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EROSION CONTROL AND PROTECTION FROM TORRENTIAL FLOODS IN SERBIA-SPATIAL ASPECTS

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Torrential floods represent the most frequent phenomenon within the category of "natural risks" in Serbia. The representative examples are the torrential floods on the experimental watersheds of the rivers Manastirica (June 1996) and Kamišna (May 2007). Hystorical maximal discharges (Q_{maxh}) were reconstructed by use of "hydraulics flood traces" method. Computations of maximal discharges (Q_{maxc}), under hydrological conditions after the restoration of the watersheds, were performed by use of a synthetic unit hydrograph theory and Soil Conservation Service methodology. Area sediment yields and intensity of erosion processes were estimated on the basis of the "Erosion Potential Method". The actual state of erosion processes is represented by the coefficients of erosion Z=0.475 (Manastirica) and Z=0.470 (Kamišna). Restoration works have been planned with a view to decreasing yields of erosive material, increasing water infiltration capacity and reducing flood runoff.

The planned state of erosion processes is represented by the coefficients of erosion Z=0.343 (Manastirica) and Z=0.385 (Kamišna). The effects of hydrological changes were estimated by the comparison of historical maximal discharges and computed maximal discharges (under the conditions after the planned restoration). The realisation of restoration works will help decrease annual yields of erosive material from $W_a=24357\ m^3$ to $W_a=16198.0\ m^3$ (Manastirica) and from $W_a=19974\ m^3$ to $W_a=14434\ m^3$ (Kamišna). The values of historical maximal discharges ($Q_{maxhMan}=154.9\ m^3\cdot s^{-1}$; $Q_{maxhKam}=76.3\ m^3\cdot s^{-1}$) were significantly decreased after the restoration ($Q_{maxcMan}=84.5\ m^3\cdot s^{-1}$; $Q_{maxcKam}=43.7\ m^3\cdot s^{-1}$), indicating the improvement of hydrological conditions, as a direct consequence of erosion and torrent control works. Integrated management involves biotechnical works on the watershed, technical works on the hydrographic network within a precisely defined administrative and spatial framework in order to achieve maximum security for people and their property and to meet other requirements such as: environmental protection, sustainable soil usage, drinking water supply, rural development, biodiversity sustaining, etc. The lowest and the most effective level is attained through PAERs (Plans for announcement of erosive regions) and PPTFs (Plans for protection from torrential floods), with HZs (Hazard zones) and TAs (Threatened areas) mapping on the basis of spatial analysis of important factors in torrential floods formation. Solutions defined through PAERs and PPTFs must be integrated into Spatial Plans at local and regional levels.

Key words: Flood protection, Erosion Control, Plans for announcement of erosive regions and protection from torrential floods, Watershed Restoration.

INTRODUCTION

Natural or anthropogenic calamities may cause severe material damage and, unfortunately, the loss of human lives (Toya and Skidmore, 2007). The occurrence of natural and anthropogenic extreme phenomena throughout the world compels us to 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 natural catastrophic event that occurs throughout the world (Berz et al., 2001; Barredo, 2007). Among natural hazards with serious risks for people and their activities, the torrential floods represent 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 events, their intensity

