WP1

Analysis of soil erosion state and torrential floods in Western Balkan Countries

Lead Organisations of WP1**:UNSCM; UB**

Participating Organisation: UNS;UNI; UBL; UNSA; INSZASUM; BOKU; UNIRC; FRI-BAS

Deliverable 1.2

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2.1. Introduction

The availability of water resources in Serbia is closely related to the climatic conditions especially rainfall and temperature. Unfortunately and because of these aspects, Serbia is not in a too convenient position with regards to the fact that the greater part of Serbia is located in a typical temperate climate continental shelf. Although the amount of precipitation of 734 mm is valuable (especially for agricultural production), a key problem is its uneven annual schedule of precipitations (WD, 2016). The territory of Serbia has an average flow of 508.8 m^3/s, respectively, about $16 \cdot 10^9$ m^3 per year, which represents an average specific runoff of about 5.7 $L/s \cdot km^2$ (Ristić et al., 2011). According to this and based on the annual distribution of surface water of 1500 m^3 per inhabitant, Serbia is one of the poorer areas of Europe form the aspect of the availability of water resources. The lowland areas that are the most populated and where soil resources are richest (northern and central Serbia) are poorest with yields water (specific discharges 2-4 $L/s \cdot km^2$), which is a particular challenge for the water supply.

A significant part of the water supply system in Serbia is based on the use of water from surface reservoirs. The water supply of settlements is based on using local sources of ground and surface water and eventually, a shortfall is resolved by using water from the regional system. This concept of water supply is based on the use of surface water reservoirs in the zone of protected water sources (2 reservoirs under construction and 33 reservoirs planned by 2021) (WD, 2016).
The problem of flood protection is always topically, even in Serbia, due to the frequent occurrence of extreme water level in many parts of the hydrological system. Disastrous flooding took place during May 2014, which were the result of extreme hydro-meteorological conditions and caused damage to the flood prevention facility which led to extremely large losses.

Depending on the hydrologic-hydraulic, psamological and morphological characteristics of the watercourse, as well as the purpose and usage of watercourses and coastal areas in Serbia different objectives, tasks, and necessary measures arise. Dominant measures for protection are classic investment measures which ensure the safety of the construction works of flow – these measures are defined as excessive. Other sets of complex measures are "non-investment measures" (administrative, regulatory and institutional measures) which by now are so far been poorly represented, but gradually more and more introduced into the application.

The backbone of the existing system of flood protection are "passive measures" (line protection, for example, defensive embankments), while the "active measures" (increase bandwidth waterbeds, retaining part of the flood wave in reserved spaces, directing part of the flood, etc.) underrepresented (Ristić et al., 2012; WD, 2016).
Strategic management of such complex and fragile natural resources like water demands various levels of regulation and policies. The main legal document in the field of water

management is the Law on Water (Official Gazette of RS, 93/12). This law emphasizes the legal status of water, operational and organization levels of management and methodological shapes financing activities. This law has defined the occurrence other legislative areas related to other water sectors like Water management strategy of the territory of the Republic of Serbia, Law on Emergency Situations and elements of Methodology for defense against torrential floods

2.2. Status of the water resources

Water resources are a fundamental element of the vitality of the infrastructure systems that affect the prosperity of the society. According to the statistical yearbooks, Freshwater abstraction and water use in Serbia varies through observed years (Table 15). Particularly noteworthy is the year 2013 when the abstraction of surface water was a noticeable largest but an abstraction of underground water among the lowest.

Table 15: Freshwater abstraction and water use, in a mill. m^3

	2011	2012	2013	2014
Fresh surface water abstracted	3731	3411	3715	2924
Fresh groundwater abstracted	502	507	478	459
Total freshwater abstraction	4 012	3680	3982	3166
Total water use	**8245**	**7598**	**8175**	**6549**

Sources: Statistical yearbooks of Serbia for years 2011, 2012, 2013 and 2014

Rivers in Serbia belong to the territory of three major recipients: the Black Sea (Danube Basin), the Adriatic Sea (Drim and Plavskariver) and the Aegean Sea (Pčinja, Dragovištica, and Lepenac). The Danube basin with an area of 817000km^2 and the average flow at the confluence at the Black Sea of 6500m^3/s is the second largest river in Europe. Coming from Hungary to Serbia the Danube collects several main tributaries: the Drava, Tisa, Sava and Velika Morava. The biggest tributary to the left side of the Danube is the Tisa (157200km^2); it enters the territory of Serbia from Hungary and in the Danube confluence forms a vast alluvial plain. The right tributary of the Danube, the Sava, is the largest river that joins the Danube on the territory of Serbia. The area of its basin is 96400km^2 and has a length of 206km on the territory of Serbia where also a large alluvial plain is being formed. This part of the Danube basin in Serbia represents a significant continental lowland area of the Pannonian Plain with a smaller number of isolated island's mountains (Fruška Gora, Vrsac mountains, Cer, Avala). The tributary on the right side of the Danube - the Great Morava River (37 400 km^2) is formed by the joining South Morava River (15400km^2) and West Morava River (15,680 km^2). The basin of the Velika Morava River is characterized by a diversity expressed relief: in the upper parts of the basin are mountain ranges belonging to the Dinarides mountain that ranges to the west and the Carpatho-Balkan mountain range to the east. In the central part of the basin is a space of the Serbian-Macedonian mass, with far less energy relief while in the downstream parts of southern present elements of the Pannonian Plain. Beli Drim

(4732km^2) and Plavska River (272km^2) drain in the direction of the Adriatic Sea. From the river basin of the Aegean Sea, the most important is the Lepenac, the left tributary of the Vardar, which rises on the northern slopes of the Sharr Mountains. The area of its basin on the territory of Serbia is about 650 km^2.

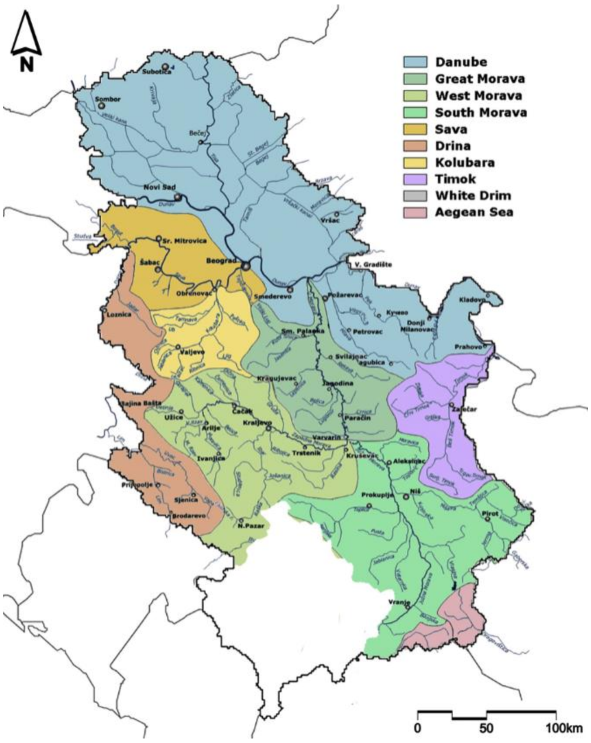

Figure 1: Main watersheds in Serbia (modified map from Water management strategy of the territory of the Republic of Serbia, 2015)

Basic characteristics of torrents

Torrential floods belong to the group of natural hydrological hazards characterized by the sudden occurrence of maximum flows on torrential streams with a high concentration of solid phase (Norbiato et al., 2008; Rocca et al., 2009; Kostadinov et al., 2017a; Ristic et al., 2012). Torrential floods are a localized hydrological phenomenon which is characteristic to steep-slope basins, small surface areas ranging from a few acres to several hundred square kilometers, responding to heavy showers within hours or less (Camarasa et al., 2001; Borga et al., 2007; Borga et al., 2011).

The torrential flood wave is a concentrated stream of water of enormous destructive power, the occurrence of which is conditioned by the interaction of intense rainfall and specific characteristics of the basin (Petrović et al., 2014). The genesis of torrential flood waves is the result of multiple natural processes on torrential basins that represent components of the hydrological cycle (Bewen, 2001; DeBarry, 2004). Thus, the runoff process on a single river basin is part of the global hydrological cycle.

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Extreme rainfall episodes are the main driver of the process of genesis of surface runoff and soil erosion that is directly and closely related. They occur almost simultaneously and their products, huge amounts of water and sediment, enter the hydrographic network and continue their movement as a two-phase fluid (Bathurst, 2007). The power of water in such processes makes the flow and transport of sediment during a torrential flood account for the largest share in the total annual flow and transport of sediment.

