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EXTREME FLOODS IN SERBIA OCCURRING SIMULTANEOUSLY WITH THE HIGH WATER LEVELS AND HEAVY RAINS
CASE STUDY

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Abstract: This paper discusses possible development or so-called scenario of extreme floods in the Republic of Serbia that would be caused by simultaneous occurrence of high-water levels/discharges on the rivers and heavy rains. As illustration, two scenarios are presented based on independently recorded cases of high water levels and heavy rains of May 2014. A scenario of the floods caused by the interaction of reached high water levels and observed heavy rains is particularly examined. Research of the floods is proposed with the parameters of flood waters that would not have highly unexpected values, but would be more extreme than all the past ones. Scenarios would yield new potentially useful information on the influence of floods on human communities. Proposals are presented for more efficient controlling and regulating of floods in the Republic of Serbia.

Keywords: floods, scenario, water level, discharge, rains, damages.

INTRODUCTION

In the past years we witnessed the increase of the sources of threats to human communities both from the detrimental events in social relations and technogenic and natural disasters. Recently, among the nat-

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ural disasters, extreme geophysical events have increasing importance, like heavy rains, high water levels, extreme torrents and vast landslides not recorded in regular evidence dating back hundred years of their existence. Until now (regularly) recorded geophysical data were accepted by human communities as universal laws of the nature, considering them as almost unchangeable. Sporadically, some geophysical events had increased intensity. As such, they created extraordinary situations causing deaths and damages, so they were recorded and classified as natural disasters. Also, for a long time these events were regarded as an exception that can always be mitigated. The conditions have changed lately. The frequency and the force of natural disasters have increased. That led to the increase in deaths and damages which considerably decreased the human power of easy mitigation. It seems that the treatment of natural disasters would have to be based more on the planned approach. Exact forecasting of the place of occurrence and duration of disasters would be the best plan. Unfortunately, deterministic approach to the forecasting of natural disasters is impossible. Disasters are nonlinear manifestations of irregular, complex and strange geophysical occurrences and, as such, they are deterministically impossible to forecast (Mladjan and Gavrilov, 2014). The acceptable planned approach in the treatment of a natural disaster would be in hypothetical assigning of parameters for a disaster and presenting a possible development of the event (so-called scenario) and/or its (numerical) simulations. Parameters of scenario/simulation should not have extremely unexpected values, but should be more extreme than the past ones. Such approach would create multitude of other data on the characteristics of simulated disaster. This would enable direct implementation of the obtained data in the plans for the protection of people and property as well as creating and implementing of the plans for the disaster management, even obtaining some benefit from it. The creation and studying of the "worst case scenario" and the assessment of the risk of the disaster achieve an important place in planning the protection in many countries (Alexander, 2002).

For human communities the safest preparation is for the worst scenario, but that is often economically unjustifiable. High protection levels are expensive because the benefit of the full protection cannot always justify all the costs. That is why the level of acceptable damages is determined through the setting of the frequency of the recurring period of the disaster. For example, in the world today scenarios are made of great flooding for the recurring periods of 50, 100 and 200 years. At the same time, the Netherlands being greatly endangered by floods defined by the law that the minimum recurring period is of 1,250 years and, in some cases, even 10,000 (Varga and Babic, 2005). Sometimes, it is necessary to shorten the recurring periods. For example, due to the climate changes and deforestation, the probability of floods has increased, so the existing statistical distribution is not sufficiently credible for the assessment of future events. That is why the recurring periods of floods in Germany on the Danube and the Rhine have been changed from 100 years to a period of 20 or even 10 years (Thywissen, 2006).

The main idea of this paper is the creation of a scenario of extreme floods in Serbia caused by the simultaneous occurrence of two different types (Lukić et al., 2013) of disasters of (a) high water levels/discharges on the rivers; and (b) heavy rains as well as the interaction of both disasters. In the case of (a) floods primarily happen by flooding of international rivers when the water is coming from the territory of other states, while in the case of (b) floods occur due to heavy rains lasting for many days on the territory of Serbia.

RECORDED HIGH WATER DISCHARGES

Table 1 shows discharges, water levels and flood defence stages of the rivers significant for the following discussion: the Danube, the Tisa, the Tamis, the Velika Morava, the Mlava, the Pek, the Kolubara and the Drava. The locations of hydrological stations from Table 1 are shown in Figure 1.

