TORRENTIAL FLOODS IN SERBIA – MAN MADE AND NATURAL HAZARDS

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ABSTRACT

Torrential floods are the most frequent phenomenon in the arsenal of "natural hazards" in Serbia, being the first when it comes to losses, causing huge damage and the loss of human lives. Torrential events are characteristic both in urban and rural landscapes. Appearance of torrential floods is mostly out of man control. Man made hazard could be increased by irresponsible activities concerning land use or decreased with preventive activities: spatial planning in endangered watersheds; afforestation of bare lands, amelioration of degraded forests, meadows and pastures; appropriate agricultural techniques; application of agroforestry; erosion control measures and torrent training works. Soil bioengineering works in the headwaters lead to improvement of interception effects and infiltration-retention capacity of soil. Performing of erosion and torrent control works in the watershed could be the way for decreasing of natural hazard partly and seriously control of man made hazard.

Keywords: torrential floods, sediment yield, maximal discharge, land use, erosion and torrent control.

INTRODUCTION

Natural or anthropogenic calamities may cause huge material damages and, unfortunately, the loss of human lives (Toya and Skidmore, 2007). The occurrence of natural and anthropogenic extreme phenomena all around the world makes us pay more attention to their environmental and economic impacts (Schmidt et al., 2006; Lerner, 2007). Floods in all their various forms are the most frequent catastrophic events of nature that occur throughout the world (Berz et al., 2001; Barredo, 2007). Among natural hazards with serious risks for people and their activities, the torrential floods constitute the most common hazard in Serbia (Ristić and Nikić, 2007), being the first when it comes to losses, causing huge damage and loss of human lives. Frequency of event, intensity and diffusion, in the whole territory, make them a permanent threat with consequences in environmental, economic and social spheres. Representative examples are torrential floods in the watersheds of main tributaries of: Kolubara, June 1996; Velika Morava, July 1999; Kolubara and Drina, June 2001; Južna Morava, November 2007; Zapadna Morava, Drina and Lim, November 2009; Timok, February 2010; Pčinja, May 2010; Drina, December, 2010; Kolubara, May, 2011.

Climate, specific characteristics of relief, distinctions of soil and vegetation cover, social-economic conditions have resulted in the occurrence of torrential flood waves as one of consequential forms of existing erosion processes. Erosion processes of different categories of destruction are present on 76355 km^2 (86.4% territory of Serbia); 70.61% of surfaces are on slopes steeper than 5%. Average annual production of erosive material amounts to $37.25 \cdot 10^6$ m^3, in other words, 487.85 m$^3 \cdot$km^{-2}, which is 4.88 times more than normal (geological) erosion. Strong and excessive erosion processes cover 35% of the territory of Serbia (IWRMJČ, 2001). 9260 torrents have been recorded in Serbia (Gavrilović, 1975). Over exploitation or mismanagement of forest and agricultural land and urbanization provoke severe erosion and torrential floods. Soil erosion induces land use changes such

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as abandonment of arable land due to declining productivity (Bakker et al., 2005). Soil erosion becomes more frequent and severe along with local economic development (Ristić et al., 2010; Ananda and Herath, 2003). As the watershed becomes more developed, it changes its hydrological regime, increasing the torrential flood volume (Ristić et al., 2001). Torrential floods that once occurred rarely during pre-development period have now become more frequent and destructive due to the transformation of the watershed from rural to urban land uses. Decreasing the surfaces under forest vegetation, urbanization and inadequate agricultural measures are some negative aspects of human work which cause torrential floods, so that former discharges with recurrence interval of 100 years, become events with recurrence interval of 20 years (Ristić et al., 2006). But most of the watersheds in the hilly-mountainous region of Serbia faced the opposite process: people moved from villages to towns looking for jobs or better social conditions. Many of them are young people who descent from traditional agricultural families but did not want to follow into the family tradition. That was the reason why the agricultural areas were deserted and neglected, and once supressed forest areas rapidly and spontaneously renewed. That resulted in the reduced pressure on arable land and forest surfaces, mitigation of erosion processes and decreased sediment yield.

