SOME GEOMORPHOLOGICAL AND GEOECOLOGICAL IMPACTS OF THE 2010 EXTREME RAINFALLS IN HUNGARY

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ABSTRACT. Some geomorphological and geoecological impacts of the 2010 extreme rainfalls in Hungary. The extreme rainfall events in the unusually wet year of 2010 brought about major changes in the floodplains of several streams in Hungary. On the small watercourses in low mountain or hill environments flash floods were generated. In the floodplains of medium-sized rivers, like the Kapos River in Southern Transdanubia, lasting inundations transformed the landscape. The system of wetlands preceeding the 19th-century river regulation and land drainage measures was restored by natural processes and within a very short time as excess water filled the entire broad valley sections in a shallow layer temporarily, for some weeks, and the former oxbows for several months. The nature conservation value of the river valley increased: reed and sedge beds and the brooding colonies of aquatic birds extended. There are, however, unfavourable impacts as well. Denser wetland vegetation significantly contributes to the organic filling of floodplain landforms. The spreading of invasive plants (allergetic ragweed, *Ambrosia artemisiifolia*, in the first place) was promoted by the prolonged survival of extensive bare but moist silt surfaces in the floodplain. The long-term effects of this colonization on floodplain communities are unpredictable. A delayed and indirect impact of extreme rainfalls was the breach of a red sludge reservoir near the Ajka alumina plant in October, 2010 and the resulting environmental disaster. After the gradual accumulation of rainwater in the reservoir, the dyke breach happened, released 600-700 thousand m^3 of basic (up to pH 13!) sludge over the floodplain of the Torna Stream, a tributary of the Marcal and Rába rivers in an area of ca 40 km^2. The emergency mitigation measures (spreading gypsum from power plants to neutralize the strong base) over the layer of red sludge accumulation proved unfortunate as it prevented that the sludge should be washed downstream and diluted. The gypsum crust hindered the natural regeneration of aquatic life. With serious damage to residential buildings, the ecological impacts on the floodplain may not be as long-standing as predicted.

Keywords: flash floods, inundation, red sludge spill, channel and floodplain changes

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1. INTRODUCTION

In late May and early June 2010 prolonged excessive rainfalls (amounts locally exceeding 300 mm per month, i.e. three or four-fold the monthly average amount) affected most of the Carpathian Basin simultaneously. In the catchments of some medium-sized and minor rivers serious inundations immediately followed. Critical flood situations occurred in Northeast-Hungary (along the Sajó, Zagyva and small streams with sources within Hungary), Northern Transdanubia (along the streams springing in the Bakony Mountains) and Southern Transdanubia (the Kapos and tributaries).