Table 1. Main characteristics of reconstructed torrential floods in Serbia

Water course	Profile	Date of appearance	Magnitude [km^2]	Q_{max} [$m^3 \cdot s^{-1}$]	q_{maxsp} [$m^3 \cdot s^{-1} \cdot km^{-2}$]	Duration/ Intensity
Ljestarska Valley	Vladicin Han	25.07.1982	2.64	16.16	6.12	90 min; 1.17 mm·min^{-1}
Kalimanska River	Vladicin Han	Summer 1929	16.04	149.0	9.3	/
Sejanicka River	Grdelica	02.07.1983	12.51	62.75	5.02	90 min; 1.01mm·min^{-1}
Manastirica	Brezdje	13.06.1996	29.5	154.9	5.25	180 min; 0.75mm·min^{-1}
Ribnica	Pastric	13.06.1996	104	418.08	4.02	180 min; 0.75mm·min^{-1}
Čađavica	Krupanj	15.05.2014	24.04	141.45	5.88	/
Kržava	Krupanj	15.05.2014	12.69	61.32	4.83	/
Brštica	Krupanj	15.05.2014	9.54	29.2	3.06	/
Vlasina	Vlasotince	26.06.1988	1,050.00	950.0	0.905	240 min. 0.92mm.min^{-1}

A torrent in general can be described as a natural channel or watercourse with: mainly small catchment, steep and irregular sections, extreme oscillation of the runoff with high peaks after rainstorms and snowmelt, high sediment transport and sedimentation. Torrents are the consequence of the intensive erosion processes in the catchment. They transport a large quantity of sediment (suspended and bed load) (Kostadinov, S., 2010).

Important facts for the danger of a torrent:

- Steepness of the landscape,
- Short time until flood-peak so there is no time for warning,
- Debris and wood (difficult hydraulic conditions in the bed),
- Jamming of bridges,
- Sediment deposition out of the riverbed,
- Debris flows (Baumann, G., 2011).

2.3. Historical evidence of floods

Among natural hazards with serious risks for people and their activities, the torrential floods represent the most common hazard in Serbia. Within the context of climate change

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in the last ten years, Serbia is exposed to more torrential floods causing huge damage and loss of human lives. According to the literature (Ristić et al., 2012), in Serbia, more than 10,000 torrents with disastrous consequences were registered. Among these, the total number of human victims is over 180 - the average is nearly 4 victims per event torrential floods with a fatal epilogue. A more detailed overview is provided in Table 16.

Table 2: Major flood events in the 2000-2015 period

Date	Affected areas, municipalities	Extent of damage
June 2002	Southern and central parts of Serbia: Grdelica, Vranje, and its surroundings, Jagodina, Paraćin, Krupaja, Svilajnac, Despotovac	252000ha flooded by outside waters, 227 settlements endanger
March–June 2005	Southern parts of Serbia and Belgrade surroundings: Bela Crva, Barajevo, Ripanj, Leskovac, Jelašnica, Leskovac, Lebane, Osečina	700000ha flooded by surface, ground and torrent waters, 227 settlements endanger
November 2009	South-westernparts of Serbia: Prijepolje, Nova Varoš, Priboj, Arilje, Novi Pazar, Sjenica, Užice	33000ha flooded, 56 settlements endanger
February 2010	Eastern and central parts of Serbia: Zaječar, Aleksinac, Požega and Knjaževac, Negotin, Svrljig Boljevac; Merošina, Doljevac, Koceljeva, Ub, Lajkovac, Ljig, Vladimirci, Žitorađa, Priboj and Prijepolje	1,306 households damaged, more than 3,150 people affected
September 2014	Eastern Serbia municipalities of Kladovo, Majdanpek, and Negotin	Approximately 7,000 people affected
May 2014	Western, South-western, central and Eastern Serbia: Sava, Tamnava, Kolubara, Jadar, Zapadna Morava, Velika Morava, Mlava and Pek at BeliBrod on the tributary river Kolubara – Obrenovac	EUR 1,525 million lost equal to about 3% of the GDP, 9,100 km^2 and 38 municipalities affected, 1.6 million people affected, 51 lives lost

Sources: Statistical yearbooks of Serbia for period 2002-2014

The frequency and the intensity of torrential floods vary both temporally and spatially. For the purposes of estimating the frequency of torrential floods in hydrologically unstudied basins, the research on the frequency of heavy rains is of great significance. Thus, Gavrilović, S (1975) has performed an analysis of average annual torrential rains for the period 1928 – 1968 for 312 gauging stations – 100 on the territory of Vojvodina, 188 in Central Serbia and 24 in Kosovo. It led to a conclusion that the highest average torrential rain in Serbia for the given period during one average year is 45 mm in Belgrade and Obrenovac area, around Kuchevo, Svetozarevo, Chachak and Nova Varosh. The greatest number of torrential floods occurs in Prizren, Kopaonik area, Priboj, Ljubovija, Pirot and Tekija.

It should be noted that in the last 30 years torrential floods have occurred as the result of extremely high precipitation: Vlasina flooding in Vlasotince in 1988 with 220 mm of rainfall in four hours, flooding of Ljeshtarska Valley in 1982 with 120 mm in 105 minutes,

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flooding caused by torrents in Krupanj in 2014 with incessant rain for three consecutive days and nights with 428 mm, etc. (Kostadinov, S., 2002, Kostadinov et al, 2014).

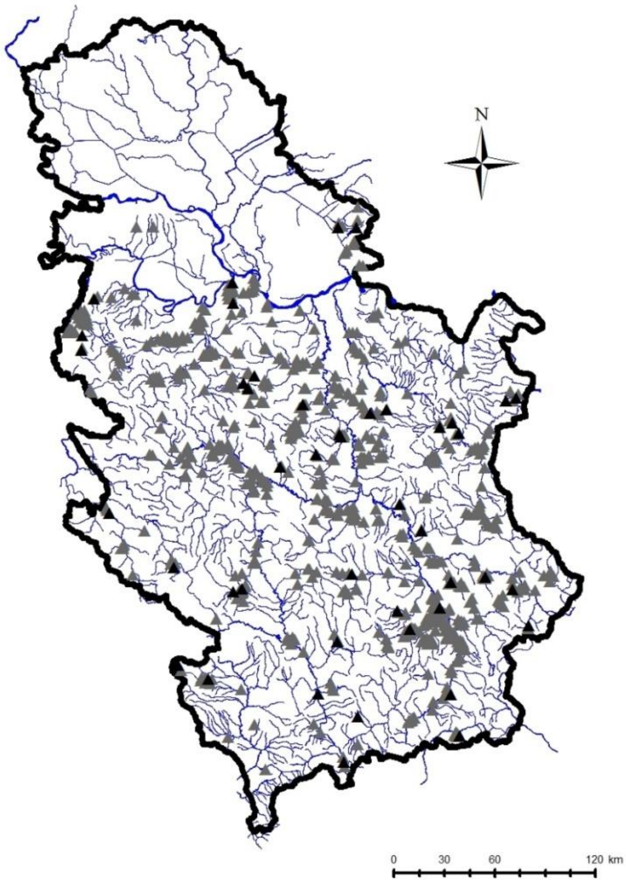

Figure 2. The most destructive torrential flood events in Serbia in the period 1915-2013
(▲ - casualties & material damage, △ material damage)
Sources: Petrović, A., 2014
Petrović, A.,et al, 2014

According to the data of the former Department of Torrent Control of the Ministry of Forestry and Mining of the former Yugoslavia, torrential floods on the Great, West and South Morava, Mlava, Timok and Drina Rivers occurred in average every third year: 1921, 1924, 1929, 1932, 1937 and 1940. After the WWII, great and harmful torrents occurred in almost all our regions in 1947, 1948, 1951, 1953, 1957, 1961, 1963, 1965, 1967, 1969, 1970 and 1972 (Gavrilović, S. 1975). The torrential floods inventory recorded the most destructive events in the eighties of the last century in the basins of Ljeshtarska Valley (1982), the Sejanichka River (1983) and the Vlasina River (1988) (Kostadinov,S.et al 2017). Deadly torrential flood in the recent period occurred on the Topchiderska River in 1994 (1 casualty), the Topchiderska River, Lugomir, Gruzha, Jasenica and Lepenica in 1999 (18 casualties), the South Morava and Resava Rivers in 2002 (2 casualties), Jablanica in 2009 (1 casualty), Timok and Pchinja in 2010 (2 casualties), Krupanj in 2014 (2 casualties) and Tekija in 2014.

