Groundwater flooding hazard in river valleys of hill regions: example of the Kapos River, Southwest-Hungary

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Abstract

In the riverine floodplains of hill regions built of sand and loess, interactions between river channels and groundwater reservoirs result from the high permeability of the riverbed and the spatial heterogeneity of floodplain deposits and soils. Although in dry periods, groundwater sustains the river in the form of baseflow, and the relationship is the opposite during wet spells, the predictability of inundations from rising groundwater levels is rather low. Also the spatial and temporal development of inundation in narrow floodplains of hill regions (like the Kapos River floodplain) takes a course in several respects different from that in broad lowlands. In the study areas of the Kapos floodplain topographic, remote sensing and soil distribution surveys are jointly applied to assess the true extent of frequent inundation hazard.

Keywords: floodplain, groundwater monitoring, Histosols, "perirheic zone", waterlogging, hill region

Introduction

The evaluation of flood hazard calls for answering a range of questions:

– where are inundations expected (i.e. the potential floodplain has to be delimited);
– how often do inundations happen;
– what duration do they have and
– in which part of the year are they expected with the highest probability?

In addition to geomorphological factors, *local flood inundation* also depends on the ecological conditions in the floodplain: the density of vegetation, tillage and other cultivation methods applied in land utilization and soil moisture state prior to the flood (Lastra, J. *et al.* 2007). Waterlogging precludes

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certain types of land use, while ephemeral wetlands are maintained by regular temporal waterlogging. Elements of infrastructure (road and railway embankments, flood-control dykes, irrigation and drainage canals) modify the passage of floods. Large-scale farming has also substantially transformed the natural pattern of inundation. The frequency and *duration of inundation* depends on flood discharge and slope of the river as well on the climate of the catchment. The floodplains of major rivers can be inundated for months, significantly reducing their agroecological value.

Since the abiotic environments of floodplains are generated at critical discharges above geomorphological thresholds, the *spatial patterns* of floodplains are also governed by the spatial and temporal pattern of floods. In order to properly appreciate the impacts of *flood*s, first of all, their *recurrence intervals* has to be compared to the duration of natural floodplain succession. If both intervals are of similar length, it is probable that a more 'mature' vegetation type, a floodplain forest of limited spatial diversity, is formed (Whited, D.C. *et al*. 2007). If floods recur within shorter intervals, such as along rivers of braided channel, their disturbance character is more pronounced, and an earlier stage of succession with a more complex pattern becomes prevalent in the floodplain (Arscott, D.B. *et al*. 2002). A medium-long recurrence interval or a more complicated history of disturbance (on a decadal scale) may create maximum spatial complexity (Ward, J.V. *et al.* 1999).

Earlier the zones of flood hazard have been delimited on hydraulic, hydrological basis. More recently *ecological considerations*, e.g. land suitability are also included in the delimitation, in the sense of the slogan 'living with floods'. Land use restrictions vary with the zones.

It is necessary to mention that from the aspect of flood and inundation hazards *small watercourses* also deserve attention. The riparian zones of headwaters may be in natural conditions and, therefore, may be more efficient in flood control than the zones along larger rivers, completely transformed by human activities (for instance, along the Rhine – Dister, E. *et al.* 1990). The restoration/rehabilitation of floodplain habitats – where it is still possible – is the most economical tool of flood control (McCartney, M.P. and Naden, P.S. 1995).

Inundation hazard from excess water in the lowlands of Hungary

Excess water (waterlogging) had been long associated with river flooding. Recently, the definitions of excess water (Pálfai, I. 2001) have been extended also to include upbursting groundwater even in total absence of any watercourse. In addition to groundwater levels raised on the floodplains of major rivers during flood stages, any waterlogging in lowland areas is included in this broad category. The presently used definition of excess water originating from rainfall or snowmelt which covers any extensive but temporary inundation of lowland areas and fully saturates the soil. Whether soil saturation necessarily leads to seasonally waterlogged surfaces, remains to be an open question (Rakonczai, J. *et al*. 2003). Recurrence intervals of extreme waterlogging have been calculated for Hungary recently (Pálfai, I. 2009 – *Table 1)* and found to be rather irregular for the mid- and late 20th century. In recent decades, excess water hazard has been observed to increase dramatically.

*Table 1. Recurrence intervals of major excess water inundations in Hungary **

Probability of occurrence, per cent	Average return period, years	Approximate minimum inundated area, hectares	Example years
50	2	60,000	1960, 1997
20	5	170,000	1963, 2010
10	10	270,000	1956, 1967
5	20	360,000	1966, 2000
2	50	480,000	1940, 1941, 1942, 1999

* Modified after Pálfai, I. 2009.