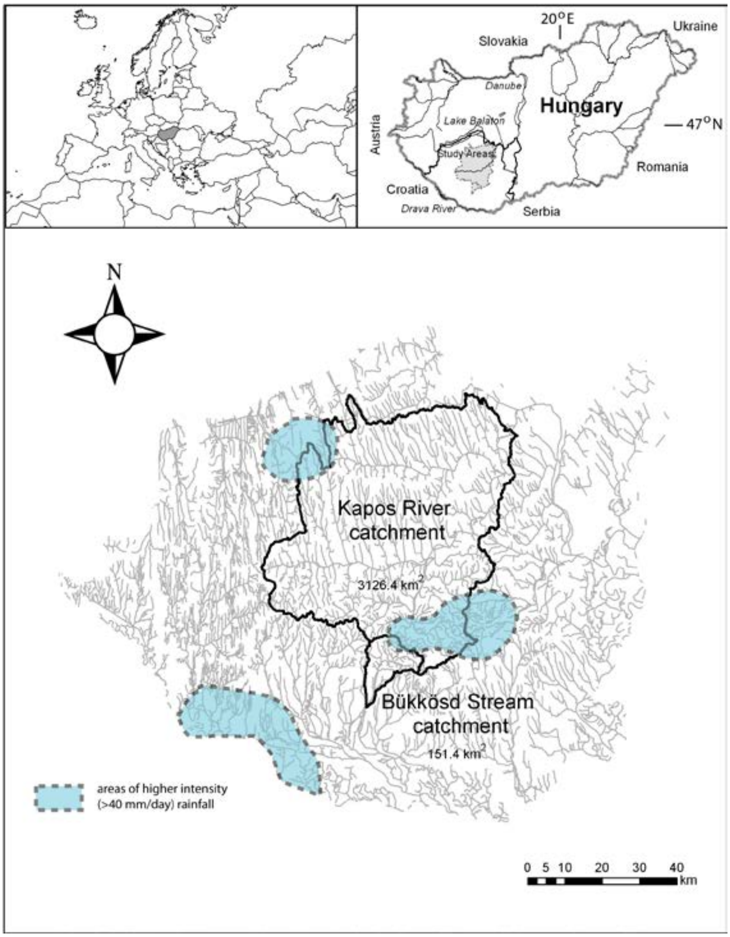

Fig. 1 ***The drainage network of Southern Transdanubia with the Kapos catchment as affected by extreme rainfall events and flash flooding in May-June, 2010***

The reason behind property damage was caused by extensive housing and commercial developments on the 100-year floodplain, which were granted permission from environmental authorities during drier periods (Lóczy, 2010a).

2. **FLASH FLOODS**

The Outer Somogy Hills is a region of minutely dissected relief, stream catchments of restricted area and large cultivated fields on loess soils replacing former continuous deciduous forests. For such reasons the hills are particularly affected by extreme precipitation events deriving from Atlantic and Mediterranean cyclones. Most of the hills belong to the catchment of the Kapos River (3,295.4 km^2 – Fig. 1). The trunk river is 112.7 km long, a 5th-order stream at confluence to the Sió Canal (the outflow of Lake Balaton to the Danube) (Lovász, 2003).

The geological substrate is a Quaternary loess mantle, in valleys up to 15 m, on hills up to 25 m in thickness, directly overlying Upper Miocene marine and lacustrine clays and sands (Szilárd, 1967; Csontos et al., 2005). Neotectonic tilting (Csontos et al., 2005) has produced remarkable asymmetry on the Kapos catchment: typical slopes on the northern valley side with Pleistocene terraces are 2.5–3.5º and only exceptionally exceed 15º, while slopes of 15–25° angle also occur in the south slopes. Channel shifting to the right also steepened the southern valley margin before channelization. Asymmetry is also reflected in the contrasting alignment of tributary valleys between the northern and southern portions of the catchment (Fig. 1).

The predominant climate types are subatlantic with a typical mean annual temperature sligthly above 10ºC and an annual precipitation of 680–720 mm (at Dombóvár, the average for the period 1901-1950: 707 mm and for 1951-2000: 673 – data from National Meteorological Service), and subcontinental (12ºC and 650–690 mm, respectively) (at Hőgyész: 654 mm for 1901-1950 and 702 mm for 1955-2000). 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 et al., 2010).

2.1. Excess water in the Kapos Valley

On 14 May 2010 the frontal system of a well-developed Mediterranean cyclone reached Hungary. The ensuing rainfall events, lasting for several days or even weeks, brought unusually high amounts of rainwater onto most of the territory, including Southern Transdanubia. In Kaposvár 139.5 mm rainfall fell between 14 and 17 May as opposed to the long-term (1951-2000) average of 63 mm (according to data from the National Meteorological Service). Peak water stages and discharges on the tributaries of the Kapos river were the following on 17-18, May: on the Surján Stream at Szentbalázs gauge: 265 cm (this means 9.5 m^3/s discharge, as opposed to the mean discharge of 0.29 m^3/s); on the Baranya Canal at Csikóstőttös 416 cm (discharge: 65.0 m^3/s; mean discharge: 1.83 m^3/s). The Kapos River itself transported 30.8 m^3/s water at Kaposvár-Fészerlaknál – 18-fold higher than the long-term average of 1.69 m^3/s (data from the Southern Transdanubian Directorate of Environmental Protection and Water Management). In spite of the high flood wave the settlements of the valley could be protected. A single dam breach took place at the village of Döbrököz, where the gardens of some homes built on the protected floodplain were inundated. Even the Orci Stream, the tributary with the most subdued longitudinal profile was impounded by the Kapos River and the stream inundated its lower floodplain.

