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Adaptation of land use based on the assessment of inundation risk in the Kapos Valley, Southwest Hungary

Péter GYENIZSE[1], Dénes LÓCZY[1], József DEZSŐ[1], Ervin PIRKHOFFER[1] and Marcin SŁOWIK[2]

Abstract

Complex river rehabilitation/restoration projects devote equal attention to the improvement of hydromorphological conditions and the neighbouring floodplain environment. Since land use exerts a heavy control on the hydrological cycle of floodplains, land use optimization is a central task in floodplain rehabilitation. In floodplains where large surfaces are temporarily inundated, the optimal allocation of land use classes involves the preservation of wetlands, maintenance of grasslands (meadows and pastures) and forests, and the restriction of arable land to higher ground with the lowest inundation hazard. The detailed mapping of land use against the distribution of soil types and fluvial landforms provides a solid basis for land use optimization. Rehabilitation design is presented in the paper on the example of the Kapos Valley, where inundations in the wet year of 2010 caused great damage to agricultural crops and efforts are directed to better water management (excess water reduction and floodwater retention) on the floodplain. Land use conversions, which are less expensive and easier to implement, are preferred to structural (engineering) solutions.

Keywords: floodplain rehabilitation, hydromorphology, paleochannels, peat bogs, Histosols, land use change, Kapos River

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Introduction

The deterioration of the hydromorphological properties of river channels and riparian environments in Europe, which is a long-term consequence of river regulation measures (Petts, G.E. *et al.* 1989), a type of land degradation (Kertész, Á. and Křeček, J. 2019), calls for restoration measures in the case of the majority of rivers (Tockner, K. and Stanford, J.A. 2002). Now experts agree that – in addition to the hydromorphology of river channels (Maddock, I. 1999) – rehabilitation should also extend to floodplain conditions (Brierley, G.J. and Fryirs, K.A. 2008; GWP-WMO 2012). The motives of joint river and floodplain restoration include (Wheaton, J.M. *et al.* 2015):

- aquatic and riparian ecosystem/habitat restoration,
- flood control and floodwater retention,
- floodplain reconnection,
- bank protection through planting arboreal vegetation,
- sediment management,
- improvement of water quality, aesthetic appearance and recreation opportunities.

From a geomorphological point of view, improving channel-floodplain connectivity is a key issue in any rehabilitation project (Dezső, J. *et al.* 2019). This is a precondition to maintain or enhance biodiversity, produc-

[1] Institute of Geography and Earth Sciences, University of Pécs, H-7624 Pécs, Ifjúság útja 6. Hungary. E-mails: gyenizse@gamma.ttk.pte.hu, loczyd@gamma.ttk.pte.hu, pirkhoff@gamma.ttk.tpe.hu
[2] Institute of Physical Geography and Environmental Planning, Adam Mickiewicz University in Poznań, ul. Wieniawskiego 1, 61-712 Poznań, Poland.

tivity, lowering and retarding flood wave peaks, reducing nutrient loads, improving water quality, trapping sediment, promoting groundwater recharge and other ecosystem services (Holmes, N.T.H. 1998).

Worldwide research for the scientific foundation and solution of the problems of river channel and floodplain restoration/rehabilitation has produced a wealth of books and papers written by geomorphologists, hydrologists, engineers, ecologists and their joint teams over the recent decades (Nunnally, N.R. 1978; National Research Council 1992; Fischer, K.J. 1994; Sear, D. 1994; Kondolf, G.M. and Micheli, E.R. 1995; Hey, D.L. and Philippi, N.S. 1995; Brookes, A. 1996; Brookes, A. and Shields, F.D. Jr. 1996; Fennessy, M.S. and Cronk, J.K. 1997; Kauffman, J.B. and Beschta, R.L. 1997; Macdonald, K.B. and Weinmann, F. 1997; FISRW 1998; Theiling, Ch. 1998; U.S. Department of Commerce 1998; Wissmar, R.C. and Beschta, R.L. 1998; Tockner, K. *et al.* 1999; Downs, P. and Thorne, C.R. 2000; Zöckler, C. 2000; ECRR 2001; Bratrich, C. *et al.* 2002; Buijse, A.D. *et al.* 2002; Clarke, S.J. *et al.* 2003; Hulse, D. and Gregory, S. 2004; Hohausova, E. and Jurajda, P. 2005; Larsen, E.W. *et al.* 2006; Newson, M.D. and Large, A.R.G. 2006; Kline, M. 2007; Dworak, T. 2008; Schneider, E. 2010; WWF International 2010; Roni, P. and Beechie, T. 2013; Guerrin, J. 2014; Kiedrzyńska, E. *et al.* 2015; Hein, T. *et al.* 2016; Opperman, J.J. *et al.* 2017).

As a theoretical background to the issue the classical concept of 'design with nature' (McHarg, I. 1969), which also includes landscape ecological aspects, can be detected. In addition to bringing planning in harmony with natural processes, sustainability is another foremost requirement, as it is common for any other planning task. Enhancement of riparian ecosystems involves raising the value of habitats for wildlife, increasing plant or community diversity (Manci, K.M. 1989), also preserving or even increasing landscape (land use) diversity.

