions whereas in the floodplains they are shifted to the categories $<10 \mu\text{m}$, in accordance with the description by Macklin and Dowsett (1989). No similar shift was observable in transects along the Tisza.

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