Carpathian Journal of Earth and Environmental Sciences, November 2012, Vol. 7, No. 4, p. 107 - 116

A HYDROLOGICAL ANALYSIS OF THE GREATEST FLOODS IN SERBIA IN THE 1960 – 2010 PERIOD

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Abstract: In this article we analyzed the greatest floods in Serbia between 1960 and 2010. The probability of flood occurrence was calculated for 21 hydrological observation stations on major rivers (Danube, Sava, Tisza, Tamiš and Velika Morava) in whose valleys great floods were recorded in the observed period. By means of probability theory and mathematical statistics, analyses of time series of maximum discharges and water levels were made and the theoretical functions of the distribution of high water occurrence were obtained. The probability of flood occurrence was calculated on the basis of these data. Most often the Log-Pearson Type 3 and Pearson Type 3 distribution showed the best agreement with the empirical distribution function. The results have shown that the greatest floods in the majority of watercourses were recorded in 1965 and 2006 and return periods longer than 100 years were observed on the Vlasina River near Vlasotince (168 years), on the Velika Morava near Varvarin (132 years) and the Danube near Bezdan (116 years) and Veliko Gradište (108 years). The analysis of floods shows that they mostly occur in late spring or early summer, in the periods of frequent cyclones.

Key words: flood, maximum water level, maximum discharge, flood frequency analysis, Serbia

1. INTRODUCTION

Among natural disasters, with serious risks for people and their activities, floods have been the most common in terms of frequency, their threat level and the damage they cause; accordingly, they deserve special attention. Even though, in most of the cases, the floods are caused by natural factors (as the climatic particularities and the morpho-hydrographic features of rivers), we can see that the human factor contributes more and more to the effects of the disasters (by the degree of anthropologic features, the way of using the fields, the presence/absence of the hydrologic engineering works, of intervening and supporting structures etc) (Ceobanu & Grozavu, 2009).

The catastrophic floods in Serbia are mainly caused by the flow of humid air masses from the Atlantic Ocean. A major role is played by cyclones in the Sava and Danube river valleys. Flood analyses show that inundation mostly occurs in late spring and early summer, i.e. in the periods when cyclones are the most frequent. The snow cover is an important factor in flood formation. Rapid snow melting and catastrophic floods may occur due to sudden flows of the foehn wind from the Dinarides in early spring. The flows of warm air from the Adriatic basin towards the Pannonian Plain mainly cause the rise of the water levels in the Sava River and its Dinaric tributaries. A particularly unfavourable situation arises when a cyclone coincides with the foehn flow. At that time, large quantities of precipitation fall and the snow cover melts, resulting in an abrupt rise of water levels and the formation of a long-lasting flood wave in major rivers. Apart from the mentioned causes, it should be pointed out that the formation of floods in Serbia is also influenced by a rather high density of watercourses (747 m/km^2), intense erosion processes and the presence of the lower courses of large international rivers in its territory.

On the basis of the main cause, the floods in Serbia may be divided into six types: 1) floods caused by rainfall and snow-melt; 2) floods caused by the coincidence of high waters; 3) ice floods; 4) torrent floods; 5) floods caused by landslides; and 6) floods caused by dam failures. The floods belonging to the first two types are the most common and wide-ranging. The majority of catastrophic floods in Serbia belong to these two types. Ice floods were frequent in the past in the valleys of the Velika Morava and Južna Morava and the Đerdap Gorge on the Danube River. However, after the regulation of these watercourses and the formation of Đerdap Lake, they have become rare. Torrent floods are rather frequent, particularly in the basin of the Južna Morava and they are caused by the unregulated water regimes of hill watercourses. The last two types of floods have also been recorded in the territory of Serbia; some of them had catastrophic consequences.

2. STUDY AREA

As the most common natural disaster in Serbia, floods potentially threaten 1.6 million hectares (18 % of Serbia's territory) (Fig.1). The largest areas exposed to floods are located in Vojvodina, Posavina and Pomoravlje. Furthermore, floods threaten 512 larger settlements with numerous industrial facilities, 4,000 km of roads and 680 km of railroads (The Spatial Plan of the Republic of Serbia 2010–2014–2020, 2010). The largest inundated areas are located in the river valleys of the Tisza (2,800 km^2), Sava (2,243 km^2), Velika Morava (2,240 km^2) and the Danube (2,070 km^2) (Gavrilović & Dukić, 2002). Due to very high concentrations of the population and industrial facilities, the dense infrastructure network and the fertile soil in the valleys of these rivers, flood damage is great.

