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ORIGINAL PAPER

The effects of the July 2005 catastrophic inundations in the Siret River's Lower Watershed, Romania

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Abstract The Siret River originates from the Wooded Carpathians (Ukraine) and has a length of 559 km on the Romanian territory. The upper river course is set on the Ukrainian territory, the middle course flows through the Suceava Tableland, and then the limit between the Moldavian Subcarpathians and the Bârlad Tableland, followed by the lower course crosses the Inferior Siret Plain. The hydrographical network includes 1,013 water tributaries (representing the richest river from this point of view in Romania) and has a length of 15,157 km, which represents 19.2% of the total length of the Romanian river network. This materializes in a density of 0.35 km/km^2, compared to 0.33 km/km^2 which is the average for Romania. The Siret River has the greatest watershed area, with a total surface of 42,890 km^2, which represents 18.1% of the Romanian territory. Its discharge is the highest of all internal rivers of Romania, with an average discharge of 210 m^3/s at the river mouth, and this is caused by the fact that most of the tributaries come from mountainous sectors, namely the Eastern Carpathians. In the summer of 2005, the most powerful floods ever occurred in the Siret River watershed with significant negative effects on the country's economy. Considering the multiannual average discharge of 210 m^3/s, the maximum discharge recorded on July 16, 2005, was of 4,650 m^3/s at Lungoci. The main cause of these events is the deforestation of the small watersheds located in the mountainous sector of the counties of Vrancea, Bacau and Neamt. The total surface affected by floods was of 58,323.936 hectares, of which: 34,142.349 ha (58.54%) arable land, 6,697.486 ha (11.48%) orchards and wine-growing plantations, 1,863.698 ha (3.20%) built areas, 2,866.313 ha (4.91%), forests 4,915.985 ha (8.43%), waters 2,081.047 ha (3.57%), and unproductive land 5,757.058 ha (9.87%). Besides the material losses (over 10,000 houses completely destroyed), 24 human deaths were recorded together with the

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loss of thousands of domestic animals, whose overall value exceeded two million Euros. The estimation of the extent of the flooding and its impact in the Siret River watershed has been performed using LANDSAT TM 2003 satellite images and the FAO-LCCS classification methodology, in the ASR-CRUTA remote sensing laboratory, with the images offered after activating the International CHARTER (Call ID-98).

Keywords Floods · River · Catastrophes · Risk · Hazard · Territorial management

1 Introduction

Siret River is the most important tributary in Danube River's lower watershed. From an economic viewpoint, Siret River represents the most important hydrographic highway for the eastern part of Romania. Because of this, numerous complex (Ujvari 1972; Romanian Rivers 1971; Atlas of the Waters Survey Romania 1992; Diaconu 1999) and specific hydrologic studies (Podani and Zavoianu 1992; Amariucai 2000; Romanescu 2003, 2005) have been conducted over more then a century (1880–2005).

The first hydrologic observations have been conducted by the Romanian scholar and former king of the Province of Moldavia, Dimitrie Cantemir in his paper entitled "*Descriptio Moldaviae*" (1716). The author mentioned for the first time the floodings, freezing, as well as tidal bore phenomena from the rivers tributary to the Danube, including Siret River. Dimitrie Cantemir was also the first to draw the map of the eastern Romanian territory, including the Siret River watershed.

Studies on the general risk phenomena in the Siret River (Sorocovschi 2002, 2003, 2004, 2005, 2006, 2007; Apel et al. 2004; Hufschmidt et al. 2005; Taramasso et al. 2005; Büchele et al. 2006; King 2006; Milelli et al. 2006; Komma et al. 2007; Dorner et al. 2008; Förster et al. 2008) and their consequences (Smith and Ward 1998; Brilly and Polic 2005; Barroca et al. 2006; Plattner et al. 2006; Romanescu 2006) as well as of the possible mitigation measures that must be considered are relatively new in Romania. Such studies have been initiated at a larger scale following 1970, when Romania was confronted with the most catastrophic floods in modern times. These catastrophic floods occurred simultaneously on all rivers on the Romanian territory and implicitly on the Danube River, where the maximum recorded discharge reached a maximum historical value of 15,500 m^3/s. For the accurate assessment of the damages generated by these floods, the authors considered the comparison with similar catastrophic phenomena which occurred in other watersheds in the world (Blynth and Biggin 1993; Walter 1990; Perry and Combs 1998; Jordan and Jennings 1991).

Unfortunately, the protective measures considered during and after the construction of dams on the most important rivers from eastern Romania were found to be generally ineffective, particularly since they were implemented linearly, on the upstream/downstream alignment, and did not consider polder emplacement. Learning from the mistakes of the past, the authors envisioned new bank protection measures, according to the most recent research.

Since the Siret River watershed includes varied landscape units, the economic development plans were usually governed and implemented based on their economic potential and risk for inundation. Mountainous rivers are used for obtaining hydroenergy, and those in the hilly regions are used for water supply for human settlements and medium flood management, while those flowing through plain regions include irrigation and catastrophic flood attenuation.

Over the past decades, the Siret River watershed basin suffered from extensive forestry industry exploitation as well as from wind-induced natural tree blowdowns. Moreover, the agricultural activities did little to implement modern soil erosion prevention and control measures. Numerous Romanian (Diaconu 1988; Musteata 2005; Rosu and Cretu 1998; Selarescu and Podani 1993) and international (Thiemeyer et al. 2005) researchers investigated phenomena such as soil erosion, landslides processes (Glade et al. 2005; Ichim and Radoane 1986), floodplain aggrading and degrading (Bravard and Petit 2000; Romanescu 2002; Radoane 2004; Dumitriu 2007), bank accretion or reservoir silting (Makaske et al. 2002; Makaske and Weerst 2005; Ichim et al. 1989). As a result of these relatively new studies, intense planning and land protection measures only started to be implemented.

The present study is based on the interpretation of the field, unprocessed data obtained from Siret Water Direction (Bacau), the Romanian Waters National Company (Bucharest), and through the authors' own data collection and research on the discharge in the sectors lacking hydrologic stations, measurements regarding floodplain geomorphologic processes and the assessment/prevention measures of catastrophic flood occurrence.

The processed data cover a period of more than 125 years. The economic evaluation of the negative consequences and of the human life losses due to flood was analyzed and compared with similar phenomena that occurred in other regions of the world. The authors analyzed and compared rivers with similar characteristics. Based on their investigation, they demonstrated that the July 2005 Siret River floods were among world's most catastrophic such events. The relatively low count of human life losses was simply due to the fact that the local warning system, although rudimentary, has functioned relatively well.

Based on an extensive literature review and on the hydrometeorological data collected and processed, the authors calculated the maximum discharge flows of July 2005 and the losses associated with these catastrophic floods on Romania's most important interior river. The massive deforestation in the upper elevations of the Siret River watershed, caused by the repossession of forest lands and their intense and careless exploitation, has lead his catastrophic flood event. At the same time, an increase in the rainfall intensity also contributed to the severity of these floods, with immediate effect on the environment and antropic activities. The paper attempts to investigate and explain the contributing factors and the consequences of the most catastrophic flood that occurred on the Romanian territory in historic times.

2 Methodology

Since the Siret River watershed is large and its morphology varied, obtaining the necessary data involved a laborious work of collecting them from various institutions and conducting field measurements in several representative locations.

Climatic data have been collected using the most important meteorological stations, prior to and immediately after the flood occurred. Hydrologic data have been obtained from the main hydrologic stations and observation points covering the entire watershed.

For the evaluation of the affected surfaces and of the damages inflicted on different domains, the authors used satellite images taken during the flood occurrence as well as aerial photographs from different institutions: University of Bucharest, University of Iasi and the Romanian Space Agency. Data were also collected with the help of the local government agencies and offices of the counties affected by the flood (Suceava, Neamţ, Bacău, Vrancea, Botoşani, Iaşi, Vaslui, Galaţi) as well as from the Service for the Protection against Natural Hazards. Data documenting the local economic and human losses were also collected from the municipal and rural city halls. The most important data regarding the hydrotechnical measures taken in the hydrographic basin and those regarding their functioning during the flood have been provided to the authors by the Romanian Water Agency.

In order to evaluate the maximum discharge in the affected sectors where hydrologic stations were missing, the authors conducted field campaigns and subsequent data processing in order to identify the missing data. This operation was performed by identifying the watermarks observed in the field, combined with accurate identification and measurement of the cross-section bathymetric profiles.

In order to identify the geomorphologic modifications, and especially bank erosion, the breaching of flood protection dikes and bank ridges, as well as the formation of longitudinal and transversal ridges, the authors consulted aerial photographs and conducted also an extensive field investigation campaign during which they performed topographic measurements by means of a GPS Total Station. At the same time, the key perimeters of the maximum discharge and their effects were identified and measured using a 3-D Radar system.

