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STUDIES AND RESEARCH ON MAXIMUM FLOWS OF THE TROTUȘ RIVER IN 1990 - 2017

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Research has analyzed components of the climate and hydrological regime on the Trotuș River and its tributaries over the past 30 years. The hydrological risk was determined by natural causes, but also by anthropogenic causes. Parameters of hydroclimatic risk are represented of the torrential rainfall, flood flows, high frequency of high flows, high erosion speeds etc. The research revealed that at very low intervals (3-5 years) there were floods with very high flows. Changing the climate regime (precipitation concentration on small days) and the natural relief forms in the hydrographical basin (the Eastern Carpathian Mountains) allowed natural risk to occur in the hydrological regime of the Trotuș River. Anthropogenic factors, in particular, the modification of the leakage coefficient by deforestation of forests and the change of agricultural use of land with large slopes have contributed to the occurrence of anthropogenic risk in the Trotuș River basin. Corroboration of the two types of risk, natural and anthropic, has led to a hydrological disaster regime in the Trotuș River Basin.

Introduction

Climate change in the southern and south-eastern parts of Europe, respectively the Black Sea basin influences the evolution of the seasons in Romania, their duration and their meteorological disposition. Romania and especially Moldova region are located in a hydroclimatic transition area, from more humid and thermal

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moderate oceanic tones to the continental ones, which leads to large thermal and rainwater discontinuities. The Siret River hydrographical areal, which is located in the South-East part of Romania, at the Eastern Carpathian barrier, can be affected by important climate changes.

A global problem, also present in Romania, is the increase in air temperature, aspect which is analysed in various studies and works (A.B.A. Siret, 2016, A.N.M. 2008). The seasonal change of meteorological parameters creates a hydroclimatic risk in the evolution of flows and levels on rivers through the flood waves resulted.

The change of the hydrological parameters influences the morphological evolution of the river and the response of the existing riverbed and riparian area structures. The hydrological regime in the Siret River basin in the last period of time is characterised by the high floods frequency. The floods generated in recent years on Trotuș River and its tributaries have caused significant economic damage and human loss (Avram & Luca, 2017).

Hydrological risk elements intensively modify the morphology of the riverbed in transversal and longitudinal section. It is also influenced the stability of riverbed constructions (bridges, regulation works) and shore (shore defence works, dikes). Hydrological risk elements affect the existing habitat in the minor and major riverbed sections. The floods with a disastrous nature have produced significant degradations to the social and economic objectives of the riparian area. The value of the damage caused by floods has become very high in recent years, which has forced the allocation of important investments into restoration work for the objectives destroyed. The effect of the riverbed morphological changes is immediately noticed, or may occur after a longer period of time. The restoration of river regulation and shore protection works depends directly on the evolution of hydrological and hydraulic parameters over time.

Study area and research method

Studies and research were conducted in the hydrographic basin of Trotuș River and its tributaries. For the comparative interpretation of the results, data from the Siret hydrographic basin was collected and singularised for the Trotuș River basin. Part of the data was taken from technical documentation of Siret Basin Water Administration and from the literature.

The Trotuș River hydrographic basin is located in the relief area of the Oriental Carpathians. The Trotuș River is for the flysch area of the Oriental Carpathians. The Trotuș River springs are located in Ciucului Mountains at an altitude of 1360 m. The main flow direction is north - south. The river crosses the geomorphological units of the Ciucului and Tarcăului Mountains, Comăneștii and Tazlău - Cașin Depressions. The Trotuș River flows into the Siret River downstream of Adjud. The river basin surface is 4 349 km² and the length is 149.2 km (Ujvari, 1972). The average

elevation of the river basin varies from springs to inflow ranges between 1140 - 734 m. The Troțuș River has the XII-1-69 cadastral code.