Inundation hazard from excess water is more difficult to delimit both temporally and spatially than river flood hazard. Rapid snowmelt in spring, early summer cyclonal rains as well as occasional summer cloudbursts are held to be responsible for it. Although the average depth and duration of snow cover is on the decline, extreme values of such parameters often occur. The excess water hazard map of Hungary (Pálfai, I. 2009) identifies four classes:

1 – no hazard areas, where highly permeable surface deposits (sands) prevent enduring inundation;

2 – moderate hazard, where natural levees in floodplains and lower sections of alluvial fans are occasionally affected;

3 – medium hazard, where one-time floodways and backswamps and swamps enclosed between alluvial fans are exposed to rising groundwater and

4 – serious hazard, where inundations regularly recur in wet years.

The first three categories make up more than two million hectares in Hungary, i.e. one-third of the agricultural area. In wet years excess water is a source of great damage to Hungarian agriculture, public transport (washing away railway embankments) and tourism (the proliferation of mosquitoes).

Waterlogging in river valleys of hill regions

The spatial and temporal development of inundation in narrow floodplains of hill regions (like the Kapos River floodplain under study) takes a course different from that in broad lowlands (for instance, of the Tisza River and its tributaries). In the former case concentrated cloudbursts create inundations which affect the floodplain all along the river, particularly in broader sections (embayments), while in the Great Plain extensive partial areas are flooded with rapid and hardly predictable dynamics.

The *'flood pulse' concept* (Junk, W.J. *et al*. 1989) portrays a simple time sequence of *floodplain flooding* (*Figure 1*, I. A–C). However, during floods the incursion of river water across the surface of a 'convex' floodplain may be strongly affected by floodplain 'wetness' (groundwater, hyporheic water, run-off from the hillslopes surrounding the floodplain, direct precipitation and antecedent water from earlier floods) (Mertes, L.A.K. 1997).

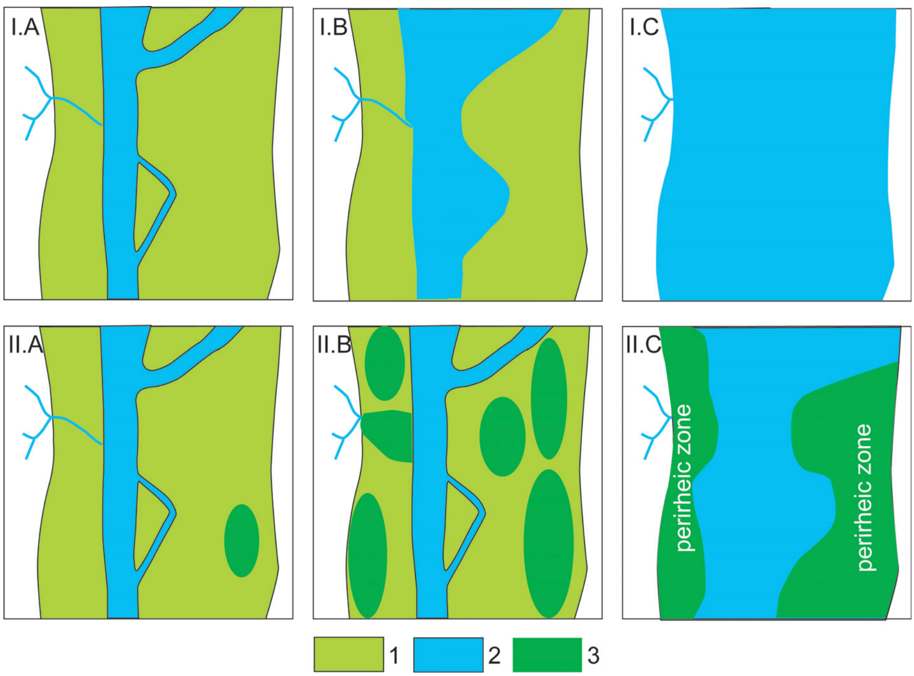

Fig. 1 Comparison of flood development according to the flood pulse concept (I.A–C, after Junk, W.J. and Wantzen, K.M. 2004) and according to the perirheic zone concept of floodplain inundation (II.A–C, after Mertes, L.A.K. 1997). I.A = dry floodplain before flood; I.B = flood inundation extending from river channel; I.C = complete inundation of the floodplain; II.A = floodplain with high groundwater table and local wetlands before flood; II.B = extending excess groundwater patches during rising river stage; II.C = inundated floodplain with streamwater/groundwater mixing ("perirheic zone"). 1 = floodplain; 2 = river channel and streamwater-inundated areas; 3 = excess groundwater-inundated areas and the perirheic zone

Consequently, somewhat different temporal and spatial patterns of flooding result: along with the hyporheic zone, a mixing zone of stream and (excess) groundwater, the *'perirheic zone'*, is created (*Figure 1*, II.A–C, after Mertes, L.A.K. 1997).