Following this extensive data collection, the next step consisted of their careful processing, analysis and interpretation. The data set has been processed in the Geo-Archeology Laboratory of the Faculty of Geography and Geology, University "Alexandru Ioan Cuza" Iasi, Romania.

3 Analysis, results and discussion

The Siret River originates from the Wooded Carpathians (Ukraine). Its main course has a total length of 559 km on the Romanian territory, from the entrance into the country until its discharge into the Danube River (Fig. 1). The upper course develops on Ukraine's territory, the middle course crosses the Suceava Tableland and then the limit between the Moldavian Sub-Carpathians and the Barlad Tableland, while the lower course crosses the Inferior Siret Plain. The hydrographical network includes 1,013 water courses (the richest hydrographic basin in Romania) and measures 15,157 km (19.2% of the total length of the Romanian river network, with a density of 0.35 km/km^2, compared to 0.33 km/km^2 which is the average for the entire country). Siret River has the largest watershed, with a total area of 42,890 km^2, which represents 18.1% of the Romanian territory. The surface covered with forests occupies an area of 15,882 km^2, which represents 37% of the basin's surface and 25% of the total forested surface of Romania (Atlas of the Waters Survey Romania 1992).

As shown in Fig. 2, the most important tributaries of Siret River and their river lengths and watershed area, respectively, are as follows: Suceava (173 km; 2,298 km^2), Moldova (213 km; 4,299 km^2), Bistrita (283 km; 7,039 km^2), Trotus (162 km; 4,456 km^2), Barlad (207 km; 7,220 km^2), Putna (153 km; 2,480 km^2), Ramnicul Sarat (137 km; 1,063 km^2) and Buzau (302 km; 5,264 km^2).

The discharge of Siret River is the highest of among all other internal rivers of Romania, with a multiannual average discharge of 210 m^3/s at confluence with Danube River. This is due to the fact that most of its tributaries come from the mountainous sector of the Eastern Carpathians. The average discharge specific to the mountainous basins is relatively high: 7–12 l/s/km^2 on Suceava River, 8–11 l/s/km^2 on Moldova River, 11 l/s/km^2 on Moldovita River, 14–15 l/s/km^2 on Bistrita River, 8–9 l/s/km^2 on Trotus River, 9 l/s/km^2 on Oituz River, 6 l/s/km^2 on Putna River, 6 l/s/km^2 on Buzau River, with an obvious decreasing trend in magnitude from north to south. Exceptions from this rule are the Tarcau River

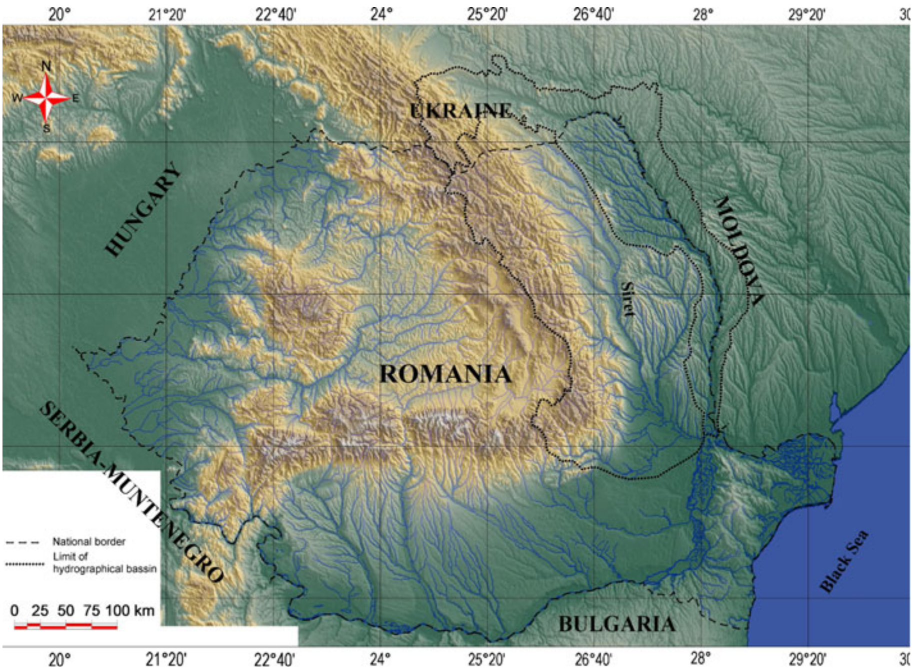

Fig. 1 The geographical position of Siret River watershed

(1.40 l/s/km^2), with a highly reduced circularity coefficient, and Ramnicul Sarat River (1.92 l/s/km^2), which has a part of its watershed in the sub-Carpathian area and which looses a significant part of its flow by infiltration and evapotranspiration due to the "foehn" phenomena. Barlad River, a tributary of the Siret on its left side, has a specific average discharge of 1–2 l/s/km^2. Such small values are characteristic to all the local rivers influenced by the continental charter of the climate in this area. Consequently, the contribution of tributaries from the Moldavian Plateau is very low compared to that of the Eastern Carpathians tributaries.

In the summer of 2005, Siret River experienced the highest flow rate ever (4,650 m^3/s) ever recorded at the Lungoci hydrometric station, located near Siret's discharge into the Danube River. This maximal value represents the maximum historical discharge ever recorded on any of the internal rivers in Romania. The authors reconstructed the flow rate for the sectors where no hydrometric stations were available and found that, in the Cosmesti area, the flow rate varied between 5,000 and 5,500 m^3/s (Water Direction Siret Bacau 2005).

The occurrence of the floods on the Siret River and particularly on its inferior course was a consequence of a combination of natural and anthropic factors. The main contributing natural factors were the torrential rainfalls, the high elevation of initial soil moisture, the high declivity and the litologic nature of the soil which does not favor rapid infiltration. Some of the anthropic factors that played an important role in the severity of these floods were the high deforestation degree, especially in the small tributary watersheds, the presence of hydrotechnical constructions that were affected by the high solid discharge,

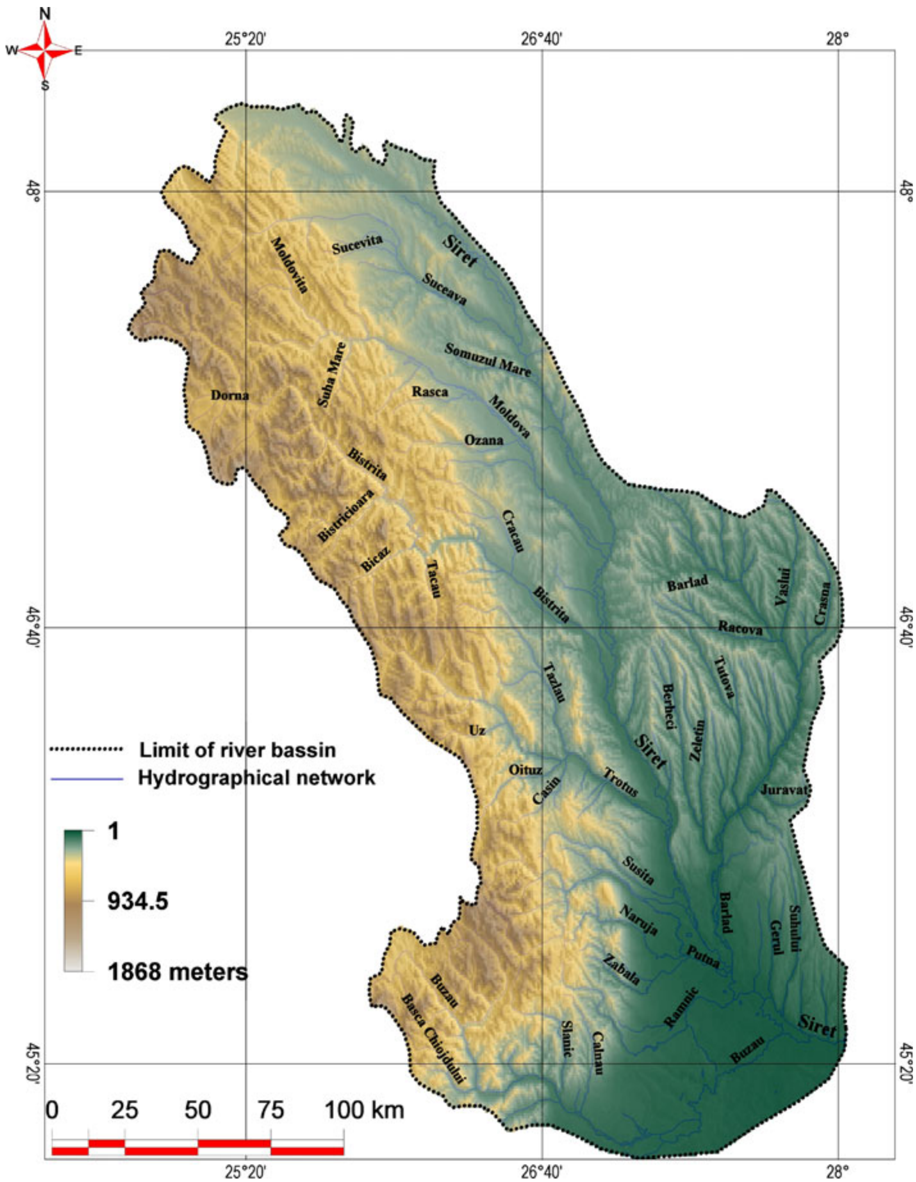

Fig. 2 The Siret River watershed and its most important tributarie

specific to the mountainous areas, the improper management of the minor and major riverbeds and the overloading of the major riverbeds with poorly located constructions.