The main tributaries on the left side of Troțuș River are: Bolovăniș, Tărhăuși, Șanț, Cuchiniș, Brusturoasa, Camenca, Agăș, Seaca, Ciungi, Asău, Urmeniș, Plopul, Cucuieți, Vâlcele, Tazlău; on the right side: Ciugheș, Cotumba, Grohotiș, Sulița, Ciobănuș, Supan, Uz, Dofteana, Slănic, Nicorești, Oituz, Cașin, Gutinaș, Căiuți, Popeni (Ujvari, 1972).

The tributaries on the right side are more numerous, drain higher mountain areas, have a richer discharge, and have larger accumulation surfaces. The rivers Uz (469 km²), Oituz (337 km²) and Cașin (308 km²) are representative. The most important tributaries on the left side are Asăul (208 km²) and Tazlăul (1104 km²) (Fig.1). Tazlău River has a lower flow rate than other tributaries, although it has a much larger hydrographic basin surface (Enea et al., 2016).

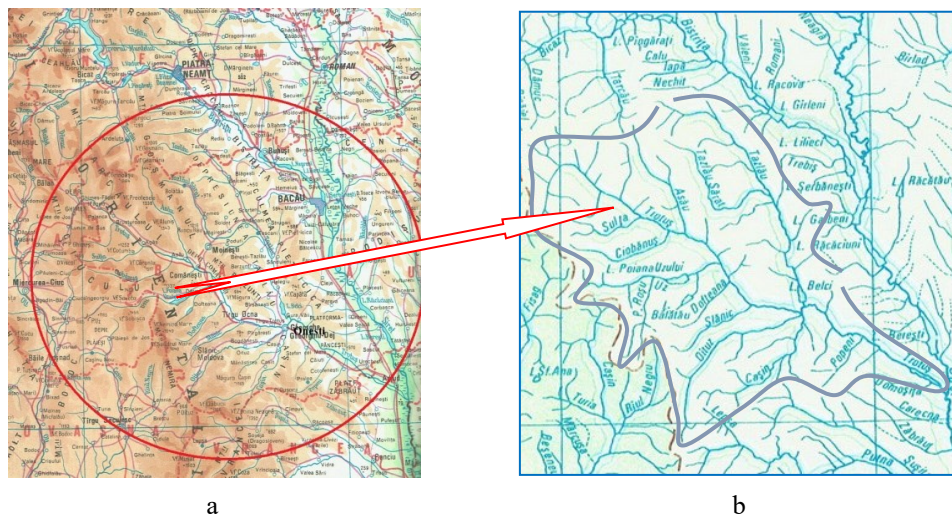


Figure 1: Framing of the study area (Troțuș HB) in Siret hydrographic basin: a - area location in the Eastern Carpathians relief; b - area location in the Siret River hydrographic network.

Through documentation and fieldwork, data has been collected and studies have been compiled on meteorological, hydrological, hydraulic, topographic and geotechnical parameters for the Troțuș River and its tributaries hydrographic basin and riverbed. Studies and researches have been conducted over time periods (30-50 years). The research has determined the natural and anthropic risk forms that have occurred in the past 30 years in the Troțuș River basin.

Field investigations were carried out in Troțuș River and main tributaries characteristic sections, where maximum flows and their consequences were recorded.

Photo and video surveys were taken during field research. Studies on the current structural state and analysis on the degree of degradation (technical expertise) were conducted for hydrotechnical riverbed regulation and shore defence works.

Results and discussions

In „Clima României” (Romania’s Climate) paper (A.N.M., 2008) the increase in global temperature is analysed and it highlights an increase of $0.6^{\circ} - 0.8^{\circ}\text{C}$ during the 20th century in Romania. Based on the studies carried out, it is possible to admit that the growth trend is higher in Moldova area (the eastern and south-eastern regions of Romania) and smaller in the west and northwest of Romania. From the point of view of precipitation, there is no clear tendency of their volume decrease, but there are large and very large variations from one year to the next.