The main causes of floods in the Tisza River valley include mild riverbed slopes, the nature of the geological substratum (Quaternary and Tertiary sediments) and wide alluvial plains. The average width of the flooded belt is about 10 km. In the Sava and Danube rivers, floods are caused by precipitation, as well as by the coincidence of flood waves in their tributaries. In the entire drainage basin of the Velika Morava River (including the Velika Morava and its headwaters, Južna and Zapadna Morava) about 35% of flood-exposed areas is protected by embankments and floods mostly occur in unprotected areas. As far as the drainage basins of its tributaries are concerned, floods occur in the valleys of the Lugomir, Belica, Lepenica, Resava and Jasenica rivers. In the drainage basin of the Južna Morava, the most severely flood-affected sector is the area downstream from the confluence of the Toplica with the Južna Morava; considerable flood-exposed areas can be found in the valleys of its major tributaries: the Vlasina, Veternica, Jablanica, Pusta Reka, Toplica and Nišava rivers. Compared to the basins of the Velika and Južna Morava, the drainage basin of the Zapadna Morava is less threatened by floods due to the direction of the main watercourse, relief, less pronounced erosion and greater forestation. Major flood regions are also in its tributaries the Ibar and Sitnica rivers. It is noteworthy that the entire Velika Morava drainage basin is particularly threatened by rapidly formed torrent floods, unpredictable and devastating.

In the rivers of Serbia, floods are a common phenomenon. There are particular areas that are prone to repeated inundation. During the past fifty years, a great number of large floods have been registered in Serbia: 1961, 1962, 1963, 1965, 1970, 1974, 1975, 1976, 1977, 1980, 1981, 1986, 1988, 1999, 2000, 2005, 2006 and 2007. The greatest floods were those of 1965 and 2006 and they were the most severe ones in Serbia during the 1960 – 2010 period. At that time, water levels on many rivers reached the absolute maximum values.

3. METHODOLOGY

Estimation of flood and other natural disasters is an important issue. Determination of the magnitude of design floods with a specified frequency probability is required for many engineering works, such as the design of bridges, dams, canals, and water intakes, and for the development of flood risk management projects.

Frequency analysis focuses on data collection and flood event interpretation; and the technique can be used to understand and predict flooding behavior. Sometimes for analysis, calculation and construction are taken into consideration used maximum flow, the increase time, the total time and the high flood volume as the main elements defining the high flood hydrograph (as in case study of Vaslui River Basin in Romania) (Romanescu et al., 2011), and sometimes the analysis based on statistical calculations of maximum water level or discharges with a probability of occurrence and return period. General problems of flood frequency analyses are discussed in Kidson & Richards (2005) and Stedinger & Griffis (2008). Flood frequency analyses can be divided by the issue there are dealing with: nonstationarity of data, regional flood frequency analyses, seasonal frequency analyses and uncertainty in flood frequency analyses.

Many current flood management policies and designs are based on an estimate of the 100-yr flood, an event that has a 1% chance of occurring in a given year. Existing methods to estimate the 100-yr flood, however, assume flood records are stationary even though multiple nonstationary factors, such as climate change and urbanization, influence measured hydrologic data.