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Annual distribution of registered torrential floods

Based on the available information obtained from various reliable sources 848 torrential flood events in Serbia for the period 1915-2013 were registered in the Inventory of torrential floods in Serbia presented in the research of Petrović (2014). It must be noted that most of them occurred in mountainous area of Serbia, south from the Sava and Danube rivers, while floods that occurred in Autonomous Province of Vojvodina were mainly caused by large alluvial rivers Danube, Sava, Tisa, Tamiš (Fig. 1. Tab 2.).
The following valuable findings on past torrential flood events are presented from the research of Petrović (2014) and Petrović et al. (2014). According to annual distribution for observed in the period 1915 – 2013 period, the peak years which are distinguished on the basis of number of events are 1969 (54), 1999 (51), 2005 (47), 1956 (47) and 1986 (43). The annual mean of registered torrential flood events is 8.57. Trend line (Fig. 4) clearly shows exponential increase of torrential flood events which is in line with the distribution of registered torrential floods per periods: 1931-1960 and 1961-1990 which are recommended by the Republic Hydromethorological Service of Serbia in order to perform detailed comparative analysis on precipitation and air temperature changes. This increase of events (Tab. 2.) can be explained as a consequence of global climate changes which is also in accordance with the data from the literature about high increase in average annual natural hazards in the world per decades Nowadays, scientists all over the world have agreed that discharges with recurrence interval of 100 years become events with recurrence interval of 20 years which increase the importance of studies on torrential floods. Even though the precipitation height on the annual level is unfavorable, the circumstances are such that they occur mainly in the form of heavy rainfalls which result in sudden water concentration having torrential floods as a consequence.

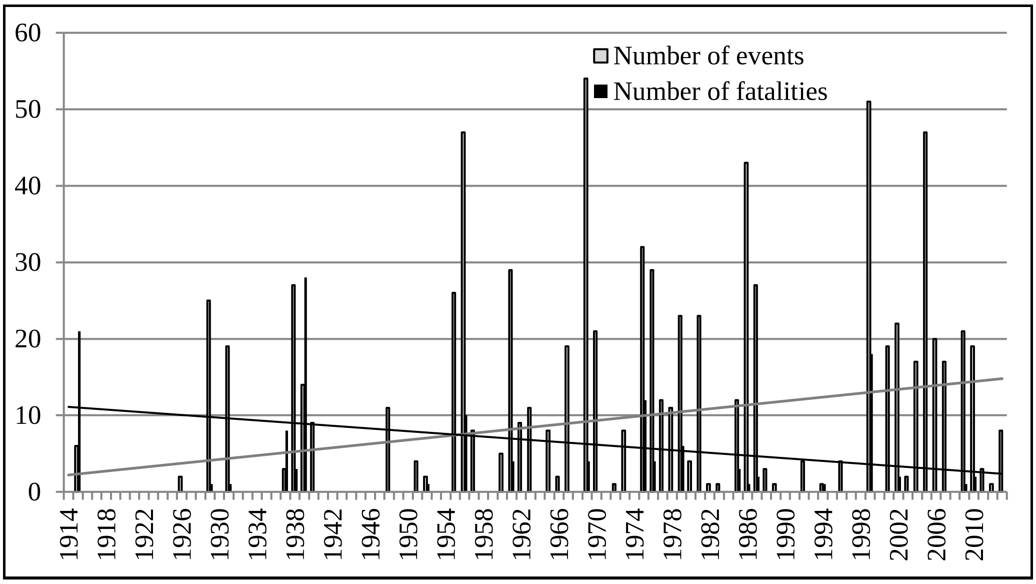

Figure 3. Annual distribution of torrential flood events and casualties in the observed period with trend lines. Source: Petrović, A., et al,2014

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In the terms of number of people affected and fatalities, the occurrence of flash floods is among top natural disasters and thus of great concern in natural hazard science. The following data on casualties in Serbia from the Inventory of torrential floods in Serbia (Petrović 2014) should draw attention to the phenomenon of torrential floods. In terms of death toll, the peak years are 1939 (28 deaths), 1915 (>21), 1975 (12), 1999 (18) and 1956 (10) and peak months are May (45 deaths), June (28), July (21). Top torrential flood events in terms of casualties took place in Koritnička river - October 1939 (17 deaths), Korbevačka river - May 1975 (12), Selska river - June 1939 (11), Brestovačka river - May 1915 (11), Sikolska reka - May 1915 (>10), Topčiderska river - July 1999 (10). Data on injured people as a consequence of torrential flood event are rare.

Tabele 3. Distribution of registered torrential floods in the periods

Time period	Number of torrential flood events	Average of number of torrential flood events per period	Number of casualties per period
1915-1930	33	2.06	>22
1931-1960	175	5.83	>51
1961-1990	384	12.80	36
1991-2013	256	19.69	24
Total	848		>133

Source: Petrović, A., et al,2014

It is understandable that the greatest number of torrential floods is registered in Southern Morava basin (15.000 km^2) since the most intensive soil erosion processes are present here (Tab. 3.)(Petrović et al., 2014). Natural conditions but also an extreme forest exploitation and destruction in Grdelica gorge and Vranje Valley have resulted in extremely intensive erosion processes and frequent striking torrential floods causing disastrous damages including casualties . Two major international routes, railway and motorway Belgrade – Skopje – Athens, situated in Southern Morava valley, were often interrupted by torrential floods, which escalated after the World War II when those interruptions lasted up to 15 days. Grdelica Gorge of Southern Morava is particularly important since 137 torrential streams, direct tributaries to Southern Morava, were registered on the small area from Grdelica to Vladičin Han at the length of 28 km. Grdelica Gorge turns into Vranje Valley from Vladičin Han to border with Macedonia where 80 torrential streams were registered.

2.4. Preventions measures for torrential floods

According to Dragicevic et al. (2011) multihazard map for the territory of Serbia which depends on the type of hazard and potential damage shows that natural hazards are various and the vulnerability is not uniform. Serbia is most threatened by riverine and torrential floods (more than 12 000 torrential river basins were inventoried in Serbia from 1930 to the end of 1960 (Kostadinov et al. 2014)) which are the most frequent and the most destructive natural disasters regarding huge material damage and loss of human lives (Kostadinov et al., 2017).

The torrential flows due to their characteristics and nature (the sudden appearance of destructive torrential floods) present a permanent danger to settlements, infrastructure, housing, and industrial facilities. This hydrological phenomenon occurs almost every year in Serbia causing significant material damage to agriculture and settlements, industrial, housing and traffic infrastructure. Some occasions of the torrential floods in history were fatal to humans and the local economy, especially in underdeveloped regions of Serbia (Institute of Forestry, Belgrade, Serbia, 2018). Based on the latest researches, in the period of 1915-2013 on the territory of Serbia were 848 occurrences of the torrential floods in which more than 133 people lost their lives (Petrović,A., 2014). In the Inventory of torrential floods in Serbia (2014), the largest number of the registered torrential floods was recorded in the South Morava Basin (195), then in the basin of West Morava (157) and Velika Morava (127). The defense against torrential flows and torrential floods due to their characteristics differs from the flood defense of main rivers. The flooding in the case of the main rivers can be predicted several days in advance, while the torrential floods occur only a few hours after a high-intensity precipitation, so there is practically no possibility for any defense, but only for recovery after the flood. Therefore, the only way of defense against the torrential floods is prevention. The prevention involves controlling the erosion and torrential processes in the basins, which is achieved by the permanent conducting erosion control works in the basin and the torrential hydrographic network, that is, the integrated river basin management.

The river basin management presents a complex of the protective measures and methods directed to the regulation of outflow of surface water into the river basin, the protection of soil erosion, the forming and the increasing of the fertility of eroded soils and their more rational use, the elimination of reasons that can cause erosion on the slopes of the basin, the prevention of deep erosion and sediment discharge as well as the torrential floods in the hydrographic network of watercourses (Kostadinov, S., 1996).
In order to mitigate the negative effects of the soil erosion and the torrential floods the multiple systems are applied, each of them being a combination of the erosion control measures and works that take effect on a particular river basin (Institute of Forestry, Belgrade, Serbia, 2016).

The erosion control measures (economic, administrative, educational, etc.) are actions that affect the way of utilization, maintenance, and management of land and water.
The erosion control works (technical, biological, biotechnical and agro-technical) are the works targeted at the direct repairing of the torrent basin or erosion area.