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and diffusion into the whole territory, make them a permanent threat with consequences in environmental, economic and social spheres. The representative examples are torrential floods on 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. The climate, specific characteristics of relief, distinctions of soil and vegetation cover, social-economic conditions resulted in the occurrence of torrential flood waves as one of the consequential forms of the existing erosion processes. Erosion processes of different categories of destruction are present on 76355 km^2 (86.4% territory of Serbia); 70.61% of the eroded areas are located on the slopes steeper than 5%. The average annual production of erosive material amounts to $37.25 \cdot 10^6\ m^3$, or $487.85\ m^3 \cdot km^{-2}$, which is 4.88 times more than normal (geological) erosion. Strong and excessive erosion processes cover 35% of the territory of Serbia (WRMBPS, 1996). 9260 torrents have been recorded in Serbia (Gavrilović, 1975). Overexploitation or mismanagement of forest and agricultural land along with urbanisation provoke severe erosion and torrential floods. Soil erosion induces land use changes such as abandonment of arable land due to declining productivity (Bakker et al., 2005). Soil erosion becomes more frequent and severe with increased local economic development (Ristić et al., 2010; Ananda and Herath, 2003). As the watershed becomes more developed, it changes its hydrological regime, by 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, urbanisation and inadequate agricultural measures are some of the negative aspects of human activity 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). Torrential flood represents a sudden appearance of maximal discharge into the river bed with a high concentration of hard phase (bed load sediment). In extreme cases, two-phase fluid flows out from the torrent bed, with enormous destructive energy. Two-phase fluid could content fractions (60% of total volume) of different granulations: from particles of clay to rocks, with a diameter of up to 5.0 m and a mass of over 200 tons (Jevtić, 1978). Torrential watershed represents a hydrographic entity with riverbeds of mainstream and tributaries and gravitating areas along with erosion processes at a certain level of intensity. The attribute "torrential" refers to any watershed with a sudden appearance of maximal discharge with high concentration of hard phase, regardless of the magnitude and category of a stream. The erosion and torrent control works (ETCW) in Europe started around the middle of the 19th century. In Serbia, the works started at the end of the 19th century and, as an organised activity, in 1907. In the period from 1907–2006, a significant scope of works had been performed: technical works (check-dams, bank protective structures, river training) - 1.501.656 m^3; biotechnical (afforestation; forest protective belts; silt-filtering strips; grassing; terracing; contour farming) - 120.987 ha (Kostadinov, 2007). Effective torrential watershed management lies in achieving maximum security and avoiding or mitigating damages. Best management practices (BMPs) could be obtained through a specific combination of biotechnical, technical and administrative measures, through concept of "natural reservoirs" (the essence of this concept is represented through necessity to retain water in soil on slopes, instead of running off as a fast surface runoff, minimizing erosion and enabling agricultural activities). Each storage component (forest stands; parcels of arable land; pastures; meadows, etc.) represents a kind of reservoir, able to keep and retain a certain volume of water. Integral watershed management must meet different requirements: protection from soil erosion and torrential floods; drinking water supply; rural development; biodiversity sustaining. Cooperation and overcoming conflicts between various sectors of forestry, agriculture, water resources management and local economy development is essential at following levels: policy; planning; practice; investments; education.

MATERIAL AND METHODS

The flood risk assesment at watershed level is based on a historical overview of floods which occurred in the past. Typical examples are experimental watersheds of the rivers Manastirica (profile at village Brežđe, between Mionica and Divčibare) and Kamišna (profile at village Glibetići, nearby Mokra Gora), located in the western part of Serbia (Figure 1). Experimental watersheds have experienced severe torrential floods at the mentioned profiles. The village of Brežđe was struck by a flood in June I996: almost 130 hectares of land and 37 buildings were flooded (out of which 15 severely damaged), roads damaged or blocked and 140 inhabitants evacuated. The village of Glibetići also suffered heavy floods in May of 2007 and in 1994: one person died, and the local roads and the railway were destroyed. The discharges into the rivers Manastirica and Kamišna increased 815 and 347 times, respectively: from $Q=0.19\ m^3 \cdot s^{-1}$ to $Q_{maxhMan-1996}=154.9\ m^3 \cdot s^{-1}$ in Manastirica river; from $Q=0.22\ m^3 \cdot s^{-1}$ to $Q_{maxhMan-2007}=76.3\ m^3 \cdot s$-1, in the Kamišna river. The water levels increased from 30-40 cm to up to 6.2 m (Manastirica) and 3.8 meters (Kamišna).

Spatial relations between dominant factors in torrential floods forming have been analysed: natural characteristics (hydrographic characteristics; soil and geological conditions), human impact (land use; disposition of surfaces; relation between surfaces with low and high water infiltration-retention capacity), effects of urbanisation (disposition of endangered residential and infrastructure objects in relation to riverbeds) and consequences or missing of application of spatial planning documents. This investigation is also concerned with the analysis of impacts (erosion and torrential floods) under the actual and planned conditions of the watersheds (after restoration). Planned restoration works involve biotechnical (reforestation of eroded or abandoned arable land; forest protective belts; silt filtering strips; contour farming; terracing), technical (check dams; river training works) and administrative measures (PAER-Plans for announcement of erosive regions; PPTF-Plans for protection from torrential floods).