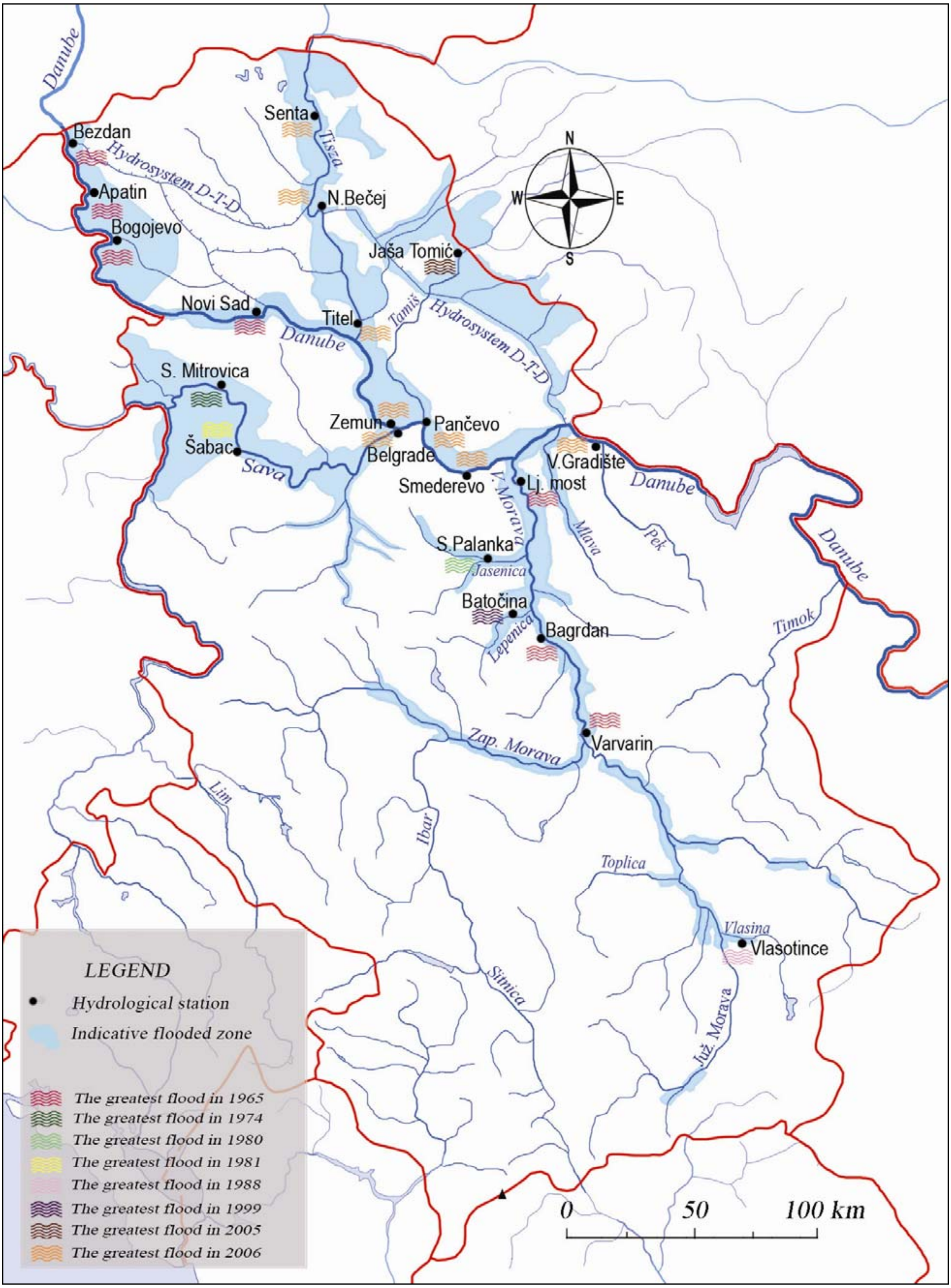

Figure.1 Map of the potentially flooded areas with years when greatest floods occurred.

Gilroy & McCuen (2012) developed and applied a nonstationary flood frequency analysis method that accounts for urbanization and climate conditions for a future design year. The method was applied to the Little Patuxent River in Guilford, Maryland, and the results showed a 30.2% increase in the 100-yr flood for the design year 2100. Other papers dealing with nonstationarity problems are Cunderlik & Burn (2003) and Alila & Mtiraoui (2002).

During the last 10 years a growing number of regional flood frequency estimation studies have used flood seasonality descriptors for delineating hydrological homogeneous regions. Regional flood frequency analyses are used for the estimation of floods at sites where little or no data are available. It involves the identification of groups (or regions) of hydrological homogeneous catchments and the application of a regional estimation method in the identified homogeneous region (GREHYS, 1996). Regional flood frequency analyses are developed and used in hydrological studies all over world (Sveinsson et al., 2001; He et al., 2007; Ellouze & Abida, 2008; Hussain & Pasha, 2009; Sarhadi & Modarres, 2011).

Seasonality of floods reflects a complex catchment's hydrologic response to flood producing processes. A seasonal flood frequency analysis is discussed in number of papers (Seidou et al., 2006; Karmakar & Dutta 2010). Flood risk analyses are based on assumptions and decisions about models, parameters and data. In many cases it can be argued for different options.

In order to estimate flood frequency and the probability of the high water levels occurrence in the largest rivers in Serbia, we have performed a statistical analysis for the data collected at 21 hydrological observation stations, where the maximum water levels and discharges were recorded between 1960 and 2010. In the first stage, thirty-year or longer time series of the maximum annual discharges and water levels were established. It was then necessary to examine the representativeness of the time series of the registered data for the analysed process, seen as a whole. The application of mathematical statistics and probability theory implies that the elements of an available time series of the maximum discharges and water levels are random values. In the randomness analysis of the maximum annual discharges series, the consecutive differences test (Neyman's test) and the first-order serial correlation test (Anderson's test) were used. This was followed by a stationarity examination of the statistical parameters for particular sequences of the established time series, i.e. by determining the time series homogeneity. It often happens that a departure of the average discharges and water levels from the natural situation arises as a consequence of man-made interventions in a river basin, resulting in the so-called non-homogeneous monthly and annual hydrologic series. In this study, we used Student's t-test for testing the homogeneity of average values, Fischer's F-test for testing the homogeneity of dispersion and the Wilcoxon inversion test for the distribution function.

After the examination of the time series randomness and homogeneity, the empirical distribution and the probability distribution function parameter were calculated. The maximum discharges and water levels for theoretical functions of the probability distribution commonly used in hydrology were also calculated: the Normal, Log-Normal, Gumbel, three-parameter gamma distribution – Pearson Type 3 and Log-Pearson Type 3 distribution. The testing of the agreement (fitting) between the empirical and theoretical distribution functions was performed using the Chi-squared test, the Kolmogorov-Smirnov test and the Cramér-von-Mises test. On the basis of the data obtained by these tests, the final selection of the applicable theoretical distribution function was made and the corresponding confidence intervals were calculated.