The synoptic maps for the period of 10–14 July 2005, show that Romania has been under the influence of the contact between an Azores baric maximum dorsal, which occupied Central Europe, and an atmospheric depression front, which occurred over Southeastern Europe. The Balkan Peninsula experienced a well-organized depression nucleus with a pressure in the vicinity of 500 hPa. This nucleus received air of tropical

Table 1 Comparison between the monthly average precipitation for January–June 2005 and the multiannual average precipitation

Hydrometric station	Precipitation distribution for the period of January–June, 2005											
	I 2005	I m.m	II 2005	II m.m	III 2005	III m.m	IV 2005	IV m.m	V 2005	V m.m	VI 2005	VI m.m
Tasca	24.2	17.6	16.2	18.5	22.6	28.8	58.9	57.1	76.5	78.7	128.2	93.3
Cuejdiu	42.1	24.2	43.8	26.5	18.1	37.7	60.7	67.6	59.5	96.0	142.0	116.6
Borlesti	43.5	24.6	48.5	28.8	5.1	37.5	47.2	69.7	89.7	91.2	109.2	108.3
Ghimes-Faget	29.0	19.0	27.5	21.8	18.6	22.6	46.0	46.8	65.5	81.9	141.2	96.8
Goioasa	34.6	18.3	32.9	22.8	12.8	25.4	65.8	56.5	89.2	91.7	147.0	105.1
Tg. Ocna	32.6	24.0	35.9	22.7	17.9	24.4	70.9	50.6	117.2	76.6	141.5	91.8
Onesti	20.5	20.5	34.8	24.2	17.4	30.2	75.7	50.6	138.8	78.5	131.6	91.7
Vranceni	30.8	19.2	43.8	22.8	12.3	28.3	80.5	46.0	151.1	68.6	112.2	75.6
Sulta	25.5	18.1	21.2	21.2	9.7	25.0	41.1	54.5	56.5	76.2	137.1	99.7
Ciobanus	32.9	20.2	23.8	23.4	16.6	29.4	63.2	59.6	88.3	92.1	166.7	106.1
Asau	38.7	20.9	40.4	26.8	11.7	30.0	87.6	58.0	82.4	93.2	137.2	115.5
Cremenea	46.6	24.5	26.4	28.2	16.9	39.4	59.8	62.6	81.6	92.3	145.2	98.5
Darmanesti	46.6	21.6	43.6	25.9	16.8	27.7	54.7	58.0	85.9	84.1	133.6	107.9
Dofteana	30.5	24.7	33.5	30.9	8.2	34.6	49.2	60.6	84.9	94.8	149.3	119.9
Ciresoaia	33.9	25.9	37.0	28.3	7.0	35.9	55.5	78.6	88.6	83.1	130.1	99.7
Ferastrau	21.4	25.5	21.4	31.4	16.9	29.8	51.3	67.4	128.7	89.4	139.9	96.4
Halos	39.0	22.1	47.8	25.0	46.5	38.1	68.0	66.6	142.7	102.8	149.3	100.4
Ciuruc	19.1	20.1	52.2	21.7	24.5	31.6	72.1	57.6	154.5	75.8	145.7	87.1
Lepsa	30.9	24.4	49.4	26.8	50.0	36.3	106.5	57.5	134.3	86.7	184.3	94.5
Colacu	27.6	29.0	62.8	32.4	31.8	40.4	65.2	60.1	140.7	87.8	143.3	96.4
Botarlau	6.2	19.5	48.3	24.9	33.5	26.8	32.7	34.9	85.6	55.7	92.6	67.3
Nereju	80.1	39.3	98.9	45.0	53.7	53.0	67.3	74.8	146.2	102.0	170.1	111.4
Herastrau	35.3	32.6	72.1	34.0	36.2	45.1	38.7	62.9	179.0	93.4	165.5	106.2
Reghiu	22.1	18.5	79.6	23.2	30.0	28.1	66.3	53.0	140.2	76.0	165.6	84.8
Gr.Tufei	19.4	24.0	63.5	22.9	31.4	27.0	44.8	47.3	90.7	63.0	93.9	72.2
Jiliste	16.9	23.1	57.9	31.3	35.8	26.6	44.6	40.1	70.8	60.4	96.1	64.0
Puiesti	18.4	18.6	55.3	18.4	35.0	32.1	38.0	38.8	71.5	63.6	107.2	76.2
Martinesti	7.0	23.6	40.1	26.8	34.5	28.3	41.9	38.6	70.1	56.7	115.8	55.8

m.m Multiannual monthly average rainfall

origin that came in contact with the Atlantic mass and generated extremely intense rainfall over an extended period of more than 48 h. The most affected areas were the ones located in the middle and lower watersheds of Bistrita (the Bistricioara, Schit, Bicaz, Tarcau, Cuejd, Cracau, Nechit, Trebes basins), Trotus (including Tazlau), Susita, Putna, Ramnicul Sarat and Buzau rivers.

One should note that the first 6 months of 2005 were characterized by a significant rainfall surplus comparing to the average rainfall for the same period. Except for the month of March, usually the driest month, in all other months, for the entire area we are referring, except Vrancea area, monthly precipitations values have significantly exceeded the average. As shown in Table 1, the surplus of precipitations was obvious for the month of May and even more accentuated for the month of June 2005. The maximum rainfall for the month of June was of 184 mm at Lepsa, 170 mm at Nereju, 166 mm at Ciobanus and of 165 mm at Herastrau si Reghiu).

The maximum exceedance of the normal values for June 2005 was over 150% in several recording stations. The relatively high volume of precipitation restored the soil water deficit from precedent years and created, particularly in the mountainous areas, significant water accumulation in excess within the soil. The excess of humidity further prevented infiltration and thus accentuated the surface flow.

An agro-meteorological bulletin issued on July 11, 2005, by the National Institute of Meteorology indicated the existence of optimum soil humidity with certain excess in most of the Siret River watershed. It is obvious that the humidity reserves from the soils of the mountainous area where flooding phenomena occurred were high and that the soils were oversaturated.

Besides these humid and cool weather conditions, the intense rainfall induced strong surface flow on the denuded slopes, which subsequently led to flash floods on the small water courses (Trebes). The phenomenon was favored by the massive deforestations of the mountainous watersheds especially during the last 15 years.

In the first decade of July 2005, precipitations fell almost every day, in general with moderate values, but with some local intensifications in the Moldova and Bistrita watersheds (located in the middle sector of the Siret watershed) on July 1, 2005, in Vrancea area on July 4, 2005, and almost over the entire watershed on July 7, 2005 (Table 2).

Looking at the volumes of precipitations fallen in the first decade of July, one can notice that they were significant, representing 30–50% from the average multiannual average rainfall for July. In certain locations, such precipitations caused tremendous flash floods on relatively small rivers (Voronet, Sucevita), and also on the abrupt and deforested slopes. The July 10, 2005, rainfall also covered the entire Bistrita and Trotus River watersheds. Often, the amount of rainfall during the first decade of July 2005 was greater than the multiannual average rainfall (119.7 mm at Botarlau, 101,1 at Lunca de Sus, etc.).

These massive precipitations created relatively high discharge rates on the water courses, with values significantly above their multiannual monthly averages (sometimes twice the averages), with the exception of the Vrancea region, where the increase was modest.

The runoff that generated the catastrophic inundations in the second period of July 2005 was caused mainly by the heavy rainfall that fell over the entire watershed of Siret River, between July 11 and 14, 2005 (Table 3).