The humid summer was also unusually cool and rainwater from repeated precipitation events could not evaporate. Rising groundwater levels resulted in extensive but shallow excess water inundations all over the valley floor of the Kapos River and its tributaries. The situation was most serious along the Tolna County section of the Kapos, where first of all meadows, pastures and tree plantations were flooded but some arable land was also affected. The depth of the temporary ponds was 15-20 cm on the average and only exceptionally exceeded 0.5 m. In the summer of 2010 hot weather was only restricted to two or three weeks and, thus, evaporation was not able to considerably reduce the extension of inundated areas but it warmed up their water and speeded up biological processes.

The extension of areas affected by excess water was reconstructed by field survey and remote sensing (oblique aerial photographs and satellite images) techniques (Lóczy, 2010b). To establish the morphological floodplain the GoogleEarth image for 5 February 2007 showing dry conditions was employed and compared with the extension of alluvial deposits (”fluvial clay, silt, sand or gravel” marked as Qh2) on maps of the 1:200,000 scale geological map of the Hungarian Geological Survey (Budai & Gyalog, 2010).

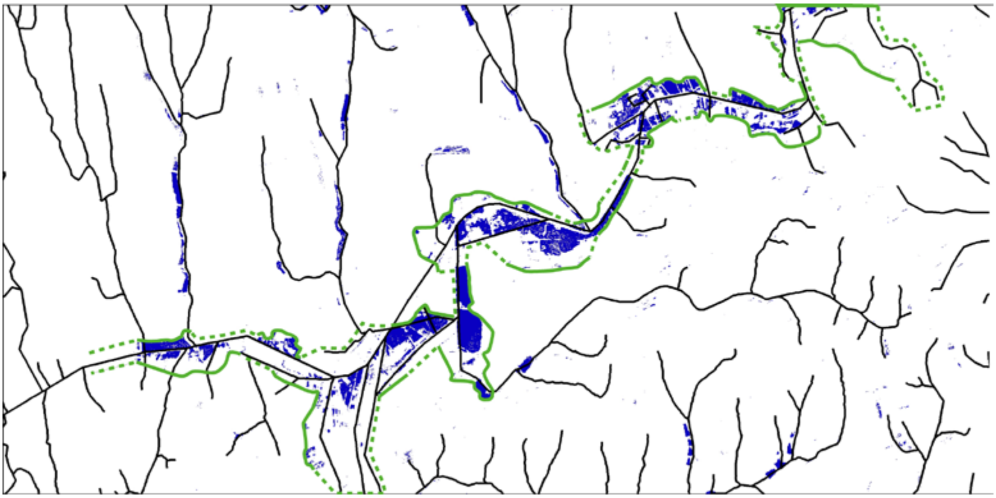

Fig. 2 ***Inundated areas along the Kapos River on 23 September 2010 interpreted from Landsat ETM image.*** The boundary line of the reconstructed morphological floodplain is marked (with dashed line where only assumed)

On the inundation maps (see extract in Fig. 2) it is clearly visible that the boundaries of inundated spots adjust to the anthropogenic elements (dirt and surface roads, railway embankments, accumulations of materials dug from drainage ditches etc.). During the 19th century drainage measures numerous ditches were excavated in the floodplain perpendicular to the channelized river. Most of them are now almost entirely filled up with sediments and incapable to function as a drainage ditch. Today they are rather obstacles to than instruments of floodplain drainage. A more careful regulation of the river channel and the floodplain would have prevented this situation (Lóczy, 2010b).