Today experiences on floodplain restoration are available for assessment from all parts of the world and all geographical environments (Moss, T. and Monstadt, J. 2008). Using physical (channel and floodplain morphology, sediment, flow, water quality [temperature and nutrients]) and biological indicators (fish, invertebrates, and aquatic and riparian plants), Roni, P. *et al.* (2019) evaluate the effectiveness of various floodplain restoration approaches on the basis of 180 papers. Bernhardt, E.S. *et al.* (2005) report about a comprehensive database of more than 37,000 river restoration projects of various scale across the United States. The most common objectives were to enhance water quality, manage riparian zones, improve in-stream habitat, allow fish passage, and stabilize stream banks. Only 10 per cent of project records, however, mention continuous project monitoring. This means that the ecological effectiveness of restoration activities cannot be evaluated in the majority of cases.

In the first stage the morphological floodplain and, within that, the floodway zone (i.e. the active floodplain – Bogárdi, I. and Balogh, E. 2014), allowed for inundation during floods and reserved for fluvial processes, should be delimited. The theoretical concepts to be applied in this delimitation are the geomorphic recovery potential (Brooks, A.P. and Brierley, G.J. 2004; Fryirs, K.A. and Brierley, G.J. 2016), the streamway or erodible river corridor (Piégay, H. *et al.* 2005), dyke set-back (in the German literature: *Deickrücklegung*) (Fischer, K.J. 1994), and 'room for the river' (Rohde, S. *et al.* 2006). The essence of these concepts is that free channel migration should be allowed within a zone (corridor) defined by human structures or agricultural land or any other land use types which have to be protected from bank erosion and flooding. Allowing free channel migration would spare considerable costs of water management and flood defence (Piégay, H. *et al.* 2005). The reconstruction of river history is indispensable for planning restoration, to define realistic goals of restoration actions (Brierley, G.J. *et al.* 2002; Słowik, M. 2013).

While in the floodway flood control is of decisive significance (ÖKO Rt., FÖMI and VÍZPART Kft. 2000; APFM-WMO 2017), over the protected portions of the morphological floodplain a wide range of land use classes can be present. Floodplain soils have long been used for arable farming, horticulture and grazing with increasing intensity (Posthumus, H. *et al.* 2008; Xie, H.L. *et al.* 2019), while lower-lying wetlands are valuable for water management, forestry, tourism and nature conservation purposes (WWF 2004). The broad range of floodplain land uses makes the setting of rehabilitation objectives difficult. Rehabilitation can only be successful if it is designed parallel to an incessant process of reconciliation of interests in various circles of stakeholders (see e.g. Ball, T. 2008).

Intensive agricultural use of floodplains has led to environmental problems. For instance, reclaimed peatlands have suffered deterioration through oxidation of peat and the related ground subsidence (Verhoeven, J.T.A. and Setter, T.L. 2010). In spite of their significance for landscape ecology and nature conservation, wetlands continue to be under threat of being drained and reclaimed. Agriculture is the most important non-point source of water pollution and, in addition to their hydrological role (Bullock, A. and Acreman, M.C. 2003), the buffering capacity of wetlands is vital for the efficient functioning of floodplains (Fennessy, M.S. and Cronk, J.K. 1997).

A new aspect of the optimization of floodplain land use is related to climate change (Didovets, I. *et al.* 2019; Fehér, Z.Zs. and Rakonczai, J. 2019). In addition to catchment management, river runoff, the temporal and spatial patterns of floods and droughts increasingly depend on the changing climate (Klug, H. 2016). Rainfall distribution tends to be the sole control of the regimes of rivers (like the Kapos in Southwest Hungary) which only drain low hilly regions with negligible winter snow cover. Extreme floodplain inundations closely correlate with extreme rainfall events (such as in spring and autumn of 2010). It has only recently been incorporated into water management policy that surplus water has to be stored in the floodplain to mitigate ensuing drought hazard (Somlyódy, L. 2011).

A land use analysis from nature conservation aspect (ÖKO Rt., FÖMI, VÍZPART Kft. 2000) and feasibility studies of development (Gergely E. *et al.* 2000) have considered rehabilitation needs for the Kapos catchment. These studies, however, failed to investigate all aspects of a complex transformation of the floodplain. The conclusions drawn from both our hydrogeomorphological studies (the description of embayments and gaps, valley and floodplain asymmetry, channel reconstructions) and landscape ecological assessments supply further information to the achievement of the rehabilitation goals (Lóczy, D. 2013).

Objectives

In order to identify the tasks of floodplain rehabilitation, within the complex hydromorphological and landscape ecological research project of the Kapos floodplain the following questions have been raised (Lóczy, D. 2013):

- How serious is the flood hazard in the morphological floodplain?
- How do the landscape patterns of the broader catchment, the protected floodplain (its wetlands) and the active floodplain compare with each other?
- What is the land capability of the individual floodplain sections? To what extent does the actual land use pattern provide ecosystem services? What would be an optimal land use pattern like and how to achieve it?
- How can the rehabilitation potential be rated for the Kapos floodplain?

The present paper does not cover all of these issues. It is restricted to those which are relevant for land use optimization, i.e. assessments of flood hazard, land capability, land use pattern and rehabilitation potential.

Study area

In Hungary morphological floodplains extend over 30 per cent of the county's territory. In lowland areas huge expanses of land are affected by excess water hazard (Pálfai, I. 2009).

They are vulnerable as almost 3 million people live there in 400 settlements, and 200 major industrial plants, 32 per cent of the railway network, and 15 per cent of public roads are also located in these areas (Somlyódi, L. 2011).

The medium-sized catchment of the Kapos River covers 3,295.4 km^2 in the South Transdanubian Hills region and the Mecsek Mountains (Lóczy, D. 2013 – *Figure 1*). The Kapos River is 112.7 km long. The morphological floodplain (without that of the tributaries) extends over 104.2 km^2, which makes up 3.3 per cent of the total catchment area. Consequently, runoff from the hilly parts of the catchment is concentrated in an area of limited extension.