If in the upper sector of the Siret River watershed, which is on the Siret River, from lower course of the confluence with Bistrita River and in the hydrographic watersheds of the Suceava, Somuzuri, Moldova, Upper Bistrita rivers, the precipitations have not exceeded, with a few exceptions, 30–40 l/m^2, in its middle and lower courses, they reached extremely high values. The heaviest precipitations that fell at Nicolae Balcescu, Roman, (78.6 l/m^2) and Leghin, on the Ozana River, (127.6 l/m^2), did not have a significant hydrologic impact, since they were rather isolated; on the ensemble of these areas, the quantities were much lower. Yet, in the central-western and southwestern parts of the Siret River watershed, the amount of rainfall, exceeding 100 l/m^2 (in some places even 200 l/m^2), was generalized and generated extremely high floods on the water courses draining these areas. The precipitations exceeded the maximum historical levels for the majority of the monitoring hydrometric stations, with catastrophic values such as 176.0 mm at Sendreni on Siret River, between July 12 and 13, 2005 (Table 3).

For some of rivers, the increased water levels were caused by the extreme flow rates that surpassed the average multiannual discharge for the month of July. For example, a

Table 2 Rainfall during the first decade of July, 2005, in comparison with the multiannual July monthly average

Hydrometric station	Rainfall quantities July 1–10, 2005											July monthly average
	1	2	3	4	5	6	7	8	9	10	Total	
Bicaz-Chei	10.5	0.0	6.2	4.2	0.4	0.6	13.0	0.0	0.0	12.0	46.9	109.1
Tasca	13.6	0.0	4.7	3.2	1.2	1.4	10.5	0.0	0.0	30.0	64.6	101.1
Cuejd	23.5	0.0	1.8	2.4	2.5	0.0	10.5	0.0	0.0	7.5	48.2	114.2
Luminis	25.6	0.0	1.8	1.8	0.6	0.0	8.2	0.0	0.0	10.5	48.5	101.8
Magazia	28.5	0.0	3.4	1.0	0.6	0.1	6.9	0.0	0.0	5.0	45.5	100.8
Slobozia	17.3	0.0	5.4	3.0	0.0	0.0	12.0	0.0	0.0	14.2	45.5	96.2
Lunca de Sus	0.4	0.0	5.7	4.0	0.0	3.0	8.0	0.0	0.0	80.0	101.1	87.6
Ghimes-Faget	0.5	0.0	1.5	3.5	0.0	1.0	5.5	0.0	0.0	23.1	35.1	90.2
Goioasa	0.5	0.8	8.0	4.1	0.0	0.4	3.5	0.0	0.0	17.0	34.3	101.9
Tg. Ocna	0.7	0.0	6.4	3.1	0.0	0.0	13.6	0.0	0.0	0.0	23.8	87.3
Onesti	0.3	0.0	3.5	2.5	0.0	0.0	8.8	0.0	0.0	39.6	54.7	84.5
Vranceni	0.3	0.0	1.3	3.2	0.0	0.0	8.9	0.0	0.0	0.0	13.7	75.4
Darmanesti	0.6	0.0	8.8	3.8	0.3	2.7	10.3	0.0	0.0	20.1	46.6	91.3
Dofteana	0.2	0.0	3.6	4.9	0.0	1.7	6.1	0.0	0.0	12.6	24.1	103.1
Tazlau	9.3	0.0	5.1	3.1	0.0	0.3	7.9	0.0	0.0	15.3	41.0	111.8
Helegiu	0.3	0.0	3.8	4.2	0.0	0.0	11.0	0.0	0.0	0.0	19.3	92.5
Lucacesti	0.0	0.0	2.4	2.2	0.0	0.5	3.8	0.0	0.0	7.9	16.8	86.1
Lepsa	0.0	0.0	3.7	11.6	0.0	0.0	7.3	0.0	0.0	0.0	22.6	87.9
Botarlau	0.7	0.0	0.0	10.0	3.0	0.0	6.0	0.0	0.0	0.0	119.7	60.7
Lepsa	0.0	0.0	3.7	11.6	0.0	0.0	7.3	0.0	0.0	0.0	22.6	87.9
Nereju	1.0	0.0	7.2	19.6	4.5	0.0	1.1	0.0	0.0	0.0	33.4	102.5
Golesti	2.4	0.0	0.0	10.4	0.8	0.0	4.5	0.0	0.0	0.0	18.1	63.5
Gr.Tufei	6.5	0.0	1.7	10.8	0.0	0.0	4.7	0.0	0.0	0.0	23.7	66.9
Jiliste	3.3	0.0	1.7	10.3	0.8	0.0	4.1	0.0	0.0	0.0	20.2	58.9
Puiesti	4.1	0.0	16.5	13.9	1.1	0.0	6.4	0.0	0.0	0.0	42.0	58.3
Martinesti	11.0	0.0	3.0	19.5	1.5	1.0	13.0	0.0	0.0	0.0	49.0	56.7

maximum discharge of 4,650 m^3/s was recorded at Lungoci on Siret River, compared to a multiannual average discharge for the month of July of 256.0 m^3/s; 1,200 m^3/s recorded at Frunzeni on Bistriţa River, comparing with 82.5 m^3/s; 2,800 m^3/s recorded at Vrânceni on Trotuş River, comparing with 41.3 m^3/s; 1,600 m^3/s recorded at Helegiu on Tazlău River, versus the multiannual average discharge for the month of July of 8.10 m^3/s (Table 4).

The hydrologic monitoring of the flood events has generally been conducted in an appropriate manner, with some exceptions caused by gauge destruction, the flooding of their locations or the destruction of he operators' houses and the interruption of the lines connecting the recording instrumentation with the data processing centers. Such events were identified at the following hydrometric stations: Ceahlău on Ceahlău River, Ghimes-Faget, Goioasa, Targu Ocna, Vranceni on the Trotus River, Sulta on Sulta River, Ciobanus on Ciobanus River, Asau on Asau River, Ciresoaia on Slanic River, Scorteni and Helegiu on Tazlau River, Ciuruc on Susita River, Lepsa on Putna River, Nereju on Zabala River,

Table 3 Rainfall over the Siret watershed between July 11 and 14, 2005

Code	River	Hydrometric station	Rainfall (mm)			Total
			11–12	12–13	13–14	
42707	Siret	N. Balcescu	1.4	34.7	42.5	78.6
42714	Siret	Lungoci	17.4	80.4	2.6	100.4
42715	Siret	Sendreni	16.6	176.0	0.0	192.6
42753	Ozana	Leghin	15.2	63.1	49.3	127.6
42783	Bistrita	Straja	65	92.2	3.0	160.2
42808	Bistrita	Bistricioara	19.6	104.0	0.0	123.6
42811	Putna	Tulghes	39.2	22.3	2.5	64.0
42817	Bicaz	Tasca	43.2	62.2	1.5	106.9
42825	Bicaz	Slobozia	14.0	62.7	14.0	90.7
42832	Bicaz	Ghimes-Faget	31.5	51.0	0.0	82.5
42838	Bicaz	Onesti	39.6	112.0	0.0	151.6
42839	Bicaz	Vranceni	41.4	114.0	6.7	162.1
42848	Dofteana	Dofteana	35.0	130.0	0.0	184.5
42849	Slanic	Ciresoaia	79.9	74.6	0.0	109.6
42851	Oituz	Ferastrău	54.5	62.5	13.2	155.6
42853	Casin	Halos	73.7	132.0	12.5	218.2
42855	Tazlau	Tazlau	23.8	150.0	11.5	185.3
42862	Tazlau S.	Lucacesti	33.2	117.0	0.0	150.2
42868	Putna	Lepsa	66.0	109.0	0.0	175.0
42871	Putna	Colacu	25.0	148.0	26.5	199.5
42875	Lepsa	Lepsa	66.0	109.0	0.0	175.0
42880	Naruja	Herastrau	73.4	147.0	0.0	220.4
42890	Ramna	Jiliste	9.2	100.0	0.0	109.2
42899	Cotatcu	Martinesti	14.0	101.0	0.0	115.0

Herastrau on Naruja River and Reghiu on Milcov River. Other negative factors affected the recordings at the above-mentioned stations: the lack of hydrometers replacement for defective ones, the lack of a controlled operation schedule for certain stations and the uncertain employee status of many operators manning the hydrometric stations.

The authors conducted flow discharge reconstruction for several locations of interest. In order to ensure an increased level of detail and in order to ensure a correct estimation of the flood effects, the authors used satellite images that were processed in the laboratories of the Romanian Space Agency. In order to determine the extent of the flooding, comparative analysis of the pre- and during-flood satellite images was performed.