Table 1- *Maximum, minimum and mean discharges and water levels on major international and national rivers of Serbia as per date and place of measuring flood defence stage (Internet 1; Dukić, 1984; Document 1)*

River	Maximum		Measuring date	Measuring place (hydrological station)	Flood defence stage			Minimum discharge (m^3/s)	Mean discharge recurring periods (m^3/s)
	discharge-Q_{max} (m^3/s)	water level-H_{max} (cm)			regular (cm)	extraordinary (cm)	critical (cm)		
Danube	8,380	776	24 June 1965	Bezdan	500	700	920	898	2,400
Danube	14,820	845	16 April 2006	Smederevo	600	700	822	1,750	5,260
Sava	6,600	863	17 May 2014	S. Mitrovica	650	750	938	200	1,620
Tisa	3,720	926	21 April 2006	Senta	600	800	1,045	122	727
Drava	-	-	-	Osijek	-	-	-	-	620
V.Morava	2,930	692	16/18 May 2014	Bagrdan	500	600	700	20.40	242
Tamis	1,050	846	20 April 2005	Jaša Tomić	340	600	706	-	-
Kolubara	870	827	15 May 2014	Beli Brod	250	430	-	-	-
Mlava	166	536	15 May 2014	Gornjak	-	-	-	-	-
Pek	368	425	16 May 2014	Kučevo	144	324	-	-	-

Let us remind that maximum discharges are mostly the main causes of high water levels, rivers flowing out of their beds and creating floods. The confirmation of this statement is in Table 1 where simultaneousness is noted of the dates of maximum discharges and maximum water levels in all cases. It shall be deemed that the water level increases by the increase of discharge which not only creates the conditions for the occurrence of floods, but they do really happen.

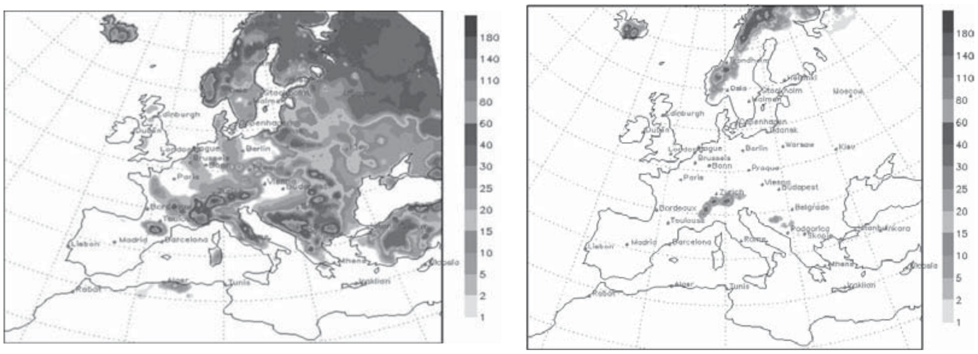
Figure 1- *Location of hydrological stations in Serbia*

SCENARIO OF HIGH DISCHARGES

Let us consider a simple scenario of high discharge on the Danube downstream of Smederevo as the sum of upstream discharges. Now, on the maximum discharge of the Danube at Bezdan (8,380 m^3/s), if maximum discharges of downstream tributaries are added: of the Tisa (3,720 m^3/s), the Sava (6,600 m^3/s), the Tamis (1,050 m^3/s), the Velika Morava (2,930 m^3/s) and the mean discharge of the Drava (620 m^3/s), downstream of Smederevo at the mouth of the Velika Morava, the total (hypothetical) discharge of the Danube would be 22,680 m^3/s. This value is 65 % higher than the maximum recorded discharge of 14,820 m^3/s at Smederevo, which would downstream be even higher by the contributions from the Mlava and the Pek rivers respectively. All this should be accepted under the presumption that there is no water loss, which can happen in conditions of long lasting precipitation/rains when the saturation of the soil is at its maximum and when the ground waters are high. This scenario would be feasible when the maximum discharges on the tributaries of the Danube would have synchronised occurrence. Let us note that the discharge of the Danube at Smederevo can also reach the values close or higher than the maximum in other cases.

Table 1 shows that maximum discharge of the Danube (14,820 m^3/s) at Smederevo creates maximum water level (845 cm) which is even higher than the critical flood defence stage (822 cm). It is quite certain that the hypothetical discharge of 22,680 m^3/s will cause even higher water level than the maximum one and even greater floods. Detailed analysis of the connection of high discharges with high water levels and occurrence of floods cannot be presented here because this is exactly what will be a part of the contents of the main research that is yet to be carried out.