In the last period of time there has been noticed an increase in the degree of torrentially. The analysis of the maximum rainfall accumulation during 24 hours confirms this observation. There are also noticed monthly pluviometric discontinuities highlighted through the analysis of rainfall distribution over seasons, months and days (Avram, 2017). The analysis presented in "Clima României" shows significant ratios between the quantities recorded during the hot season compared to the ones in the cold season (Iași - 2.13, Suceava - 2.72, Roman - 2.74). These ratios are among the largest in the country, fact which confirms the continental nature of the Moldova area climate. The analysis shows that during the last 25 years the torrential nature of the precipitations is noticeable and the intensity of the storms has reached alarming levels.

A study conducted in the Siret hydrographic basin at 120 stations and weather posts shows that the maximum precipitation frequency during 24 hours increased especially after 1960. The precipitation produced significant hydrological effects (over 100 mm in 24 h), amplified by the presence of anthropogenic factor. The study conducted shows that during the last 15 years there have been at least 6 catastrophic flood sequences in the Trotuș River Basin (2004, 2005 and 2016 years). These situations are correlated with those on the lower Siret river course (in 2006, 2008 and 2010) in the northern half of the Siret River basin (2015 and 2016), but also in Bistrita hydrographic basin (downstream of Izvoru Muntelui) (Avram, 2017, A.B.A. Siret, 2016).

The analysis conducted over the time interval under consideration highlights a series of positive or negative variations, but there is no clear tendency of precipitation increase or decrease. Based on this analysis, it can be said that in the past years, on the background of global warming, there is no definite increase in rainfall. The analysis conducted over two long time periods (1950-1983 and 1984-2015) shows that in the first part, the frequency of transgression of the average

multiannual precipitation was higher (20 cases) than in the second period (only 11 cases) (Avram, 2017).

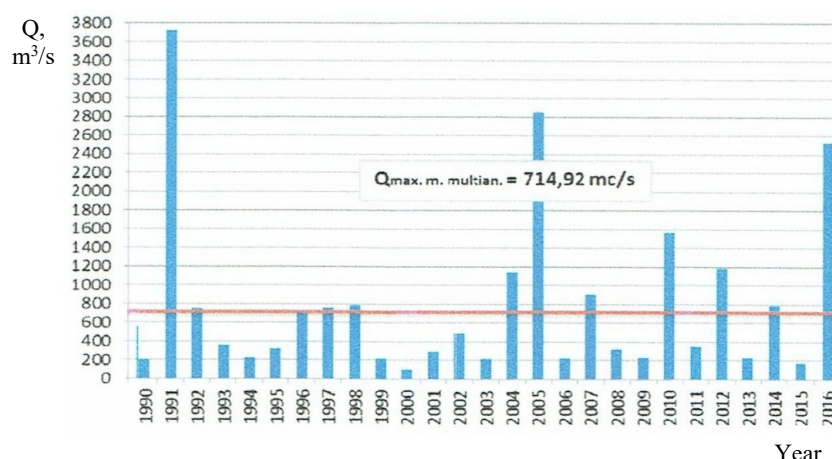


Figure 2: The variation of maximum 1997-2016 annual flows at H.S. Vrânceni

The precipitation variation effect is felt in the way in which maximum flow rate floods on the Trotuș River and its tributaries develop. The data presented in figure 2 shows the high frequency of maximum flows during 2004-2016 periods.

Floods with maximum flow rates in 1991

The year 1991 comes after a drought period (about 9 years), in which rainfall was almost at half its normal value. The year 1991 was characterised by significant quantitative precipitation in the Trotuș River basin. Just between May and July the quantities recorded represented 75-125% of the annual average.

On the night of 28/29.VII 1991, the rainfall in Tazlău River hydrographic basin, occupied a larger area, which generated floods with high flow rates on all Tazlău River tributaries up to the confluence with Trotuș River. Simultaneously with the floods on the Tazlău River there were also floods on the Trotuș River, downstream of Tg. Ocna. The large volume of rainfall on the night of 28-29 July 1991 in Tazlău River hydrographic basin, the oval shape of the collecting surface, the network layout, the riverbed morphometric characteristics and other hydrological factors have led to the generation of high amplitude floods on this river. The discharge concentration time was very low, about 1.0 h - 1.0 h 30' on small courses and 3.0 h on the main water course. Concentration was faster in the Helegiu section due to smaller tributaries from the middle and lower sectors, where main core of the rainfall was located (Vamanu & Olaru, 2005). The flood hydrograph is significant for such a flood (Fig. 3).