The source of the Kapos is south of the village Kiskorpád at ca. 180 m above sea level and its confluence with the Sió Canal (the outflow of Lake Balaton to the Danube) is at 96 m elevation.

The upper Kapos catchment has a sub-atlantic climate with mean annual temperature sligthly above 10 °C and annual precipitation of 680–720 mm, while the eastern part is subcontinental (10.8–11.0 °C and 650–690 mm). The water regime shows low-water stages in August–early September and high water most often in March (caused by snowmelt in the hills) *(Table 1)*. Most of the other extremes in the regime are due to summer showers. In the embayments downstream of the town of Dombóvár rainy weather can raise groundwater levels rapidly and create extensive temporary waterlogging (Gergely, E. *et al.* 2000).

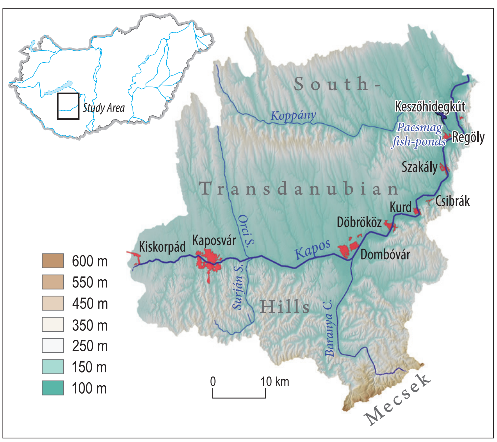

Fig. 1. Topography of the Kapos catchment.
Source: DEM with 10-metre resolution, DDVÍZIG.

As a direct corollary of regional tectonics, a remarkable asymmetry and remarkably regular alternation of floodplain constrictions (gaps) and relatively wide embayments are typical for the geomorphology of the middle and lower sections of the Kapos Valley. In the loess landscape a low-energy meandering planform evolved superimposed over landforms of coarser alluvia inherited from a high-energy Pleistocene braided river system (Słowik, M. *et al.* 2020).

At the mouths of tributary valleys small and very flat alluvial fans have accumulated. In the abandoned channels and backswamps of the embayments peat bogs formed in historical times. Poor drainage was only improved by river flow regulation (Bencze, G. 2000). The inventory of peatlands in Hungary, compiled in the 1970s, recorded former peat bogs of 851 ha area (9,140,000 m^3 peat reserves) in the abandoned channels and backswamps of the Kapos and its tributaries (Dömsödi, J. 1980). Flow regulation and the accompanying floodplain drainage induced peat decomposition. Fibric Histosols (fibrous peat) have been humified to Hemic Histosols (mucky peat, muck) and, finally, to Humic Histosols (earthy peat or 'black earth'). Along the headwaters fibrous peat is found in 5–6 m thickness, while in the lower valley segment of the valley muck and humified peat beds occur in 1 m thickness (Gergely, E. *et al.* 2000). On fluvial sand deposits Fluvisols are predominant.

Methods

The steps followed in the present research were the following:
- delineation of the morphological floodplain of the Kapos River;
- reconstruction of a historical drainage pattern which had existed before river regulations started;

Table 1. Basic hydrological data on the watercourses of the Kapos system, 1995–2005

Stream	Length	Catchment	Site of gauge	Low flow	Mean flow	Median high flow	Absolute record flow
	km		river km	$m^3 s^{-1}$			
Kapos	112.7	3126.4	Kaposvár-Fészerlak, 86.0	0.055	1.724	7.54	45.5
			Kurd, 43.7	1.000	6.160	46.80	130.0
			Pincehely, 7.9	1.040	6.190	42.40	174.0
Koppány	63.6	747.1	Tamási, 14.5	0.160	1.210	30.90	77.0
Baranya Canal	38.0	606.5	Csikóstőttős, 3.2	0.120	1.830	68.00	110.0
Orci Stream	27.2	133.1	Orci, 5.1	0	0.550	27.00	27.0
Surján Stream	23.8	112.8	Szentbalázs, 4.5	0	0.290	10.30	37.0

Sources: Hydrological Yearbooks 1997–2008; Dövényi, Z. 2010

– survey and assessment of present-day land use based on remote sensing information;
– mapping floodplain soils and landforms;
– assessment of inundation hazard;
– determination of criteria for and estimation of rehabilitation potential;
– identification of needs for land conversion and design of an optimal land use pattern.

The morphological floodplain of the Kapos River was delimited using the Multiresolution Valley Bottom Flatness (MrVBF) index (Gallant, J.C. and Dowling, T.I. 2003). The algorithm identifies several assumptions referring to the flatness and low elevation of floodplains and their dependence on terrain pattern properties. The computing algorithm of the MrVBF index is compatible with the ArcInfo GRID module. The valley bottoms are delimited at a range of scales. A given site is considered to belong to valley bottom at a given scale if it is sufficiently low and flat at that scale. At each step of the procedure, in the newly generated DEM cell size increases by a factor of 3, and the slope threshold reduces by a factor of 2. (For more details see Lóczy, D. *et al.* 2012). The floodplain reconstruction based on the MrVBF index was compared with the delimitation relying on the interpretation of the Second Military Survey map sheets (from 1857–1859). The land use class 'wet meadow' approximately coincides with the floodplain, where no arable fields were cultivated at that time. Another opportunity for correction was provided by aerial photographs from the time of the 2005 flood.