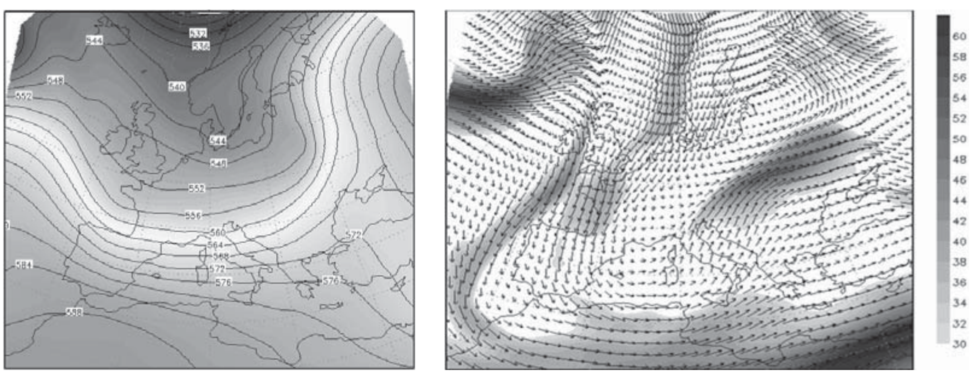
Geophysical conditions that would create such a scenario could happen in case of synchronized melting of great snow on the Alps, the Tatras, the Carpathians and the Dinarides that could lead to the extreme discharges on the international rivers and the Velika Morava. As an illustration of the said scenario, Figure 2 shows two maps of hypothetical distribution of snow in Europe ten days before melting and during or mostly after the melting of the snow.



(a) *(b)*

Figure 2 - *Hypothetical snow distribution in Europe (a) ten days before melting on 25 April 20XX and (b) during and/or after melting on 6 May 20XX.*

Hypothetical synoptic situation of sudden snow melting is shown in Figure 3. It shows that strong south-western upper air circulation above middle and south-eastern parts of Europe causes advection of warm air and creates sudden snow melting on the Alps, the Tatras, the Carpathians and the Dinarides. Run-off waters created by the melting of the snow flow down into the southern Pannonia, accumulate before the Djerdap Gorge and create high discharges and water levels on the Danube and its tributaries.



(a) (b)

Figure 3 - *Hypothetical synoptic situation in the period of sudden snow melting with (a) upper pressure at 500 hPa and (b) aloft wind.*

Besides the scenarios obtained by combining reached/recorded discharges/water levels, the main research would also take into account the scenarios where discharges are higher than all the past ones. Scenarios of high discharges which would create water levels above the critical flood defence stages would be particularly researched. Then, the assessments of the risks of the occurrence of critical water levels would help to elevate critical water stages or to undertake other protective measures against river flooding, like planned flooding of designated areas and/or directing of water surpluses to other water courses and similar.

HEAVY RAINS IN MAY 2014

Figure 4 shows extreme precipitation sums observed from 14 May 2014 to 16 May 2014 in Serbia. In some areas they reached the values of 225.1-375.0 mm (blue) which are approximately average six-month precipitation sums in those areas. These values have not been recorded in meteorological observations before. At the same time, greater part of Serbia was exposed to heavy precipitation of 25.0-225.0 mm (green). These three-day precipitations caused great influx of surface waters that caused floods, torrents, landslides, deaths and damages across Serbia (Marić et al., 2014).

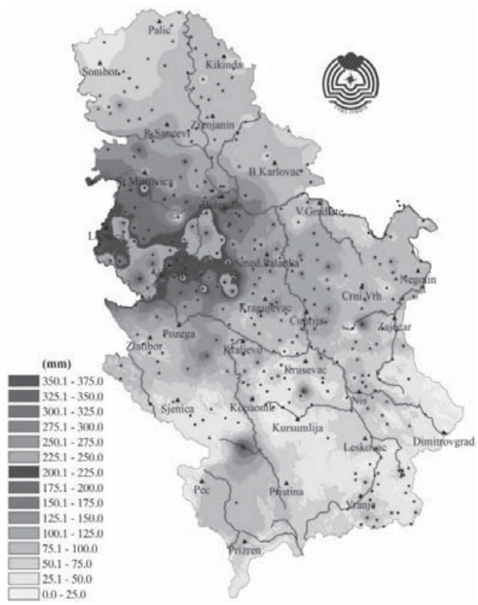


Figure 4 - *Distribution of total precipitation in Serbia in the period of 1 May to 16 May 2014 (Internet 1)*

Table 2 - *Precipitation in 15 regions, area of the region, total water quantities per region and whole Serbia*

i - region index	h_i - precipitation in the region (mm)	P_i -area of the region (km²)	H_i -total water in the region (m³)
1	0.0-25.0	1,391.9	34,797,500
2	25.1-50.0	9,986.6	499,330,000
3	50.1-75.0	25,289.0	1,896,675,000
4	75.1-100.0	24,136.0	2,413,600,000
5	100.1-125.0	1,907.1	238,387,500
6	125.1-150.0	8,489.8	1,273,470,000
7	150.1-175.0	4,050.2	708,785,000
8	175.1-200.0	5,641.2	1,128,240,000
9	200.1-225.0	1,985.5	446,737,500
10	225.1-250.0	875.3	218,825,000
11	250.1-275.0	268.7	73,892,500
12	275.1-300.0	399.4	119,820,000
13	300.1-325.0	3,372.5	1,096,062,500
14	325.1-350.0	376.8	131,880,000
15	350.1-375.0	191.1	71,662,500
Total		88,361.1	10,352,165,000