The erosion and torrent control works (ETCWs) in Europe started around the middle of the XIX century. In Serbia they started at the end of the XIX century (Kostadinov et al., 1999) and as an organized activity in 1907 in the region of Grdelička Gorge (South-Eastern part of Serbia), which is 23 km long with 143 torrents. In the past, especially in the first half of the XX century, this region was extremely endangered by very destructive erosion processes and severe torrential floods (Jelić, 1978). One of the most dangerous torrents was Kalimanska river with several torrential floods (1929, 1946, 1948 and 1951) that brought huge damages to the town Vladičin Han and international railway Belgrade-Skopje-Athens. The torrential flood in summer 1929 destroyed a few hundred houses in the town of Vladičin Han and interrupted the railway traffic for more than 10 days. The first technical documentation for erosion and torrent control in the watershed of the Kalimanska river was prepared in 1923 and the projects started in 1927. The most intensive undertakings were carried out in the period between the end of the World War II and the mid 1970s.

MATERIAL AND METHODS

The torrential flood risk assessment at watershed level is based on historical overview of floods which have occurred in the past. Typical example is experimental watershed of the Kalimanska river (profile at the town of Vladičin Han-confluence into the South Morava river), located in southern Serbia (Fig. 1).

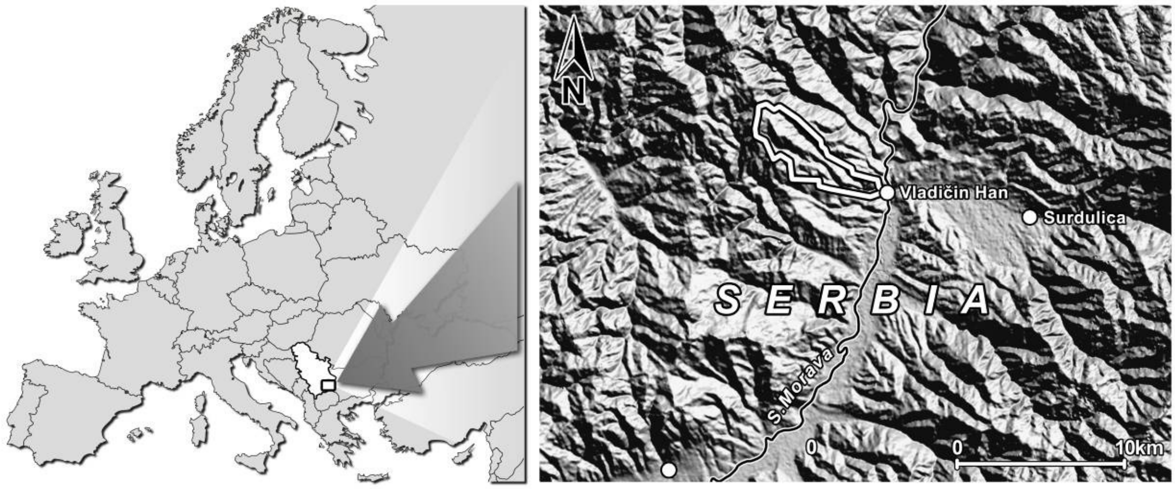

Fig. 1 Location of the experimental watershed of the Kalimanska river

Dominant factors for torrential floods forming have been analyzed: natural characteristics (hydrographic characteristics; soil and geology conditions), human impact (land use; disposition of surfaces; relation between surfaces with low and high water infiltration-retention capacity). Land use changes were analyzed on the basis of the existing technical documentation and data collected from 1923 to 2010, field investigations, usage of aerial and satellite photo images, topographic, geological and soil maps. Land use classification was made on the basis of CORINE methodology (EEA, 1994). Area sediment yields and intensity of erosion processes were estimated on the basis of the "Erosion Potential Method" (EPM). This method was created, developed and calibrated in Serbia (Gavrilović, 1972) and it is still in use in all the countries which originated from former Yugoslavia. Historical maximal discharge ($Q_{maxhKal-1929}$=149.2 $m^3 \cdot s^{-1}$; $q_{maxsphKal-1929}$=9.3 $m^3 \cdot s^{-1} \cdot km^{-2}$) was reconstructed by method of ″hydraulic flood traces″ (Jelić, 1978).