Study area: the Kapos River catchment

The medium-sized catchment of the *Kapos River* covers 3,295.4 km^2 in the Outer Somogy Hills region (*Figure 2*). The trunk river is 112.7 km long, a 5th-order stream at confluence with the Sió Canal (the outflow of Lake Balaton to the Danube). The topographical floodplain (without that of the tributaries) extends over 104.2 km^2, which makes up 3.3 per cent of the total catchment area.

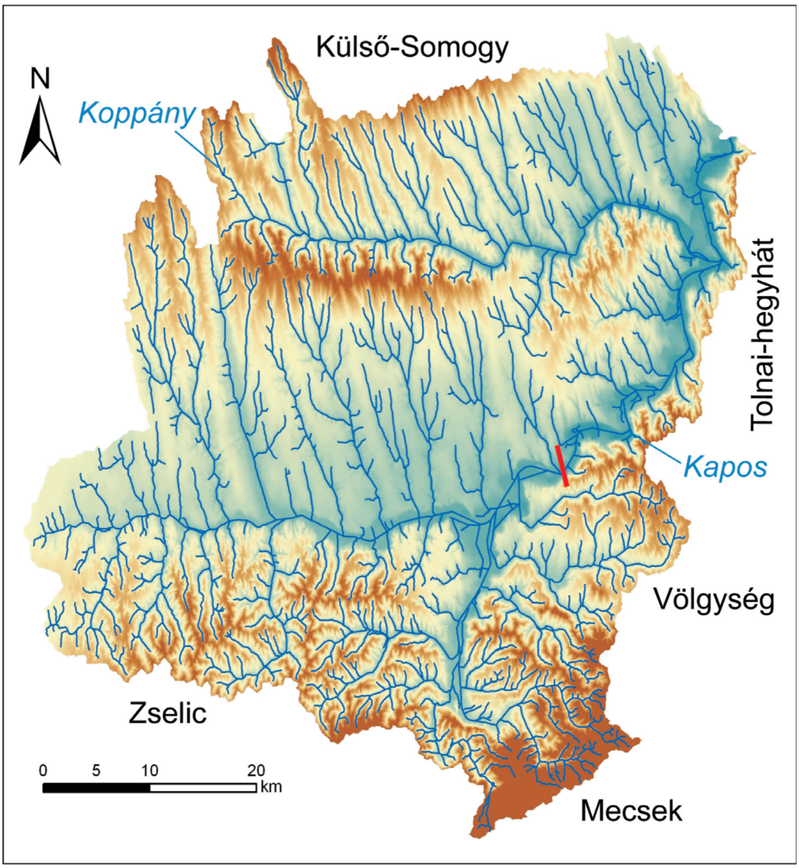

Fig. 2. DEM representation of the Kapos River catchment

High-water flow regulation in the early 19th and mid-20th century (Ihrig, D. 1973) did not fully eliminate flood and inundation hazards in the Kapos Valley. Even today all streams of the catchment show *high flood hazards* since global climate change increases the probability of non-predictable rainfall events and flash floods (Czigány, Sz. *et al.* 2010). Water regime shows low-water stages in August–early September and high water most often in March (caused by snowmelt in the hills). Most of the other extremes 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*. Water seepage beneath dykes and impoundments at the confluences of tributary streams may further aggravate the situation.

The events of May and June 2010 called attention to inundations in the perirheic zone and increased vulnerability to flooding also along smaller tributaries (Lóczy, D. *et al.* 2012). For the mapping of the spatial extension of waterlogging and estimating inundation hazard, alternative methods have been tried. Although it cannot be confirmed yet by groundwater table monitoring, the 2010 flooding in the Döbrököz embayment clearly shows a waterlogged perirheic zone also significantly contributed to the inundation of the floodplain.

