EXCEPTIONAL FLASH FLOODS IN THE UZ HYDROGRAPHIC BASIN – CAUSES AND CONSEQUENCES

DOI: http://dx.doi.org/10.18509/GBP.2016.05
UDC: 556.166.04:627.51(498)

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ABSTRACT
The high frequency of torrential rains and the high probability of floods occurrence are due to the excessive continental climate which influences the most rivers from the eastern part of Romania. The Uz river is one of the main tributaries of the Trotus river. Its length is about 46 km. In the year 2005, the exceptional high floods have been recorded on this river. These have occurred following the summer torrential rains which have recorded values between 100 and 200 mm within 24 hours. The maximum flow has reached exceptional values, resulting in historical high floods recorded at the hydrometric Cremenea (229 m^3/s) and Darmanesti (132 m^3/s) stations. The occurring floods in the Darmanesti locality have affected the neighborhood: Bratulesti, Mascas, Joseni, Salatruc. The households and the land areas have been damaged. Because 14 households have been completely damaged, the evacuation of the local population has been required. For this high floods study, geostatistical methods and hydrological analyses have been utilized. Graphic data processing has been made in Excel. Analyzing the features of exceptional floods is made based on studying the elements of flood waves. The shape of flash floods hydrographs has highlighted the necessity of river planning and engineering (impoundage) and other prevention measures against floods.

Keywords: flash floods, floods, flash flood hydrograph, maximum flow, torrential rains

INTRODUCTION
The first decade of the XXIst century has been catastrophic for Romania from an extreme hydrological phenomena standpoint. The zone of Moldova, in which the Uz hydrographic basin is situated, has been hit the hardest by catastrophic floods. Numerous human victims have been registered and major material damages. The extent of the floods phenomena has manifested progressively for the years 2001, 2002, 2004, 2005, 2006, 2007, 2008, 2010 and 2011. During the years 2005 and 2006, 93 human victims have been registered for the whole of Romania and material amount of damages totalled two billion euros. Statistical data includes as well material damages registered in the Uz hydrographic basin which constitutes a convincing argument for performing the research on historic flash floods from July 2005.
Numerous researches exists referring to the changes occurred in the thermal, pluviometric, hydrologic regimes and their impact on the future hydroclimatic evolution [1, 2]. The floods are considered to be the representation of major natural risk factors [3-5]. The main control factors of the flow and flash flood formation are determined by the geographical positioning of the Uz hydrographic basin (at the eastern fringe of the

Oriental Carpathians mountains), by the geology and the morphology of the territory, by the climate, by the biopedological geosphere, by the extent and complexity of the anthropical impact. The flash floods in the Uz hydrographic basin are mainly determined by the torrential rainfall, especially the ones with high intensity (several mm in a few seconds).

STUDY AREA

The geographical positioning of the river Uz is situated in the eastern part of Romania. It covers a surface of 475 km^2 and falls between the meridians 26°00'16" and 26°30'56" eastern longitude and the parallels 46°08'44" and 46°23'27" northern latitude (Fig. 1). The river Uz and its most important tributaries have played a major role in the fragmentation of the landscape. The Uz river is a right tributary of the river Trotus and springs from the Ciucului mountains at an altitude of 1175.33 m. It crosses the hydrographic basin on a length of 46 km and encounters the river Trotus at Darmanesti, at an altitude of 320.43 m (Table 1).