The computation of maximal discharge (for control profile P, Fig. 2), under hydrological conditions after restoration (ETCWs) of the watershed, was performed using a combined method: synthetic unit hydrograph (maximum ordinate of unit runoff, q_{max}) and Soil Conservation Service (SCS, 1979) methodology (deriving effective rainfall, Pe, from total precipitation, Pb). This combined method is the most frequently used procedure in Serbia for the computations of maximal discharges at unstudied watersheds. The computation was performed for AMC III (Antecedent Moisture Conditions III-high content of water in the soil and significantly reduced infiltration capacity). Synthetic triangular unit hydrographs were transformed to synthetic (computed) curvilinear hydrographs of total discharge, using the SCS basic dimensionless hydrograph (Chang, 2002). The changes of hydrological conditions were estimated by the comparison of the historical and computed values of maximal discharge in the conditions before (1927) and after the restoration of the Kalimanska river watershed (2010). The computation of maximal discharge was based on the regional analysis of lag time (Ristić, 2003), internal daily distribution of precipitation (Janković, 1994) and classification of soil hydrologic groups for CN-runoff curve number determination (Djorović, 1984).

The aim of this investigation is to show how the performed ETCWs, as well as adequate land use changes, which are based on the analysis of historical cases, can help to improve the hydrological conditions on endangered watersheds, and provide effective erosion control and torrential flood protection.

RESULTS OF INVESTIGATION

The main hydrographic characteristics of the experimental watershed are presented in Tab. 1:

Tab. 1 Main hydrographic characteristics of the experimental watersheds

Parameter	Mark	Unit	Kalimanska
Magnitude	A	km^2	16.04
Perimeter	P	km	21.90
Peak point	Pp	m.a.s.l.	1261
Confluence point	Cp	m.a.s.l.	325
Mean altitude	Am	m.a.s.l.	810
Length of the main stream	L	km	10.16
Absolute slope of river bed	Sa	%	9.21
Mean slope of river bed	Sm	%	7.60
Mean slope of terrain	Smt	%	40.86
Density of hydrographic network	D	$km \cdot km^{-2}$	2.10

The Kalimanska river is the left tributary of the South Morava river, flowing through the center of Vladičin Han. The watershed is built by Paleosoic metamorphosed schists of the Vlasina complex (leptynolites, micaschists, amphibolites, leucogneiss and finegrained gneiss) and neogene sediments (red and gray tuffaceous sandstone, conglomerates and sandy marles) (IG, 1970). The soil in the watershed consists of several varieties of Distric Cambisol (Kostadinov et al., 1995).

Anthropogenic pressure on the soil in the watershed was very strong during the 1920s of the last century, because the population of the villages in the watershed amounted to more than 3300 people or 205 persons per 1 km^2. In 2010 there were 804 inhabitants or 50 per 1 km^2 (SORS, 1923-2010). Forests were used for timber, fuel and fodder production. Meadows and pastures had a degraded grass cover and a compacted surface soil layer because of the abundant cattle and sheep populations.

Farming was carried out down the slope, in straight rows, often with wooden ploughshare drawn by ox. Numerous activities initiated intensive sheet and gully erosion, decreased water storage capacity of soil and in this way created ideal conditions for fast surface runoff forming, development of erosion processes and loss of soil. Besides intensive sheet erosion, systems of furrows and gullies developed on the bare land that was previously forest or arable land. Also, deep erosion developed in the drainage pattern of the watershed as well as landslides on very steep slopes (Kostadinov, 1985).

In the 1927–2006 period a wide scope of technical, biological and biotechnical activities were performed (Fig. 2). The technical activities involved the regulation of the Kalimanska river, 39 stone masonry check-dams, and 185 check dams of dry laid masonry. The Kalimanska river was regulated in the zone of Vladičin Han, on a 700 m long section, upstream from the confluence into the South Morava river, in the 1927-1953 period. The regulation was carried out as trapeze channel lined with stone masonry. Stone masonry check dams (1.5-5 m high), in the Kalimanska river and its main tributaries, were intended for bed-load control, decrease of stream bed slope and stream bed and bank stabilization. The storage areas of check dams were filled with sediment which was subsequently overgrown with autochthonous shrubs and trees (Kostadinov et al., 1995). Check dams of dry laid masonry (0.5-1.0 m high) were built mostly in gullies and temporary streams.