In general it is claimed that in recent decades, along with riverine flood hazard, excess water hazard has also been observed to increase dramatically in Hungary (Víz- és környezetgazdálkodás, 2010). The construction of artificial structures in the landscape (Pálfai, 1988) and the neglected conditions of land drainage systems (National Water Management Framework Plan, 1984) all contribute to the higher frequency of inundation in particular areas of the Great Plain. Excess water generation is only partially related to high water stages along major rivers. In some cases it is the flood-control dykes themselves which hinder the flow of excess water back to the river channel.

2.2. Landscape changes caused by inundation

The temporary Kapos ”lake district” had a remarkable wildlife. The expansion of amphibians attracted large numbers of waders (mallards, grey herons, great egrets and mute swans). The proximity to some Ramsar bird refuge areas (the Pacsmag and Rétszilas lakes) was also instrumental in the proliferation of bird life. The meander loops which became dry during the retreat of excess water proved to be excellent nesting sites. Among the mammals the presence of roe-deer was the most conspicuous. The damage to agricultural porduction is considerable since crops are only able to tolerate inundation for limited periods (Table 1). If lands treated with artificial fertilizers are inundated, the enrichment of nutrients is a real danger.

Table 1. ***Yield loss as a consequence of inundation for major crops grown in the floodplain (Petrasovits & Balogh 1975)***

crop	*duration of inundation (days)*							
	May				June			
	3	7	11	15	3	7	11	15
maize	10	50	80	100	10	40	75	100
sunflower	15	30	80	100	20	40	80	100

Some weeds which prefer moist and nutrient-rich soils – primarily common ragweed *(Ambrosia artemisiifolia)* – can spread rapidly – even in cultivated fields. The ragweed reached continuous and homogeneous coverage over several hectares.

After floodplain drainage cultivation obliterated the geodiversity produced by microtopography (Lóczy and Gyenizse, 2010) but the shallow inundation may enhance variations and increase landscape biodiversity. Along the middle valley section tree plantations are unfavourably affected as a lot of black and noble poplars were uprooted by gusts of wind from the saturated soil. For the general public the most unfavourable impact of unundation was the blocking of traffic on the Budapest-Pécs railway line. It took a whole year to strengthen loosened railway embankments and restore the normal timetable. The damage from rapid and local floods in residential homes, transport and production insfrastructure shows an increasing trend in Hungary in recent decades (Czigány et al., 2010; Lóczy 2010a).

3. THE ’RED MUD’ DISASTER

A delayed and indirect consequence of the rainy summer of 2010 was an industrial (not natural) disaster, the breach of the dyke of the red-sludge reservoir in the immediate vicinity of the Middle-Transdanubian town of Ajka, where the Hungarian Aluminium Producing and Trading Company (MAL) operates storage facilities for the voluminous by-product of alumina processing, red sludge. For each ton of alumina produced by the old but still universally employed Bayer process, ca two tons of red sludge are generated.

The unusually high precipitation during the summer of 2010 resulted in the gradual accumulation of rainwater in the reservoir. As a consequence, instabilities arose along the northern dyke of reservoir number 10 and on 4 October 2010 a breach happened in the northwestern corner (Fig. 3) and released at least 600-700 thousand m^3 of alkaline (up to pH 13) sludge. The disaster demanded ten fatalities. More than 150 people were seriously injured in three settlements, Kolontár, Devecser and Somlóvásárhely (BBC, 2010). Although there have been other notable examples of accidental release of caustic wastes to river systems, the Ajka incident is unprecedented given the scale of the release and the type of material involved (Mayes et al., 2011).

3.1. The area affected by the red sludge spill

Three microregions of Hungary were affected by the flow of red sludge from the breached reservoir: the Veszprém–Devecser Graben, the Devecser section of the Bakony Foothills and the southernmost part (the Pápa–Devecser Plain) of the Marcal River basin. The Torna Stream, the direct reception watercourse of the red sludge flow, runs on the boundary of the Graben and the Foothills and builds the flat alluvial flat of the Pápa–Devecser Plain. The Graben follows a general west to east strike with embayments where transversal fault-lines cross the main Veszprém–Devecser fault-line.