4. RESULTS AND DISCUSSION

Based on statistical analyses of the data collected at hydrological observation stations in the drainage basins of the largest rivers in Serbia and judging from the values obtained by the mentioned tests, it may be concluded that the Log-Pearson Type 3, Pearson Type 3, Log-Normal and Gumbel distributions show the best agreement with the empirical distribution. This indicates that the empirical distributions of the annual maximum water levels and discharges agree with the three-parameter gamma distribution. The use of directional statistical methods for flood frequency and the high water probability can be also found in many studies, such as Gumbel distribution, which was used for Gumbel mixed model developing (Yue et al., 1999) and Normal, Log-normal and Log-Pearson Type 3 distributions for Bayesian Markov Chain Monte Carlo (MCMC) methods in flood frequency analysis (Reis & Stedinger, 2005). Another interesting study is one from Prohaska et al. (2009), which compared empirical distribution functions with defined outlier limits to indentify historic floods. They also used Log-Pearson Type 3, distribution to determine the exceedance probability (return period) of floods.

Table 1 presents an overview of the greatest floods on the Danube River. One of the most severe floods of this river in the instrumental observation period occurred in 1965, when the maximum water levels and discharges recorded at the hydrological stations in the northern, lowland areas of Serbia reached 776 cm (Bezdan) and 9,290 m^3/s (Bogojevo), with the return periods of 116 and 121 years, respectively.

This flood occurred in May–June due to an abundant snow-melt in the upper basin of the Danube and abundant precipitation in Serbia. Flood waves were formed in major watercourses and at a number of hydrological observation stations and elsewhere in the drainage basin, maximum water levels and discharges were recorded in the instrumental period (Tables 1 and 4). Embankments were breached at several places and the inundated area covered about 250,000 ha, 16,000 houses, 214 km of roads. The greatest damage was recorded in the northern areas of Serbia, in Vojvodina, where the inundated area covered 47,000 ha in 43 municipalities (Gavrilović & Dukić, 2002).

Other noteworthy example is flood in 2006. Abundant precipitation and snow-melt caused great floods in Germany, Slovakia, the Czech Republic and Austria during March and April of 2006. The situation was similar in Serbia, where water levels and discharges reached maximum values in the instrumental period at certain hydrological observation stations, like Zemun, Pančevo, Smederevo and Veliko Gradište in the Danube drainage basin (Table 1); Belgrade in the Sava drainage basin (Table 2) and Senta, Novi Bečej and Titel in the Tisza drainage basin (Table 3). Downstream from the Đerdap II Hydropower Plant, Kladovo and Negotinska Krajina were affected by flood; this was followed by catastrophic floods all along the banks of the Danube in the territory of Bulgaria and Romania. During this flood, 213 human settlements in the Danube valley in Serbia were threatened and about 1,000 people were evacuated. The floods were accompanied by a total number of 3,069 landslides in Serbia, registered primarily throughout the drainage basins of the Velika Morava and Kolubara rivers. The landslides damaged 2,300 residential buildings, 639 roads and 17 bridges (Milanović et al., 2010).

Statistical analyses show an increased frequency of catastrophic floods in the Danube and its tributaries in the late 20th and early 21st century. Between 1974 and 2002, air and water temperatures, as well as precipitation levels rose. Despite the water loss caused by water grabbing and evaporation, the discharges in the Danube increased, resulting in an increased frequency of extreme hydrological events in the Danube drainage basin (significant floods were recorded in 1980, 1981, 1988, 1999, 2002, 2005 and 2006).

Table 1. Exceedance probabilities (P) and return periods (T) of greatest floods on the Danube River

Year	***Hydrological observation station***	***Theoretical distribution***	Q_{max} ***or*** H_{max}	***P (%)***	***T (year)***
1965	Bezdan	Log-Pearson Type 3	776 cm	0.87	116
	Apatin	Pearson Type 3	825 cm	1.91	52
	Bogojevo	Log-Normal	9290 m^3/s	0.83	121
	Novi Sad	Pearson Type 3	778 cm	1.24	81
1970	Zemun	Log-Pearson Type 3	715 cm	5.40	19
	Pančevo	Gumbel	722 cm	5.34	19
	Smederevo	Gumbel	766 cm	5.61	18
1975	Bezdan	Normal	732 cm	2.70	37
	Apatin	Pearson Type 3	812 cm	2.30	43
	Bogojevo	Log-Normalna	8360 m^3/s	2.67	37
	Novi Sad	Pearson Type 3	710 cm	3.94	25
1981	Zemun	Log-Pearson Type 3	757 cm	2.88	35
	Pančevo	Gumbel	756 cm	3.28	31
	Smederevo	Gumbel	804 cm	2.98	34
	Veliko Gradište	Pearson Type 3	915 cm	2.96	34
2006	Bezdan	Normal	736 cm	2.45	41
	Apatin	Pearson Type 3	808 cm	2.44	41
	Bogojevo	Log-Normalna	8630 m^3/s	1.91	52
	Novi Sad	Pearson Type 3	745 cm	2.20	45
	Zemun	Log-Pearson Type 3	783 cm	1.94	52
	Pančevo	Gumbel	777 cm	2.42	41
	Smederevo	Gumbel	845 cm	1.50	67
	Veliko Gradište	Pearson Type 3	960 cm	0.92	108

The above-mentioned floods in the Danube, as well as the catastrophic floods in the drainage basins of the Elbe, Kuban and Terek and other rivers during the past years confirm the hypothesis that global warming, the intensification of synoptic processes and increased precipitation in certain regions of the planet could lead to an increased frequency of extreme hydrological phenomena (Mikhailov et al., 2008).