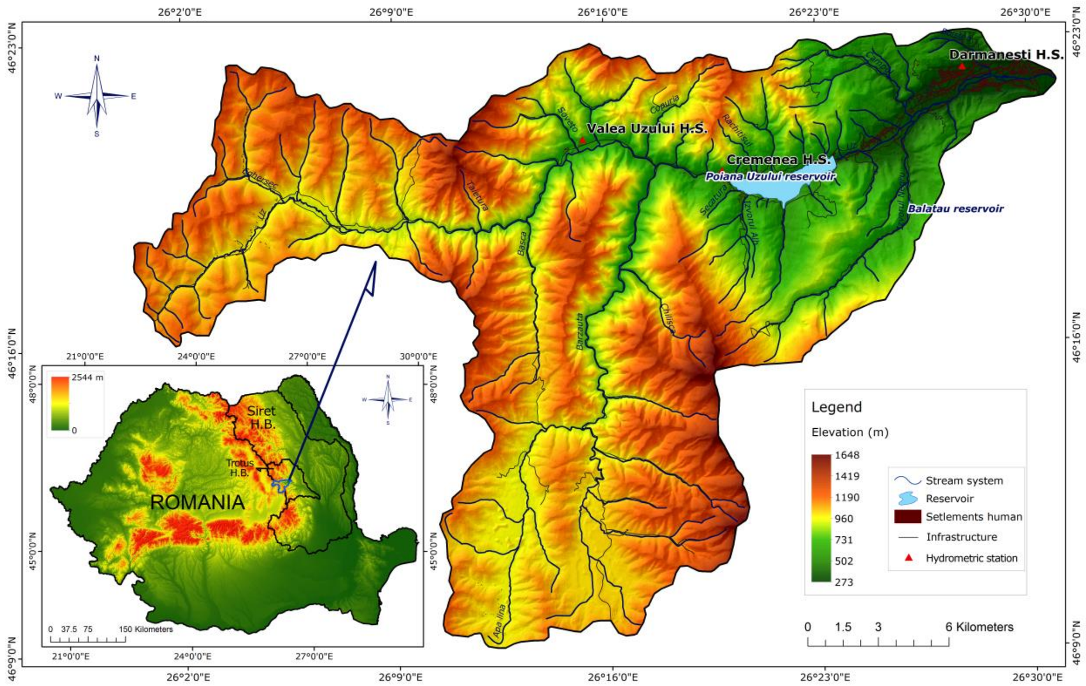

Figure 1. The geographical location and mathematic coordinates of the Uz river basin

Table 1. Characteristics of the water courses and river basins

River	Confluence position	Length (km)	Altitude (m) (upstream/ downstream)	Average slope (°)	Sinuosity coefficient	Area (km^2)	Average altitude (m)	Forest cover area (km^2) 2006
Eghersec	Left	6.9	1305.9/949.0	44	1.4	17.7	1155.1	8.7
Oreg	Left	5.1	1183.3/881.2	23	1.1	11.6	1146.4	28.3
Basca	Right	9.1	1130.1/814.0	36	1.2	25.1	1117.3	22.5
Copuria	Left	5.9	1301.3/584.9	24	1.1	10.1	1019.5	8.4
Barzauta	Right	25.8	1089.7/571.0	40	1.3	152.3	1091.8	116.5
Izv.Alb	Right	6.1	1184.0/503.9	24	1.1	12.7	868.4	11.8
Groza	Right	8.4	1478.3/513.6	38	1.3	11.9	809.0	11.8
Camp	Left	8.0	974.0/392.3	39	1.3	16.3	654.7	9.3
Izv.Negru	Right	16.1	1506.2/381.2	30	1.1	30.5	782.9	28.3

The hydrographic basin has a dense drainage network as a consequence of the general elevated slope. The sub-basins of the main affluents have elongated forms and *above par* sinuousity coefficients. At the majority of the tributaries, the river slopes are highly elevated and the runoff coefficient is high. On the course of the river Uz, relative to Poiana Uzului reservoir, Cremenea station is situated upstream and Darmanesti station downstream.

MATERIALS AND METHODS

Performing the research was made possible using the database compiled from much older and more up-to-date bibliographical sources [1, 4, 5]. The hydrological data were obtained from the archive of the Water Basin Administration of Siret, Bacau; the data consists of the of average daily, monthly and annual values, the maximum values of the liquid drain for different measuring periods from the interval 2000-2009 etc. The databases are represented in average values for the precipitations obtained from the same archive. The topographical map 1:25000 (elaborated by the Romanian Military Topographical Directorate) and the ortophotoplans 1:5000 have been used, in order to generate the vectorial layers (stream system, reservoir, infrastructure, human setlements, locality) and the Digital Terrain Model. The TNTMips v.6.9 and ArcGIS v.10.2.2 have been used. Hydrometeorological databases have been processed using Ms. Excel.

RESULTS AND DISCUSSIONS

The flow are one of the main issues to manage in practical hydrology [6,7]. The knowledge of the flows is necessary to design, execute and exploit the hydrotechnical constructions, to estimate the resources, etc. [8,9]. The maximum flow is immensely complex, being influenced by a multitude of factors: the shape and dimension of the hydrographic basin, lithology, degree of vegetation covering, slope inclination and the riverbed morphology, the presence of the lakes etc [10].