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In the contemporary combat against erosion and torrential floods, the following groups of works are applied:
- Technical works,
- Biotechnical works,
- Biological works,
- Administrative measures, and
- Educational and promotion measures.

Technical works - Technical works include building of structures for the regulation of the beds of the torrential streams which main purpose is the direct protection from flood waters and sediment retention. For the regulation of the beds of the torrential streams different structures have been built which relative to the watercourse axis can be transverse and longitudinal.
The transverse structures are made in straight or in non-straight angle relative to the axis of the watercourse, while the longitudinal are parallel to the river banks. The purpose of the transverse structures is to protect transverse profiles of the beds of the torrential streams from the further deep erosion processes, keep the sediments from the stream bed and banks in the accumulation space upstream of the facility by forming siltation and thanks to that the unstable slopes upstream of the facility become more stable, the longitudinal bed slopes decline, water speed decreases as well as the destructive power and the transport ability of the stream. These structures include consolidation belts, sill and dams.
The purpose of the longitudinal structures is to prevent bank erosion and water outflow from the stream bed. The longitudinal structures are the following: structures with and without lining of channels of stream, dykes, groynes and training walls.
Biotechnical works - Biotechnical works in the basin are works that most often complement biological works and create conditions for establishing vegetation on steep and bare slopes, that is, create conditions for better success of afforestation, grassing, establishing orchards, etc. For this purpose, several types of measures can be applied: contour terraces (infiltration banks, "gradoni" terraces, terraces with walls, etc.); contour canals; walls along the contour line (horizontal walls according to Rosić, dry laid masonry wall, gabion wall, etc.).
Biological works - These works have a great significance in the erosion control of the catchment area and their role in the rehabilitation of slopes of the basins in danger of erosion is very important. These works include afforestation, grassing, amelioration of forests and agricultural areas, regeneration felling, establishment of orchards, etc.
Administrative measures - Regarding the comprehensive fight against erosion, administrative measures and prohibitions take a significant place, and their adoption and implementation make certain obligations to landowners and relevant inspection authorities. The field evidences related to the erosion prevention led to the conclusion on the necessity of applying the following prohibitions and obligations: the obligation of introducing contour tillage; the prohibition of excessive grazing in pastures and forest

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land, pruning of trees, and uncontrolled deforestation; the transition from cultivating annual to perennial cultures and other similar restrictions in relation to landowning and keeping livestock in erosion areas and near torrential river basins.
One very effective way of protecting soil from erosion, established on valid legal acts, is the adoption of the Decision on the designation of the erosion area and the prescription of erosion control measures. This Decision determines the soil endangered from erosion in the observed area and prescribes the obligations to users and owners of land and facilities to implement all planned works and measures aimed at rehabilitation and conservation of the land.

Educational and promotion measures - This group comprises the organization of trainings, lectures, exhibitions, printing of popular books and brochures, all related to the fight against soil erosion, torrential floods, drought, etc.
The erosion and torrent control works (ETCW) in the territory of Serbia started by the end of 19th century, but the organized work started in 1907. The first works refer to torrent control and channel training in the zones of intersections with railway, aiming at railroad protection. There were works in the torrents of the Grdelička Klisura gorge in the South-East of Serbia, where the international railway line Belgrade - Skopje - Athens passes (Kostadinov,S., 2007).

Based on the to date business policy, i.e. so far performed works, organizational changes and methods of financing in the Republic of Serbia, there are nine stages of development and realization of ETCW (Kostadinov,S., 2007).

<u>The first stage,</u> 1907-1940, is characterized by the predominance of torrent control works (construction works in the torrent channel). The extent of technical works was 56,194.00 m^3. On-site soil conservation was performed only by small-size afforestation (only about 575 *ha*). Direct protection of arable soil was not applied at all because the land was in private ownership and also probably because, at that time, the knowledge in this field was insufficient, as well as due to the lack of financial support.

Torrent Control Service was organized together with the Hydrotechnical Service, as the Department of the General Direction of Waters at the Ministry of Agriculture and Waters. In 1927 Department of Torrent Control separated from the General Direction of Waters and joined the Ministry of Forests and Mines. The so-called French School was adopted (French system of torrent control). From 1927 to 1930 the development was more intense, preparatory field sections were organized for carrying out the works, and the projects were prepared in the Department of the Ministry itself. The works were co-financed by the budget of the Ministry and Railway Administration.
In <u>the second stage</u> (1941-1944), during the Second World War, on the occupied territory of Serbia, very little was done regarding torrent control. Nine torrents were treated with 1,301 m^3 of masonry and 5 *ha* of afforestation.
<u>The third stage</u>, 1945-1954, was characterized by only the most necessary torrent control works (construction works in the torrent channel) in order to protect the railway line

and roads. The extent of works was very small (56,774.0 m^3 masonry and 457 *ha* afforestation).

The period between 1945 and 1951 can be considered as the age of progress of the Erosion and Torrent Control Service in the sense of organization, because the first signs of independence could be seen. During 1945-1946, the Service was an Office in the Department of bareland afforestation and torrent control and, already in 1950, the Administration for torrent control and civil engineering was formed in the Ministry of Forestry of the Republic of Serbia. ETCW were financed by the budget of the Ministry of Forestry and, to a less extent, by the budget of Railway Administration in Belgrade. However, due to the lack of finances, there were comparatively few works. In that period, the funds were directed to the building and reconstruction of the country devastated by the Second World War.

Figure 4. Check dam in the Panovljanska torrent

<u>The fourth stage</u>, 1955-1966, is characterized by significant legislative activities, by a sudden development of the Service organization, the participation of a higher number of professionals, technical equipment, increasing investments and the application of the new technologies: American (contour ditches, bench terraces, strip farming, etc.), French (Algerian banquettes with the establishment of orchards, etc.), Italian (terraces, gabions, etc.). There was a sudden rise of investments that affected the extent of erosion and torrent control works (masonry 386.334.0 m^3 and biological works 16,008.0 *ha*, Table 2). During this stage of development, the organized on-site erosion control on farmland operated by forestry and agriculture experts, occurred for the first time and developed rapidly. This action culminated in 1962, and then it declined permanently, so that by the end of this stage, it almost disappeared. Finally, the method of financing was reorganized, as well as the Service and the companies which carried out the works.

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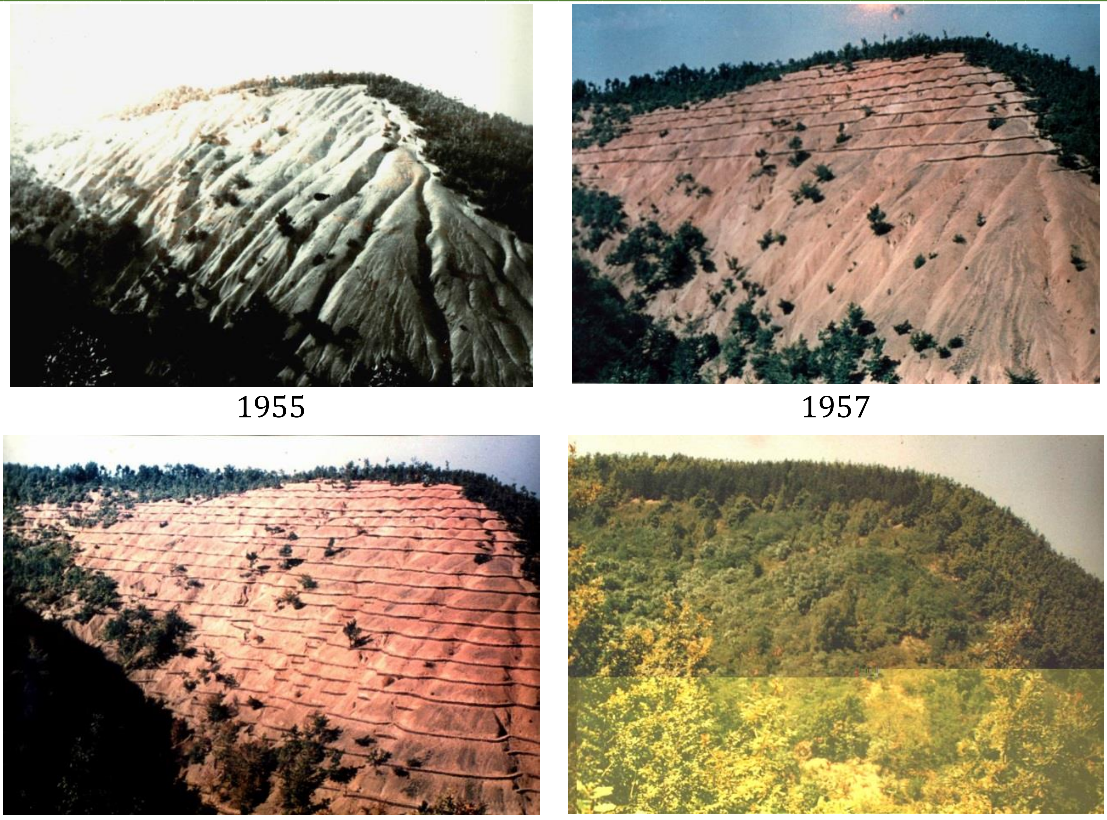

1955 1957

1958 1978

Figure 5. Effect of afforestation of bare land in the Vlasina river watershed. Photograph V.Milojević and Kostadinov,S., 2007

In Serbia, during this period, Prof. S. Rosić conceived the "torrent extinguishing" system, in which the main components are the special dams with a filter system "for the separation of water from the sediment", named by the author "settling basins" (filtration check dams). Their use in the regulation of torrent channels showed a series of advantages regarding the efficiency and economicity, compared to classical torrent-control check dams (Kostadinov, 1995).