For this purpose, total quantity of water obtained from three-day precipitation for the whole territory of Serbia will be calculated. For that, Figure 4 and the formula will be used,

$$H_i = h_i \, x \, P_i \tag{1}$$

Here H_i is the total water quantity of three-day rain, h_i is the three-day precipitation sum and P_i the area, all according to the regions, i = 1, 2, 3,...,15, of the same sums/colours of the precipitation in Figure 4. By replacing in (1) the values from Table 2 with h_i (higher number from the second column) and P_i (the third column), and by reducing the units, the calculation is made as per all the regions and (the first column) total water quantity H_i in m³ (the fourth column). For the total water quantity H_S from the rains observed from 14 May 2014 to 16 May 2014 on the whole territory of Serbia, the result is,

$$H_S = \sum_{i=1}^{15} H_i = 10{,}352{,}165{,}000 \text{ m}^3 \tag{2}$$

For the purpose of checking, the area of Serbia is calculated,

$$P_S = \sum_{i=1}^{15} P_i = 88{,}361.1 \text{ km}^2 \tag{3}$$

Finally by dividing (2) and (3) the result is,

$$h_S = \frac{H_s}{P_s} = \frac{10{,}352{,}165{,}000 \text{ m}^3}{88{,}361.1 \text{ km}^2} = 117.2 \text{ mm} \tag{4}$$

where h_S is average three-day precipitation sum for the whole Serbia. Calculated value is close to three-month average multi-year precipitation in Serbia (Sokolović et al., 1984).

In calculating the area of 15 regions from Figure 4, software package Q GIS 2.6 open source GIS (Internet 2) was used whose error is 0.2 %. Water quantity as per the regions and the whole Serbia will not be further analyzed here, but it could certainly be the topic for further research. More information on meteorological causes of precipitation from 14 May 2014 to 16 May 2014 can be found in the paper of Zarić (2014).

HEAVY RAINS AS PER SCENARIO

For the purpose of simplifying further presentation, three presumptions are introduced. The first will place heavy rains, similar to the above described, in the Pannonian part of Serbia (Vojvodina, the plains on the right bank of the Sava, the plains of Srem and Banat that belong to Belgrade and the plains on the right bank of the Danube from Belgrade to its exit from Serbia) (Ćalić et al., 2012). That part is shown in Figure 5 and its area is P_p=25,000 km^2. In the second presumption it is accepted that in three days the Pannonian part of Serbia received the total of h_p=250 mm = 250 l/m^2 = 0.25 m^3/m^2 of water. Finally, by the third presumption we neglect all surface losses of rain water, which means that the Pannonian part of Serbia could be covered by the water level of mean depth of 250 mm. Let us remind that in Pannonia the average sum of annual precipitation is around 600 mm (Tošić et al., 2014), thus, the three-day precipitation presumption can be regarded as high.

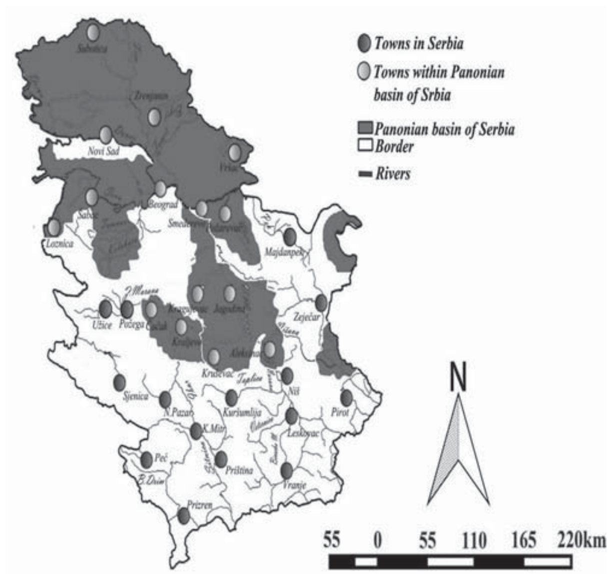
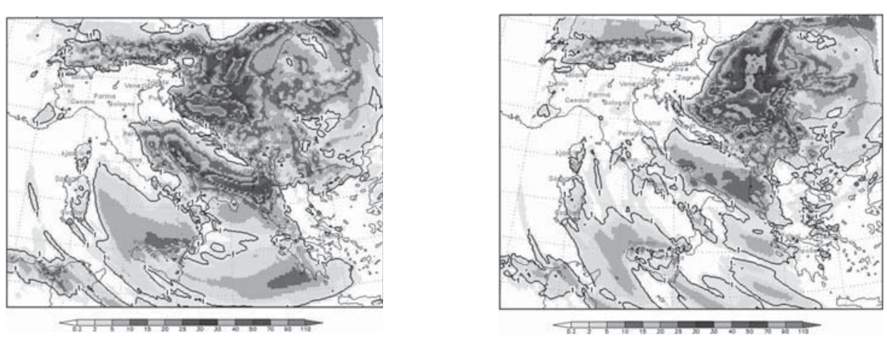
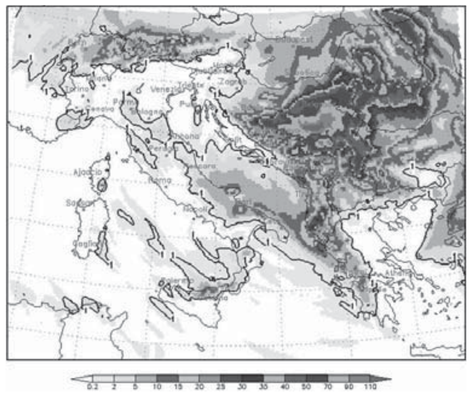