The maximum flows from the mountainous sector of the Uz hydrographic basin (upstream of the dam) are registered predominantly (50%) during summer, after which follows the spring (33%) and the autumn (16%). The high frequency of the maximum flow from the depresion sector (downstream of the dam) was registered during summer

(66%), spring (22%) and autumn (11%). The cold season (winter) is differentiated by the lack of maximum flows due to low temperatures and to snow confinement. The month with the highest occurrence frequency of the maximum flows at Cremenea station was July and at Darmanesti station was August (Fig. 2).

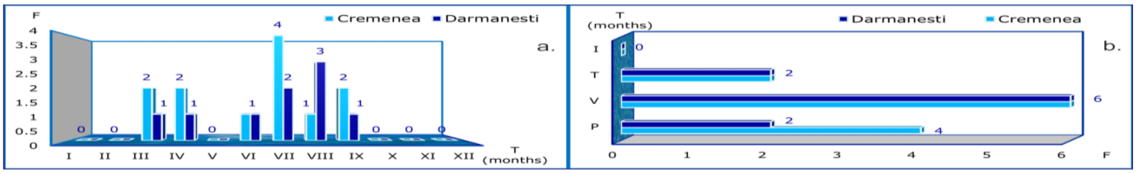

Figure 2. The annual (a) and seasonal (b) occurrence frequency of the maximum flow occurrence in the Uz basin

The analysis of the most important flash floods have began with the study of the annual maximum flows. The highest values from the Cremenea station have been registered during the years 2005, 2001 and 2007, and at the Darmanesti station in 2005 (Fig. 3).

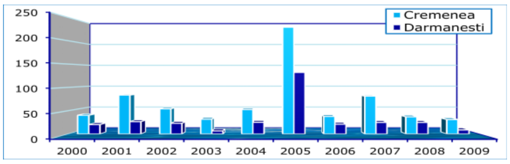

Figure 3. The maximum annual flow hydrograph in the Uz basin

The maximum annual flow variations registered at Cremenea, for the periods 2000-2003 and 2006-2009, are similar. During the first period, the year 2001 bears witnesses to a sudden arrival of a high flow, while during a second period a similar phenomenon is registered in 2007. The period 2003-2006 bears witness to an exceptional rise in the maximum annual flow in 2005. At Darmanesti hydrometric station, during the period 2001-2003, a decreasing tendency in the maximum flow is identified, same as for the period 2007-2009. During the period 2004-2006 a situation similar to that of Cremenea is observed, the trend being disrupted by an exceptional occurrence of the maximum annual flow in 2005. Overall, during 2000-2009, at both hydrometric stations, the trends of the maximum flows are linear, being disrupted in 2005 by the occurrence of historic flows (Fig. 4).

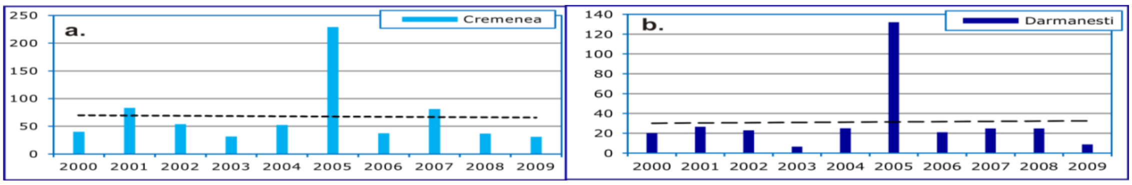

Figure 4. The multiannual variation of the maximum flows at the Cremenea (a) and Darmanesti (b) hydrometric stations

Table 2. The maximum monthly flows and the maximum multiannual flows registered on the river Uz

H.S. /Month		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
D.	Q_{max}	9.95	9.95	21	20.2	28.3	26.5	132	25.1	9.95	24.8	11.7	17.3
	Year	2006	2006	2006	2000	2005	2001	2005	2004	2005	2007	2007	2001
C.	Q_{max}	14.3	12.9	40.2	34.6	44.9	83.4	229	53.9	31.7	81.2	15	5.85
	Year	2009	2002	2000	2000	2005	2001	2005	2002	2003	2007	2002	2008

July 2005 has been a month when exceptional flows have been registered at the Cremenea hydrometric station (C.) and at Darmanesti hydrometric station (D.) (229 m^3/s and 132 m^3/s). The lowest values from the Darmanesti station were registered in 2006 (9.95 m^3/s, in January and February) and 2005 (9.95 m^3/s, in September). Meanwhile, at Cremenea station in 2008 a flow of 5.85 m^3/s was registered in December (Table 2). The value of the average annual flow at Cremenea station was 4.71 m^3/s for 2005, i.e. 1.83 times greater than the average multiannual flow (2.57 m^3/s). The value of the average monthly flow for the month of July 2005 (18.3 m^3/s) was 2.67 times higher than the average multiannual flow (6.86 m^3/s). The value of the average flow at Darmanesti station for the year 2005 (7.94 m^3/s) exceeded 1.81 times the value of the average multiannual flow (4.40 m^3/s). The value of the average monthly flow for the month of July 2005 (18.30 m^3/s) was 3.10 times higher than the average multiannual average flow (5.9 m^3/s) (Table 3).