Based on the Law of Torrent and Erosion Control of the Republic of Serbia, in the period 1954-1957, ten regional sections for erosion and Torrent control were formed in the aim to carry out erosion and torrent control works. In the financing of these works, along with the budget of the Republic of Serbia, districts and communities (national budget), the Directorate for Roads, mines, electric power industry, Railway Administration (also previously), and other interested business firms started to take part.

During this period, the Department of Erosion and Torrent Control was formed at the Faculty of Forestry of Belgrade University, by the decision of the Executive Council of the Republic of Serbia in 1959. The first generation of students was enrolled in 1960/61. The Department had its own curriculum and syllabus.

<u>The fifth stage</u>, 1967-1977, was characterized by the repeal of the Law of Erosion and Torrent Control when the direct conservation of arable soil stopped, except through a

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very modest cooperation with individual owners of farmland, by giving them free seeds of grass or forest tree seedlings, with the obligation that they must not plough the meadows on steeper slopes for 8 years.
In the fifth stage, there were no engineering works in the watershed (contour ditches, various types of terraces, etc.), except small terraces for afforestation. Bare (untillable) parts of the watersheds were afforested with or without previous technical works (small terraces, etc.) Transversal structures were built in the torrential channels and the lower courses were regulated. Previously, such works were performed almost exclusively in order to protect the communications and, in this stage, most works were designed to protect the settlements (urban regulations). The works amounted to 476,505.0 m^3 of masonry and 16,194.00 *ha* of biological works, which was an increase compared to the previous stage.

Considering the 1967 Law of Waters in Serbia, the Service for Erosion and Torrent Control was reorganized. The former independent Regional Sections for Erosion and Torrent control were integrated with Water Communities into Water Management Enterprises which coincide with the largest rivers: Morava, Sava, Dunav, Drina, Timok, Mlava, and Pek. The Direction of Erosion and Torrent Control was also repealed. In this way, the previous independent service was governed by Water-Management Department Consequently, in the following period, ECW were performed in the interest of water management. Thus the previous policy was abandoned. In the previous stage (1955-1966) there were at least some elements of soil and water conservation (ECW on arable land), as the essential factor of food production. In the fifth stage it could deal with erosion control on the slopes of the watershed only from the aspect of the adverse effect on water regime of the water courses (water management aspect). The works were financed by the Republican Fund for Waters.

<u>The sixth stage,</u> 1978-1988, starts at the time when the regional and republican "self-managing communities of interest" were established. They succeeded the former Republican Fund for Waters and continued to finance all the water-engineering works, including erosion and torrent control works.
Technical works were no more performed on the slopes of the watershed (except for small terraces for afforestation). Afforestation is also carried out on bare (untillable) parts of the watershed, with or without making small terraces. Some transverse structures (check dams) were made in torrent channels, but to a much smaller extent than in the previous stage. During this stage (even more than in the previous stage), longitudinal channel-control works were massively performed in the aim to protect the towns (torrent regulation in towns). In this stage, there were somewhat less technical works (masonry 421,234.0 m^3), but there was a rise in biological works - 55,011.0 *ha*.

<u>The seventh stage</u>, 1989 -1991. In this stage, the extent of technical works (masonry - 84,557.0 m^3) and biological works (only 10,810.0 *ha*) decreased compared to the previous stages. This is the result of the beginning of economic crisis in the country, due on the eve of the disintegration of the former SFR Yugoslavia. In addition, the lower extent of ECW is by all means also affected by the Laws adopted in this period (Republican Laws

of Waters in 1989 and 1991), because the issues of erosion and erosion control are regarded in an inadequate manner.

The eighth stage, 1992-2000. In this stage the extent of technical works (masonry -only 9,720.50.0 *m*³) and biological works (only 15,396.67 *ha*) significant decreased compared to the previous stages. This is result of very intensive economic crisis as the consequence of UN sanctions against FR Yugoslavia (Serbia and Montenegro) in the period 1992-1996, war in the neighboring countries (1992-1995), war in the Province Kosovo 1998-1999 and finally NATO bombing in 1999 year.

The ninth stage, 2001-2010. During this period, after Democratic changes in Serbia have taken their place, successive recovery of economy in total and by it the recovery of water management, which is the main investor of erosion and control works (ETCW**),** starts. In 2001 new ETCW have not been performed apart from some smaller rehabilitation works, where as biological works (BW) have been performed in 2002 on a relatively small area. ETCW are considerably larger each year starting from 2002, so that total scope of biological works BW in this period is 24,078.20 ha, and scope of Masonry is 27,592.40 m³. Table 1 show total quantities of works carried out in Serbia.

Table 4. **Erosion and torrent control works in Serbia in the period 1907-2010**

Stage	Period	Masonry		Biological works	
		Total m³	Annual average m³year⁻¹	Total ha	Annual average ha year⁻¹
I	1907-1940	56,194.00	1,652.80	575.50	16.90
II	1941-1944	1,301.00	325.20	5.00	1.25
III	1945-1954	56,774.00	5,677.40	457.00	45.70
IV	1955-1966	386,334.00	32,194.50	16,008.00	1,334.00
V	1967-1977	476,505.00	43,318.64	16,194.00	1,472.18
VI	1978-1988	421,234.00	38,294.00	55,011.00	5,001.00
VII	1989-1991	84,557.00	28,185.67	10,810.00	3,603.33
VIII	1992-2000	7,085.30	787.25	9,328.60	1,036.51
IX	2001-2010	27,592.40	2,759.24	24,078.20	2,407.82
TOTAL		1,517,576.70	14,592.08	132,467.30	1,273.72

Source : Kostadinov,S., 2007

All the works in the Tables have been classified in two groups:

- masonry (including all the construction engineering works made of concrete and stone masonry in the channel - transverse and longitudinal structures)

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- biological works (including all the areas where biological works were carried out in the watershed, such as afforestation, reclamation, grassing, establishment of orchards, shelterbelts, wattles, coppice reclamation, terracing contour farming, etc.).

Figure 6. Check dam in the Bojkovački Potok torrent

Figure 7. Regulation of lower course of the Štira torrent (Photograph: S.Kostadinov)

Figur 8. Stream Sarač (Photo: Đ. Živanović)

In the field of erosion and torrent control in Serbia, especially after the Second World War significant results have been achieves. Many roads and railways, settlements, industry, agricultural soil and storage reservoirs have been protected (fully or partially), from sedimentation and from torrent floods. Still, this is not enough, considering the present conditions and requirements.

During the period of about 100 year in Serbia mostly were applied Classical European French and Prof. Rosić's System for torrent control (Kostadinov,S., 2007).

It should be noted that after 1990 the scope of implemented erosion control works in Serbia significantly dropped. Very limited financial resources are invested in the biological and technical works. The reason for this reduction was the economic crisis caused by the breakup of the SFR Yugoslavia into 6 independent states and wars in Croatia, Bosnia and Herzegovina and later in 1998 in the autonomous province of Kosovo and Metohija. From 1992 to November 1995, the UN imposed tough economic sanctions against the FR of Yugoslavia. From March 24 to June 10, 1999, NATO bombed Serbia and Montenegro. The situation improved for a bit in the period from 2001 to 2008, but then the global economic crisis started and again the level of investment in the erosion control works was reduced to a minimum.