Inundation hazard evaluation from topographic and drainage analyses

Through the detailed survey and mapping of landforms and DEM representation of topography, most (and earliest) flood endangered tracts on the floodplain can be relatively easily identified (see e.g. Lastra, J. *et al.* 2007). Among the GIS methods the *MrVBF index* (Gallant, J.C. and Dowling, T.I. 2003) is of outstanding significance. In order to be able to use the MrVBF approach for inundation hazard assessment in Hungary, a table to assess *sensitivity to inundation* was prepared *(Table 2).* It is based on inundation frequency, soil drainage and position in relief. When applied for the Kapos floodplain, it was supplemented with reference sites field-checked after the 2010 rainfall events.

Inundation hazard evaluation by remote sensing

The interpretation of remote sensing images taken during floods (particularly high-resolution Ikonos and SPOT images and aerial photographs) can also be of help in the identification of areas with inundation hazard (Rakonczai, J. *et al*. 2003). Unfortunately, few images are suitable for this purpose. They have to be taken shortly after flooding, and the percentage of cloud cover has to remain below 10 per cent. For the floodplain embayments the *map of possible inun-*

Table 2. Inundation sensitivity classes of the floodplain *

Rank score	Sensitivity class	Description	Example from the Kapos Valley
0	not sensible (inundation not probable)	soils with medium to good water budget in higher position	natural levee (south of Regöly)
1	low	soils with medium water budget occasionally inundated in winter and spring on hill summits and slopes	footslopes on the right bank (Tolna Hills) (e.g. at Keszőhidegkút, Belecska)
2	low to medium	soils with medium water budget potentially inundated in winter and spring, limited cultivability, on hill midslopes and footslopes	footslope zone of terrace levels (e.g. Döbrököz, Kurd – back gardens)
3	medium	soils with poor water budget and reduced cultivability because of saturation or inundation, on footslopes, flat surfaces, depressions	margins of backswamps in the Dombóvár–Döbrököz embayment
4	medium to high	uncultivable soils with poor water budget, seasonally inundated, on footslopes, flat surfaces and depressions	bottom of backswamp in the Szakály embayment
5	high	soils with poor water budget under enduring inundation, cultivation is limited throughout the year, found on valley floors, in depressions	old meanders, infilled oxbows (e.g. southeast of Regöly)

* Compiled by Lóczy, D. from various sources.

dation (Figure 3) was based on the first available image after the flooding and was constructed 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 on the image from the Hungarian Water Management Database. (The allocation error of drainage lines may amount to ca 100 m.) The *smoothed envelope curve* embraces all 'water' pixels and provides at least and approximation of areas potentially affected by waterlogging *(Figure 3)*. (On the basis of field observations, it is assumed that the patches of early summer inundations survived to a large extent well into the autumn.)

Studying the figure, the following observations can be made. The contiguous inundated areas are closely associated with the elements of the drainage network (the Kapos canal, the also channelized tributary streams and the drainage canals). At the same time, minor water surfaces in the marginal zone of the

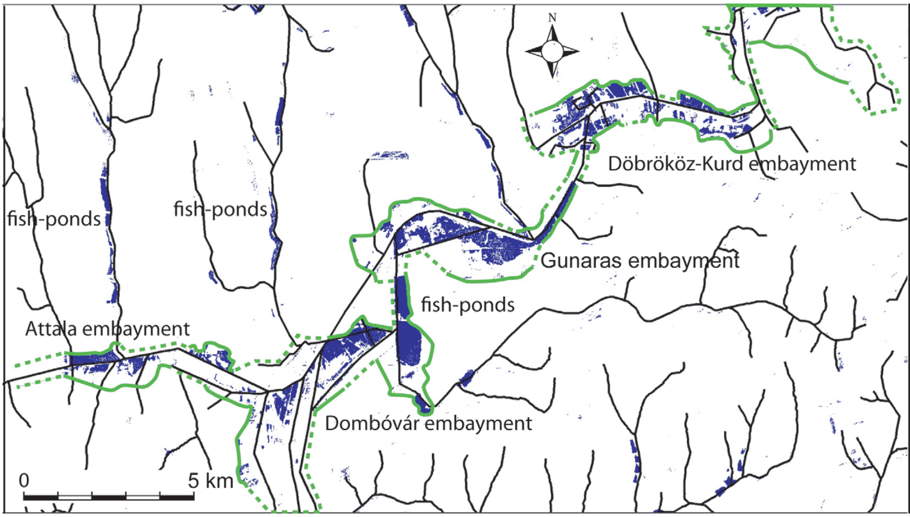

Fig. 3 Excess water inundation in the Kapos floodplain between Nagyberki and Kurd on 24 September 2010 (based on Landsat-7 ETM+ image). The dashed line indicates sections where only approximate width of the inundated zone can be established

floodplain, which derive from rainwater runoff and throughflow generated on the neighbouring hillslopes. Some manmade features of the floodplain impound both kinds of flow.