Table 3. The values of the flows depending on the exceptional floods registered in the Uz basin

H.S.	Year	Month	Q_{max} (m^3/s)	$Q_{med\ year}$ (m^3/s)	$Q_{med\ month}$ (m^3/s)-VII	$Q_{med\ multiannual\ month}$ (m^3/s)	$Q_{med\ multiannual}$ (m^3/s)
C.	2005	VII	229	4.71	18.30	6.86	2.57
D.			132	7.94	18.30	5.90	4.40

The first semester of 2005 has been characterized by a precipitation surplus in comparison with the monthly averages (Table 4). The high quantities of precipitations have restored the humidity deficit of the soil and thus have created a surplus. The agrometeorological report from the 11th of July 2005 informs about an optimum soil humidity with a trend towards surplus. For the mountainous zone the water soil reserves reached saturation before the extreme hydrological risk phenomena were to occur. The precipitations from the first ten days of the month of July, at Cremenea station, have represented 38% from the monthly precipitation average, while at Darmanesti up to 51%. The rains were widespread in all river's subbasins from the Moldova region, causing large scale floods not only on the rivers, but also on steep and deforested slopes. The rain has fallen almost daily in the first ten days of July, maintaining high flow rates, greater than the multiannual ones. The synoptic situation from the period 10-14th of July 2005 shows that the depressionary core thus formed exceeded 500 hPa. The core charged with air from the tropical region entered in contact with the Atlantic air mass and produced important precipitations within 48 hours. Back then the basin of the Trotus was affected, the Uz river included, but also other hydrographic basins from the immediate vicinity. For the period 11th-14th of July 2005, the amount of precipitations was 44.8 mm at Cremenea station and 154.9 mm at Darmanesti station.

Table 4. The values of the precipitations quantities fallen between January and June 2005 in the Uz basin

H.S.		I	II	III	IV	V	VI
C.	$P_{monthly}$ (mm)	46.6	26.4	16.9	59.8	81.6	145.2
	$P_{monthly\ multiannual}$ (mm)	24.5	28.2	39.4	62.6	92.3	98.5
	$P_{monthly}/P_{monthly\ multiannual}$ (mm)	1.9	0.9	0.4	1	0.9	1.5
D.	$P_{monthly}$ (mm)	46.6	43.6	16.8	54.7	85.9	133.6
	$P_{monthly\ multiannual}$ (mm)	21.6	25.9	27.7	58.0	84.1	107.9
	$P_{monthly}/P_{monthly\ multiannual}$ (mm)	2.2	1.7	0.6	0.9	1.0	1.2

The hydrograph of the flash flood from July 2005, at Cremenea station, highlights the fact that the flash flood began from a basis flow of 5.05 m^3/s (Fig. 5).

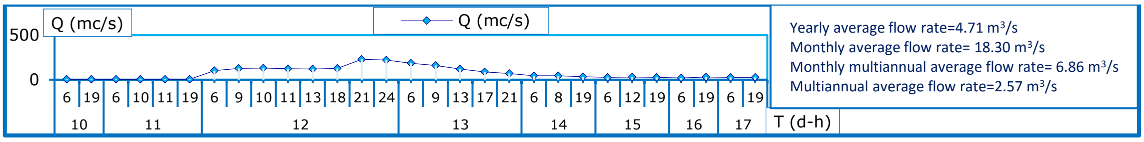

Figure 5. The hydrograph of the exceptional flash floods registered at the Cremenea station – July 2005

After maintaining the high water phase, the flow has reached its peak at 229 m^3/s after which subsided and entered in the downward phase. It returned to the basis flow afer a longer period of time. The total duration of the flash flood was 144 hours long and the growth span was 26 hours long. The complex shape of the hydrograph indicates the existence of some rich precipitations triggered after the formation of the flash floods, but also an intake of Barzauta river, as well as of other tributaries from the Nemira mountain slope. The value of the maximum flow during the flash flood exceeded 33.38 times the value of the average multiannual monthly flow (6.86 m^3/s). At Darmanesti station the flash floods have reached a basis flow of 5.4 m^3/s (Fig. 6).