According to statistical data, severe floods in the drainage basin of the Sava River were recorded in 1970, 1974, 1981 and 2006 (Table 2). One of the greatest floods occurred in October 1974. It was caused by the coincidence of high water levels in the main watercourse and the tributaries (principally in the Vrbas, Bosna and Drina rivers). The distinguishing feature of this flood wave was a rapid tide of huge amounts of water, which receded slowly. Due to fairly strong flood protection lines, the inundation was not so much catastrophic in its consequences as in terms of water level values.

During the flood in April 2006, the absolute maximum water level was reached near Belgrade (Table 2) with a return period of 47 years, but Belgrade did not suffer considerable inundation from the Sava and Danube rivers. However, some of the tributaries of the Sava River (Kolubara) were inundated.

According to statistical data, the most severe floods in the drainage basin of the Tisza River were registered in 1965, 1970, 1981, 2000 and 2006 (Table 3). Among the mentioned floods (in 1965 and 2006), which have already been discussed, the one of April–June 1970 stands out for its large scale. Due to the low terrain and the flood wave height, at certain places spilled water looked like a lake, while 7,500 houses in 14 municipalities were ruined (Đarmati & Aleksić, 2004). In March and April of 2000, high water levels occurred in the Tisza and Tamiš rivers (Table 3) as a consequence of a rapid snow-melt on the Carpathians slopes which coincided with intense precipitation. The flood wave on the Tamiš River formed in Romania and began to spread towards the Serbian part of Banat. In order to prevent the spreading of the flood wave in Serbia, an embankment was cut and water was directed towards the Danube–Tisza–Danube canal network.

Table 2. Exceedance probabilities (P) and return periods (T) of greatest floods on the Sava River

Year	***Hydrological observation station***	***Theoretical distribution***	***Q_{max} or H_{max}***	***P (%)***	***T (year)***
1970	Šabac	Log-Normal	570 cm	4.79	21
	Sremska Mitrovica	Gumbel	778 cm	4.94	20
	Belgrade	Log-Pearson Type 3	675 cm	5.65	18
1974	Šabac	Log-Normal	589 cm	2.64	38
	Sremska Mitrovica	Gumbel	800 cm	3.44	29
1981	Šabac	Log-Normal	590 cm	2.56	39
	Sremska Mitrovica	Gumbel	777 cm	5.02	20
	Belgrade	Log-Pearson Type 3	718 cm	2.93	34
2006	Belgrade	Log-Pearson Type 3	738 cm	2.15	47

Table 3. Exceedance probabilities (P) and return periods (T) of greatest floods on Tisza and Tamiš River

Year	***Hydrological observation station***	***Theoretical distribution***	***Q_{max} or H_{max}***	***P (%)***	***T (year)***
TISZA					
1965	Titel	Gumbel	791 cm	4.19	24
1970	Senta	Pearson Type 3	907 cm	2.20	46
	Novi Bečej	Log-Normal	785 cm	3.02	33
	Titel	Gumbel	757 cm	6.30	16
1981	Novi Bečej	Log-Normal	729 cm	6.53	15
	Titel	Gumbel	758 cm	6.23	16
2000	Senta	Pearson Type 3	840 cm	6.22	16
2006	Senta	Pearson Type 3	926 cm	1.59	63
	Novi Bečej	Log-Normal	820 cm	1.81	55
	Titel	Gumbel	818 cm	3.02	33
TAMIŠ					
2000	Jaša Tomić	Pearson Type 3	822 cm	3.09	32
2005	Jaša Tomić	Pearson Type 3	846 cm	1.97	51

This Hydro-system presents 664.1 km long navigable network and also plays a crucial role in such emergency situations because it interconnects all watercourses in Banat, enabling the drainage of water from the flooded area (Milanović et al., 2011). It took a whole month to drain out water from the inundated area. Due to inconsistent maintenance of the canal network over a long period, the channelling of the flood wave was considerably slower than the planned capacity of the system would allow.

The absolute maximum water level in the instrumental period recorded at the Jaša Tomić hydrological observation station in April 2005 (Table 3) was the consequence of the same factors as those that caused the previously mentioned flood. After the embankment had been breached along the Romanian river bank, near the national border, the river inundated more than 5,000 houses and 40,000 ha of arable land (Miloradović & Matin, 2007). An area of about 85,000 ha and a population of 34,000 people were potentially threatened by flood. The Jaša Tomić settlement was the most seriously affected- all of its 1,000 inhabitants were evacuated, whereas about 150 houses were ruined (Milanović, et al., 2010).