Three successive spatial phases were identified and further described during this catastrophic flooding episode:

– The flood observed in the middle part of the Bistrita River watershed, up to the confluence with Siret River;
– The floods observed from the Trotus River watershed and Vrancea area;
– The flood observed on Siret River's lower course (Fig. 3).

Table 4 Maximum levels and discharge rates produced during the flood from 12 to 15 July 2005

Code	River	Hydrometric station	CA	CI	CP	H_{max} (cm)	Q_{max} (m^3/s)	Date/hour	Total precipitations (mm)	$Q_{iul}^{med\ mult}$
42711	Siret	Adj. Vechi	250	350	450	315	1,285	13/12	50.0	185.0
42712	Siret	Cosmesti	250	300	350	490	–	13/13	90.3	–
42714	Siret	Lungoci	600	650	700	840	4,650	14/7	100.4	256.0
42715	Siret	Sendreni	550	600	650	–	2,900	–	192.6	–
42718	Suceava	Itcani	350	400	450	–	–	–	0.4	24.2
42739	Moldova	Gr. Humorului	200	300	350	–	–	–	22.7	25.9
42742	Moldova	Roman	300	400	450	–	–	–	34.3	51.0
42748	Moldovita	Dragosa	250	300	350	–	–	–	17.9	8.58
42754	Ozana	Dumbrava	150	250	300	–	–	[	36.0	4.66
42783	Bistrita	Straja	300	400	500	440	650	12/22	160.2	72.9
42785	Bistrita	Frunzeni	200	250	300	310	1,200	12/22	71.3	82.5
42808	Bistricioara	Bistricioara	100	180	250	150	102	12/20	123.6	8.06
42817	Bicaz	Tasca	220	270	320	300	188	12/8,30	106.9	6.17
42838	Trotus	Onesti	300	350	450	524	1,680	12/24	151.6	30.5
42839	Trotus	Vranceni	300	350	450	540	2,800	13/7	162.1	41.3
42846	Uz	Darmanesti	150	200	300	170	46.8	12/24	154.9	5.93
42857	Tazlau	Helegiu	200	300	350	320	1,600	12/24	140.0	8.10
42870	Putna	Mircesti	400	450	550	621	1,120	13/7	103.5	10.3
42873	Putna	Botarlau	500	550	650	822	1,323	13/15	100.0	16.8
42878	Zabala	Nereju	150	200	250	186	238	12/7.30	45.0	4.76
42880	Naruja	Herastrau	75	125	175	185	192	12/6	220.4	2.14
42893	Ramnicul Sarat	Tulburea	200	250	300	330	253	12/22	146.2	1.40
42899	Cotatcu	Martinesti	250	300	350	–	–	–	115.0	022

CA defense values; *CI* inundation values; *CP* danger values; maximum discharge rates at hydrometric stations that had no special relevance are not shown

The Bistrita River watershed is highly regularized due to the presence of 13 dams constructed along its course over the past 50 years. The most important dam is Stejaru Dam, which holds the largest artificial lake in Romania.

The rainfall that fell in the middle and lower parts of the Bistrita River watershed was larger than the rainfall that fell in its upper part. Thus, between July 11 and 14, 160.2 l/m^2 fell at Straja, 123.6 l/m^2 at Bistricioara, 112.5 l/m^2 at Ceahlau, 106.9 l/m^2 at Bicaz-Chei, 119.9 l/m^2 at Cuejd, 90.7 l/m^2 at Roznov—Slobozia, 164.0 l/m^2 at Borlesti 146.3 l/m^2 at Buhusi, 168.7 l/m^2 at Garleni and 157.4 l/m^2 at Luncani.

The maximum recorded discharge that occurred at Straja hydrometric station, located at the exit of a watershed with a total surface of 1,051 km^2, was of 650 m^3/s and included the overflow from the Izvoru Muntelui Dam. This discharge together with the discharge from the Stejaru hydropower station and the contribution of the watershed from the lower stream reached 1,400 m^3/s when routed through the lake system Pangarati-Bacau. The actual flood routing sequence was successfully performed in compliance with the rules of the company responsible with the management of the hydraulic control structures on the river,

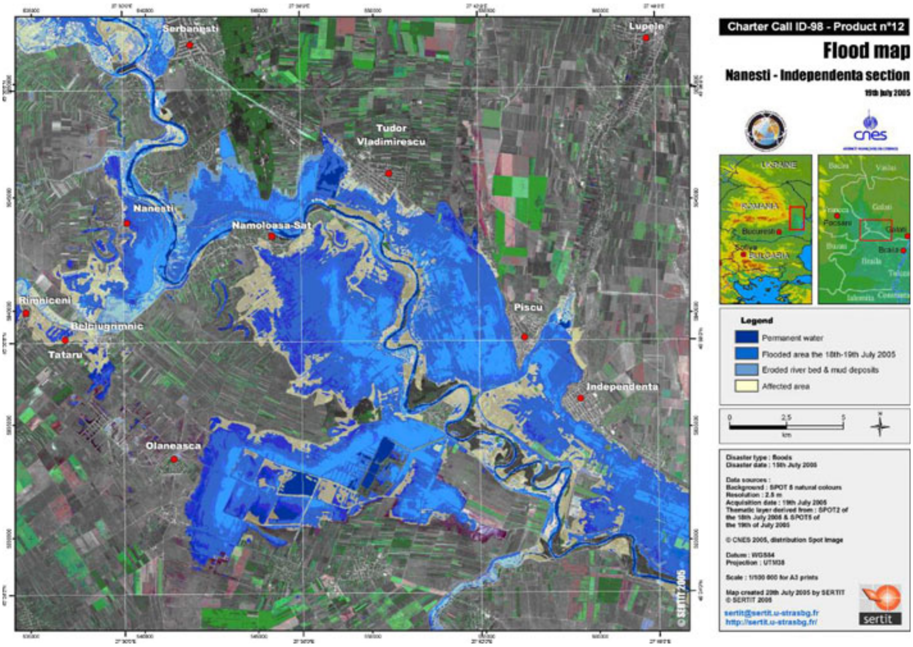

Fig. 3 Areas affected by flood on July 12–15, 2005, in the Siret River lower watershed (Romanian Space Agency 2005)

S.C. Hidroelectrica S.A. Consequently, no dangerous events occured on Bistrita River until its confluence with the Siret River.

High floods that generated inundations occurred in the watershed of Trebes River, including along the northern sector of the City of Bacau. These floods were accelerated by the breaking of dike from Negel and the lack of flood retention dams on the Trebes River. The maximum discharge was registered on Negel River at Magura, with a magnitude of 26 m^3/s, and on the Trebes River, with a maximum of 130 m^3/s. This latter flow was above the design flow in the section of the bridge of the national road. This generates significant backwater levels along the lower sector of Negel River which caused the breaking of the flood protection dikes and significant attenuation through water ponding. Due to this phenomena that occurred in the northern part of the City of Bacau, the maximum discharge of the Trebes River diminished, so that its maximum value at the hydrometric station of Barnat (on the lower stream of Trebes River) was reduced to 68 m^3/s.

During the same period of time, rainfall amounts were high in the Trotus River watershed. The highest amount was registered at Halos station on the Casin River (218.2 l/m^2), at Tazlau on Tazlau River (185.3 l/m^2), at Scorteni on Tazlau River (162.4 l/m^2), at Lucacesti on Tazlaul Sarat River (150.2 l/m^2) and at Dofteana (184.5 l/m^2).

Significant increases in discharge and associated water levels occurred on Trotus River and most of its tributaries. The values of the maximum discharge occurred at the hydrometric stations located on Trotus River corresponded to exceedance probabilities of 0.5–2%. These extreme discharge rates destroyed most of the recording devices and installations and inundated the hydrometric stations, making thus impossible to obtain reliable measurements. For all these hydrometric stations, it was necessary to reconstitute the maximum water values based on witnesses' observations and on hydrotopographical field measurements.

At Goioasa hydrometric station, on the Trotus River, the gauge was flooded and completely destroyed, so that the automatic hydrometric station did not function. Consequently, the maximum level was identified based on the remaining watermarks identified during the field campaign.

At Targu Ocna hydrometric station, on Trotus River, at 19:00, at July 12, 2005, the hydrometric station was flooded, together with the operator's house. Consequently, no water level recording was made, so that the maximum level had to be reconstructed by the authors, as shown in Fig. 4.

At Helegiu hydrometric station on Tazlau River, because of the very high discharge rates, combined with the flood of the road located on the right bank of the river, where the maximum gauge was located, bridge circulation was restricted. Therefore, the operator could not use the gauge and only visually estimated the raising water levels looking from the left riverbank, where his home was located.