Archive maps were also used to detect the positions of river channels before flow regulations. Occasionally several river branches were active in the same period. No single archive map could supply us with this information – a joint interpretation of several sources had to be employed: georeferenced map sheets of the First (1783–1784), the Second (1857–1859) and the Third Military Survey (1881–1882), a 1:10,000-scale topographic map (revised in 1999), aerial photographs of the General Directorate of Water Management (OVF) for the 2005 and 2010 floods and Google Earth maps for the identification of surfaces (paleochannels) then covered with excess water. The analyses were made in ArcGIS version 9.2 Spatial Analyst environment. In addition, paleochannels could be identified on the basis of their (peaty) soils shown on the soil map.

To prevent the transport of nutrients to water bodies, the optimal land use types along the floodplain margin are a forest zone, tree rows or grassed strips (Cronk, J.K. 1997; and Rogger, M. *et al.* 2017). The continuity of these land use classes within a 100-metre wide zone was also assessed from the land use map.

In the framework of the soil survey a total of 40 soil profiles were analyzed. The sites of soil pits and auger holes were selected on the basis of microtopography (as reflected by the DEM). Thus, the surveyed soil profiles are assumed to represent all classes of fluvial landforms in the floodplain. Soil samples were analysed in the Lovász György Physical

Geographical Laboratory of the Faculty of Sciences, University of Pécs, for grain size distribution, mineral composition, organic matter content and for type and content of carbonates. Grain size distribution was established by the Fritsch Analysette A22_32 laser equipment in the measurement range of 0.3 to 300 μm. Index values were determined according to the Hungarian standard MSZ08 0206/1-78, while water soluble salts were measured (in m/m salt%) according to the Hungarian standard MSZ08 0206/2-78. Carbonate contents were determined by Scheibler's calcimeter (German standard DIN 18 129). For the mineral composition of soil samples a Shimadzu TGA 50 thermogravi-meter was applied, which measures mass changes caused by decomposition reactions in proportion to rising temperature. Samples of 40 mg mass each were analysed at 10 °C min^{-1} heating rate.

The soil subtypes and varieties were first identified in the Hungarian genetic classification system and then referred to the WRB system. The information from point-like soil surveys was extended based on the distribution pattern of fluvial landforms. Ground Penetrating Radar (GPR) surveys were performed across abandoned Kapos channels in embayments (Słowik, M. *et al.* 2020) to reveal the internal structure of paleochannels and backswamps supplemented with 30 auger holes and corings. To estimate the age of the palaeomeanders, ^{14}C dating was carried out in the Poznań Radiocarbon Laboratory (Poland), for 20 samples of terrestrial plant macrofossils and charcoal pieces using Accelerator Mass Spectometry (AMS).

For the assessment of rehabilitation opportunities, water retention potential was used as the principal criterion. For floodplains three types of retention capacity are usually identified (Dostal, T. *et al.* 2012):
– Water retention capacity of soils – some deposits (sands) are sufficiently porous to absorb a high proportion of floodwater.
– Passive retention capacity of the floodplain – retention in backswamps, abandoned channels or other depressions of some embayments.
– Transformation effect of river channels and their floodplains – assuming that during overbank flow current velocity drops and, thus, the flood wave is decelerated.

The floodwater retention capacity of the Kapos floodplain was estimated from soil hydrological data. Maximum water capacity and storage capacity (the amount of water released from a unit volume of soil by gravitation) was rendered to the main horizons of typical soil profiles. Passive (surface water) retention capacity was estimated from the DEM and added to soil retention. Although estimations of the rate of flood peak dispersion and propagation along the river-floodplain corridor would have been useful for restoration planning, such data were not available. Therefore, flood wave deceleration was ignored in the calculations.

The classes of rehabilitation potential (mapped for the Danube by WWF International 2010 or for the Transboundary Biosphere Reserve Mura-Drava-Danube by Schwarz, U. 2013) express the degree to which connectivity between sites with high water retention potential and the main river channel can be restored. The potential varies with the floodplain segments identified (for the Kapos: Lóczy, D. *et al.* 2012). The engineering measures of floodplain restoration (Buijse, A.D. *et al.* 2002) are not treated here.

The alternatives of restoration/rehabilitation are referred into one of three groups (Smith, M.P. *et al.* 2008): 'no action', passive or active intervention *(Table 2)*. The 'no action' alternative means that the channelized river is capable of restoring its close-to-natural conditions over the long term without any human assistance. In this case the recovery potential is high. From such a strategy, however, it cannot be expected that a fully natural state is restored – not even in the very long term. Active rehabilitation aims at 'products' (creating landforms and vegetation/land use assumed to be more favourable), while passive (or non-structural) rehabilitation strives at generating processes which are expected to indirectly lead to favourable conditions later in the future (Wheaton, J.M. *et al.* 2019).

*Table 2. Comparison of the three rehabilitation approaches**

Recovery potential	General approach	Strategy	Example for intervention
High	'no action'	No intervention in the hope of natural recovery, i.e. that the river itself obliterates the consequences of minor disturbances.	Disturbances of natural origin (such as floods) lead to an equilibrium state over the long run.
Medium	passive	After implementing flood control measures, the free response of river channel is allowed and promoted.	Purchasing land in the riparian zone by the state to secure space for meander development.
Low	active	Correction of the alignment of the channelized river in order to establish a stable channel, incorporating passive procedures.	New channel alignment, bank reinforcement using natural methods but allowing space for the 'fine tuning' of flow pattern.