On the other hand, the Parliament of the Republic of Serbia adopted in 2010 the new Law on Water which imposes that the Republic of Serbia is responsible for the flood protection of only the first-order watercourses (110 largest watercourses in Serbia), while the watercourses of the second-order which are all the torrential watercourses (more than 12,000) fall under the jurisdiction of the local self-government, i.e., municipalities. But, the municipalities do not have financial resources and personnel, so the problems of the erosion control and defense against torrential floods are thus left aside. All this had a negative impact on the level of investments in the erosion control works in Serbia.
In addition, in the period from the end of 1990 to the present day, the maintenance of the constructed facilities and tending of newly established forest plantations almost completely failed. There were attempts for increasing the scope of the biological works by designing a plan to carry out afforestation of bare lands on the surface of 100,000.00 ha (10,000.00 ha per year) during the period from 2005 to 2015, but almost nothing of this plan was realized.

Therefore, the problem of the soil erosion and torrential floods in the Republic of Serbia should be resolved in a correct way, because these problems hinder the economic development of the country. So they should be solved promptly because all the analyses show that the number of destruction torrential floods increases and subsequently the material damage and the number of human victims.

Mountain watershed management should be carried out by the most modern methods which made up an integral system for management of torrential mountain watersheds. This is an interdisciplinary approach, which applies and combines different measures and the methods of ecology, biological and technical sciences in an integrated eco-socio-engineering system, in order to achieve the general aim. The integrated system presents an optimal combination of the civil engineering, biological and bioengineering works as well as the administrative measures, all in the function of soil protection from the erosion and from the torrential floods, with the improvement of the quality of life in the treated watershed. Such a system is before all deeply humane, ecologically appropriate with the

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maximum fitting into the environment (as one of the requirements of the modern times). (Hattinger, 1986).

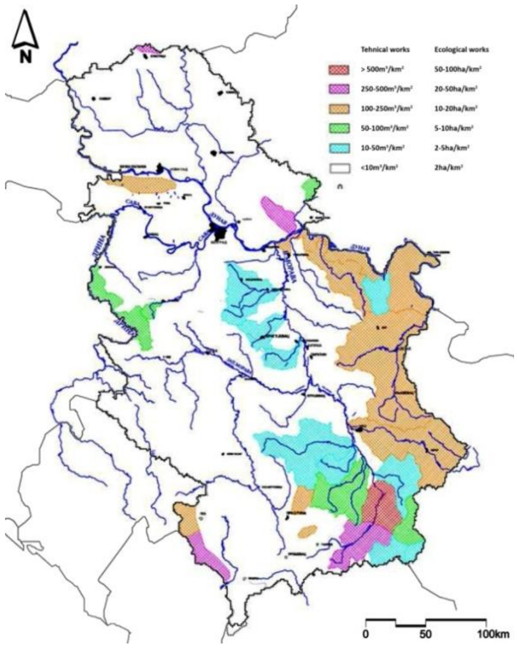

Figure 9: Technical and ecological works in the territory of Serbia

2.5. Flood risk management plan

Because of the current water legislation in place and as part of the planning documents required, in Serbia the following plans were created: plans of flood risk management, a general and operational plan for flood protection, and the plans regulating the protection of water (plan for water pollution protection and monitoring program). These plans provide a system of measures and activities for flood protection, protection from erosion and torrents and elimination of consequences of such effects of water (WBIF, 2015). The preliminary flood risk assessment is prepared for the whole territory of the Republic of Serbia and contains:

(1) maps of the river basin areas in the proper scale, with bold borders of sub-basins, as well as topography and land use are shown,

(2) a description of the history of floods which have had significant harmful consequences on human health, the environment, cultural heritage and economic activity and the possibility of occurrence of similar events in the future, which could have similar consequences,

(3) assessment of potential harmful consequences of future floods to human health, the environment, cultural heritage and economic activity, taking into consideration the topographical, hydrological and geomorphological characteristics and position of watercourses, including floodplains, the effect existing facilities for flood protection, the

position of populated areas and industrial zones, plans for long-term development and climate change impact on occurrence of floods.
The management plan for flood risks for the entire territory of Serbia was created by the responsible Ministry while plans with more detailed informational and spatial resolution (water catchment areas – a total of 7 water areas) are made by different Water Management Companies: WMC “Waters of Vojvodina” for river areas in Bačka, Banat and Srem and WMC “Srbijavode” for river areas that are in the lower parts Danube, Sava and Morava. The area and facilities protected between 2011 and 2014 against floods are presented in Table 17.

Table 5: Area and facilities protected against floods

	2011	2012	2013	2014
Total area protected against floods, thous. ha	958	1469	1249	1326
Utilised agricultural land, thous. ha	1709	1260	1089	1156
Settlements, number	644	716	603	833
Industrial facilities, number	481	586	506	666
Railway lines, roads, km	5871	3122	2857	4749
Total length of embankments, km	3446	3458	2884	3247

Sources: Statistical yearbooks of Serbia for years 2011, 2012, 2013 and 2014

2.6. Institutional and legal framework in field of erosion and torrent control

Water management in Serbia (see Figure 2) is under the authority of the Department of Protection of Water within the Republic Directorate for Water of the Ministry of Agriculture and Environmental Protection (OG, 2005). The Ministry of Agriculture and Environmental Protection and its operational body, the Directorate for Water are responsible for the development of legislation, water management policy and strategy, preparing flood risk management plans, action plans and coordinating with the concerned actors. Operational organization is organized within three basic territorial segments: the Public Water Resources Management Enterprise (PWRME) „SerbianWaters“ (founded in 1996) which is responsible for the area of Serbia without Autonomous Province (AP) Vojvodina and the administrative area of Belgrade, PWRME "VojvodinaWaters" (founded in 2002) responsible for the area of AP Vojvodina. The PWRMEs are in charge of water management, construction, maintenance and management of facilities for flood protection, erosion and flood control and development of technical documents and designs. They are also responsible for flood hazard and risk mapping and for the flood and ice defence management in coordination with the Republic Hydro-meteorological Service, municipalities, land owners, etc. PWRME "SerbianWaters" realizes its activities through the Water Resources Management Center (WRMC) "Sava-Danube" with headquarters in Belgrade and the WRMC "Morava" with headquarters in

Niš, which carry out their activities through local water resources management enterprises. The PWRME "VojvodinaWaters" has no smaller organizational units and its activities are carried out directly through local water resources management enterprises.

In addition to what was said above the following authorities are responsible as regards flood management: Republic hydro-meteorological service, Sector for Emergency Management (Protection & Rescue Sector & Civil Protection Sector) and the competent authorities of the Municipalities. The Flood Affected Areas Assistance and Rehabilitation Office (FAAARO) is also tasked with flood prevention-related issues. The Public Water Companies have to provide staff, equipment, ensure technical conditions for defence activities. The Serbian Environmental Protection Agency (SEPA) prepares reports and assesses the state of water quality in accordance with national and EU regulations. SEPA establishes and maintains a database of water quality and plans, sets up and maintains a network of monitoring stations for water quality. The International Sava River Basin Commission manages projects related to the Sava and facilities the communication among the countries of the Sava Basin. Serbia is also a full member of a similar international cooperation in the Danube Basin under the auspices of the International Commission for the Protection of the Danube River (ICPDR) targeting transboundary water management in the Danube River Basin. Priorities of the initiative include improving the environmental emergency warning system, flood forecasting, the monitoring network and the information system as well as sustainable flood prevention and risk management.

The basic legal document in the field of water management is the Law on Water ("Official Gazette of RS", no. 93/12), that regulates "the legal status of water, integrated water management, management of water facilities and water land, sources and methods of financing water activities as well as and other issues of importance to water management". In addition to the Law on Water, other laws related to water sector are: the Law on Emergency Situations (Fig. "Official Gazette of RS", no. 93/12), the Law on Environmental Protection ("Official Gazette of RS", no. 14/2016) and the Law on Meteorological and Hydrological Activities (Official Gazette of RS" No. 88/2010).

The necessary preconditions for the implementation of the Law on Water are the adoption of bylaws, taking into account the relevant EU directives. According to the Law on Water, 30 bylaws were adopted, of which 13 ordinances, 8 regulation, several decisions, and ordinances, as well as the Operational plan for flood control for the current year. The legal acts of particular importance are: the Regulation on the annual program for monitoring over the water status, and the Regulation on the program for water management, that are adopted each year, and the following ordinances: Ordinance on determining the methodology for the preparation of the preliminary flood risk assessment, Regulation on the content and application form for the issuance of water acts and contents regarding the procedure of issuing the water requirements, Regulation on

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the condition and criteria for the allocation of resources and methods of allocation of funds aimed to finance the operations of general interest in water management.