Figure 1. Location of experimental watersheds (1-river Manastirica; 2-river Kamišna)

Consequences of land use changes have been analysed on the basis of field investigations, use of aerial and satellite photo images, topographic, geological and soil maps. Land use classification has been made on the basis of CORINE methodology (EEA, 1994). Area sediment yields and intensity of erosion processes have been 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 originating from former Yugoslavia. Hystorical maximal discharges (Q_{maxh}) were reconstructed by application of method of "hydraulics flood traces" (Ristić et al., 1997). Computations of maximal discharges (Q_{maxc}), under hydrological conditions after restoration of the watersheds, have been performed by application of a synthetic unit hydrograph theory and SCS methodology (SCS, 1979; Chang, 2003). In Serbia, this is the most frequently used procedure for computations of maximal discharges at small, unstudied watersheds, enriched by a regional analysis of lag time (Ristić, 2003), internal daily distribution of precipitation (Janković, 1994) and classification of soil hydrologic classes (Djorović, 1984). Data concerning maximal daily precipitation were provided from the observing system of RHMOS (Republic Hydrometeorological Office of Serbia).

The aim of this investigation is to show how analysis of spatial relations between dominant factors in torrential floods formation can help mitigation of destructive effects and enable better prevention.

RESULTS OF INVESTIGATION

The main hydrographic characteristics of the experimental watersheds are presented in Table 1.

The main characteristics of torrential floods occurring between 1996 and 2007 along with the precipitation which caused them, are presented in Table 2.

Hazard zones (HZ) are determined on the basis of a spatial analysis of dominant factors in surface runoff forming: soil conditions; geology; slope; A_L, average length of water way from the watershed divide to the hydrographic network (Table 3). HZ are sources of impacts (fast surface runoff and sediment). HZ on the Manastirica river watershed (Figure 2) account for 32.68% of the total area (9.78 km^2) and on the Kamišna river watershed (Figure 3) 45.88% of the total area (12.36 km^2).

Threatened areas (TA) are locations under the influence of impacts (Figure 2, 3): TA on the Manastirica river watershed account for 1.34% of the total area (0.4 km^2) and on the Kamišna river 0.82% of the total area (0.22 km^2).

Table 1. Main hydrographic characteristics of the experimental watersheds

Parameter	Mark	Unit	Manastirica	Kamišna
Magnitude	A	km^2	29.93	26.94
Perimeter	P	km	29	25.1
Peak point	Pp	m.a.s.l.	983	1281
Confluence point	Cp	m.a.s.l.	309	603
Mean altitude	Am	m.a.s.l.	621	955
Length of the main stream	L	km	12.95	12.18
Absolute slope of river bed	Sa	%	5.20	5.04
Mean slope of river bed	Sm	%	3.3	4.22
Mean slope of terrain	Smt	%	28.5	29.73

Table 2: Main characteristics of reconstructed torrential floods

Water course	Profile	Date of occurrence	Q_{maxh} [m^{3}s^{-1}]	q_{maxsp} [m^{3}s^{-1}km^{-2}]	Total precipitation [mm]	Duration [min]	Intensity [mm min^{-1}]
Manastirica	Brežđe	13.06.1996.	154.9	5.18	135.0	180	0.75mm min.$^{-1}$
Kamišna	Glibetići	26.05.2007.	76.3	2.83	99.6	120	0.83mm min.$^{-1}$

Table 3: Dominant factors in surface runoff forming in HZs

Watershed	Soil conditions	Geology	Slope (%)	A_L (m)
Manastirica	✓grey-brown skeletoidal soil on diabase; ✓grey brown soil on limestone (locally leached; ✓skeletoidal black soil on serpentine rock	✓diabase-chert formation; ✓massive limestone; ✓conglomerate and limestone; ✓limestone and marl	10-20	200
Kamišna	✓skeletoidal black soil on serpentine rock	✓serpentine ✓harzburgite	20-30	210

