GROUNDWATER FLOODING HAZARD IN HILL REGIONS: EXAMPLE OF THE KAPOS RIVER, SW-HUNGARY

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ABSTRACT. Groundwater flooding hazard in hill regions: example of the Kapos River, SW-Hungary. 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. 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, soil distribution and groundwater surveys are jointly applied to assess the true extent of frequent inundation hazard.

Keywords: inundation hazards, floodplain, Kapos River catchment,

1. 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 flooding* 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. 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'. It is necessary to mention that from the aspect of flood and inundation hazards *small watercourses* also deserve attention.

2. INUNDATIONS IN LOWLANDS AND HILLS

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. Recurrence intervals of extreme waterlogging have been calculated for Hungary

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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 (modified after Pálfai, I. 2009)*

probability of occurrence (%)	*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

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. During floods the incursion of river water across the surface of a ’convex’ floodplain may be strongly affected by floodplain ’wetness’. Thus a mixing zone of stream and (excess) groundwater, the *’perirheic zone’*, is created (Mertes, L.A.K. 1997).

3. 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 (*Fig. 1*). 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 (3.3 per cent of the total catchment area – Lóczy, D. 2013). 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. Global climate change increases the probability of non-predictable rainfall events and flash floods (Czigány, Sz. et al. 2010). The events of May and June 2010 called attention to 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 indicates the presence of a waterlogged perirheic zone.

Fig. 1 ***DEM representation of the Kapos River catchment***

4. APPROACHES TO INUNDATION HAZARD 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. Among the GIS methods, the *MrVBF index* (Gallant, J.C. & 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, supplemented with reference sites *(Table 2)*, field-checked after the 2010 rainfall events.

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. The *map of possible inundation (Fig. 2)* was based on the first available image after the flooding: band 6 of the Landsat-7 (ETM+) image for 24 September 2010. 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 *(Fig. 2).*

Table 2 ***Inundation sensitivity classes of the floodplain (compiled by Lóczy, D. from various sources)***

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)

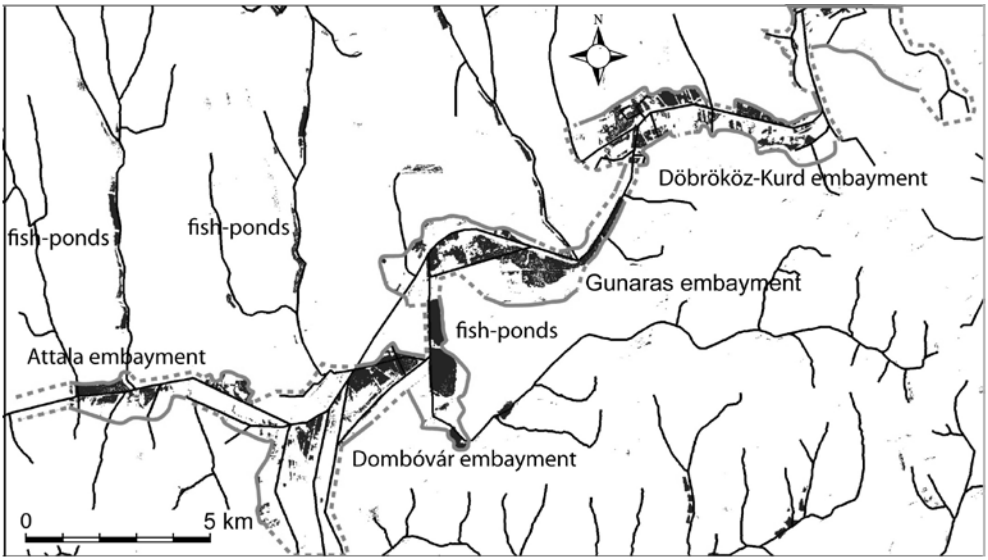

Fig. 2 ***Excess water inundation in the Kapos floodplain between Nagyberki and Kurd on 24 September 2010 (based on Landsat-7 ETM+ image).***

The dashed line indicates sections where only approximate width of the inundated zone can be established

The contiguous inundated areas are closely associated with the elements of the drainage network. Minor water surfaces in the marginal zone of the floodplain derive from rainwater runoff and throughflow generated on the neighbouring hillslopes, impounded by some manmade features.