This kind of reconstruction, however, cannot show a complete picture since, for various reasons, along some sections no water surface can be observed at all. Here the approximate boundary of maximum possible inundation is shown by a dashed envelope line. 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 authors of the mentioned paper on mapping excess water inundations in the Great Hungarian Plain cite several sources of incorrect identification.

Inundation hazard evaluation from soil distribution

Land drainage measures, as corollaries to river regulation, modify or even reverse the soil formation sequences in the former floodplains. As a consequence of the hydromorphic effect, on higher grounds of the floodplain meadow *soil dynamics* had been prevalent before river regulation. With land drainage groundwater levels dropped and chernozem dynamics became predominant.

In lower-lying spots of the floodplain (in the infilling oxbows and backswamps) bog formation had been the typical pedological process, but after water management interventions the peat bogs (Fibric Histosol) began to transform into muck (Hemic Histosol) and 'earthy' or humified peat (Sapric Histosol), where the groundwater lies at 1.5–2 m deep below the surface (Dömsödi, J. 1988). In the Kapos floodplain this process is of particularly great significance (Lóczy, D. 2013). Bog degradation in the Kapos Valley is a process with unfavourable impact on temporal waterlogging.

In the Kapos floodplain *bog soils (Histosols)* are related to the former bogs of the valley floor drained during the water regulations in the early 19th century *(Figure 4)*. Peat occurs in the most extensive areas and thickest (up to 6 m thick) beds (with silt interbeddings) along the uppermost course of the Kapos River and in the valleys of tributary streams there (Gergely, E. *et al*. 2000).

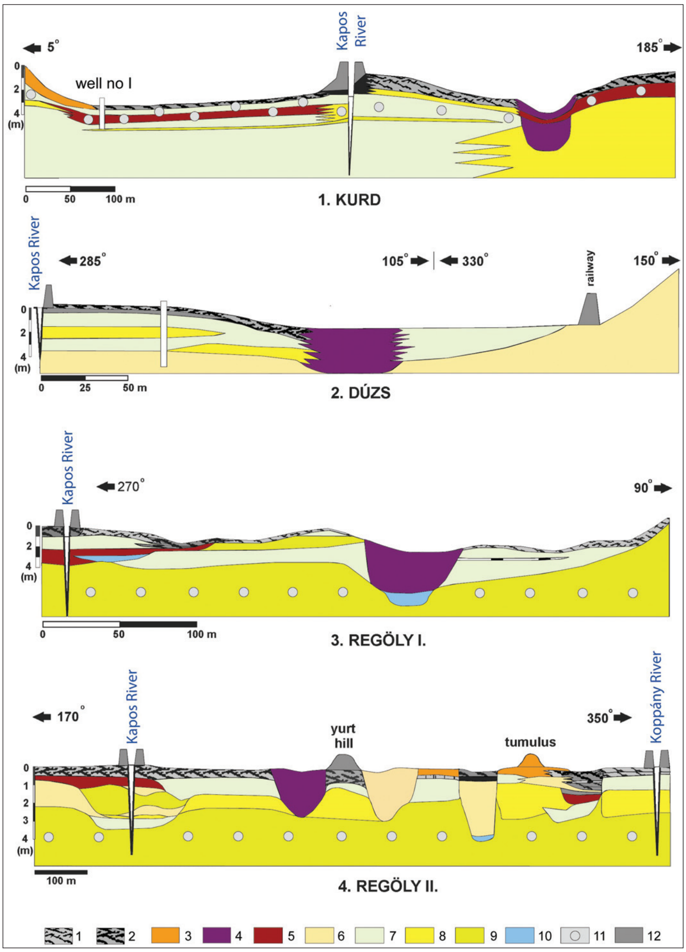

Fig. 4. Soil catenas across the Kapos Valley (edited by Dezső, J. 2012). Main soil types: 1 = Haplic Gleysol; 2 = Histic Gleysol; 3 = Cambisols; 4 = Histosols. Parent materials: 5 = clay; 6 = loess; 7 = silt; 8 = fine sand; 9 = coarse sand; 10 = layer with mollusc shells; 11 = gleyic horizon

Along the Upper Kapos the peat beds are typically underlain by unconsolidated silts, peat-bearing silt and calcareous silt deposited upon clay, sandy clay and fine sand layers. In the major floodplain embayments downstream, thinner humified peat and muck beds alternate with meadow clays. In the Upper Kapos Valley most of beds are composed of fibrous *Sphagnum* peat of fine fabric *(Table 3)*. The most extensive peat area is ca 12 km long, 400–500 m wide and the peat beds are 2 m deep.