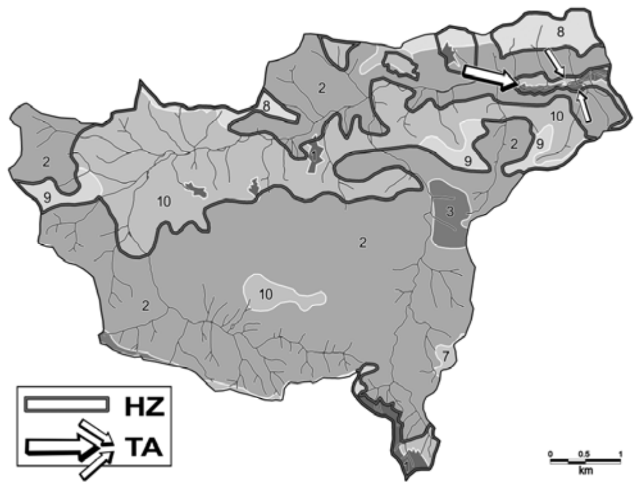

Figure 2. HZ (Hazard Zones), TA (Threatened Areas) and LU (Land use) in the watershed of the river Manastirica: 1 – Discontinuous urban fabric; 2 – Broad-leaved forest; 3 - Coniferous forests; 7 – Natural grasslands; 8 – Complex cultivation patterns; 9 – Pastures; 10 – Land principally occupied by agriculture, with significant areas of natural vegetation

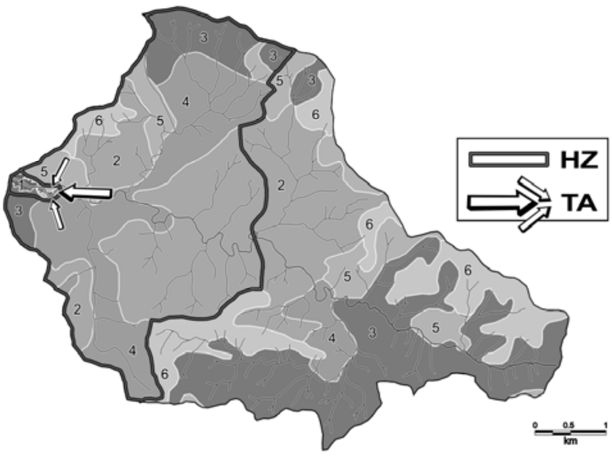

Figure 3. HZ (Hazard Zones), TA (Threatened Areas) and LU (Land use) in the watershed of the river Kamišna: 1 – Discontinuous urban fabric; 2 – Broad-leaved forest; 3 – Coniferous forest; 4 – Mixed forest; 5- Transitional woodland-shrub; 6-Natural grasslands

Erosion and sediment transport

Some characteristic outputs of computations of sediment yields and transport are presented in Table 4, along with the representative values of the coefficient of erosion Z, in actual conditions and after planned restoration of the experimental watersheds (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).

Table 4 - Characteristic outputs of computations of sediment yields and transport in the actual conditions and after planned restoration

Parameter	Actual conditions		After restoration	
	Manastirica	Kamišna	Manastirica	Kamišna
W_a [m^3]	24357.0	19974.0	16198.0	14434.0
W_{asp} [m^{3}km^{-2}year^{-1}]	813.8	741.4	541.2	535.8
W_{at} [m^3]	12738.7	10126.8	8471.6	7318.1
W_{atsp} [m^{3}km^{-2}year^{-1}]	425.6	375.9	283.1	271.6
W_{abls} [m^{3}year^{-1}]	2355.4	2025.4	1131	1196.5
W_{ass} [m^{3}year^{-1}]	10383.3	8101.4	7340.6	6121.6
Z	0.475	0.470	0.343	0.385

Changes of hydrological conditions

Hydrographs of historical maximal discharges (Q_{maxh}) have been reconstructed by application of the "hydraulics flood traces" method (Figure 4). The computed values of maximal discharges (Q_{maxc}) are presented in Figure 4, with hydrographs constructed on the basis of historical (recorded) precipitation which caused torrential floods in June 1996 and May 2007.