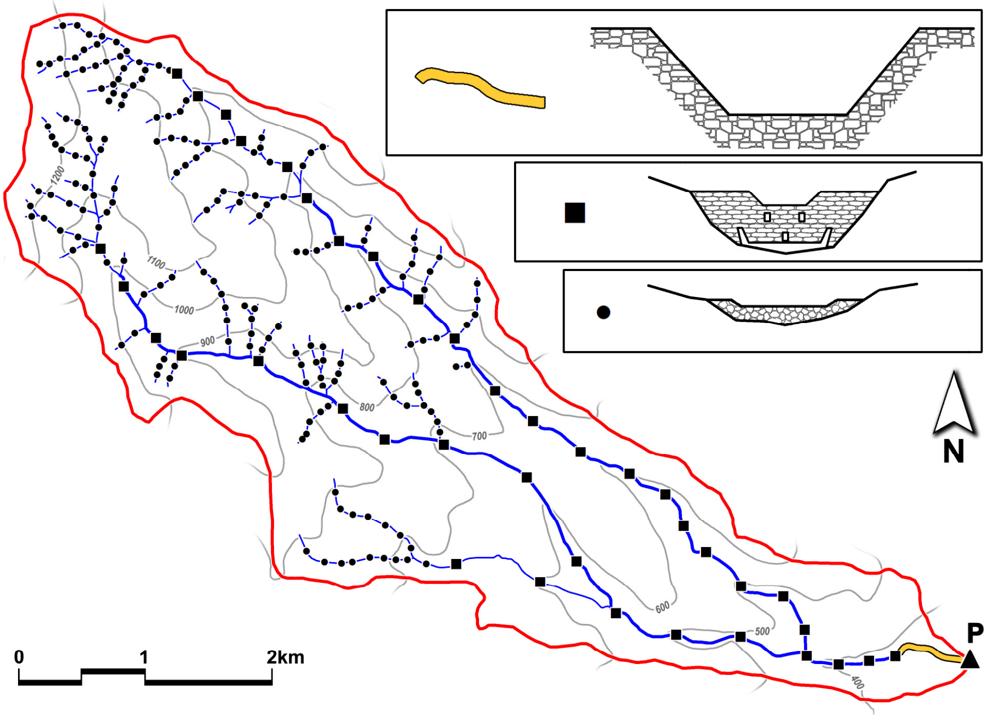

Fig. 2 Disposition of technical structures on the watershed of the Kalimanska river (regulation; stone masonry check-dams; dry laid masonry check-dams)

In the 1953-1995 period dominant biological and soil-bioengineering activities were: afforestation of bare land with *Pinus nigra* (61 ha; steep, deforested and eroded slopes; 8000-12000 seedlings per ha, two to three years old), afforestation of bare slopes (abandoned plough land) with *Robinia pseudoacacia* (104.4 ha; 6000 seedlings per ha, planted along the contours on the previously prepared bench terraces), afforestation of degraded oak forest with *Robinia pseudoacacia* (101.1 ha), grassing of bare land and degraded meadows (132.3 ha) and pasture reclamation (4 ha). During the 1960s biotechnical works were dominant, when orchards on steep slopes on former plough land were established (60.8 ha, on terraces, with grassing between terraces, mostly apple and plum trees, and a few hectares with currant). At the beginning of the 1950s the cutting of fodder in forests was prohibited. During the 1960s and 1970s some additional measures were applied: bans on clear cuttings, cuttings in protective forests, straight row farming down the slope, uncontrolled urbanization and overgrazing. Land owners had (with financial support from authorities) the duty to apply contour farming and terracing of arable land as effective measures of erosion control.