At Vranceni hydrometric station, between the 1:00 and 4:00 am, the gauge location could not be reached due to the very high water level and the complete flooding of the riverbanks. Hence, the water level was approximated by visual observation during this interval. The flood hydrograph for the Vranceni station is shown in Fig. 5.

For all of the above-mentioned hydrometric stations, as well as for the Asău and Ciobanus stations, during the flood and the next few days, telephonic connections were cut off. At the same time, the operators could not reach Onesti hydrologic station because of the destruction of connecting bridges and of all other access roads; the building of Onesti hydrologic station was also affected by the floods on the Casin River.

Due to the fact that, following the 1991 floods, on the Trotus and Tazlau rivers there have been no exceptional flows, the upper curve of the stage–discharge graph was used to determine the extreme values for the 2005 flood. These values were confirmed by the

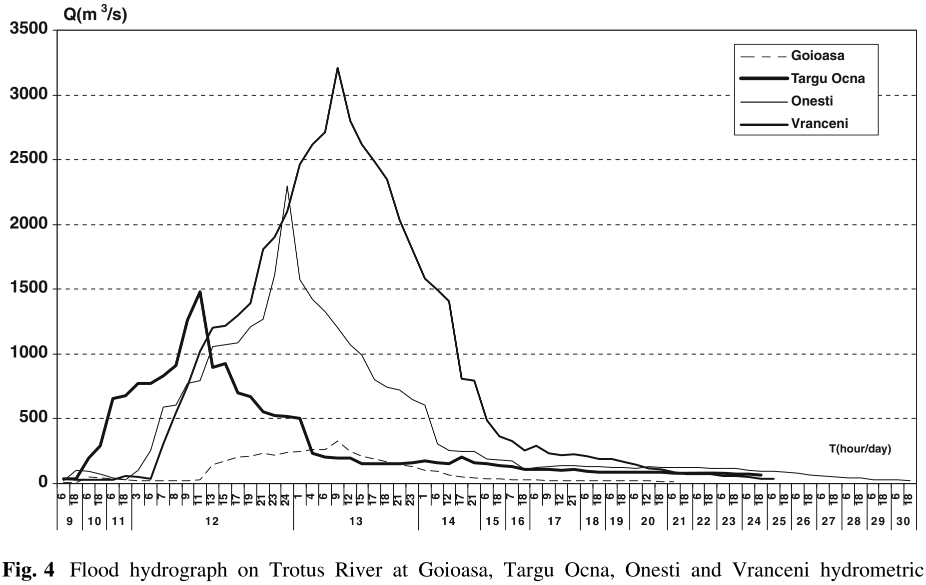

Fig. 4 Flood hydrograph on Trotus River at Goioasa, Targu Ocna, Onesti and Vranceni hydrometric stations (July 9–30, 2005)

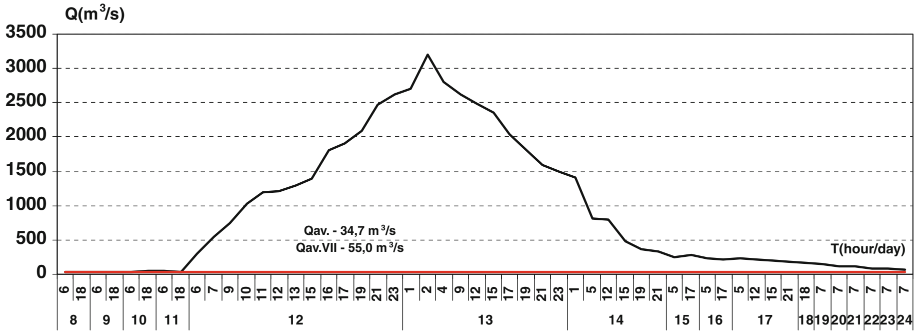

Fig. 5 Flood hydrograph at Vranceni hydrometric station on Trotus River

Table 5 Maximum discharges recorded at hydrometric stations on Trotus River and its tributaries, and their corresponding exceedance probabilities

River	Hydrometric station	Recorded Q_{max} (m^3/s)	Q_{max} exceedance probability (m^3/s)					Flood exceedance probability %
			0.5	1	2	5	10	
Trotus	Goioasa	257	940	765	610	435	320	>10%
Trotus	Tg.Ocna	1,260	1,385	1,200	1,025	795	625	0.5–1
Trotus	Onesti	1,680	1,900	1,550	1,250	875	650	0.5–1
Trotus	Vranceni	2,800	2,920	2,500	2,120	1,670	1,340	0.5–1
Sulta	Sulta	57.5	300	245	195	140	105	>10
Ciobanus	Ciobanus	55.3	325	265	210	150	110	>10
Asău	Asau	136	380	310	245	170	115	5–10
Uz	Cremenea	229	565	460	375	260	195	5–10
Dofteana	Dofteana	186	285	230	185	130	95.0	2
Slanic	Ciresoaia	117	285	230	185	130	95.0	5–10
Oituz	Ferastrau	349	435	370	300	220	160	1–2
Casin	Halos	400	735	600	485	340	250	2–5
Tazlau	Tazlau	153	765	620	495	355	260	>10
Tazlau	Scorteni	470	1,280	1,040	840	590	435	5–10
Tazlau	Helegiu	1,700	1,785	1,515	1,240	910	660	0.5–1
Tazlau S.	Lucacesti	451	655	542	430	300	210	2

authors' calculations. In the case of Tazlau River, the morphometric modifications determined by the destruction of the Belci Dam have only occurred downstream of the Helegiu bridge. The hydrometric gauge was installed on the upstream side of this bridge.

At several other hydrometric stations from the Trotus River watershed, the discharge flow rates that occurred during the flood from July 12–15, 2005, were large and reached exceedance probabilities of 1–2% (Table 5).

Significant precipitation that generated destructive floods fell in most of the watersheds in Vrancea region. The highest rainfall was recorded in the mountainous and piedmont areas, where high floods occurred: Herastrau—220.4 l/m^2, Colacu—199.5 l/m^2 and Tulburea—146.2 l/m^2 (Table 6).

Table 6 The maximum flow rates occurred at some hydrometric stations from Vrancea region, compared to the values of different exceedance probabilities

River	Hydrometric station	Recorded Q_{max} (m^3/s)	Q_{max} exceedance probability % (m^3/s)					Flood exceedance probability %
			0.5	1	2	5	10	
Putna	Tulnici	213	710	595	475	340	240	>10
Putna	Colacu	1,510	1,350	1,100	880	630	460	<0.5
Putna	Mircesti	1,120	1,710	1,390	1,110	790	585	2
Putna	Botarlau	1,323	2,090	1,795	1,500	1,130	805	2–5
Zabala	Nereju	238	790	675	570	430	325	>10
Naruja	Herastrau	192	600	495	380	270	180	5–10
Milcov	Reghiu	345	565	460	370	260	195	2–5
Milcov	Golesti	572	920	780	670	525	420	2–5
Ramna	Gr.Tufei	354	705	590	470	335	235	2–5
Ramna	Jiliste	666	590	490	385	265	180	<0.5
Rm. Sarat	Tulburea	253	690	560	450	320	235	10
Ramnicul Sarat	Puiesti	857	950	775	620	440	325	0.5–1
Ramnicul Sarat	Tataru	182	610	525	440	335	255	>10
Siret	Lungoci	4,630	4,510	3,950	3,425	340	1,160	>0.5

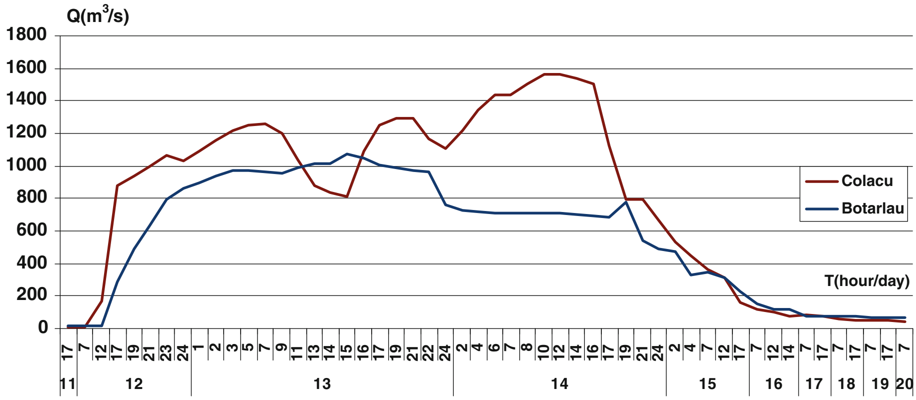

Fig. 6 Flood hydrograph of Putna River at Colacu and Botarlău hydrometric stations (July 11–20, 2005)

Severe inundation occurred also due to the rapid rainfall concentration caused by the extensive deforestations on the slopes of the watershed. Through flood propagation, combined with supplementary rainfall inflow from the middle part of the hydrographic basins, the flood waves amplified in the lower part of the river course. Thus, the maximum recorded discharge rates were of 1,510 m^3/s on Putna River at Colacu hydrometric station, 572 m^3/s on Milcov River at Golesti hydrometric station, 666 m^3/s on Ramna River at Jiliste and 857 m^3/s on Ramnicul Sarat River at Puiesti. The flood hydrographs for two stations in Vrancea are indicated in Fig. 6.