*Modified after Smith, M.P. *et al.* 2008.

For mapping the extent of inundation during floods, an important information for floodplain rehabilitation and land use optimization, was estimated from aerial photographs taken by the Pécs Aeroarchaeology Theca *(Photo 1)*. The distribution of inundated areas was confirmed by satellite image interpretation (Rakonczai, J. *et al.* 2003), using the image first available after the most recent major flooding of autumn 2010 (from band 6 of the Landsat-7 [ETM+] image for 24 September 2010). It shows the actual distribution of pixels where reflectance was predominantly controlled by water surface. (Reflectance was calibrated for fish-ponds in the study area.) The drainage network was superimposed

Photo 1. The Döbrököz area on an aerial photograph (May 2010) taken by the Pécs Aeroarchaeology Theca (Photo by Szabó, M.)

on the image from the Hungarian Water Management Database (although with substantial allocation error). The smoothed envelope curve embraces all 'water' pixels and provides at least an approximation potentially waterlogged areas. (This kind of reconstruction, however, only shows a partial picture of excess water inundation. Also areas with groundwater table immediately [less than 20 cm] below the surface could have been rightfully included among those stricken by excess water – Rakonczai, J. *et al.* 2003.)

The need for land conversion was identified based on a rapid land capability assessment with limited data requirement ('practical land assessment' Dömsödi, J. 2011). It only covers eight (complex) components of land quality in a weighted system (*Table 3*). According to their productivity, the genetic soil types which occur in floodplains are referred into four classes (numbers III and IV are only usable for meadow and reed economy). The assessment was supplemented with land suitability considerations, where a crucial criterion was how long the individual crops can tolerate spring–early summer inundation without severe reduction in yields (Petrasovits, I. and Balogh, J. 1975 – *Table 4*).

*Table 3. Main factors in land evaluation for practical agricultural purposes**

Number	Factor of land quality	Maximum score of agricultural site quality
1	Topography (topographic position, slope, mean depth to groundwater table, erosion and deflation hazards) Local climate (exposure)	18
2	Genetic soil type (obtained from the map 'Genetic soil types of Hungary')	9
3	Chemical properties of topsoil (pH, carbonates, salinity)	10
4	Physical soil type (specific resistance) Soil structure	9
5	Properties reducing subsoil quality (water conductivity, soil properties causing deficiency in productivity down to 150 depth)	18
6	Depth of humus layer, Soil depth	9
7	Suitability for arable and other land uses	9
8	Land capability (how many crops can be cultivated profitably)	18
Total		*100*

*Revised after Dömsödi, J. 2011.

*Table 4. Inundation tolerance of agricultural crops widely grown in Hungary measured in percentage of yield loss**

Crop	Duration of inundation, days							
	March				April			
	3	7	11	15	3	7	11	15
Winter cereals	5	15	30	50	10	25	40	70
Maize	–	–	–	–	20	80	100	100
Sunflower	–	–	–	–	10	20	50	80
Sugar-beet	10	50	100	100	10	50	90	100
	May				June			
	3	7	11	15	3	7	11	15
Winter cereals	20	40	70	100	20	50	80	100
Maize	10	50	80	100	10	40	75	100
Sunflower	15	30	80	100	20	40	80	100
Sugar-beet	10	50	90	100	10	40	90	100

*After Petrasovits, I. and Balogh, J. 1975.

Enduring waterlogging primarily precludes arable farming, while tree plantations and grazing lands are tolerant for inundation of several weeks' duration. In the case of maize even one-week duration means 80 per cent yield loss. Sunflower is also somewhat less sensitive to inundation in May.

Results and discussion

The map reconstruction of the groundplan of the Kapos paleochannel system presents an intricate low-energy anastomosing/braiding pattern with some meandering channels (*Figure* 2). There is a zone along the floodplain margin where paleochannels could not be mapped. This fact can be explained by intensive sheetwash from the neighbouring slopes onto the floodplain. The washed-down loess deposits obliterate the traces of paleochannels from the surface and also raise the elevation of the ground surface. This has important implications for land use (see later).

Creating new Kapos channel sections requires space and it is only feasible in the broadest embayments. Previous rehabilitation proposals for the Kapos floodplain (for instance, Gergely, E. *et al.* 2000) suggested channel rearrangements (primarily along the Kurd section) to reduce flood hazard. From a purely geomorphological viewpoint, the establishment of several more or less parallel, meandering channels would be an optimal solution for the restoration of a close-to-natural drainage pattern. This can be achieved through taking advantage of the infilled channels still traceable in microtopography and returning to the 19th-century regulation plans, which relied on several lateral canals running along the floodplain margins (Beszédes, J. and Herman, J. 1829). Such marginal canals could have some benefits even today:

- they conduct away the flash floods generated on tributary streams;
- dissipate the energy of floods;
- isolate the main channel from the non-point pollution of agricultural (or accident) origin (see Kronvang, B. *et al.* 2004);
- raise groundwater levels even during dry spells.

A detailed reconstruction of paleochannels was conducted by Słowik, M. *et al.* (2020) for the Kapos-Koppány confluence area. They discovered that single-thread meandering planform was active here since the Late Glacial. This low-energy meandering system was characterized by elongate bends with circular pools near apexes. The meanders evolved through oblique accretion, periods of cut-offs in the Late Glacial, and periods of flow discontinuation during the last 4,000 years (cf. Słowik, M. *et al.* 2020).