This reconstruction, however, cannot show a complete picture. 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 interpretation of *soil survey* information is another useful approach to the delimitation of temporarily waterlogged areas. *Land drainage* measures, as corollaries to river regulation, modify or even reverse soil formation processes. Meadow *soil dynamics*, prevalent before river regulation, was replaced by chernozem dynamics. After water management interventions, in the infilling oxbows and backswamps, peat bogs (Fibric Histosol) began to transform into muck (Hemic Histosol) and 'earthy' or humified peat (Sapric Histosol) (Lóczy, D. 2013).

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 *(Fig. 3)*. *Meadow soils* are the widest spread soil type of the floodplain, typical of the waterlogged bottom surfaces of *backswamps* and *oxbows*. Located in depressions, such soils receive surplus water from the surrounding, somewhat higher, surfaces and, therefore, are usually waterlogged. The water budget classes of the genetic soil types occurring on the floodplain are identified *(Table 5)*.

In summary, 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).

5. GROUNDWATER TABLE MONITORING

At high (flood) stages the unconsolidated floodplain deposits and soils are assumed to temporarily store water and attenuate flood peaks. In the narrow Kapos floodplain the spatial continuation of throughflow from the neighbouring hillslopes also causes waterlogging during high river stages (perirheic zone).

To realistically depict groundwater flow a dense network of observation wells with long time series would be necessary. The national monitoring system only sparsely covers the Kapos floodplain. 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. An uninterrupted record of groundwater table fluctuations could be obtained for the period November 2011–October 2012 (Fig. 4).