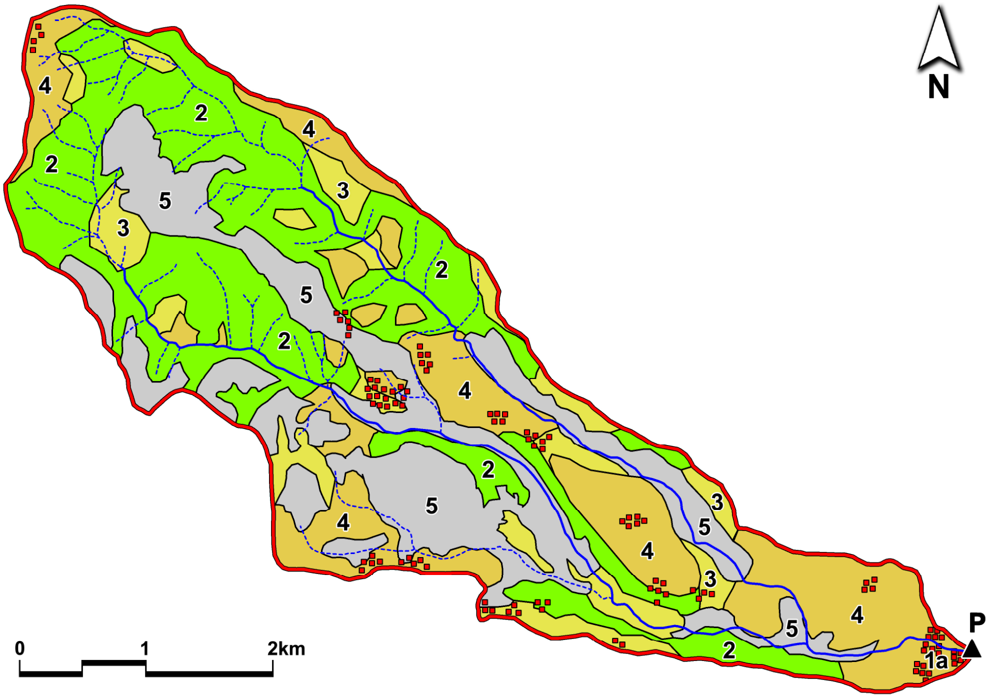

Fig. 3 Land use in the watershed of the Kalimanska river (1927): 1a – Discontinuous urban fabric (0.31 km^2); 2 – Broad-leaved forest (5.72 km^2); 3 – Pastures (1.76 km^2); 4 – Complex cultivation patterns (3.97 km^2, of which 3.93 km^2 are arable land and 0.04 km^2 are orchards); 5 – Bare rocks (4.28 km^2)