In Serbia's largest national river, the Velika Morava, great floods were recorded in 1961, 1962, 1963, 1965 and 1976 (Table 4). In the past, ice floods were a characteristic feature of this river. They were caused by numerous meanders, bridges, embankments for roads in the riverbed, which were significant barriers for water and ice runoff. This was the reason that approximately every third flood of the Velika Morava belongs to this type (Gavrilović, 1988). For example, a severe flood occurred in February 1963, when the cold winter and the total freezing of the Velika, Južna and Zapadna Morava rivers and their tributaries were followed by a sudden rise of air temperature, snow-melt and the rise of water levels. The Velika Morava was ice-clogged at eight places. For less than twenty days, more than 25,000 ha were inundated (Gavrilović, 1981). Similar factors brought about the catastrophic flood of 1965, when the maximum discharges and return periods were recorded at the hydrological observation stations on the Velika Morava.

Apart from the drainage basins of the Velika Morava and its headwaters, severe floods were recorded in some of its tributaries (Table 4). Particularly noteworthy among them are the floods in the drainage basins of Vlasina in June 1988, Lepenica in July 1999 and Jasenica in 1980. A severe flood caused by dam failure in Vlasotince municipality occurred in June 1988 in the Vlasina drainage basin (Southeast Serbia). In terms of the precipitation amount, water levels, discharges and the damage made, this flood is considered a historical natural disaster. According to radar data, registered rain in Rakov Dol gauging station has a return period of 3000 years ($H_{sr.}$ for the Vlasina drainage basin is 830 mm, whereas in Rakov Dol 220 mm of rain fell for three hours). It was established that the water level reached 536 cm, while the discharge was 1200 m^3/s. This value is 150-fold higher than to the average discharge – 8 m^3/s. Three people were killed, 1,800 buildings were flooded, damage was made to agriculture and industry, roads were destroyed and 18 bridges were swept away (Gavrilović, 1991).

In the drainage basins of major tributaries of the longest national river, the Velika Morava, severe torrent floods occurred in 1999. Eight people were killed on that occasion, several dozen thousand residential buildings and several hundred economic facilities were damaged, and 30 bridges in the drainage basins of the Zapadna Morava, Jasenica and Lepenica were swept away (Milanović, 2006). The flood was preceded by abundant precipitation, particularly on Rudnik Mount, where the sources of some mentioned rivers are situated. However, along with the listed natural factors, the inadequate flood protection systems, insufficient system maintenance and the construction of residential and other buildings near the rivers also played a role in the floods of July 1999, causing the flood consequences to be large in scale. On that occasion, the water levels in the Lepenica River reached the values with a return period of 81 years (Milanović, 2007).

The floods in the Jasenica drainage basin were somewhat smaller in scale and they were caused by sudden snow-melt on Rudnik Mount near the source of the river and intense precipitation in the lower part of the drainage basin. The low terrain around the lower course of this river, high levels of ground-water and an unregulated riverbed result in severe floods near its mouth. The same factors brought about the flood of May 1980, which was the most severe in this drainage basin in the instrumental observation period. On the basis of the presented tabular data and analyses, it may be concluded that in Serbia floods most frequently occur in late spring and early summer. In the Tisza drainage basin, 92 % of catastrophic floods occurred in spring; the respective percentages for the Velika Morava, Sava and Danube rivers are 72 %, 68 % and 67 %. The main cause of severe floods in Serbia has been intense precipitation, usually accompanied by snow-melt. Furthermore, torrent floods are frequent during summer and autumn; they occur suddenly and cause a great damage. Only in a few cases, the return periods of flood waves were longer than 100 years.

Table 4. Exceedance probabilities (P) and return periods (T) of greatest floods in the Velika Morava River Basin

Year	***Hydrological observation station***	***Theoretical distribution***	***Q_{max} or H_{max}***	***P (%)***	***T (year)***
VELIKA MORAVA					
1961	Varvarin	Gumbel	2088 m3/s	7.44	13
	Ljubičevski most	Gumbel	1770 m3/s	9.74	10
1962	Varvarin	Gumbel	2175 m3/s	6.11	16
	Bagrdan	Log-Normal	1934 m3/s	10.48	10
	Ljubičevski most	Gumbel	1830 m3/s	8.16	12
1963	Varvarin	Gumbel	2880 m3/s	1.20	83
	Bagrdan	Log-Normal	2700 m3/s	1.83	55
	Ljubičevski most	Gumbel	2320 m3/s	1.85	54
1965	Varvarin	Gumbel	3080 m3/s	0.75	132
	Bagrdan	Log-Normal	2840 m3/s	1.33	75
	Ljubičevski most	Gumbel	2390 m3/s	1.49	67
1976	Varvarin	Gumbel	2050 m3/s	8.11	12
VLASINA					
1988	Vlasotince	Log-Pearson Type 3	536 cm	0.60	168
2007	Vlasotince	Log-Pearson Type 3	384 cm	2.51	40
LEPENICA					
1986	Batočina	Pearson Type 3	491 cm	2.70	37
1999	Batočina	Pearson Type 3	545 cm	1.23	81
JASENICA					
1977	Smederevska Palanka	Pearson Type 3	398 cm	6.96	14
1980	Smederevska Palanka	Pearson Type 3	403 cm	5.12	20
1981	Smederevska Palanka	Pearson Type 3	389 cm	6.51	15
1999	Smederevska Palanka	Pearson Type 3	385 cm	6.96	14