Are there real opportunities for dyke relocation (ECRR 2001; Clarke, S.J. *et al.* 2003) in the Kapos Valley? In the densely built-up upper (Kaposvár–Dombóvár) section any channel translocation would be difficult to implement. Downstream, however, in the broad embayments, where the floodplain rehabilitation potential is higher, they are worth of consideration. In the reach between settlements Szakály and Regöly (river km 27–24), dyke relocation seems to be an obvious and low-cost solution. Here dyke construction was unnecessary in the first place since parallel with the dyke, at ca

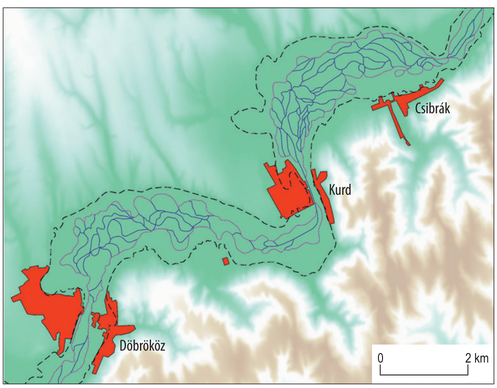

Fig. 2. Reconstruction of old Kapos channels in the Döbrököz and Kurd–Csibrák embayments (38–51 river km) for the early 19th century (drawn by Gyenizse, P. after information from military survey maps). The black dashed line indicates the boundary of the morphological floodplain and the magenta enveloping lines the channels farthest away from the valley centre line.

50 m distance, a relatively high natural levee of sand rises *(Photo 2).* The functioning of this landform of natural origin as a flood-control structure would also improve the water supply of the floodplain. To the space between the present dyke and the natural levee (which was probably also deepened as a navvy pit from where material for dyke construction was gained) the active floodplain could be extended. The bank zone being suitably landscaped, it would add to the wetlands of the Kapos Valley, store water during floods and create valuable habitats for nature conservation.

Using soil survey information, a remarkable soil water retention capacity was identified. The calculations resulted in a total maximum dynamic water capacity of 6,139,000 m^3 for the 4.45 km^2 area of embayments. Out of this amount 2,251,000 m^3 can be pumped out.

The assessment of the rehabilitation potential is primarily based on the opportunities for floodwater retention and flood risk reduction (see Lóczy, D. 2013). The results show that the rehabilitation proposals should focus on floodplain segments IV and V (*Figure 3*), where a combination of a range of interventions could improve the ecological conditions of the floodplain. Rehabilitation potential is relatively high along the reach around the confluence of the most important tributary, the Koppány (although the channelized rivers are deeply in-sized). The riverine wetlands can only be restored if groundwater levels are raised. The silt layers of low permeability in this floodplain section favours water retention after floods. (By sporadic measurements typical grain size of suspended load was found to range from 0.033 mm to 0.079 mm with a median value of 0.040 mm – cited by Bogárdi, J. 1971). However, it is doubtful whether this would be sufficient to maintain the wetlands during summer drought.

The constructed wetlands to be formed in the confluence area could be connected to the already existing Pacsmag fish-ponds, an important bird refuge, Ramsar site and Nature Reserve of 487 ha area. The constructed wetland would also increase the aesthetic value of the floodplain landscape.

Photo 2. The natural levee at Szakály with a row of poplars on the right bank of the Kapos River (Photo by Lóczy, D.)

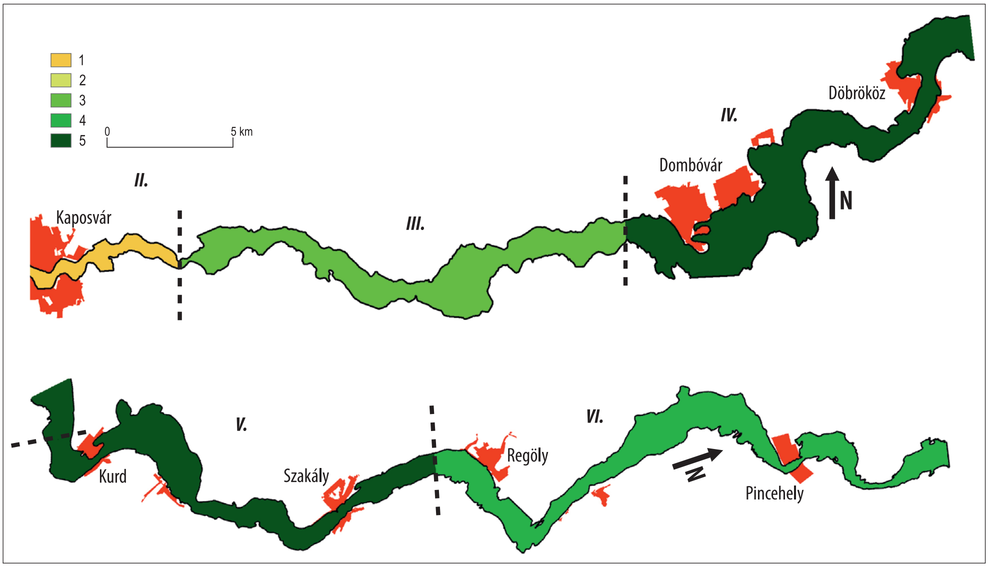

Fig. 3. Rating the rehabilitation potential of the various hydromorphological sections of the Kapos floodplain (by Lóczy, D.). The floodplain sections are identified according to Lóczy, D. (2012). II–VI = floodplain sections (river section I. has no floodplain); 1–5 = rehabilitation potentials (1 = lowest; 5 = highest one).