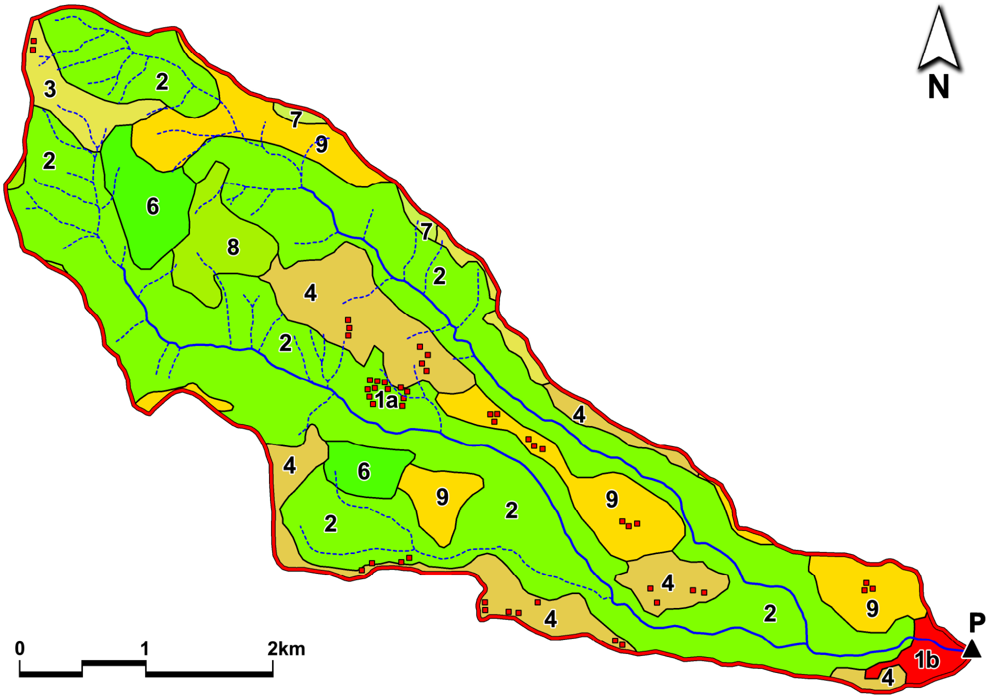

Fig. 4 Land use in the watershed of the Kalimanska river (2010): 1a – Discontinuous urban fabric (0.27 km^2); 1b – Continuous urban fabric (0.87 km^2); 2 – Broad-leaved forest (8.96 km^2); 3 – Pastures (0.51 km^2); 4 – Complex cultivation patterns (2.05 km^2, of which 1.9892 km^2 are arable land and 0.0608 km^2 are orchards); 6 – Mixed forest (0.73 km^2); 7 – Natural grasslands (0.09 km^2); 8 – Transitional woodland-shrub (0.49 km^2); 9 – Land principally occupied by agriculture, with significant areas of natural vegetation (2.07 km^2, of which 1.5 km^2 are arable land and 0.57 km^2 are shrub land)

The number of livestock on grazing surfaces was limited (1-3 pieces per hectare, depending on terrain steepness), in order to avoid negative effects: compaction of soil surface layer and reduction of water infiltration capacity. Total cost of the performed ETCWs (1927-2006) amounts to 4370850 euros.

Comparison of land use maps from 1927 and 2010 shows great differences in the structure of surfaces (Fig. 3 and 4).

Erosion and sediment transport

Some characteristic outputs of computations of sediment yields and transport are presented in Tab. 2, as well as representative values of the coefficient of erosion Z, in conditions before ETCWs performing (1927) and actual conditions (2010): W_a-annual yields of erosive material; W_{asp}-specific annual yields of erosive material; W_{at}-annual transport of sediment through hydrographic network; W_{atsp}-specific annual transport of sediment through hydrographic network; W_{abls}-annual amount of bed-load sediment; W_{ass}-annual amount of suspended sediment.

Tab. 2 Characteristic outputs of computations of sediment yields and transport in the conditions before ETCW and actual conditions

Parameter	Before ETCW-1927	Actual conditions-2010
W_a [m^3]	60551.0	8552.0
W_{asp} [$m^3 \cdot km^{-2} \cdot year^{-1}$]	3775.0	533.17
W_{at} [m^3]	40011.0	5624.6
W_{atsp} [$m^3 \cdot km^{-2} \cdot year^{-1}$]	2494.45	350.7
W_{abls} [$m^3 \cdot year^{-1}$]	13031.6	527.61
W_{ass} [$m^3 \cdot year^{-1}$]	26979.4	5096.99
Z	1.25	0.36

Changes of hydrological conditions

Historical maximal discharge ($Q_{maxhKal-1929}$) was reconstructed using the method of “hydraulic flood traces”.