The soil profile shows evidence of *organic matter accumulation* and *decomposition* as well as biotic action and hydromorphic influence. If exposed, the decomposed muck of porous structure and low bulk density is highly susceptible to *wind erosion*, particularly in spring when the surface is still barren.

Meadow soils are the widest spread soil type of the floodplain, typical of the waterlogged bottom surfaces of *backswamps* and *oxbows*. The uppermost, ploughed horizon is of crumbly structure, but often degraded to porous. It is underlain by a ferric horizon of marked red colour *(Table 4).* Hydromorphic effect (mottled fabric) is observed at 0.5 to 1 m depth.

Located in depressions, such soils receive surplus water from the surrounding, somewhat higher, surfaces and, therefore, are usually waterlogged.

In addition to the reconstruction of former channels and wetlands, which are important elements of the landscape structure, another benefit of collecting *soil survey information* is the help they provide for the delimitation of areas of excess water hazard.

The *water budget classes* of the genetic soil types occurring on the floodplain are identified using a table *(Table 5)* compiled from various literary sources and also drawing information from the interpretation of the Landsat image. When detailed soil data are available, the *wetness classes* of the Soil Survey of England and Wales can also be applied (McRae, S.G. and Burnham, C.P. 1981 – *Table 6)*.

Classification is based on depth to groundwater table and the duration of soil water saturation. The subtypes and varieties of meadow soils (Histosols and Gleysols) which are liable to be waterlogged in rainy periods can be identified on the soil map: boggy meadow soil, mucky meadow soil, 'earthy peat' and peaty meadow soil.

Since all the typologies presented in the three tables define six classes, comparisons between them are relatively easy. Having completed the assessments, the embayments of the Lower Kapos floodplain are mostly found to belong to the inundation sensitivity classes 2–3 (low to medium sensitivity); show rank scores 2–3 (medium susceptibility to inundation; poor to medium infiltration capacity and permeability; high water storage) and fall into the British wetness classes II or (less typically) III (moderately well drained or imperfectly drained).

Table 3. Field description of a widespread Histosol variety from the Kapos floodplain (by Dezső, *J. and* Lóczy, *D.)*

Locality	Locality description				Genetic soil type	WRB soil type
Code:	Regöly R7F	Land use: meadow/grazing land (ancient root traces indicate one-time floodplain softwood forest) Landform: bottom of oxbow				
Date of survey	21.08.2011	GPS coordinates			*Pseudogleyic meadow soil*	*Gleyic Histosol*
		x	y	z	Parent material: silt	Groundwater table: -280 cm
Soil pit	0–150 cm	137711N	601580E	101 m		

Horizons, cm	Profile description	Colour	Physical type	Effer-vescence/ carbonate, %	K_A*	Salts, per cent
0–15	crumbly in the root zone, muck, not ploughed	dark yellow to light brown, 10YR 3/4	clayey silt	strong/>10	66	0.11
15–25	decomposed peat of porous structure, red ferric precipitations	yellowish red, 5YR 6/8	–	very slight/<2	66	0.11
25–45	compact, disintegrating into slabs, pitch black, shiny clay films on skeletal particles	black, 10 YR 2/1	clay loam	non-effer-ves-cent/0	47	0.08
45–50	bioturbated (?), transitional towards gleyed heavy clay	mixed	clayey silt	strong/ 10–25	47	–
50–90	pseudogleyic horizon with rusty precipitations along root traces, root and bioturbation chan-nels	grey	compacted silt	violent/ >25	47	0.09
90–120	layer rich in rusty precipitations along root channels	mixed with olive grey ma-trix, 5Y 6/2	fine silt	violent/ >25	32	0.09
120–150	rusty ferric and soft calcareous precipitations along root channels	mixed	fine silt	violent/ >25	–	–