Figure 5 - *Pannonian basin of Serbia*

Table 2 shows that average three-day heavy precipitation sum of 202 l/m^2 was already observed in the area of 25,079,000 km^2 consisting of ten regions, i = 6, 7, 8,..., 15, . Hypothetical precipitation (250 l/m^2) introduced here can be considered as not having extremely unexpected value, since they are close to already observed heavy rains (202 l/m^2) on the territory of similar magnitude (25,079,000 km^2), but they are more extreme than former precipitation which will be the main rule in setting a scenario for the future researches. Also, in some regions of Serbia, precipitations up to 375 l/m^2 were observed, which can be repeated and include the whole Pannonian part of Serbia. As illustration of such an event, Figure 6 shows hypothetical heavy rains in four days.



(a) *(b)*



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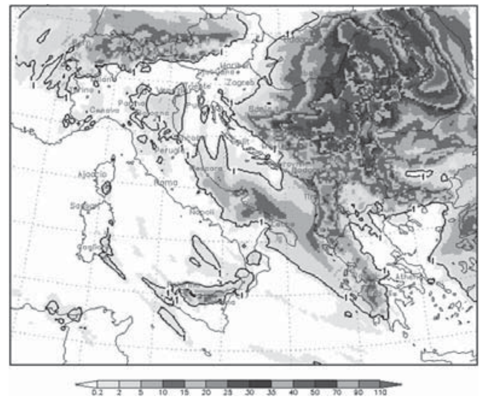
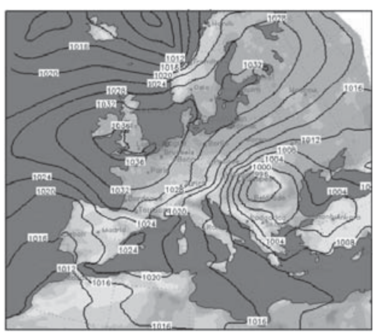


(d)

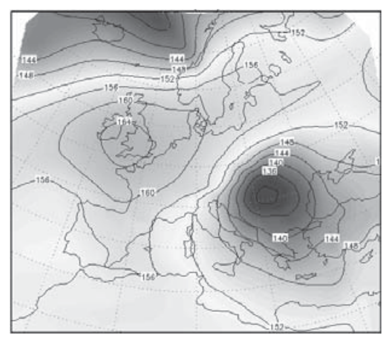
Figure 6 - *Hypothetical spatial distribution of total precipitation per days (a), (b), (c), and (d) in the period from 5 May 20XX to 8 May 20XX, respectively*

Hypothetical synoptic situation of heavy rains is presented in Figure 7 where four maps show: (a) surface pressure, (b) and (c) upper pressure at 850 hPa and 500 hPa and (c) aloft wind circulation. Synoptic situation shows a strong cyclone stationing and renewing in several days over the Pannonian part of Serbia and producing heavy rains shown in Figure 6, similar to the rains in May 2014.

Future research will be also directed to other scenarios. There, the rains would be more intensive and with longer duration than in all the cases observed so far.