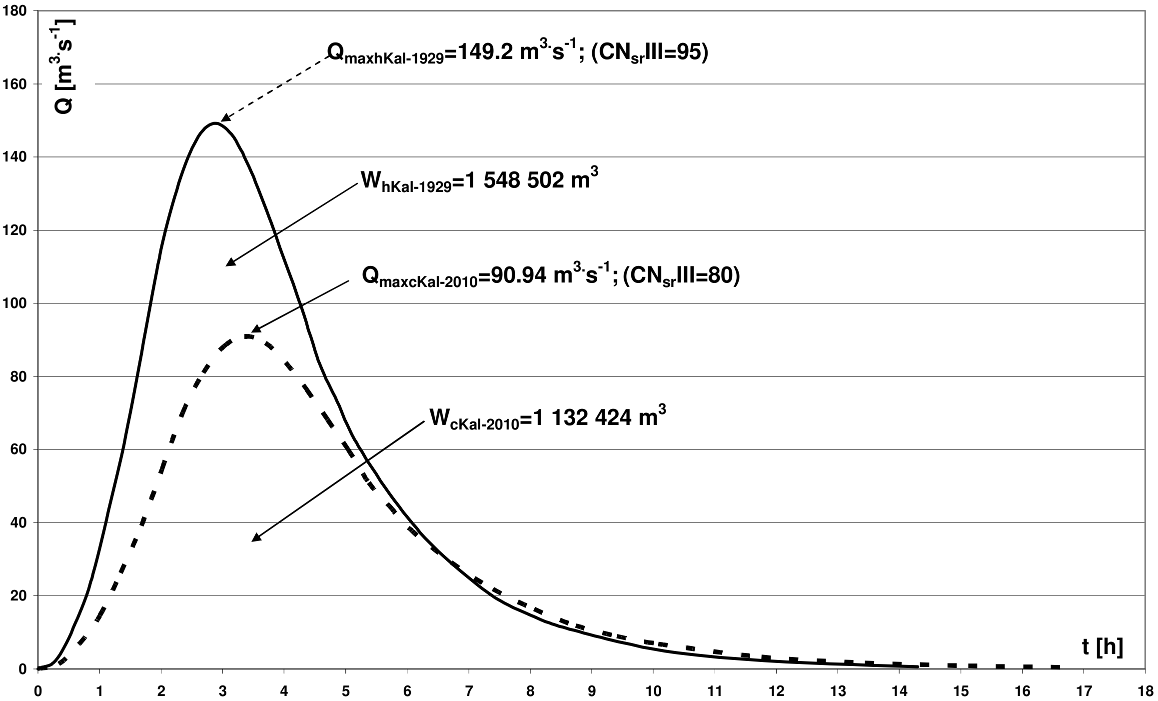

Fig. 5 Historical (1929) and calculated (2010) hydrographs of maximal discharges on the Kalimanska river

Maximal discharge ($Q_{maxcKal-2010}$) in actual conditions was computed using designed precipitation on the basis of DM (Malošević, 1995) and DJ (Janković, 1994) models, due to the lack of data regarding the precipitation which caused the torrential flood in August 1929. Hydrographs of historical and computed discharges are presented in Fig. 5.

The value of computed maximal discharge ($Q_{maxcKal\text{-}2010}$=90.94 $m^3 \cdot s^{-1}$) is significantly reduced in comparison to the historic (recorded) value of maximal discharge ($Q_{maxhKal\text{-}1929}$=149.2 $m^3 \cdot s^{-1}$), as a direct consequence of the performed ETCWs and land use changes. At the same time, other significant parameters such as physical characteristics of the watershed (magnitude, mean slope of terrain, mean slope of river bed) and total precipitation remained the same. Some characteristic outputs of these hydrologic computations, in the conditions before and after the ETCWs, are presented in Tab. 5 (CN-runoff curve number; Pbr-total precipitation; Pe-effective rain; Tp-rising time of hydrograph; Tr-recession time of hydrograph; Tb-time base of hydrograph). All these facts indicate more favorable hydrological conditions in the post-restoration environment (2010).

Tab. 3 Characteristic outputs of hydrologic computations in the conditions before (1927) and after ETCWs (2010)

Parameter	1927	2010
q_{max} [$m^3 \cdot s^{-1} \cdot mm^{-1}$]	1.545	1.288
$CN_{sr}III$	95	80
P_{br} [mm]	214.2	214.2
P_e [mm]	96.54	70.60
Tp [h]	2.86	3.36
Tr [h]	3.39	3.98
Tb [h]	6.25	7.34

DISCUSSION

Natural hazards cannot be prevented, but better understanding of the processes and scientific methodologies for prediction can help to mitigate the impacts (Alcantara, 2002). In most cases, torrential floods are caused by natural incidents (such as the climatic and morpho-hydrographic particularities of the watersheds), but the human factor contributed significantly to the effects of the disasters (the mismanagement of forest and agricultural surfaces, uncontrolled urbanization and the absence of the erosion control and flood protection structures).