The Tazlău River flood propagated into Belci storage reservoir and spilled over the dam's wave crest, situation which caused its breaking. Spillage of the dam was favoured by natural risk factors, as well as anthropic risk factors. Among the anthropic risk factors, two were of great importance in the dam's breaking: the lack of reservoir unsilting works and the blocking of tainted gates.

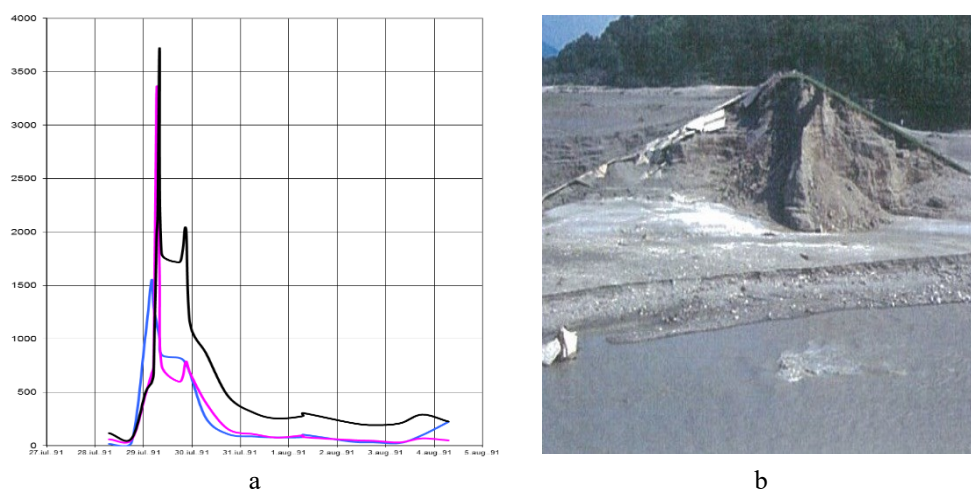


Figure 3: The flood hydrographs recorded in Belci area in 1991 at Helegiu (Blue Line), Slobozia (red line) and Vrânceni (black line) hydrometer stations; b - detail on Belci earth dam breaking area

The maximum flow rate in the Trotuș River Vrânceni section, located downstream of the confluence with Tazlău River, reached 3720 m³/s. The dam breaking had disastrous effects downstream.

Studies and research have shown that there have been two successive floods in the Belci dam section. These were confirmed by eyewitnesses (staff at the Helegiu hydrometric station located towards the end of the lake (Vamanu & Olariu, 2003)). The water volume from Tazlău streams Brătîla, Văereni, Bârșănești, Helegiu and from a local catchment area of 30.4 km² generated a first maximum flow rate of 2095 m³/s, which reached the Belci dam section. This volume is also generated by an area of 30.4 km² located in the rainfall's core, with values above 150 mm. The second maximum flow rate was generated through the actual intake of Tazlău River from its hydrographical basin upstream of Lake Belci's end section.

Floods with maximum flow rates in 2004

In the Trotuș River middle and lower sectors a flood was generated at the end of July 2004, which had an exceptional nature, especially on Goioasa area small tributaries. The Trotuș River flows, though quite large, did not generate significant floods, but those on the tributaries were disastrous in nature. The analysis

conducted showed that the maximum precipitation core was located in the Goioasa-Ciobănuș-Asău-Poiana Uzului-Tg.Ocna area. The synoptic context that generated these precipitations was determined by the existence of a low atmospheric pressure field in the south-east middle of Europe which was in contact with an anticyclone located in the north-west of Europe on the alignment of the East Baltic countries, Poland – Romania centre - Greece.