(a)



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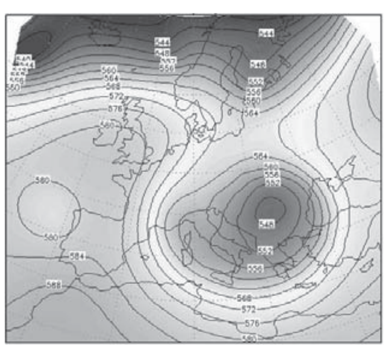

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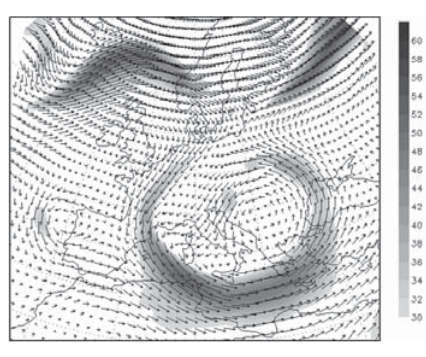

(d)

Figure 7 - *Hypothetical synoptic situation of heavy rains in Serbia with (a) surface pressure, (b) and (c)upper pressure 850 hPa and 500 hPa, and (b) aloft wind, all in the period of 5 May 20XX to 8 May 20XX*

HIGH WATER LEVEL

In order to compare previously stated water quantities that reach the Pannonian part of Serbia through rivers and precipitation in the same period, two simple calculations will be made first.

In the first calculation discharge water quantity should be obtained at a certain section and a certain period. By using the formula

$$Q_{\Delta t} = Q_{max} \text{ x } \Delta t \qquad (5)$$

where $Q_{\Delta t}$ is (total quantity of) discharge waters in m^3 that flow through some river section in maximum discharge Q_{max} in m^3/s, in a certain time period $Q_{\Delta t}$ in s. By changing in (5) previously considered two values of maximum discharges at Smederevo, Q_{max} *(=14,820.0; 22,680.0 m^3/s)*, in the duration of three days, Δt = *(72h x 60 min x 60 s =) 259,200 s*, obtained values for $Q_{\Delta t}$ are shown in Table 3 (second column).

Table 3 - *Maximum discharges of the Danube at Smederevo and three-day water discharges calculated of them*

Q_{max}-maximum discharge (m^3/s)		$Q_{\Delta t}$-discharge waters (m^3)
Measured	Hypothetical	
14,820.0	-	3,841,344,000
-	22,680.0	5,878,656,000

We know from our past experience that maximum discharges last less than three days, so that the values used here should be taken as mean three-day discharges same/close to the values of maximum discharges. Such presumption is allowed in scenario approach. Speaking in statistical language, probability of this presumption coming true is small, but possible. Main research would also include cases where discharge waters would be higher than all the previously measured cases and of longer duration. Also, main research would deal with the calculation of recurring periods of such cases.

In the second calculation it is needed to obtain water quantities from precipitation or runoff water in a certain period. Now total quantity of heavy precipitation from the previous chapter we turn into the height/quantity of runoff water to the Danube and its tributaries. It will be done by using again the formula (1)

$$Q_p = P_p \, x \, h_p \qquad (6)$$

where, let us remind, Q_p is total water quantity from hypothetical three-day rains in m^3, P_p is area of the Pannonian part of Serbia in km^2 and h_p is hypothetical three-day precipitation sum in m^3/m^2. After substituting in (6) values for $P_p = 25{,}000{,}000{,}000\ m^2$ and for $h_p = 0.25\ m^3/m^2 = 250\ l/m^2$, the obtained result is,

$$Q_p = 6{,}250{,}000{,}000\ m^3 \qquad (7)$$

As can be seen from (7), hypothetical discharge waters of three-day rain as per the scenario are of the same order of magnitude with the high discharge waters from Table 3 that flow through the Danube at Smederevo in three days.

INTERACTION OF HIGH WATERS

Let us remind that the main idea of this paper was to make a scenario of extreme floods in Serbia caused by simultaneous occurrence of high water levels/discharges on the rivers and heavy rains. Now, after obtaining the quantities of three day water discharges on the Danube, approximately at Smederevo, and runoff waters after three-day rains, the simplest interaction of these two disasters will be presented as total water quantity that could in three days be found in the Pannonian part of Serbia. Total water quantity is shown in Table 4.

Table 4 - *Maximum discharges on the Danube at Smederevo, calculated three-day discharge waters based on that, runoff waters calculated on the basis of three-day hypothetical precipitation and water sums*

Q_{max}-maximum discharge (m^3/s)		$Q_{\Delta t}$-discharge waters (m^3)	h_p -hypothetical precipitation sum (m^3/m^2)	Q_p -hypothetical runoff waters (m^3)	$Q_{\Delta t} + Q_p$ -water sums (m^3)
Measured	Hypothetical				
14,820.0	-	3,841,344,000	0.25	6,250,000,000	10,091,344,000
-	22,680.0	5,878,656,000			12,128,656,000

Table 4 shows that maximum discharges of the Danube at Smederevo (first column) during three days bring the quantity of water (second column) of the same order of magnitude (fourth column) as three-day heavy precipitation (third column) all in the Pannonian part of Serbia. In other words, it is possible that in three days in the Pannonian part of Serbia around 10,000,000,000 m^3 of water occur (the fifth column). If, in the most extreme probability, all the quantity of this water would flood, a lake would be made in the Pannonian part of Serbia of 25,000 km^2 with the depth of around 0.5 m. It is clear that this water would not be equally and simultaneously distributed everywhere, and the lowest parts of the Pannonian part of Serbia would be flooded first and the greatest damages would be in large coastal urban zones of Belgrade, Novi Sad, Smederevo and other coastal communities. Immense material damages would be also accompanied by numerous human deaths.