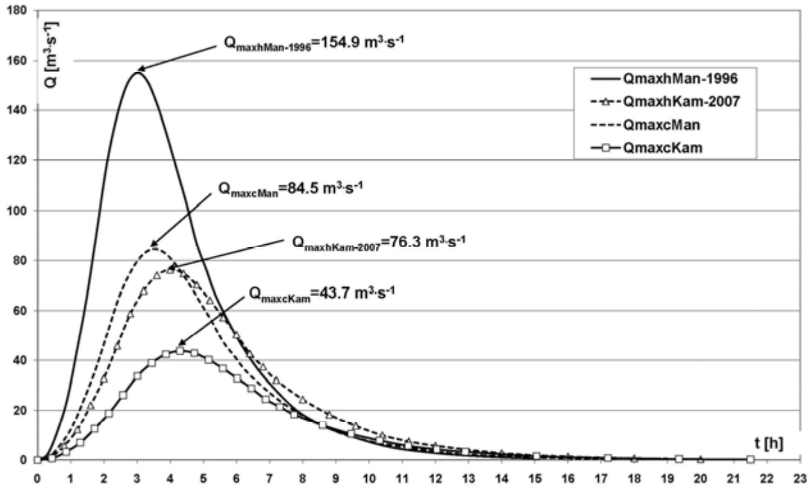

Figure 4. Historical and calculated hydrographs of maximal discharges into the rivers Manastirica and Kamišna

The values of computed maximal discharges ($Q_{maxcKam}$=43.7 m^3·s^{-1}; $Q_{maxcMan}$=84.5 m^3·s^{-1}), are significantly reduced in comparison to historical (recorded) values of maximal discharges ($Q_{maxhKam-2007}$ =76.3 m^3·s^{-1}; $Q_{maxcMan-1996}$= 154.9 m^{3}s^{-1}), as a direct consequence of restoration measures. Restoration measures are planned on the basis of spatial analysis of dominant factors in surface runoff forming. At the same time, other significant parameters such as physical characteristics of the watersheds (magnitude, mean slope of terrain, mean slope of river bed) and total precipitation remained the same.

DISCUSSION

Natural hazards cannot be prevented, but better understanding of the processes and scientific methodologies for prediction can help the mitigation of their impacts (Alcantara, 2002). The authorities in some European countries have recognised the need to convince the public of flooding threats, thus the need to use watersheds wisely (Pottier et al., 2005). In Switzerland and Germany, environmental protection and flood management are tasks of similar importance, and the optimum flood control system is a compromise between these two competing objectives (Plate, 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 urbanisation and the absence of the erosion control and flood protection structures).

The flood risk assesment must include the main natural characteristics of the watershed and anthropogenic changed characteristics such as: land use, urbanisation and the position of residential and infrastructure objects. It is also very important to take into the consideration other relevant aspects, such as plan documents, social and economic conditions and water management policy. Problems of erosion processes and torrential floods in Serbia have been integrated into spatial planning documents in the last few years, but we are facing years of hard work in order to define precise methodology of investigation and implementation of results. The final aim is to provide the basis that helps creating sustainable solutions to planners. Integral planning and management at local and regional levels (Maksin-Mićić et al., 2009) play a very important role in overcoming the collapse of strategic thinking in Serbia present in past 20 years, which has been reflected in various areas, especially in the domain of natural hazards prevention (Vujošević, 2010). The lack of the representative database for determining spatial relations between dominant factors in torrential floods formation, influences establishing of an inappropriate perception of risk or its absence, which can have fatal consequences.

The watersheds of the rivers Manastirica and Kamišna have geological composition consisting of rocks of low permeability. The geological composition of the watersheds influenced forming soil types with a small water infiltration capacity and high erodibility under atmospheric and anthropogenic impacts. Soil erosion on HZ was initiated by the removal of forest and inadequate agricultural activities (straight row farming, overgrazing). The actual state of erosion processes is represented by the coefficients of erosion Z=0.475 (Manastirica) and Z=0.470 (Kamišna). Restoration works have been planned in order to decrease yields of erosive material, increase water infiltration capacity and reduce flood runoff. The planned state of erosion processes is represented by the coefficients of erosion Z=0.343 (Manastirica) and Z=0.385 (Kamišna). The effects of hydrological changes have been estimated by the comparison of historical maximal discharges, and calculated maximal discharges (under the conditions after the planned restoration of endangered surfaces in the HZ). Realisation of planned restoration works will help decrease annual yields of erosive material from W_a=24357 m^3 to W_a=16198.0 m^3 (Manastirica) and from W_a=19974 m^3 to W_a=14434 m^3 (Kamišna). Additionally, specific annual transport of sediment through hydrographic network will be reduced from W_{atsp}=425.6 $m^3 \cdot km^{-2} \cdot year^{-1}$ to W_{atsp}=283.1 $m^3 \cdot km^{-2} \cdot year^{-1}$ (Manastirica) and from W_{atsp}=375.9 $m^3 \cdot km^{-2} \cdot year^{-1}$ to W_{atsp}=271.6 $m^3 \cdot km^{-2} \cdot year^{-1}$ (Kamišna). The values of historical maximal discharges ($Q_{maxhMan}$= 154.9 $m^3 \cdot s^{-1}$; $Q_{maxhKam}$=76.3 $m^3 \cdot s^{-1}$) were significantly decreased after the restoration ($Q_{maxcMan}$=84.5 $m^3 \cdot s^{-1}$; $Q_{maxcKam}$=43.7 $m^3 \cdot s^{-1}$), indicating the improvement of hydrological conditions, as a direct consequence of ETCW.