The precipitation amount which generated the floods, the maximum levels and flow rates recorded and the values with which the defence levels were exceeded are shown in Table 1.

Table 1: Flows and levels recorded in July, year 2004 (selective data) (A.B.A. Siret, 2004)

No.	River	Hydrometric station	Rainfall l/m ²	Q _{max} (m ³ /s)
1	Trotuș	Ghimeș Făget	27.6	
2	Trotuș	Goioasa	88.4	358
3	Trotuș	Tg. Ocna	62.9	682
4	Trotuș	Onești	24.5	869
5	Trotuș	Vrânceni	15.9	1136
6	Ciobănuș	Ciobănuș	94.2	67.2
7	Asău	Asău	61.5	120
8	Uz	Dărmănești	104	23.0
9	Dofteana	Dofteana	41.7	116
10	Oituz	Fereastră	46.2	13.2
11	Cașin	Haloș	54.7	166
12	Tazlău	Scorțeni	52.0	
13	Tazlăul Sărat	Lucăcești	25.3	140

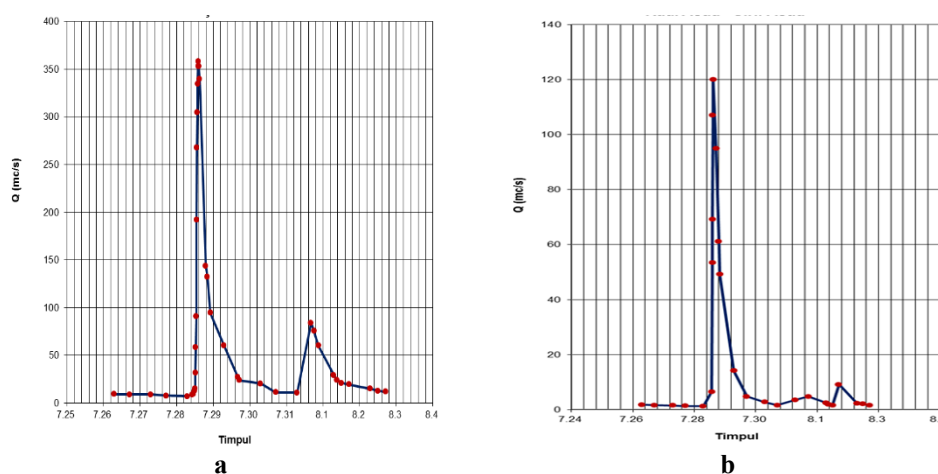


Figure 4: Flood hydrograph of the 28 – 31 July 2004 in the hydrographical basin River Trotuș: HS Goioasa on Trotuș River; HS Asău on Asău River.

The table data analysis shows that on the Trotuș River upper course (upstream of Goioasa), in the Valea Rece, Sultă, Slănic, Oituz, Tazlău hydrographic basins and on the lower course of Trotuș River, no floods were generated, or their volume was insignificant. The data analysis shows that the largest floods occurred in the Goioasa - Tg.Ocna sector, on the large Ciobănuș and Asău tributaries and especially on the small tributaries from Goioasa area (Fig. 4).

The catastrophic floods produced on the small tributaries were the result of precipitations concentrating in a short time span, but especially due to the configuration of the lower riverbed sectors. At the exit point from the versant, in the Trotuș alluvial plain, the slopes of the river suddenly decrease and the large quantities of transported alluviums are deposited, in which case, the capacity of the riverbed is greatly reduced and sometimes it is obstructed. In these cases, alluvial cones are formed in the riverbed, which favour the riparian area flooding.