These exceptional discharge rates resulted in massive destruction of the downstream flood protection dikes and subsequent inundations. As a result of the flood attenuation by ponding, the maximum discharge rates on the lower courses of Putna and Ramnicul Sarat rivers were somewhat diminished. However, the actual magnitude of the natural flood attenuation in the downstream sector of these rivers could not be estimated.

Over the entire Vrancea region, as well as in the Trotus River watershed, the rainfall amounts were impressive. Extremely rich and active rainfall nuclei generated important flood waves on the upper sectors of the Asau, Ciobanus, Oituz, Casin, Zabala, Naruja and Ramna rivers. For most of these rivers, the maximum discharge flow rates occurred exceeded probabilities of 0.5–1%. In the case of the flood on the lower sector of Siret River, this was generated mainly by the extremely high inflow from the upstream Trotus River watershed with flow rates of 2,800–3,000 m^3/s, corresponding to an exceedance probability of 0.5%.

The presence of artificial lakes on the Bistrita River and on the middle course of Siret River had a limited influence in the attenuation of the flood. The exploitation in normal conditions of these lakes could not ensure significant attenuation rates for the flood occurring on Bistrita River or those occurring on Trotus River. The maximum flow rates on the Bistrita River in the Piatra Neamt—Bacau sector exceeded 1,400 m^3/s. For such flow rates, the attenuation provided by the Galbeni-Racaciuni-Beresti Lake Complex was small. Therefore, the flow rates that entered Galbeni Lake, mainly from Bistrita River, further transited the Beresti Dam. At the entrance into the Calimanesti Lake, these flow rates cumulated with the ones from Trotus River, leading to a maximum flow rate of approximately 4,000 m^3/s.

In the present calculations, the authors used the values directly recorded at Vranceni hydrometric station, considered to have occurred in real time, without taking into account the inherent flood attenuations which may have occurred downstream, since such calculations would have needed extensive field measurements.

Based on the data available and the ones collected by the authors, as well as on the flow regime characteristics of previous years, it can be estimated that the degree of attenuation of the floods on the lower Trotus River was of approximately 4%, while in the Adjud—Calimanesti sector of Siret River was at least of 5%.

For the case of the Trotus River, the data processed and analyzed revealed that:

a. The watershed area corresponding to the sector downstream of the Vranceni hydrometric station is of 419 km^2. However, this area comprises only a few small tributaries that already exhaust their maximum flow rate before the maximum peak occurs on the main course. Except for this area, a large part of the watershed is relatively flat, occupying the large major riverbeds of Trotus and Siret rivers. In this context, the maximum flow rate registered at Vranceni indicates downstream attenuation. Thus, the maximum discharge rate with an exceedance probability of 0.5% (equivalent to the one which occurred on July 13, 2005) is of 2,805 m^3/s at the confluence with Caiuti and of 2,690 m^3/s at the confluence with Siret River.
b. In the Adjud area, the existing railroad bridge and adjacent groundwork attenuated to a certain extent of the maximum discharge rate.
c. The Trotus River watershed is wide and the flow concentration is therefore less efficient than in the case of an elongated watershed. This is why the attenuation degree is relatively reduced, and the lateral water inflow from downstream Vranceni hydrometric station surely contributes to this reduction.

In the case of Siret River, on the Adjud (from the confluence with Trotus River)—Calimanesti sector the degree of attenuation is higher. The discharge passes from flow rates of 1,400–1,600 m^3/s (evaluated at Beresti Lake) to flow rates of close to 4,000 m^3/s.

Based on the calculation of the transit of the maximum flow rates, it was determined that the attenuation of the flood peak on Siret River on the sector from the confluence with Trotus and Calimanesti Lake is close to 5%. The authors took into consideration the maximum flow rates with exceedance probability of 1% on Siret River, determined at the main confluences with Trotus, Zabrauti and Susita rivers. No attenuation corrections of the maximum flow rates from Siret and Trotus rivers were applied.

According to data released by S.C. Hidroelectrica—Piatra Neamt, in order to maintain water levels in Calimanesti Lake at safe levels, it was decided to evacuate water at a flow rate of approximately 4,000 m^3/s.

The reconstruction of the flow rates performed for the sector located downstream Calimanesti, respectively in for the Cosmesti and Movileni cross-sections, showed that on this sector, the maximum flow rates may have reached 5,000–5,500 m^3/s. The outflow from Calimanesti Dam added to the lateral supplementary inflow of several tributaries such as Zabrauti and Susita.

These extreme flows induced destructions of some of the older flood protection dikes, followed by local inundations. Hence, at Lungoci monitoring station, which is located downstream of the confluence with Barlad and Putna rivers, the maximum flow rate did not exceed 4,650 m^3/s (Fig. 7).

Given these conditions, the water level raised in only 4 days with more than 8 m along this sector. This extreme water level translated into the inundation of large areas, especially of those that did not have an adequate flood protection system. This particular value of 8 m above the multiannual level was the highest recorded in the entire Siret hydrographic basin. High level values were also recorded also on Siret River and its tributaries: almost 7 m at Adjudul Vechi on Siret River, almost 6 m at Tataru on Ramnicul Sarat River, almost 5 m at Helegiu on Tazlau River and 3 m at Asau on the same river. In the narrower sectors located upstream of Lungoci station, where the flow rates were even higher (evaluated on the basis of flow rate reconstitution), water levels were also high, with important repercussions on inundation of the agricultural fields, as well as that of the human settlements (Fig. 8).

In order to conduct a more detailed analysis of the consequences of flood on the Siret River, downstream Calimanesti Dam, the determination of the real maximum flow rates and the separation of the natural flow from the artificial one (resulting from dam spilling), the authors are currently conducting a new extensive field measurements campaign.

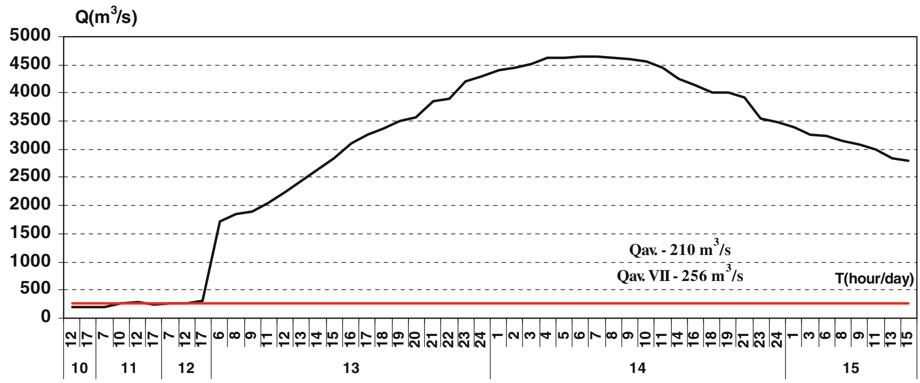

Fig. 7 Flood hydrograph for Siret River at Lungoci hydrometric station; the red line represents the multiannual base flow for July

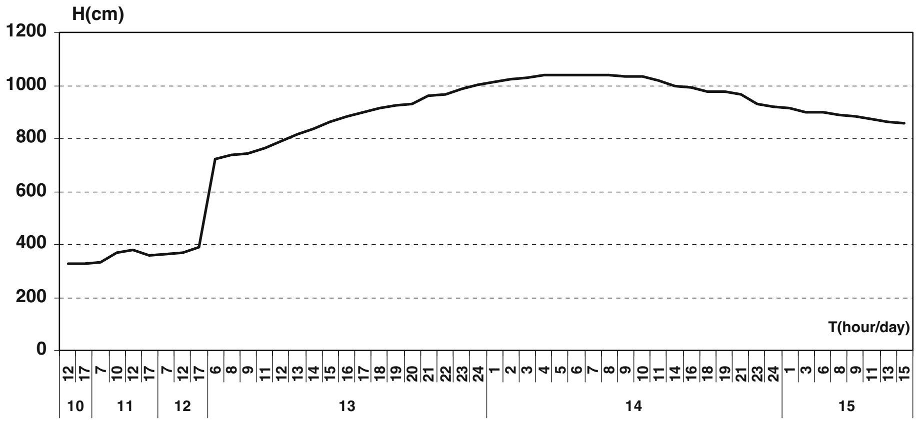

Fig. 8 Water level hydrograph on the Siret River at Lungoci hydrometric station

Fig. 9 Dike breached by flood in the Siret River lower watershed (Romanescu 2005)

Unfortunately, downstream of the confluence with Trotus River, the continuous monitoring of the flow discharge on Siret River is performed only in the Lungoci section. At the other two hydrometric stations (Cosmesti and Sendreni), only level observations are performed, as these stations do not have operative gauging equipment. The authors were able to prepare a stage–discharge relationship for the Cosmesti hydrometric station. According to it, the maximum flow rate evacuated from Calimanesti Lake would be 4,500 m^3/s, if the lateral inflow is not taken into account. For Sendreni cross-section, the estimation of the water levels was rather difficult, because of the significant backwater curve generated by the confluence with the Danube River. Some of the significant destructions generated by the flood in the lower Siret River watershed are presented in Figs. 9, 10 and 11.