Table 3. folytatása

Locality	Locality description								
Code:	Regöly R7F	Land use: meadow/grazing land (ancient root traces indicate one-time floodplain softwood forest) Landform: bottom of oxbow			Genetic soil type		WRB soil type		
Date of survey	21.08.2011	GPS coordinates			*Pseudogleyic meadow soil*		*Gleyic Histosol*		
		x	y	z	Parent material: silt		Groundwater table: -280 cm		
Soil pit	0–150 cm	137711N	601580E	101 m					
Horizons, cm	Profile description				Colour	Physical type	Effer-vescence/ carbonate, per cent	K_A*	Salts, per cent
150–210	fluvially reworked loess?				light grey, 5Y 7/2	silt	violent/ >25	–	–
210–270	homogeneous fluvial deposit				light grey, 5Y 7/2	silt	strong/ 10–25	–	–
270–310	redeposited loess, groundwater table at 280 cm				light grey, 5Y 7/2	silt	strong/ 10–25	–	–
310–340	homogeneous fluvial deposit				light grey, 5Y 7/1	fine sand	strong/ 10–25	–	–
>340	homogeneous fluvial deposit				light grey, 5Y 7/1	silt	strong/ 10–25	–	–

* Arany's Plasticity Index (for explanation see the text)

Table 4. *Field description of a typical Gleysol (meadow soil) from the Kapos floodplain (by* Dezső, *J. and* Lóczy, *D.)*

Locality	Locality description				Genetic soil type		WRB soil type
Code:	Regöly R3F	Land use: arable field with horse raddish Landform: bottom of backswamp			*Meadow soil under cultivation*		*Mollic Gleysol*
Date of survey	20.08. 2011	GPS coordinates			Parent material: fine sand		Groundwater table: >150 cm
Soil pit	0–150 cm	x	y	z			
		134644N	598925	95 m			
Horizons, cm	Profile description				Colour	Physical type	Effer-vescence/ carbonate, per cent
0–25	reddish brown matrix with dark grey bioturbated elements				yellowish red; 5YR 5/6	silt	strong/ 10–25
25–45	compacted, homogeneous, slab structure, dark grey shiny clay films				black, 10YR 2/1	clay	non-effer-ves-cent/0
45–55	crumbly with rusty precipitations, gleyic matrix with black clay in channels				mottled	fine sand, clay	strong/ 10–25
55–120	gleyed sand with pale ferric precipitations				light yellowish brown, 2.5Y 6/4	medium sand	strong/ 10–25
>120	indistinct structure				light grey, 5Y 7/2	medium sand	slight/ 2–10

*Table 5. Evaluation of genetic soil types occurring on the Kapos floodplain according to their susceptibility to inundation **

Rank score	Predictable saturation		Genetic soil (sub)types	Drainage properties		
	Frequency, years	Duration, weeks		Infiltration capacity, mm d^{-1}	Transmission capacity, mm d^{-1}	Storage capacity, mm m^{-1}
0	50–100	less than one	meadow chernozem, chernozem meadow soil	good: 300–1000	good: 150–500	good: 100–150
1	20–50	1–2	meadow soil, calcareous alluvial meadow soil	high: >1,000	high: 500–1,000	medium: 50–100
2	10–20	3–4	boggy meadow soil	medium: 100–300	medium: 50–150	high: 150–200
3	5–10	4–8	earthy peat ('black earth')	poor: 50–100	poor: 10–50	high: 150–200
4	2–5	several months	bog soil with muck	poor: 10–100	very poor: <10	high: 150–200
5	1	several months	bog soil with peat	poor: 10–100	very poor: <10	very high: >200

* Compiled by Lóczy, D.

Table 6. Wetness classes of soils according to the depth of the soil horizon saturated to water capacity

Wetness class	Water saturation		Drainage class (approximate)
	Depth, cm	Duration, day per year	
I	>70	<30	well drained
II	<70	30–90	moderately well drained
III	<70	90–180	imperfectly drained
IV	<40	>180	poorly drained
V	<40 or <70	>180 or >335	very poorly drained (waterlogged)
VI	<40	>335	very poorly drained (regularly inundated)

Source: Soil Survey of England and Wales.

Groundwater table monitoring

At high (flood) stages the unconsolidated floodplain deposits and soils are assumed to temporarily store water before it is conveyed downstream. The overall effect of this water storage is the delay and attenuation of the flood peak in downstream areas. *Flow pathways* are often deflected from the alignment of the main channel and often run diagonal towards the channel in a downstream direction (Kelly, B.P. 2001). Over a narrow floodplain (such as that of the Kapos River) another major element of subsurface flow is the spatial continuation of *throughflow* from the neighbouring hillslopes, which is close to perpendicular to the channel. It often causes waterlogging during high river stages (perirheic zone). The major controls on the alignment of groundwater flow ('underflow') paths are the hydraulic properties of floodplain deposits, regional slope and sinuosity (Larkin, R.G. and Sharp, J.M. Jr. 1992).