5. CONCLUSION

The analysis of the data presented in this study shows that the greatest floods occurred in the spring of 1965 (in terms of material damage) and the spring of 2006 (in terms of the absolute maximum water levels and discharges recorded at numerous hydrological observation stations on the Danube and Tisza rivers, as well as on the Sava in Belgrade). The occurrence probability of the 2006 flood varies for different hydrological observation stations from 2.2 % (Novi Sad) to 0.92 % (Veliko Gradište) on the Danube, 1.2 % on the Tisza near Senta and 2.15 % on the Sava near Belgrade. During the flood of April 2005, the absolute maximum values were surpassed at the hydrological station on the Tamiš. The occurrence probability of the 2000 flood is 3.09% and of the 2005 flood is 1.97 %. During the observed period, the most important causes of floods include the coincidence of snow-melt with intense rainfall in major rivers and intense rain showers in torrent-prone rivers.

Due to urbanization and dynamic economic development, flood protection becomes an increasingly topical issue because the values threatened by flood, both human and material, are far greater than in the past, whereas the damage becomes more severe every year.

According to the data provided by the Water Directorate of the Ministry of Agriculture, Trade, Forestry and Water Management of the Republic of Serbia, the damage caused by floods in last five years was about 100 million EUR. The most severe damage was inflicted by the flood of 2006: it was estimated at 35.7 million EUR. Although floods are the most common natural disaster in Serbia, the current flood control capacities are not satisfactory. Flood protection measures are enforced in the Danube, Sava and Morava water regions and they commonly include embankments and water regulation works and facilities. According to the data provided by Spatial Plan of the Republic of Serbia (2010), the total length of embankments is 3,550 km (1,597 km in the Danube water region, 771 km in the Sava water region and 1,182 km in the Morava water region). The most common type of regulation works and facilities are embankments (486 km) and concrete riverbed lining (418 km). An important role in flood protection in Vojvodina is played by the Danube–Tisza–Danube hydro-system, particularly in Banat. In that context, reservoirs are of a secondary importance, though they are the most efficient flood protection measure. There are only 39 reservoirs that serve this purpose but their effect is merely local. Long-term investment reduction into regular maintenance of protection facilities has led to their significantly diminished reliability and, accordingly, to a decrease in the protection levels, compared to earlier periods.

Besides flood-control facilities, which will remain the main means of flood protection in Serbia, the activities should be complemented by the flood zones mapping (actual and potential) in order to adjust the activities in these zones to the flood risks. The inundation lines for characteristic discharges should be determined on the basis of hydraulic calculations; they should serve as the basis for the valorisation of potential damage and defining the rules of behaviour in determined zones. This study presents the mentioned calculations for 21 hydrological observation stations: we have calculated the probability of maximum discharges and water levels. It is possible to construct the maps of flood risk in flood-threatened areas using the results of these calculations. In order to ensure a more active flood protection, the drafting of the Preliminary Flood Risk Assessment in the Territory of Serbia has been undertaken by the Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia, i.e. by the Republic Water Directorate and the Jaroslav Černi Institute for the Development of Water Resources.

Acknowledgements

The paper shows the results obtained within the Project No. 47007, financed by the Ministry of Education and Science of the Republic of Serbia

REFERENCES

Alila, Y. & Mtiraoui, A., 2002. *Implications of heterogeneous flood-frequency distributions on traditional stream-discharge prediction techniques.* Hydrological Processes, 16, 1065–1084.

Ceobanu, C. & Grozavu, A., 2009. *Psychosocial effects of the floods. Perception and attitudes.* Carpathian Journal of Earth and Environmental Sciences, 4, 2, 25-38.

Cunderlik, J.M. & Burn, D.H., 2003. *Non-stationary pooled flood frequency analysis.* Journal of Hydrology, 276, 210–223.

Đarmati, A.Š. & Aleksić, Đ.Lj., 2004. *Destructive natural hazards.* Radnička štampa, Belgrade 106-134.

Ellouze, M. & Abida, H., 2008. *Regional flood frequency analysis in Tunisia: Identification of regional distributions*. Water Resource Management, 22, 943–957.

Gavrilović, Lj. & Dukić, D., 2002. *Rivers of Serbia.* Serbian State Company of Textbooks, Belgrade, 218 p.

Gavrilović, Lj., 1981. *Floods in the Socialist Republic of Serbia in the XX century - Causes and Consequences.* Special edition, 52, Serbian Geographical Society, Belgrade.

Gavrilović, Lj., 1988. *High water frequency at the Velika Morava river.* Journal of the Geographical Institute “Jovan Cvijić” SASA, 40, 111-119.