Table 2: Maximum recorded flows and morphometric elements of hydrographic basins on the Trotuș River tributaries (A.B.A. Siret, 2004)

No.	River	Section	HB S. (km ²)	Q _{max} m ³ /s	Q _{max} R m ³ /s	Q _{max.p} %		
						0.1	0.5	1
1	Sugura	Get up on Trotuș	12.0	39.8	47.7		102	84.0
2	Agăș	Get up on Trotuș	16.0	183	195	189	134	110
3	Seaca	Get up on Trotuș	6.34	22.3	27.1			
4	Beheghet	Get up on Trotuș	2.19	50.7	69.8	38.0	27.0	22.0
5	Gooioasa	Get up on Trotuș	4.75	67.1	80.5	55.0	39.0	32.0
6	Țiganului	Get up on Trotuș	0.75		16.8	13.0	10.0	7.50
7	Iedera	Get up on Trotuș	2.75		127	70.0	50.0	40.0

HB S. - hydrographic basin surface; Q_{max}R - maximum recalculated flow

Floods with maximum flow rates in 2005

The flood formation conditions in the Siret hydrographic basin in 2005 were achieved in two stages (Avram, 2016). The first stage took place in the first decade of July, when in the Trotuș catchment area a great amount of rainfall was recorded. These precipitations led to rising soil moisture and contributed to watercourses level rise. The second stage took place in the second decade of July, when the precipitations were registered in the entire Trotuș River hydrographic basin and their value was extremely high (80 mm/24 h at Lunca de Sus H.S. (A.B.A. Siret, 2005)). This situation generated floods with very high flow rates on Trotuș River and tributaries, with calculus probabilities of 0.5 - 0.1% (Table 3) (Avram, 2016, Romanescu & Nistor, 2011, Romanescu & Stoleriu, 2013).

The cumulative hydrograph on the four analysed hydrometric stations (Vrânceni, Targu Ocna, Onesti and Goioasa) highlights the high flow rates values and their historical flow nature (Fig. 5). The chart shows the particular way of

flood formation, the maximum flow rate propagation on Trotuș River from upstream to downstream and the end of the flood.

Table 3. Trotuș River flood analysis elements, July 2005 (A. B. A. Siret, 2005)

No.	River	Hydrometric station	$Q_{\max}$ m ³ /s	$p\%$
1	Trotuș	Goioasa	331	10
2	Trotuș	Tg. Ocna	1490	0.5
3	Trotuș	Onești	2296	0.5-0.1
4	Trotuș	Vrânceni	2845	0.5

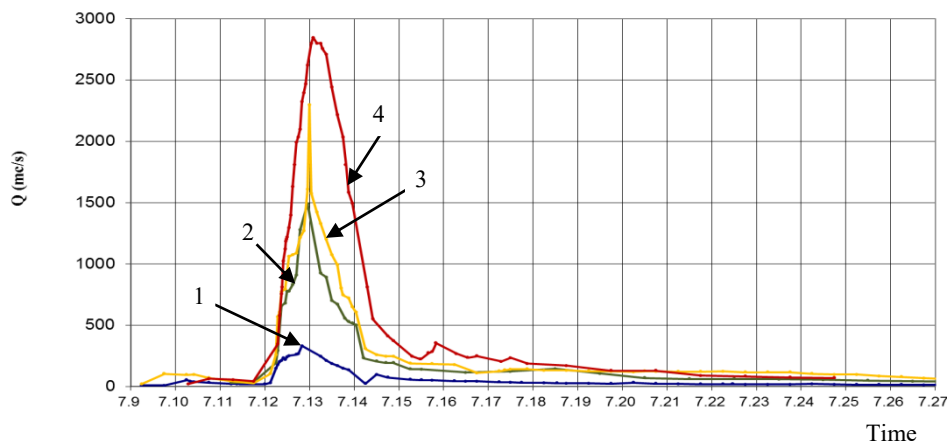


Figure 5: Joint hydrograph for the four Trotuș River Hydrometric Stations (HS) at 09.07.2005: 1 - HS Goioasa, blue line; 2 - HS Târgu Ocna, black line; 3 - HS Onești, orange line; 4 - HS Vrânceni, red line.