Detailed analysis, primarily quantification, of the floods created by the interaction of high water levels/discharges on the rivers and heavy rains as well as their influence on human communities and the country cannot be further presented here because it is the content of the main research yet to be carried out.

MANAGEMENT AND MITIGATION OF FLOOD RISKS

In this paper the notion of "management" will include all planned and appropriate actions that can, by removing the water from one place to another, not only mitigate the detrimental effects of flood, but also the opposite, to make some benefits out of floods. The ideas presented here are not new, so this is the place for some reminding. The foundations of today's civilizations are in the ancient civilizations from the valleys of the Nile, the Tigris and the Euphrates and the Yangtze and other rivers. People of that time understood that they can make living out of floods and, thus, they founded complex technical and organizational systems for their management, like building of channels and lakes, irrigation, drainage, river/channel traffic, etc. In time, the management of floods was sufficiently improved to secure progress to civilizations for many millennia. These civilizations, founded on a good flood control, survived longer than others. They are also mentioned as "hydraulic civilizations" (Gavrilov 2005). Many achievements of these civilizations are forgotten, but flood "management" is still relevant. Let us remind that thousand kilometres of channels were excavated all around the world and they are still being excavated in Russia, the USA, China, Germany, Great Britain, the Netherlands, Serbia and elsewhere for the purpose of managing waters on the land and on the sea.

This paper will further discuss some of the procedures for moving water, like methods for great flood management similar to the ones discussed above. Two possibilities will be discussed in this context.

The first possibility for moving water is realistic and relates to the existing waterway, known as the channel **D**unav-**T**isa-**D**unav (DTD). More information on the channel DTD can be found with Milovanov (1972). Strategically speaking, the channel DTD is designed and constructed as an alternative flow of the Danube through Serbia. As such, DTD could receive and change flow direction of high level waters of the Danube and its tributaries. First, this could decrease the discharges and water levels as well as flood risks. Second, the capacity of the Danube and the tributaries for receiving high level waters from elsewhere would be increased. Even if the channel DTD is used only as the reservoir for temporary storage of surplus water from the Danube and the tributaries until this surplus returns to the Danube, the conditions are created for better flood protection of the most sensitive parts of Serbia, and these are urban areas of Novi Sad, Belgrade and other places in parts of the alluvial plain of the Danube and the Sava. Channel DTD is connected with the Tisa, the Tamis and other waterways and in this way its use against great floods is increased. More details on the use of the channel DTD in the protection of life and property against great floods, potential benefits of such floods as well as other benefits will not be presented here, but that also could be the main research topic yet to be undertaken.

Other possibility of moving water is imaginary and deals with the planning and construction of man-made waterway from the Danube to the Aegean Sea which would connect the Serbian river Velika Morava with the Macedonian river Vardar and enable the Serbian river to flow into the Aegean Sea through Greece. This waterway we shall call the channel **D**anube-**M**orava-**V**ardar-A**E**gean Sea (DMVE). More information about the idea, plan, purpose and the like on the channel DMVE can be found with Veličković et al., (1995) and the following documents: CGGC (2013) and Design Institute "Ivan Milutinović" (1973).

The channel DMVE is so designed as to fulfil two strategic goals. The first goal of the channel is to directly connect the centre of Serbia with the Mediterranean Sea so that all geopolitical and economic benefits of that connection could be realized for Serbia, surrounding and other interested states. The details of this strategic goal will not be discussed here because they are out of the scope of this paper.