The Torna Stream (51 km long, catchment area: 498 km^2, mean discharge: 0,25 m^3/s) rises in the Northern Bakony Mountains. Leaving the built-up area of Ajka, the stream load accumulates in an alluvial fan at 220-170 m above sea level. Then the stream follows the Veszprém-Devecser fault-line, under natural conditions forming a meandering pattern and floodplain embayments, for instance at the footslopes of the volcanic Somló Hill (432 m), filled with Upper Miocene sands and gravels. The lower alluvial fan (of 170-150 m elevation) at the confluence with the Marcal River (between Kisberzseny and Karakó was built together with the Kígyós Stream, which arrives from the Southern Bakony. Traces of the former braided channel pattern are only locally recognizable. The Marcal River (length: 120 km, catchment area: 376 km^2, mean discharge: 6 m^3/s) occupies the terraced valley of the Ancient Zala River, a former tributary of the Danube. This river and its tributaries represent the most spectacular example of a yazoo stream pattern in the Carpathian Basin. The Torna Stream as well as the Marcal River are extensively channelized with dykes minimizing floodplain extent.

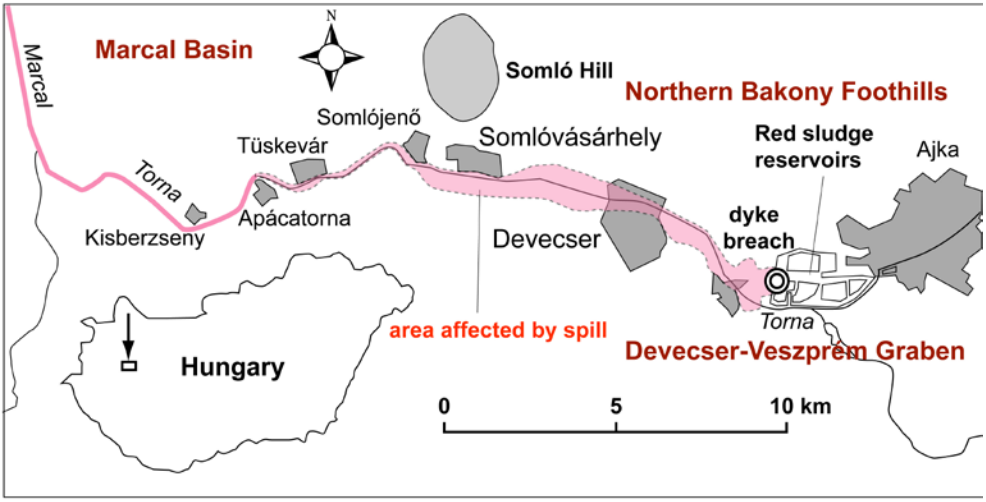

Fig. 3. ***The area affected by the red sludge spill at Ajka on 4 October 2010 (based on the NASA satellite image for 9 October, 2010)***

Bedrock geology in the upper catchment is primarily Triassic dolomites and limestones covered by fluvial marls, gravels and sands of Upper Miocene (Pannonian) age. Land cover on the right-bank side of the Torna Stream valley is dominated by arable land and villages on the valley floor, between Main Road 8 and the stream channel. Except for the urban area of Ajka, there is only one village on the left bank (Apácatorna), where pastures and riparian forests (willow, hornbeam, Turkey oak) and tree plantations are typical.

3.2. Environmental damage

The red sludge spill had crossed and spread over a broad (more than 1 km wide) and gentle (5°) slope of the upper alluvial fan before it reached the active floodplain of the Torna Stream, where it covered an area of ca 40 km^2 (Fig. 3). Along the reach between the villages of Kolontár and Somlóvásárhely the sludge flow could not be contained in the narrow channel and active floodplain of the Torna Stream but it overflowed onto the protected floodplain and exerted a lethal effect on vegetation. The floodplain accumulation was of minimum extent and temporary nature. Downstream the channels of the higher-order rivers (the Marcal and Rába) were also affected. When the current reached the low-gradient and slow-flowing Marcal river, it decelerated and deposition was observed in the riverbed without considerable dilution.