Strategic, planning and normative activities that are the basis for water management in the territory of the Republic of Serbia are defined by the Law on Water. Harmonization of these and other strategic and planning documents, adopted at the national level is required and refers to: the National Strategy for Sustainable Development (2009-2017), the Spatial Plan of the Republic of Serbia (2010-2020), The National Environmental Protection Programme (2010-2019), the Water Master Plan for Serbia (2002-2012), and the National Strategy for Sustainable Use of Natural Resources (2012-2022).

The National Environmental Approximation Strategy – NEAS („Official Gazette RS" No. 80/2011), the Approximation Strategy in the water sector, a sector supplement to the NEAS (April 2012) and the National Programme for Adoption of EU Acquis NPAA (Office for European Integration, July 2014) have also transposed the requirements of Water Framework Directive and Flood Directive. The National Water Management Strategy addresses flood management in separate relevant chapters; however, its development is still in progress.
Although several legal regulations on water are currently in effect, the transposition of the EU legislation has not been fully achieved. The relevant pieces of legislation fully complying with the Water Framework Directive and the Flood Directive are under preparation after adaptation by-laws and decrees will follow. The adoption of the National Water Management Strategy is expected in 2017. The enforcement of legislation is relatively strong; new regulations will also be applicable according to the new legislation. The enforcement of the legislation on the use of flood ways and flood areas is not at a sustainable level yet (construction, mining, waste management, property issues).

As important requirements of the Flood Directive, preliminary assessments have been carried out in the country. Detailed flood risk and flood hazard maps were prepared under the ICPDR initiative for the Morava and Danube River Basin and within other projects. Maps were produced for 27 flood basins out of the total 99 identified as areas of potential significant flood risk.

Floods in Vojvodina

According to statistical data, the most common natural disasters are: floods (40%), tropical cyclones (20%), earthquakes (15%) and droughts (15%). The problem of flooding is of great importance worldwide, because the water regime and the state of water flows are constantly worsening, and flood damage continuously increase. Unlike some other natural disasters that are rapidly occurring and last for short period of time, floods are a disaster that can last for quite a long time (months) with the inclusion of large areas. The damage from floods are very large, because by the river and river valleys of

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the large concentration of population and economic facilities, dense infrastructure network, as well as the most fertile land (Milanović i sar, 2010). Flooding is most often due to the discharge of water from the watercourse to the offshore unprotected terrain, both in the lower and upper parts of the basins. In addition to the natural causes of this phenomenon, such as very large amount of precipitation and sudden snow melting, there is a significant contribution to the phenomenon of floods by human activities, which, by its destructive action, affects the absorption of the surface runoff and aggravates the state of the watercourse.

The area of Vojvodina, the northern part of the Republic of Serbia, has been endangered by floods since ancient times, primarily because of the predominantly flatland terrain, as well as due to a very diverse network of water courses, different in size and hydrological-hydraulic characteristics. In addition to the plain area, floods are also endangered along the coastal areas along smaller torrential flows on Fruška Gora and Vršac mountains. The most frequent causes of floods in Vojvodina were extremely high water levels in the large and middle size rivers, which flows from the territory of neighboring countries. In such flood waves, unprotected inundation areas are first flooded, while protected areas are flooded most often due to the breakdown of the flood protection dikes and levees, and rarely due to the overflow of the crown of embankments or because of the accumulation of ice. Local floods were also occurring from the waters that were flooded out of the watercourse outside the borders of Serbia, and then came through the state border. The occurrence of torrential floods in the area of Vojvodina is caused by the occurrence of high intensity precipitation, often accompanied by rapid snow melting (Božinović et al., 1995).

According to the Water Resources Master Plan of the Republic of Serbia (2001) and the JVP "VodaVojvodine" (2010), in the territory of Vojvodina, about 1.290.000 ha of land is endangered from floods of 100 year return period, which makes up about 60% of its total area. Thus, over 80% of the most fertile agricultural land, 260 inhabited places, about 1.200.000 inhabitants, 3840 km of roads, 150 km of railway tracks and about 800 industrial facilities are located in the affected area.

Review of the state of flood protection in Vojvodina

Protection from external waters is one of the first water management activities carried out in Vojvodina since the beginning of the 18th century. Particularly intensive works on the construction of embankments along the rivers were carried out at the end of the XIX and the beginning of the 20th century.

The number and diversity of watercourses by hydrological, hydraulic and morphological characteristics, have conditioned the application of various measures, facilities and structures in existing flood protection systems and water flow regulation in Serbia. It is undeniable that the backbone of the flood protection and watercourse protection system are the so-called "passive measures", that is, defensive embankments and classical regulation structures in river beds. The so-called "active measures", in the form of accumulations and retentions, are of secondary significance. The exception is the Main channel network of the Danube-Tisa-Danube Hydro System (HS DTD), which is also a significant active measure of flood protection in Vojvodina.

As a consequence of the floods on the Danube in 1965, a unique principle of constructing and reconstructing defensive lines in Vojvodina was adopted on a 1% water levels (water that occurs once in a century). It is important to note that defense systems, in particular the construction of embankments and reclamation of flood plains and river inundation, besides increasing the defensive security of the area, have led to an increase of the high water levels. Ditches along the major watercourses in Vojvodina were reconstructed on centenary water (1% water level) at about 95% of the total length of the Danube, and on Tisa and Sava about 85% of the total length. The length of the undeveloped sections of the embankment is 204 km, or 283 km along with the border embankments. However, another 101 locality on the embankment body are endangered by leakage and erosion processes and should be rehabilitated. According to the General and Operational Plan, the flood defense in Vojvodina is carried out on 20 rivers and 7 reservoirs for the acceptance of flood waves. The total length of the defensive embankments is 1,460.02 km (Table 1).

Table 6. Length of the levees and dikes in Vojvodina (JVP „VodeVojvodine", 2010)

Watercourse	Length (km)
Dunav	304,16
Tisa	289,63
Sava	119,77
Tamiš	86,04
Stari i PlovniBegej	127,80
Ostali vodotoci	532,62

For successful flood protection in Vojvodina, channels, embankments and corresponding sluices are also of great importance along the Main Channel Network of the Danube-Tisa-Danube Hydro System. In Banat, HS DTD and watercourses: Zlatica, Stari Begej, Plovni Begej, Tamiš, Brzava, Moravica (with Rojga), Vršački kanal and Karaš, make up one functional system in flood protection. Defense line sections in Banat are capable of accepting high water levels of 1% -5% probabilities and in Backa water levels of 2% -5% probabilities of occurrence. Although bad spots on the Main Channel Network shares in Banat (at the mouth of the Kikinda Canal, Idjos and Nova Crnja) were noticed, it can be noted that the situation on the Main Channel Network sections and the sloped streams in Banat is generally satisfactory, except on Karas, where the flood protection system does not exist. For the purpose of defending against torrential floods, 14 artificial reservoirs have been built on Fruška Gora Mountain, which besides the defensive role, represent a local resource for irrigation purposes.

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Torrential floods in Vojvodina

When it comes to torrential floods, it should be kept in mind that this term is much wider than in the case of floods on large plain rivers. Hence, it is more correct to speak about "torrential processes" than about floods, because it really is about a set of phenomena that take place in a torrent stream and the coastline. In addition to the classic manifestation of floods (due to the spillage of high waters from the riverbed), the phenomena of the so-called torrential lava, landslides and landslides appear simultaneously. Due to the sudden downpour of high waters, torrential flood waves have a very pronounced steep forehead, which has a great destructive power. The head of the waves crushes trees, undermines the shores, and creates flecks and landslides. All the affected material is mixed with water, and everything that is in its path is carried away. Only well-designed and constructed objects for streamlining can survive and perform a protective function from a mass burst, called "torrential lava" (Stefanović et al., 2014).

The hydrological regime of torrential watercourses is also specific. The dynamic character of the hydrological regime is manifested by a large range of flows and a characteristic form of hydrograms of high waters. On the other hand, the duration of high waters is very short, the order of several hours. Hydraulic wave hydrographs have a short base time, with a particularly short rise time (ascending branch) due to rapid formation and sudden downpours of high waters.

Considering the widespread distribution of mountainous areas in Serbia and the developed hydrographic network, torrential floods occur very often, almost every year. When it comes to torrential currents in the territory of Vojvodina, they occur exclusively in the area of Fruškagora and Vršački breg. Here are mostly streams, which in certain periods of the year, after intense precipitation, take on a torrential character.