As far as the rationalization of land use is concerned, it has to be kept in mind that following the great river regulations and even in the period between 1960 and 1980 an important objective of water management was the increase of arable land (by 25–30 per cent) and formation of large agricultural fields (up to 300 ha area) (Bognár, Gy. 1989). Nature conservation requirements have only been observed since the late 1980s. The land use map of the Kapos floodplain *(Figure 4)* shows that forests predominant in floodplain section II are replaced by agricultural land in section III; a balance is struck between land use classes in section IV, while grasslands occupy the largest area in V and in the embayments of section VI, where forests entirely disappear. In addition, the continuity of land use classes in the floodplain sections was described quantitatively *(Table 5)*. It was found that in sections IV and V the buffer strip is continuous over almost one-third of the floodplain margin, which offers some protection against environmental pressure. Interruption of this buffer zone by arable fields have to be eliminated in the future.

Floodplain areas critical for land use have been identified relying on the findings of soil mapping and land capability assessment. There are sections, e.g. the Koppány confluence area, where flood and excess water hazard is so high that in land use planning nature conservation has absolute priority over agricultural production. Arable farming should retreat to areas where excess water hazard is low. As a general guideline, because of their relative close association, land use classes can be made correspond to the main landform units *(Table 6)*. In particular cases, however, exceptions can be made.

The land capability assessment only shows minor variations in land quality *(Table 7)*, but it is striking that in both embayments studied former peat bogs (with Eutric Histosol) are least suitable for arable farming, while the chernozem meadow soils on loess (Mollic Gleysol) favour this type of land use. This finding has to be considered in the design of land use pattern.

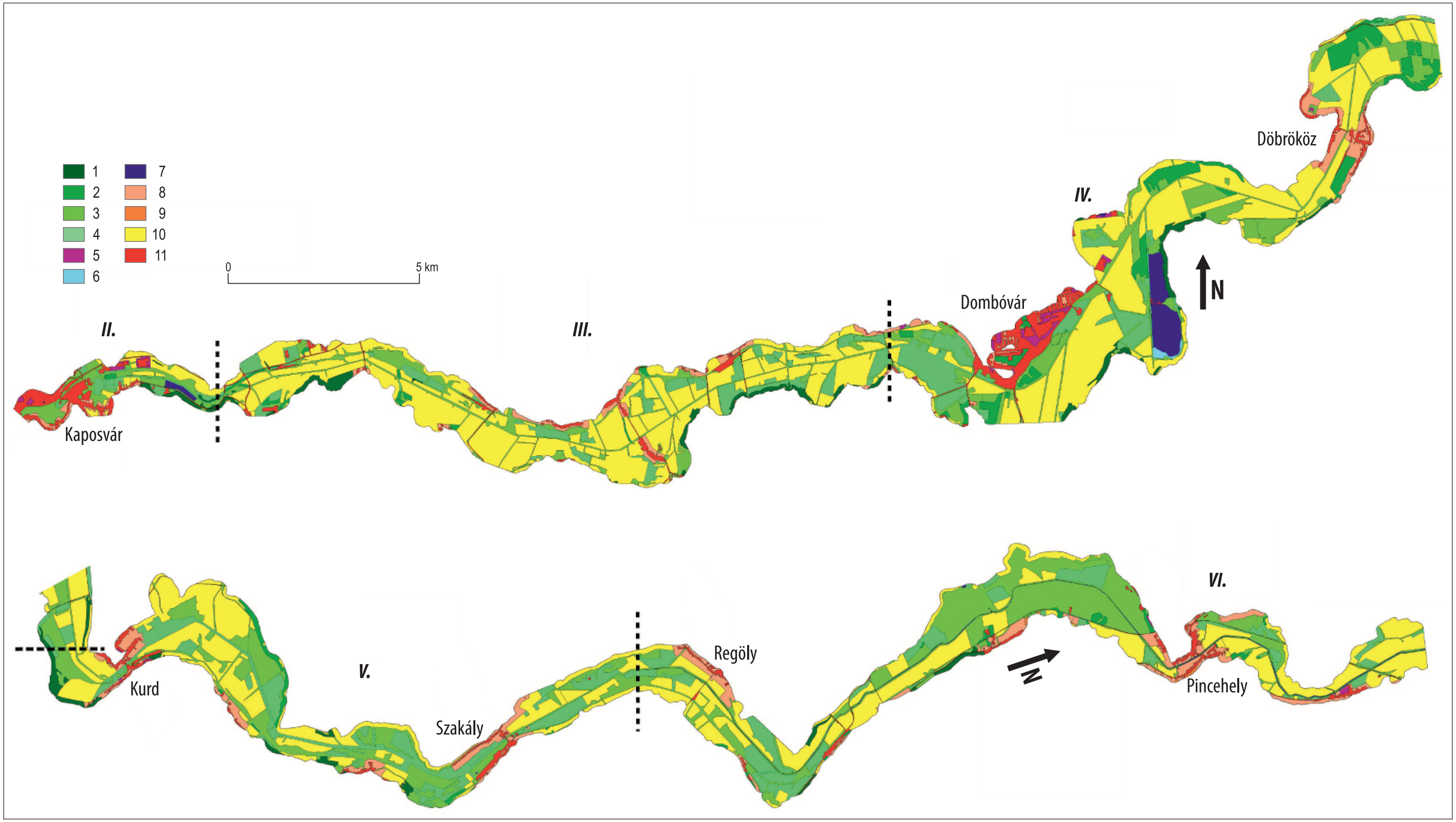

Fig. 4. Land use map of the Kapos floodplain (by Gyenizse, P.). 1 = close-to-natural forest; 2 = other forest (tree plantation); 3 = shrubs, tree rows; 4 = meadows; 5 = green area in settlement; 6 = waterlogged area, reed-bed; 7 = fish-pond; 8 = garden, orchard; 9 = vineyard; 10 = arable land; 11 = built-up area.