HZs have been determined on the basis of spatial analysis of important factors in torrential floods formation. Spatial identification of HZs helps effective action with a view to decreasing the intensity of erosion processes and the amount of surface runoff. The optimal means is a combination of technical, biotechnical and administrative measures. TAs on the experimental watersheds are positioned in the downstream sections, at the watershed outlet, in the zone of settlements. The morphology of narrow river valleys, with steep downhill, influenced the development of infrastructure and residential areas in the proximity of torrential streams and exposed them to the destructiveness of torrential floods.

Administrative measures should be applied through PAERs and PPTFs for the city of Užice and the municipality of Mionica. The plans impose bans on: clear cuttings; cuttings in protective forests; straight row farming down the slope; uncontrolled urbanisation; overgrazing. Land owners have the duty to apply contour farming and terracing of arable land as effective measures of erosion control. The number of livestock on grazing surfaces is 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. PAERs and PPTFs should be integrated into Spatial Plans (local, regional) in order to improve planning process and help establishing sustainable solutions. The previous Water Law (articles 15, 30; The Offical Gazette of the Republic of Serbia, No. 54/1996) stipulated that local authorities were obliged to make PAERs and PPTFs, but the funding for the planned solutions had to be provided by State Authorities (Directorate for Waters and State Owned Company "SerbianWaters"). The latest Water Law (article 61; The Offical Gazette of the Republic of Serbia, No. 30/2010) stipulates that making and financing of PAERs and PPTFs along with the implementation of planned solutions must be conducted at the local level. This is not a sustainable solution unless the fact that local authorities, with negligible exceptions, do not have financial and human resources (experts) to apply ETCW, is taken into consideration.

Integrated watershed management in Serbia must be jointly supported by the sectors of Water Resources Management, Forestry and Agriculture. However, despite the fact that they all form a part of the same Ministry, the coordination between them seems to be absent. The State Owned Company "Serbian Waters" has jurisdiction over all water streams on a territory of 55953 km^2, while "Serbian Forests" manage 19083 km^2 (9057 km^2 of state forests and 10026 km^2 of private forests,); nonetheless, there are no instances of joint activity in the protection from erosion and torrential floods.

CONCLUSIONS

Torrential floods are the most frequent catastrophic event occurring in Serbia, producing serious risks for people and their activities. The Serbian tradition in ETCW is longer than 100 years, with significant results in the domain of biotechnical and technical works. The frequency of occurrence and destructivity of torrential floods in 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 involves biotechnical works on watersheds, technical works in hydrographic network, within a precisely defined administrative and spatial framework in order to achieve maximum security for people and their property and to meet other requirements such as: environmental protection, sustainable soil usage, drinking water supply, rural development, biodiversity sustaining, etc. The lowest and the most effective level is attained through PAERs and PPTFs, with HZs and TAs mapping on the basis of spatial analysis of important factors in torrential floods forming. Solutions defined through PAERs and PPTFs must be integrated into Spatial Plans at local and regional levels.

The forecast and simulation of torrential floods is essential for planning an operation of civil protection measures and early flood warning. The development of HZs and TAs mapping and detailed risk assessments, enhanced early warning systems support readiness for the disasters. HZs and TAs maps provide the basis for torrential flood prevention and mitigation, by means of identifying „source" zones of impacts (fast surface runoff and sediment) and areas subject to flooding and sediment depositions which threaten life safety and property. These maps then guide the local authorities in adopting torrential flood management programmes, including restoration measures, prevention, education and preparedness. All levels of planning (spatial, urbanistic, regulation) must consider spatial aspects of dominant factors analysis for fast surface runoff forming. Cooperation and overcoming conflicts between the sectors of forestry, agriculture, water resources management and local economy development is essential at the following levels: policy; planning; practice; investments; education.

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