Gavrilović, Lj., 1991. *The catastrophic flood at the Vlasina river in 1988.* Proceedings of the conference "The geographical problems of Serbian border regions", Faculty of Geography, Belgrade, 111-119.

Gilroy, K.L. & McCuen, R.H., 2012. *A nonstationary flood frequency analysis method to adjust for future climate change and urbanization.* Journal of Hydrology, 414–415, 40–48.

Groupe de recherché en hydrologie statistique (GREHYS), 1996. *Presentation and review of some methods for regional flood frequency analysis.* Journal of Hydrology, 186, 63-84.

He, H., Zhou, J., Yu, Q., Tian, Y. Q. and Chen, R. F., 2007. *Flood frequency and routing processes at a confluence of the middle Yellow River in China.* River Research and Applications, 23, 407-427, doi: 10.1002/rra.983.

Hussain, Z. & Pasha, G.R., 2009. *Regional flood frequency analysis of the seven sites of Punjab, Pakistan, using L-Moments.* Water Resources Management, 23, 1917-1933.

Karmaker, T. & Dutta, S., 2010. *Generation of synthetic seasonal hydrographs for a large river basin.* Journal of Hydrology, 381, 287–296.

Kidson, R. & Richards, K.S., 2005. *Flood frequency analysis: assumptions and alternatives.* Progress in Physical Geography, 29, 3, 392–410.

Mikhailov, V.N., Morozov, V.N., Cheroy, N.I., Mikhailova, M.V. & Zav'yalova, Ye.F., 2008. *Extreme Flood on the Danube River in 2006.* Russian Meteorology and Hydrology, 33, 1, 48–54.

Milanović, A., 2006. *Hydrological forecast of maximal water level in Lepenica river basin and flood control measures.* Bulletin of the Serbian Geographical Society, 86, 1, 47-54.

Milanović, A., 2007. *Analyses of river regime and water balance in the Lepenica river basin*. Journal of the Geographical Institute “Jovan Cvijić” SASA, 56, 35-50.

Milanović, A., Milijašević, D. & Brankov, J., 2011. *Assessment of polluting effects and surface water quality using water pollution index: a case study of Hydro-system Danube-Tisa-Danube.* Carpathian Journal of Earth and Environmental Sciences, 6, 2, 269–277.

Milanović, A., Urošev, M. & Milijašević, D. 2010. *Floods in Serbia in the 1999-2009 period-hydrological analysis and protection measures.* Bulletin of the Serbian Geographical Society, 90, 1, 93-121.

Miloradović, M. & Matin, Z., 2007. *Hydrological and hydraulic analyses in function of flood control at the river Tamis in 2005.* Vodoprivreda, 39, 1-3, 119-132.

Prohaska, S., Ilić, A., Miloradović, B., & Petković, T., 2009. *Identification and classification of Serbia's historic floods.* Bulletin of the Serbian Geographical Society, 89, 4, 191-199.

Reis, D.S. Jr. & Stedinger, J.R., 2005. *Bayesian MCMC flood frequency analysis with historical information.* Journal of Hydrology 313, 1-2, 97-116.

Romanescu Gh., Jora I. & Stoleriu1 C., 2011. *The most important high floods in Vaslui river basin -causes and consequences.* Carpathian Journal of Earth and Environmental Sciences, 6, 1, 119-132.

Sarhadi, A. & Modarres, R., 2011. *Flood seasonality-based regionalization methods: a data-based comparison.* Hydrological Processes, 25, 3613-3624.

Seidou, O., Ouarda, T.B.M.J., Barbet, M., Bruneau, P. & Bobe´e, B., 2006. *A parametric Bayesian combination of local and regional information in flood frequency analysis.* Water Resources Research, 42, W11408, doi:10.1029/2005WR004397.

Stedinger, J.R. & Griffis, V.W., 2008. *Flood Frequency Analysis in the United States: Time to Update.* Journal of Hydrologic Engineering ASCE, 13, 4, 199-204.

Sveinsson, O.G.B., Boes, D.C. & Salas, J.D., 2001. *Population index flood method for regional frequency analysis.* Water Resources Research, 37, 11, 2733–2748.

Yue, S., Ouarda, T.B.M.J., Bobe´e, B., Legendre P. & Bruneau, P., 1999. T*he Gumbel mixed model for flood frequency analysis.* Journal of Hydrology, 226, 1-2, 88-100.

Republic Agency for Spatial Planning of the Republic of Serbia, 2010. *The Spatial Plan of the Republic of Serbia 2010–2014–2021.* Ministry of Environment, Mining and Spatial Planning of the Republic of Serbia- Republic Agency for Spatial Planning of the Republic of Serbia, 314 p.

Republic Hydrometeorological Service of Serbia. (1960–2010). *Annual Report – Surface water levels and discharges.* Belgrade: Republic Hydrometeorological Service of Serbia.

Received at: 27. 03. 2012
Revised at: 04. 08. 2012
Accepted for publication at: 08. 08. 2012
Published online at: 10. 08. 2012