The second strategic goal of the channel DMVE is directly linked to the discussion raised here on great floods in Serbia. The Danube basin has the area of around 800,000 km^2 with very specific flow through the Pannonian plain from which it draws surface waters and collects greater part of the water from the surrounding mountain massifs, the Alps, the Tatras, the Carpathians and the Dinarides, accumulating all that water in Serbia before passing through the Djerdap Gorge where, after fiercely surmounting it, it peacefully flows to the Black Sea. In other words, the Danube has a slowdown in its flow through Serbia. This slowdown is all the bigger if the discharge of the Danube downstream of Smederevo is higher. The concept of the scenario on great floods discussed here is based on the fact that in the southern part of the Pannonian plain (Pannonian part of Serbia) which, for the sake of clarity, should be considered as a type of a drain, the immense quantities of water arrive through the Danube and its tributaries which slow down, accumulate and flow out before reaching the Djerdap Gorge. If we also add the water from heavy rains to these hydrological processes as the scenario here forecasts, the Pannonian parts of Serbia will be exposed to great floods. In the most extreme situations of great floods, the help from the channel DTD would be limited. But, it is these most extreme situations, as others too, that can be mitigated by the channel DMVE. Then, the channel could accept all the surpluses of water from the Danube at the most critical place at the mouth of the Velika Morava (around Smederevo) and direct surpluses of water to the upstream flow of present Velika Morava towards the Vardar and further to the Aegean Sea or, otherwise, to keep these waters as a reservoir and later return them to the Danube or make other uses for them. This illustration of the use of the channel DMVE in the protection against great floods does not limit the significance of this channel. The point of the second strategic goal is also to indicate that by building the channel DMVE, Serbia would in a way control the major and more important part of the waters that belong to the Danube basin, with all else that stems from it. More details on the use of the channel DMVE will not be discussed here, but that could be a topic of the main research yet to be undertaken.

FLOOD PROTECTION

Protection against floods is an important measure in managing a river basin. In Serbia, "flood defence" is primarily applied which requires the construction of expensive objects (dams, accumulations, embankments, locks etc.,) in blue zones to increase the safety of people and property (Varga and Babić, 2005). In the development of flood protection, the introduction of the principle of "living with floods" (Varga and Babić, 2005) is expected. This principle fits into the concept of sustainable development because it aspires to harmonize "human" (protection of people and property) with "ecological" (saving and/or revitalization of natural processes) interests in flooded area. "Living with floods" requires an adequate coupling of: (1) non-investment and (2) investment (hydro-construction) measures. The first group of measures influences the reduction of damages by prevention; categorizing the endangered area, informing, educating and organizing of defence. The second group of measures influences the reduction of deaths and damages by building construction. Making and discussing scenarios as proposed here could significantly improve non-investment and investment protection measures against great floods.

CONCLUSION

Simple analysis shows that in the Pannonian part of Serbia where big rivers such as the Drava, the Sava, the Tisa, the Tamis, the Velika Morava and others, flow into the Danube, high water levels close or higher than maximum can occur almost simultaneously, which could lead to great floods. Also, it is shown that three-day heavy precipitation can leave in the same region immense quantity of water which could already by itself cause great floods which could be all the more greater if the runoff waters would be prevented from flowing into the rivers because of their high water levels. In future, it should be expected that flood parameters presented in scenario would be reached and become higher which means that they would also become more dangerous for people and property.

The consequences of disastrous floods discussed here can be best understood if the fact is taken into account that around 650,000 people live only in the area of Novi Sad and Belgrade in the parts of alluvial plain of the Danube and the Sava. Thus, densely populated parts of Novi Sad, Novi Beograd, Pančevo swamp and other areas located in the lowest geo-morphological zone would be directly exposed to the destructive action of water. In the discussed case, destructive flooding activity would be followed by disastrous floods in densely populated lowest parts of the valleys of the tributaries of bigger rivers as well as by the occurrence of spread landslides, great torrents, flowing out of ground water and sewerage water. High probability of the occurrence of this extraordinary situation should motivate us to urgently create unified strategy of defence against natural disasters with the participation of all relevant institutions and individuals.

Detailed analysis of floods caused by the interaction of high water levels/discharges on the rivers and heavy rains based on scenario and the influence of these floods on human communities and the country cannot be further presented here because it should be the main research topic yet to be carried out. One such research would yield plenty of data on the characteristics of simulated floods, above all, on their influence on human communities. Also, the simulations would make possible not only to reduce or remove potential detrimental effects, but to draw benefits, too, from the floods. Great quantity of flood water can be a resource which can bring benefit, but only if the water is managed well.

In writing such conceptual papers, and in this case even of the scenario type, speculative method is unavoidable. But, in the future researches, which were announced several times, speculative method will be minimized and give leading way to the modelling approach. Within the modelling approach to the research of great floods in Serbia, the statistical method will have significant place and it will, by using the most advanced statistical methods and stochastic models process hydrological and meteorological data. Also, it is planned that special place in modelling approach in the announced research will be devoted to explicit mathematical simulation of great floods. For that purpose, hydrodynamic equations will be used for the description of the condition and water flows (Gavrilov et al., 2014) and their solution could yield knowledge on the situation in the Pannonian parts of Serbia in the conditions of great floods. Carrying out of this research would create significant data on the characteristics of great floods which would enable direct implementation of these data in the plans for the protection of people, their property and creation of plans for flood management.

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