These flood waves have generated flooding that have caused extensive social and economic damage, and also human losses. The hydrographic basins most affected by the floods were Trotuș, Tazlău, Bicăz, Cracău, Trebeș, Sușița, Putna, Rm. Sărat etc., and especially Siret River's interior flow, by collecting the floods on the tributaries (the highest contribution being given by Trotuș River).

From the calculus probability (p) analysis the large values are noted, which exceed those allowed for the maximum flood flows on the studied river sectors. The probabilities calculated were 0.5% at Tg. Ocna H.S. and Vrânceni H.S. and 0.5% and 0.1% at Onești H.S (Table 4). The Trotuș River flood produced in July 2005 showed a historic nature through the value of the recorded flow rate (Table 3). The area where the floods occurred are the most densely populated, and the damage caused by the flooding, even by the torrential and semi-torrential streams, was particularly high.

The 2005 Trotuș River floods were favoured by natural and anthropic risk factors. The main natural risk factors were: 1 - cumulation of two large volumes of precipitations at a 5-7 day interval; 2 - soil layer wetting during the first rain, which determined the limitation of infiltrations in stage II. The main anthropic risk factor was the hydrographic basin drainage coefficient alteration through uncontrolled deforestation and the transfer of natural land into agricultural land (Avram, 2016).

Floods with maximum flow rates in 2016

The flood from 02.06-05.06.2016 in Trotuș H.B. was generated after the rainfall registered on 02.06.2016 which had prevailing values of over 80 mm (A.B.A. Siret Bacau). Precipitations continued on 03.06.2016 and on the night of 3-4.06.2016, still with significant values (the maximum being 40 mm). These cumulative precipitations with those of the previous days, totalised very important values and generated floods, especially on the middle and lower sector of the Trotuș River and in Tazlău H.B. The maximum flow rate at Vrânceni hydrometric station was 2525 m³/s, with an exceeding probability of 1%. In other sections of Trotuș River and tributaries the following flows were recorded: at Helegiu HS - 1280 m³/s, at Onești HS - m³/s, at Tg. Ocna HS - 686 m³/s, at Lucăcești HS - 342 m³/s, etc. Maximum flow rates have 1 to 5% exceeding probabilities.

Significant floods occurred on all Trotuș River tributaries, and the highest flow rates were recorded on the rivers Tazlăul Sărat, Tazlău, Asău, Cașin etc. In other sections the following flow rates were recorded on Trotuș River and tributaries: at Helegiu HS - 1280 m³/s, at Onești HS - 964 m³/s, at Tg. Ocna HS - 686 m³/s, at Lucăcești HS - 342 m³/s, etc. Maximum flow rates have 1 to 5% probability calculations (Luca & Avram, 2017).

The natural risk factors are given by the hydrographic basin hydroclimatic control elements: precipitation, temperature, wind, floods, river freeze-thaw phenomena, drastic drainage decrease and depletion of small water courses. All control elements are developing under moderate temperate climate conditions, characteristic of medium altitude mountains and sub-Carpathian hills and depressions located to the east of the Oriental Carpathians and around the peripontic space. The risks result mainly from the magnitude and frequency of thermal and pluviometric discontinuities characteristic to the Trotuș River geographic areas. Torrential rains are the main source of hydroclimatic risk in the Trotuș River hydrographic basin.

Conclusions

1. During 1991-2016 in Trotuș H.B. were registered important floods generated by torrential rainfall produced over a small time period, which resulted

in flow rates with maximum values and of historical nature in the riverbed of Trotuș River and its tributaries.

2. The most important maximum flow rates were generated on Trotuș River (year 2016), on Tazlău River (year 1991) and Tazlăul Sărat River (year 2016), but also on the tributaries from piedmont area (Asău, Cașin, Goioasa etc., year 2004).

3. The flow rate of 3720 m³/s generated on Tazlău River is the result of the cumulation of two floods, where the hydroclimatic risk factors (torrential rain, concentration time) had the prime role.

4. Anthropogenic risk factors (deforestation, lack of regulation works) have an important role in maximum flow rates development, but especially in increasing the flood damage.

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