Fig. 10 Riverbank erosion on Siret River in the Cosmesti de Jos sector (Romanescu 2005)

Fig. 11 Destroyed houses in the village of Cosmesti de Jos, on the Siret River (Romanescu 2005)

4 Conclusions

The analysis of all data collected as well as the field investigations and the subsequent calculations led to the formulation of several conclusions presented herein:

1. The flow hydrograph for the discharge evacuated from Beresti Lake, confirmed by the recordings of the Adjudul Vechi hydrometric station, indicates the presence of extremely high flow rates on Siret River at the confluence with Trotus River between July 12 and 13, 2005.
2. The maximum flow rate registered on Trotus River at Vranceni hydrometric station was of 2,800 m^3/s. This value was reduced by natural downstream attenuation and by the associated lateral inundations, until the moment that the flow reached the Calimanesti Lake.
3. Barlad River did not show had a significant discharge ($Q_{max} = 155$ m^3/s) and, hence, did not affect significantly the flow rates on the Siret River. This was due to the fact the Barlad River watershed is located in a precipitation-deficient geographic area.
4. At the confluence with Putna River, the flow rates were reduced due to natural attenuation.
5. On Ramnicul Sarat River, on the lower sector, the maximum flow diminished due to natural attenuation or the breaching of flood protection dikes and subsequent inundations.
6. For the interpretation and analysis of the surfaces affected by inundations, a number of satellite images were processed to asses the extent of the flood. The estimation of the affected surfaces has been conducted based on the interpretation of the LANDSAT TM 2003 images, using the FAO-LCCS classification methodology. The data processing has been conducted in the remote sensing laboratory ASR-CRUTA on July 19, 2005, using the images obtained as a consequence of the activation of the international CHARTER (Call ID-98, Romanian Space Agency, 2005). Figure 12 shows the results of the analysis conducted in this sense and the extent of the flooding on the lower course of the Siret River.

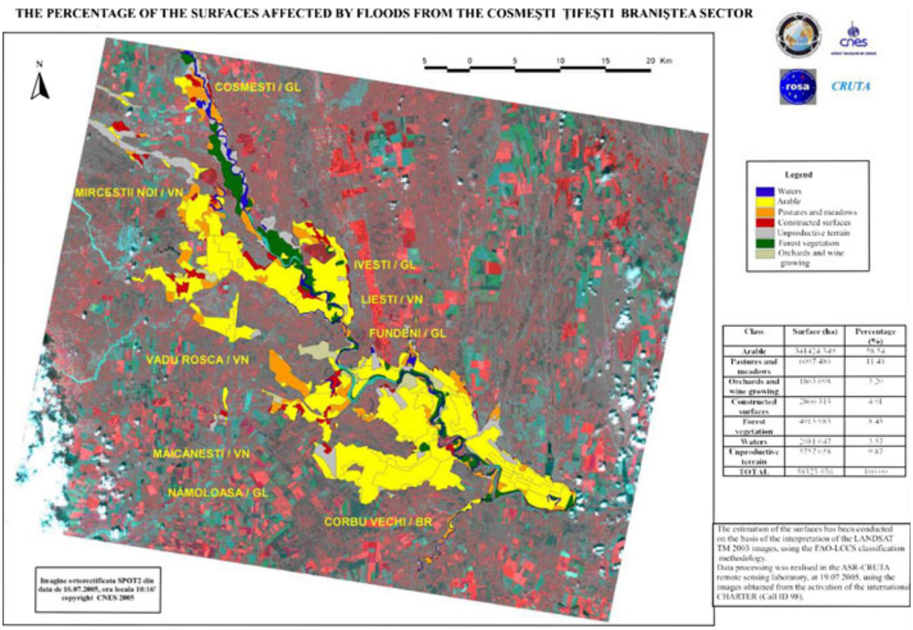

Fig. 12 Surfaces affected by floods in the Siret lower course

Table 7 The balance of the surface affected by floods in the Siret lower watershed

Land classification	Surface affected (ha)	Percentage of the total land surface affected by flood (%)
Arable	341,424.35	58.5
Pasture and meadows	6,697.49	11.4
Orchards and wineries	1,863.70	3.2
Constructed surfaces	2,866.31	4.9
Forests	4,915.99	8.4
Lakes and rivers	2,081.05	3.5
Non-productive terrain	5,757.06	9.8
Total	58,323.94	100.0

The total surface affected by inundations was of 58.323 ha. Table 7 identifies the various types of areas affected by floods, depending on the land classification system.

The floods generated tremendous material losses reflected in the destruction of more than 10,000 houses and the death of tens of thousands of domestic animals, mainly poultry, cows and sheep. The total material losses, including animal losses, amounted to more than 2 million Euros. Unfortunately, 24 human loses were also registered; most of them elder persons. Thousands of families from the counties of Galati, Vrancea, Bacau and Braila completely lost their houses and properties due to the flood.

Although the watershed of Siret River comprises a relatively high number of artificial lakes, located in the tributary basins or along the main course, their contribution to the flood attenuation, though minimal, was still important. Thus, an incommensurable catastrophe at local and regional level has been avoided. The flood was created also as a result of the high runoff that occurred in the mountainous hydrographic watersheds, where the ill-designed hydraulic structure combined with the massive deforestation led to massive runoff and flash floods. The authors would like to draw the attention to the massive deforestation that intensified after 1990, when illegal logging went out of control in these particular areas. Summing up, as flow rates increased, the presence of the lakes with retention role was essential as they were able to reduce the peak of the flow, attenuating thus the impact of the flood in downstream regions. In order to reduce the flow rates at the attention or danger levels, some of the flood protection dikes were purposely breached in certain locations in order to allow further attenuation by controlled lateral flooding. Though these inundated surfaces were large, the downstream human and economic losses diminished significantly.

Besides the material losses that had a negative impact on the local and national economy, the authors would like to draw the attention to a number of other important changes associated with the river geomorphology or the soil cover. Several phenomena were observed: the occurrence of islets and the disappearance of others, the extension of the concave banks through the erosion and subsequent accentuation of the steep banks, the spatial modification of the minor riverbeds, modifications of the water courses as a consequence of auto-capture through overflows, the re-inundation of old river courses, the sedimentation of polders and the occurrence on new, young soils. Some of these aspects have been illustrated in Figs. 9 and 10.

The catastrophic flood of July 2005 demonstrated that many of the rural settlements, and rarely the urban ones, which are located in the riverbeds, took the brunt of the flooding waters (Fig. 13). The lack of a national program of integrated management of the watersheds and the lack of comprehensive hydrologic and geomorphologic risk maps contributed to a poor

Fig. 13 The mark level (on the building's walls) of the Siret River's waters at Cosmestii de Jos (Romanescu 2005)

Fig. 14 The destruction of the national road and railway Tecuci-Marasesti (Romanescu 2005)

management of this extreme hydrologic phenomenon. In many cases, human settlements were partially or completely affected (Vadu Rosca). The situation described in this case occurs almost on an annual basis, mainly at the end of spring and beginning of summer, when the snow completely melts and fall great quantities of liquid precipitations (Figs. 13 and 14).

It is clear that management of crisis created by such extreme natural phenomena must be governed by a well thought and detailed national emergency management and mitigation plan, with ramifications at local county level. For the case of Romania, in order to prevent the repetition of such a disaster, the current plan, unanimously judged to be outdated, is under review. Particularly, the location of human settlements must account for their exposure to the important hydrologic or geomorphologic risks (Romanescu 2003).

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