Table 5. Continuity of land use in the 100-m wide strip along the river in the different floodplain segments*

Number of segment	Length of river reach, km	Area of marginal strip with bushes and trees, km²		Ratio of strips with close-to-natural vegetation in the marginal zone	
		left-bank	right-bank	Total area, km²	%
III	17.7	0.88	1.63	2.51	25.35
IV	19.2	1.19	2.14	3.34	30.38
V	21.3	1.12	2.07	3.19	30.31
VI	28.2	1.96	1.52	3.48	27.21

*Compiled by Lóczy, D. 2019.

Table 6. Land use proposals for floodplain landforms of different elevation

Landforms	Frequency of inundation	Proposed land use, economic activities
River terraces	Flood-free, occasional excess water from precipitation	Built-up, arable, forest, grazing land, orchard, hunting, gathering (mushrooms, forest fruits etc.)
Natural levees	Rare and short-term inundation	Orchard, horticulture, arable, forest, hunting, gathering (mushrooms, forest fruits etc.)
Low floodplain level	Irregular inundation (in 5–10-year intervals)	Pasture, meadow, forest, fishing, growing medicinal plants, hunting
Backswamps, abandoned channels	Regular (seasonal) long-term inundation	Reed-cutting, aquatic plants, waterfowl, hunting, gathering (medicinal plants, dried flowers etc.)

Table 7. Assessment of overall land capability in the major embayments of the Kapos floodplain*

Genetic soil subtype or variety	Approximate WRB equivalent	Floodplain landforms	Main properties	Soil parent material	Soil score	
					A	B
chernozem meadow soil	Mollic Gleysol	loess slope deposit along margins	gentle slope, medium deep groundwater table	loess	70	70
'humous carbonate' soil on sand	Mollic Arenosol, Regosols	natural levees	higher relief, deeper groundwater table	medium sand	50	52
meadow soil, meadow alluvial soil	(Fluvi-mollic) Gleysol	medium floodplain level	flat, seasonally waterlogged	fine sand	67	65
boggy meadow soil	Eutric Histosol	oxbows, backswamps	low position, waterlogged	calcareous silt with muck	48	48
earthy peat ('black earth')	Humic Histosol	backswamps	low position, waterlogged	calcareous silty clay	58	57

*Compiled by Lóczy, D. 2019. A = Döbrököz–Csibrák embayment; B = Szakály–Keszőhidegkút embayment.

Conclusions

The proposed changes in floodplain land use could have beneficial effects even on the short run. The damage caused by flooding would be reduced and floodwater retention enhanced. Over an undeveloped and vegetated floodplain floodwater can spread out without major damage and can be stored in floodplain soils and landforms before it evaporates. The biggest challenge of successful restoration of the wetlands, however, is the raising of the groundwater levels. Silt layers of low permeability in the floodplain may reduce infiltration. However, the incised Kapos and Koppány canals drain groundwater from the underlying layers of coarse sands inherited from high-energy braided system active in Late Pleniglacial and at the beginning of the Late Glacial.

Afforestation is desirable in the higher levels of the Kapos floodplain since the roots of arboreous vegetation promote infiltration, recharge groundwater and store moisture in multi-fold higher amounts than the soils of arable fields or meadows. At the same time, the trees and herbaceous plants of the riparian zone transfer huge amounts of water from the floodplain to the atmosphere by transpiration and reduces flood wave crests. This contradicts the river engineers' view who are critical about floodplain roughness and flood protection infrastructure and claim that higher retention in a floodplain forest could lead locally to raised groundwater tables. For restoration projects a certain freeboard at dykes has to be permitted to secure local flood protection.

Through improving connectivity and water availability floodplain biodiversity could also be enhanced and the nature conservation function strengthened. In the backswamps arable farming should be replaced by meadows connected to the ecological network and gallery forests along watercourses.

Arable (or possibly organic) farming should be restricted to higher-lying, terrace-like surfaces with minimum excess water inundation hazard, favourable soil properties and water availability (ÖKO Rt., FÖMI and VÍZPART Kft. 2000). Although the marginal floodplain zone with washed-down loess veneer ('higher floodplain level') is suitable for arable farming, the intensity of cultivation has to be kept within limits even here and a buffer zone has to be excluded from intensive cultivation. In arable fields of poor productivity cereal and oil crop growing should be gradually replaced by the cultivation of or horticultural crops (e.g. horse raddish, which has some tradition in the region), while the lowest-lying tracts could be used for medicinal plants, as meadows or forests – with regard to landscape ecological consideration.

The main goals of rehabilitation should be flood control also including temporal floodwater retention (subordination of land use to flood control); improvement of landscape pattern (providing connections in all directions); increasing the effectiveness of buffer zones in order to reach better river water quality and establishing a floodplain economy in harmony with nature conservation considerations.

Future research should exploit the advantages offered by a systematic hydromorphological survey and hydraulic modelling for a more precise definition of the sites and tasks of restoration with purposes of flood control as well as the establishment of ecological corridors and buffer strips.

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