Unfortunately, to realistically depict groundwater flow a dense network of observation wells with long time series would be necessary. The national *monitoring* system of *groundwater levels* only very sparsely covers the Kapos floodplain and the embayments of the lower segments are not monitored at all. In order to receive information on the position of groundwater in the floodplain for the period November 2011–October 2012, we installed measuring instruments (Dataqua DA-S-LRB 122 SMART rigid sound water level gauges, precision: ±0.1 per cent; measurement range: 0–200 cm; manufactured by Dataqua Electronic Co., Balatonalmádi, Hungary) into two observations wells (at Kurd, at a short distance from the river gauge, and downstream of the constriction, at Dúzs). The first year when an uninterrupted record of groundwater table fluctuations could be obtained was 2012 *(Figure 5).* Naturally, the laws of groundwater flow could only be revealed after a much longer period of monitoring.

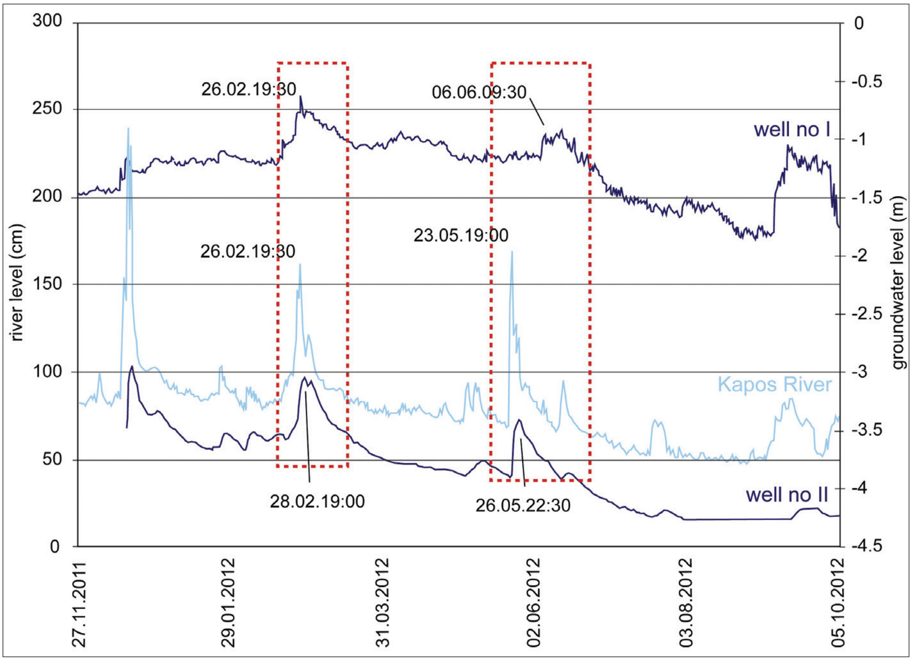

Fig. 5. River stages of the Kapos River at the Kurd gauge and groundwater levels recorded in observation wells I (Kurd) and II (Dúzs) between November 2011 and October 2012 (by Dezső, J. 2012)

Assessing the intensity of mutual stream/groundwater interactions in the Kapos floodplain, Considerable recharge is observed from infiltration (snowmelt) and early spring floods, when evaporation losses are not yet remarkable, and in the saturated floodplain deposits *perirheic flow* (Mertes, L.A.K. 1997) is regularly observed. The river stages and water levels of observation well I were raised by rapid snowmelt in late February. The much lower groundwater table in well II responded with a remarkable *delay.* The groundwater reserves, however, are heavily depleted by evaporation caused by rising temperature in the first third of the growing season. Although the highly variable amounts of (early) summer precipitation are of great ecological significance, high temperatures considerably reduce their contribution to groundwater recharge. The rainfall event in July did not influence water level in well I, while its impact with a three-day delay (similar to that in February) was observed for well no II.

Since infiltration does not reach the groundwater table, summer showers are mostly inefficient in groundwater recharge. In lack of by-channels and oxbows and backswamps in the perirheic zone drained, higher river water stages are unable to saturate floodplain soils. Where high-porosity layers are uninterrupted between the channel and more remote areas of the floodplain, groundwater recharge also occurs in drought periods.

Conclusions

Different approaches have been tried to present inundation hazard in the narrow floodplain of a medium-sized river in a hill region of Hungary. Supplemented with long-term groundwater level monitoring, the joint application of the presented methods can lead to realistic identification of areas with high-probability groundwater flooding.

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