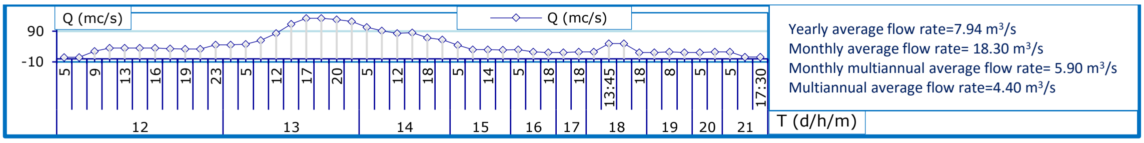

Figure 6. The hydrograph of exceptional flash flods registered at Darmanesti hydrometric station – July 2005

After the high water phase, the flow manifested a sudden rise up until the 132 m^3/s. The downward phase had a relatively long duration in comparison with the ascending one. The hydrograph of the flash flood present an unusual form. The flash flood begins with the high water phase which precedes the arrival at the maximum flow. The rounded shape of the peak, as well as the shape of the hydrograph and the defining elements of the flash flood suggest the pluvial nature of its occurring cause. The value of the maximum flow during the flash flood has exceeded 22.37 times the value of the average monthly multiannual flow (5.9 m^3/s). The flash floods have occurred during a broader period of time. After reaching the historic maximum flows, the descending phase stays at the high water level for a longer period of time, because the precipitations have continued to fall during the flash floods as well (Table 5).

Table 5. Characteristic parameters of the high floods at the Cremenea (C.) and Darmanesti (D.) stations

Year	H.S.	Q_{max} (m^3/s)	Q_b (m^3/s)	T_t (h)	T_c (h)	W_t (mil.m^3)	W_c (mil.m^3)	H (mm)	γ	F (km^2)
2005	C.	229	5.05	144.0	26	24.3	5.1	72	0.2	337
	D.	132	5.30	225.5	34	26.6	5.7	66	0.3	404

Knowing the characteristic parameters of the flash floods presents a particular importance in the hydrological practice. These parameters are determined based on the hydrographs and on the forecasts. The extremely high flows registered at the Cremenea station and the heavy rains have favoured the exceptional water rise in the Poiana Uzului reservoir. Within just 25 hours the water levels on the reservoir have increased with 6 m. The elevation that triggered the alarm has occurred when the water reached the spillway crest

(511.44 mdM), after which it remained constant for several hours. The maximum discharged flow was 133 m^3/s from which 100 m^3/s was through spill. The flash flood began on 11th of July when the water level rose suddenly, reaching its maximum on the 13th of July. The attention stage of the warning parameter was 1.00. The exceeding of the riverbed downstream capable flow (100-120 m^3/s) would have increasted the severity of the situation. The excessively large level of the reservoir Poiana Uzului registered during the historic flash flood, would have brought a disaster through the braking of the dam. The calamity was avoided through the suitable water management.
The maximum flow at the Cremenea hydrometric station has exceeded the attention stage (AS) with 292 cm, the flooding stage (FS) with 242 cm and the danger stage (DS) with 192 cm. At Darmanesti station the attention stage (AS) was exceeded with 370 cm, the flooding stage (FS) with 320 cm and the danger stage (DS) with 220 cm (Table 6).

Table 6. The levels registered during the exceptional maximum flows in the Uz hydrographic basin

Year	Flow nr.	H_{max}		A.S.		F.S.		D.S.	
		C.	D.	C.-150 cm	D.-150 cm	C.-200 cm	D.-200 cm	C.-250 cm	D.-300 cm
2000	1	297		147	-	97	-	47	-
	2	262		112	-	62	-	12	-
	3	263		113	-	63	-	13	-
2001	1	338	323	188	173	138	123	88	23
	2	323		173	-	123	-	73	-
	3	285		135	-	85	-	35	-
2002	1	277	320	127	170	77	120	27	20
	2	314		164	-	114	-	64	-
2003	1	286	270	136	120	86	70	36	-
	2	294		144	-	94	-	44	-
2004	1	300	325	150	175	100	125	50	25
	2	312	320	162	170	112	120	62	20
2005	1	442	520	292	370	242	320	192	220
	2		340	-	190	-	140	-	40
2006	1	293	300	143	150	93	100	43	0
	2		292	-	142	-	92	-	-

Knowing the maximum flows with different exceeding probabilities has a special importance for efficiently managing the water resources and for designing and executing the hydrotechnical constructions suitable to the economic process (Fig. 7).