On the north and south side of the Vršački breg, the terrain is hilly, from 120 to 200 m above sea level, with stream valleys. On the south side the brook Mesić flows through the city of Vršac. Fizeš Stream builds a large valley near Sočica. On the north side are the stream valleys of the Markovac stream, Alažur, Majdan and Kozluk.

The north face of the Fruska Gora mountains is characterized by deep valleys in the upper and mid-course, while the in the lower parts of streams the valleys are widen. The longest streams and rivers lie on the northern face of Fruška Gora. As far as the south face are concerned, only the spring parts of streams belong to the area of Fruška Gora. Streams of the south face are significantly shorter compared to the streams of the northern slop. Most of these streams (from the north and south face) produce intense deep fluvial erosion. The south face of Fruška Gora, in the Sava River Basin, has 30 streams of length from less than 2 kilometers to 27 kilometers, and the longest are: Međeš (27), Šelevrenac (26), Kudoš (25), Manđelos (23), Jelence 21), Borkovac (20), Čikas (19) and Šidina(18). In the Danube basin, the Fruška Gora streams are usually shorter, with 53 of them. The longest is Patka-Budovar near Krčedin (52 km). In Figure 1, a hydrographic map of the

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north face of Fruška Gora is shown. Many of these streams flow through populated areas and during periods of torrential waves, inflict heavy damage on the infrastructure located in the flood zone.

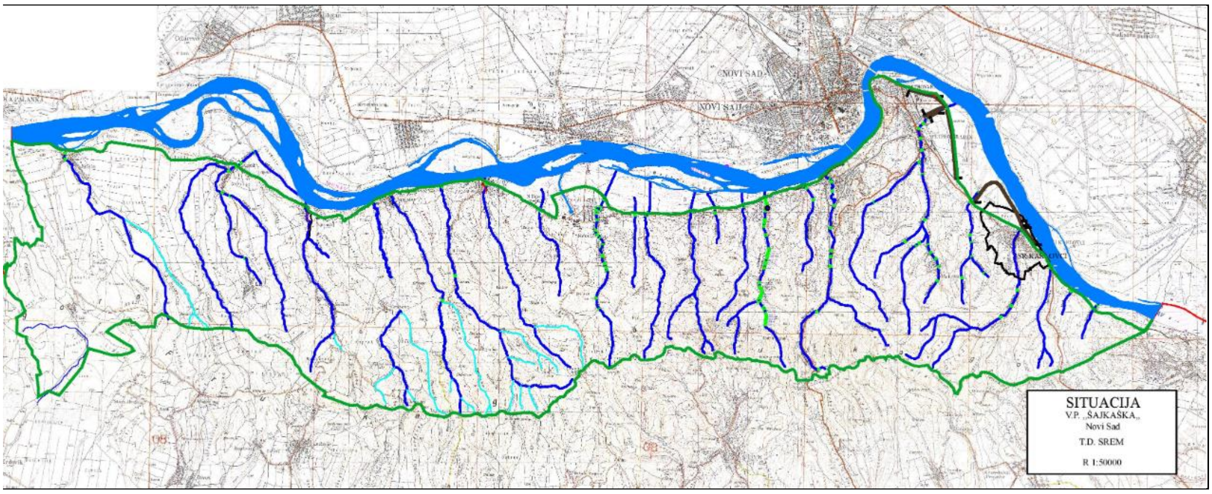

Figure 10. Hydrographic map of the north face of the Fruška Gora Mountain

In order to prevent the damage caused by torrents, lately, the work on the arrangement of the riverbeds is intensified on the sections that pass through the populated areas. The rehabilitation of the riverbeds of these streams usually involves the removal of unwanted vegetation from the streambed profile, as well as the installation of concrete linings of different profiles, on critical sections, which are affected by erosion processes. An additional problem in this case is the illegally built objects along the streams.

Figure 11. Regulation work on Rokov and Bukovac streams (north face of the Fruška Gora)

Chronology of floods in Vojvodina

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Beginning from the second half of the 20th century, to date, significant floods in the area of Vojvodina have been recorded: in the Danube coast (1965), Tisa (1970), Sava (1974 and 1981). In other areas, numerous floods have been reported on watercourses with damages that exceeded the total annual national income of the certain territorial units. The tragic balance of floods must include the loss of human lives, as well as indirect damages caused by the interruption of economic activities, deterioration of hygienic and health conditions, environmental degradation, etc.

The beginning of the XXI century brought several flood events that took on the situation of natural disasters. In March and April 2000, high waters on Tisa and Tamis appeared. Due to the above-average precipitation for this period of the year and sudden snow melting, there was a flood wave on the rivers mentioned. The flood wave on the Tamis started at the beginning of April on the Romanian side of Banat. The Municipality of Sećanj was in the most difficult situation, and three village settlements are flooded: Boka, Konak and Šurjan. In addition to the mentioned villages, the village of JašaTomić was also endangered. By crossing the embankment of the Zrenjanin-Vršac railway line, the water was directed towards Brzava, and further to the Danube-Tisa-Danube canal. The floods occurred on the Tisza River, where regular flood protection measures on certain parts lasted 61 days, and extraordinary flood protection measures lasted 28 days.

At the end of March 2005, high daily temperatures, which with rainfall caused sudden snow melting in the Carpathians, led to the formation of a flood wave at the beginning of April. According to the data of the Republic Hydrometeorological Service of Serbia, during just two days, from 40 to 75 mm of precipitation occurred in the Upper Tamiš River Basin, and from 50 to 75 mm in the upper Begej Basin. The outflow of the Tamiš River flooded large areas in Romania and also in the territory of Serbia. From the village of JašaTomić, all 1000 inhabitants were evacuated.

During March and April 2006, heavy flooding and snow melting occurred in Germany, Slovakia, the Czech Republic and Austria. Danube also flooded territories in Bulgaria and Romania. In Serbia, the historical highs water levels have been recorded on the Danube, Tisa and Sava rivers. Extraordinary flood defenses were also introduced on the Tamis River. The flood occurred in the following municipalities: Apatin, Sombor, Bogojevo, Zrenjanin, Beočin, Senta, Titel, Sečanj, Žabalj, Novi Sad, Bačka Palanka, Inđija, Belgrade and Zemun. In addition to damage caused by direct water spillage, numerous landslides have also been made, which further aggravated the situation.

Day-time heavy rains over saturated land caused a devastating flood in mid-May 2014. Due to the specific cyclone, a large part of the Sava River Basin in Bosnia and Herzegovina and Serbia was under uninterrupted and heavy rain. Previously, throughout April 2014, the weather was unstable, with intensified cyclonic activity. In mid-May, in some parts of the basin, the soil moisture was twice as high as the average value. In mid-May, the most critical situation was on the Sava River, where the historical maximum water level (869 cm) was recorded. An extraordinary flood defense was proclaimed on all 120 km of the Sava Defense Line in Serbia. The most vulnerable were the cities of Sremska Mitrovica and Sabac, as well as other settlements located along the course of this river. The dikes were reinforced by hundreds of sandbags, and the Republic Hydrometeorological Service of Serbia predicted that the Sava near Sremska Mitrovica would reach incredible 917 cm. Fortunately, the forecasts did not come true. Two kilometers from the state border with Croatia, the embankment on the Sava River has been released, and the water has been flowing uncontrolledly by the defended side, through forests and arable lands, endangering the Srem villages of Jamen, SremskaRača, Bosut, Morović, Višnjićevo and, ultimately, Sremska and Macvanska Mitrovica. Jamena settlement was completely under water, and the population was evacuated. During the May 2014 disasters, major problems were reported on the Fruska Gora fountains Čikas and Kudoš. In the lower parts of the settlement Vrdnik, where 220 mm rain fell in two days, three Fruškagora streams were united into one river. In the vicinity of Ruma, channel Jelenci flooded out, and also in the vicinity of Sremska Mitrovica, stream Čikas flooded out. Special measures had to be taken at Pavlovac Lake. At the accumulation of Kudos near Pavlovci, the water level exceeded the maximum water level by 40 cm, and an emergency flood defense was proclaimed here (Keravica, 2015).

Lessons learned during the May floods in Serbia in 2014 indicate that existing flood protection programs, as well as current and future projects, should be aimed at increasing the level of protection against floods and torrential floods. Future flood protection concepts in Serbia should be based on contemporary methods, while respecting the current status of the flood protection system and the economic strength of the society. An adequate combination of non-investment and investment (hydro engineering) measures should provide a quality solution for the integral design and protection of flood areas in Serbia (Milanović et al., 2010).

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