Unfortunately, to the impact of the contamination with high-pH sludge was added the influence of several tonnes of gypsum, applied in a desparate effort to neutralize the alkaline sediment load. The coarse-grained gypsum deposited from the streamwater and created a hard crust upon the red sludge deposition. The unfavourable effect of gypsum treatment was that the crust prevented the rapid removal of the red sludge accumulation downstream and this way hindered the natural regeneration of aquatic life (Üveges, V. et al. 2011).

Although radioactivity is not a major hazard as the activity of the sludge is relatively low, the accumulation of red sludge on the floodplain is potentially dangerous. The highest hazard is represented by the fine dust blown out from the dried red sludge which can cause lungs cancer (Viczián, 2003, 2004; Gelencsér et al., 2011). Radon emanation can have similar effects as α particles accumulate in the lungs and decompose there.

Preliminary studies on the fluvial sediment contamination have highlighted the abundance of vanadium, chromium, nickel and arsenic from the red sludge spill (Mayes et al., 2011). The relatively limited spatial extent of high concentrations of trace elements downstream of the site and the preponderance of residual phases is encouraging in terms of the longer term recovery of the downstream river systems. Although the caustic nature of the released material caused acute water pollution issues in the immediate aftermath of the spill, the physicochemical nature of the spill material is unlikely to be as persistent a problem as those found in rivers affected by other tailings failures.

3.3. Geomorphological impact

Although the environmental impacts of the spill (deriving from the chemistry of the red sludge) are far more significant, there have also been remarkable physical consequnces. Geomorphologically, this kind of impact is similar to that of debris (hyperconcentrated) flows (Iverson 1997). The initial driving force of sludge movement was provided by the high potential energy: the large mass and the height of the reservoir dyke (25 m). The hydraulic radius at the site of the dam breach, estimated from aerial images, could be close to $R = 1$. The hydraulic radius and the energy of flow was reduced as the sludge flow of ca 2 m depth spread over the gently sloping alluvial fan ($R \sim 0.6$) of low surface roughness but increased again where it became restricted between flood-control dykes ($R \sim 0.7$). This was a positive development from the aspect of environmental damage but negative regarding geomorphology: intensified undercutting of banks resulted along the few bends of the artificial channel, while incision followed along straight reaches. The comment has to be made, however, that no systematic field survey of geomorphological impact has yet been performed.

4. SOCIETAL RESPONSE

The recent flood disasters provoked response from the general public, academic bodies and governmental agencies. The public reaction was embitterment in the case of the flash floods, while concerning the red sludge spill it was dominated by outrage at the irresponsibility of the company operating the reservoirs. In the latter case legal action also followed. As far as academic research is concerned, attention turned to flash flood studies and a national supervision programme of the security of red sludge reservoirs ensued. The GIS experts of the Károly Róbert College (Gyöngyös) analyzed the spill with thermal, near-infrared imagery and on a 3d model constructed from LIDAR measurements of 5 cm resolution. Recently, a channel replacement proposal was elaborated for the Torna Stream in the environs of Devecser in order to prevent further catastrophes (Schweitzer, 2011). The National Disaster Relief Directorate also became interested in the studies aiming at the prevention of both kinds of disasters, e.g. in the design of a national flash flood warning system (Czigány et al., 2010) and monitoring the stability of all three red sludge reservoirs in Hungary.

It is particularly important to emphasize the impact of extreme events on legislation. Back in 2006 the Hungarian government already passed legislation preventing housing, industrial and commercial development in so-called ”high-water channel” areas (i.e. the channel which belongs to the design flood level or to the highest water level recorded to date – Government Decree … 2006), as well as restricting insurance and the state flood-control pledge for property in flood-prone areas. The decree ensures the priority of flood control considerations in land use options. In the case of red sludge, the Hungarian legislation on sludge storage used to be much stricter than the European one. After Hungary’s EU accession in 2004, the harmonization of laws led to the situation that red sludge ceased to be a hazardous material and the control on its disposal conditions loosened. The present disaster calls for the re-introduction of a stricter regulation of storage circumstances.

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