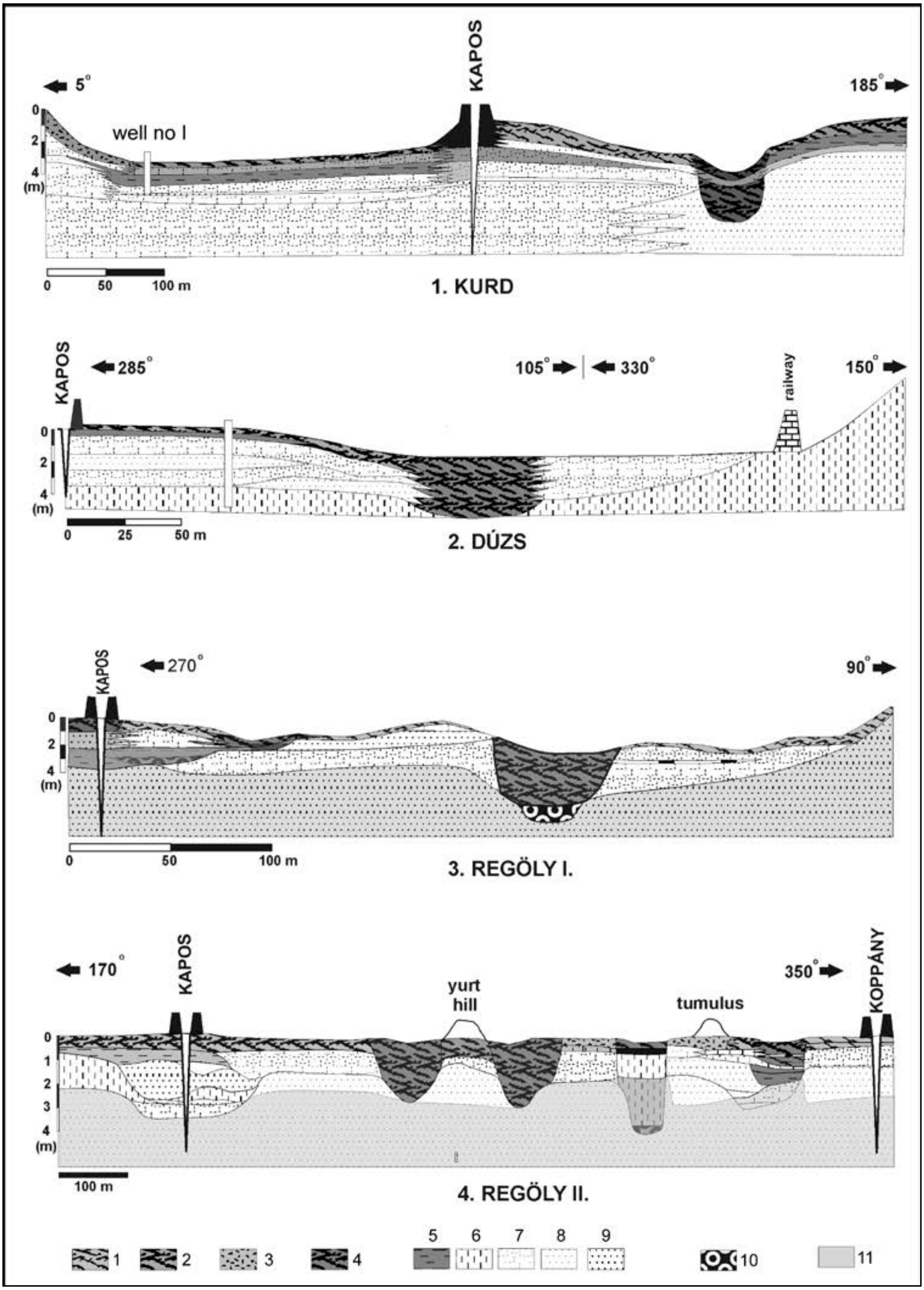

Fig. 3 ***Soil catenas across the Kapos Valley (by Dezső, J.).***

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

Table 5 ***Evaluation of genetic soil types occurring on the Kapos floodplain according to their susceptibility to inundation (compiled by Lóczy, D.)***

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: >1000	high: 500–1000	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

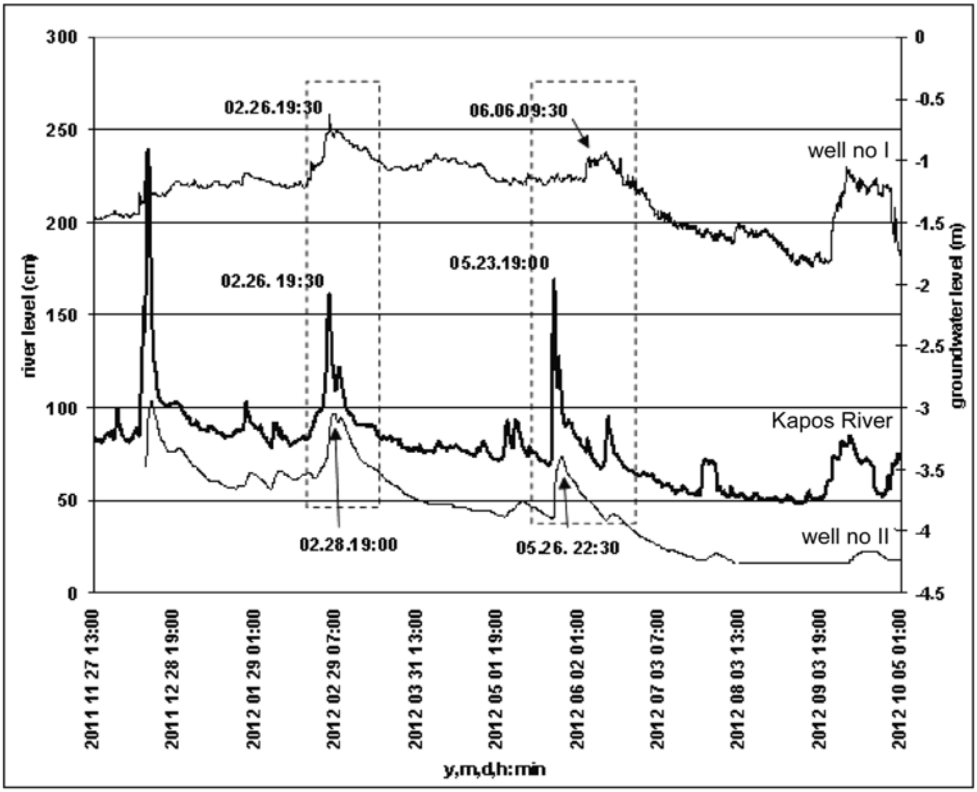

Fig. 4 ***River stages of the Kapos River at the Kurd gauge and groundwater levels recorded in observation wells I (Kurd) and II (Dúzs) between November 2011 and October 2012 (by Dezső, J.)***

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, while well II. responded with a remarkable *delay*. High temperatures considerably reduce the contribution of summer rains to groundwater recharge. Since infiltration does not reach the groundwater table, summer showers are mostly inefficient in this respect. Even higher river water stages are unable to saturate floodplain soils, but high-porosity layers between the channel and more remote areas of the floodplain ensure groundwater recharge also 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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