The watershed of the Kalimanska river has a geological composition with low permeability rocks. The geological composition of the watershed influenced the formation of soil types with average water storage capacity, but anthropogenic impacts provoked the development of erosion processes and a decrease in the soil infiltration capacity. Soil erosion on the watershed was initiated by the removal of forest (clear cuttings, trunk transport down the slope) and inadequate agricultural activities (straight row farming down the slope, overgrazing). Nowadays, members of most of the households are old people, because young people relocated to the neighboring towns. Depopulation contributed to a significant decrease of pressure on agricultural and forest surfaces in the watershed. Huge surfaces of former arable land and pastures were spontaneously overgrown with shrubs and trees.

The initial state of erosion processes (1927) was marked with a Z=1.25 coefficient of erosion (excessive erosion). ETCWs were carried out in order to decrease yields of erosive material, increase water storage capacity of soil and reduce flood runoff. The actual state of erosion processes is marked with a Z=0.36 coefficient of erosion (weak erosion). The effects of hydrological changes were estimated by the comparison of historical maximal discharge (1929), and computed maximal discharge, under the conditions after the complete restoration of the Kalimanska river watershed (2010). The realization of restoration works helped decrease annual yields of erosive material from W_a=60551.0 m^3 to W_a=8552.0 m^3. Also, specific annual transport of sediment through hydrographic network is reduced from W_{atsp}=2494.45 $m^3 \cdot km^{-2} \cdot year^{-1}$ to W_{atsp}=350.7 $m^3 \cdot km^{-2} \cdot year^{-1}$. The computed value of maximal discharge ($Q_{maxcKal\text{-}2010}$=94.90 $m^3 \cdot s^{-1}$) is significantly decreased in comparison to historical maximal discharge ($Q_{maxhKal\text{-}1929}$=149.20 $m^3 \cdot s^{-1}$), indicating the improvement of hydrological conditions, as a direct consequence of ETCWs. Also, the volume of computed hydrograph of direct runoff ($W_{cKal\text{-}2010}$=1132424 m^3) is significantly reduced in comparison to the volume of the historical flood wave ($W_{hKal\text{-}1929}$=1548502 m^3).

CONCLUSIONS

Torrential floods are the most frequent catastrophic events that occurs in Serbia, with serious risks for people and their activities. Serbian tradition in ETCWs is longer than 100 years, with remarkable results in the domain of biotechnical and technical works. Frequency of occurrence and destructivity of torrential floods in the last 15 years indicates that it is necessary to achieve a higher degree of coordination of different activities related to the problems of erosion control and torrential floods. Integrated management in torrential watersheds encompasses technical works in a hydrographic network and soil bioengineering works on the slopes, within a precisely defined administrative and spatial framework in order to achieve maximum security for people and their property and to satisfy other demands such as environmental protection, sustainable soil usage, drinking water supply, rural development, biodiversity sustaining, etc.

Natural hazard of extreme hydrological events is still present in the watershed of the Kalimanska river but the man-made hazard is significantly reduced. Once extremely eroded watershed with frequent appearance of destructive torrential floods is now restored after large-scale ETCWs, performed in the 1927-2006 period. In the last 40 years there were no significant flood waves of the Kalimanska river. Thanks to the ETCWs the possibility of sudden concentration of fast surface runoff (after extreme rain events, snow melt or their coincidence), is reduced. Land use changes in the watershed helped balancing the runoff regime by increasing the low flow and decreasing the maximal discharges. The intensity of erosion processes has been reduced from excessive erosion ($Z=1.25$) before the beginning of ETCWs to weak erosion ($Z=0.36$), with the tendency of transition to the category of very weak erosion ($Z<0.19$). Former bare rocks were transformed into forest surfaces or transitional woodland-shrub land. Sediment yield has decreased 7 times, because of a remarkable decrease of erosion on watershed hill slopes due to the performed ETCWs.

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