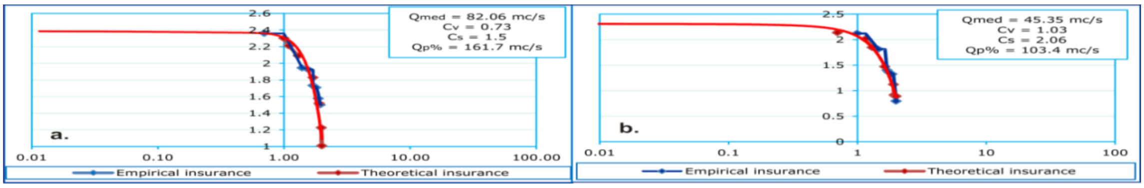

Fig. 7 The theoretical and empirical probability curves plotted for the Cremenea (a) and Darmanesti (b) hydrometric stations

At Cremenea station the maximum flash flood flows have fallen within the range 1% and 5%, and at Darmanesti between 5% and 10%. Establishing the correlations on ensured values (with certain exceeding probabilities) represents expressions of statistical processing recommended in the analysis of random data series. For the probability of 1% the values of the water volume amounts are 8.99 million m^3 at Cremenea station and 6.84 million m^3 at Darmanesti station; the water layer has 266.79 mm at Cremenea and 169.23

mm at Darmanesti (Table 7). The historic flows from within the Uz hydrographic basin have been registered in the year 2005 when the river Siret has reached its maximum flow for all the rivers in Romania (4650 m^3/s) [6, 9]. The maximum, minimum and average values of the maximum flows from the studied period are highlighted statistically in the Table 8.

Table 7. The maximum annual flows, the specific maximum flows, the maximum volumes and the leaked maximum water layer equivalent to the maximum volumes with different exceeding probabilities determined for Cremenea (C.) and Darmanesti (D.) hydrometric stations

p%	Q_{max} (m^3/s) for the probabilities		q_{max} ($l/s/km^2$) for the probabilities		W_{max} ($mil.m^3$) for the probabilities		H_{max} (mm) for the probabilities	
	C.	D.	C.	D.	C.	D.	C.	D.
0.01%	520.6		1544.7		16.4		487.8	
0.1%	403.7	338.8	1198.1	838.5	12.7	10.7	377.8	264.5
1%	285.1	216.8	846.1	536.6	9.0	6.8	266.8	169.2
5%	199.5	136.5	591.9	337.9	6.3	4.3	186.7	106.6
10%	161.7	102.0	479.9	252.6	5.1	3.2	151.3	79.6

Table 8. Statistics of the maximum monthly flows in the Uz river basin

H.S.	Q_{max} (m^3/s) (maximum value)	Year	Q_{max} (m^3/s) (minimum value)	Year	Q_{max} (m^3/s) (average value)	Cv	Cs	Cv /Cs
C.	229	2005	31.7	2003	96.3	0.7	1.5	2.0
D.	132		6.2		45.4	1.0	2.1	

CONCLUSIONS

There is a connection between the torrential character of the precipitations and the maximum values of the river Uz. For this reason the climatic data has been permanently correlated with the hydrological ones. The data thus obtained was processed and compared in order to conclude the causes and the consequences of the flash floods from July 2005 (Fig. 8). The defining elements of the flash floods hydrographs have emphasized with clarity the climatic nature of the cause for the exceptional flash floods occurrence. The character of the flash flood was special, unique, proven as well by the shape of the hydrographs. The flash floods' consequences were proportional to their severe impact. The evacuation of the local population was implemented. The most damaged zone was Salatruc, where 14 houses were completely destroyed, many of them crippled and important land surfaces were impaired. The psychological impact over the local population was extremely negative, because many of them were seniors in age. The existence of the hydrotechnical works on the rivers would have had a big contribution to the damage prevention and limitation. After the 2005 floods, structural measures were taken for alleviating the effects of the floods. The existence of exceptional floods similar to those of 2005 proves the necessity for hydrotechnical works.

Figure 8. Flash flood from July 2005 – Uz river basin

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