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Exceptional floods on a developed river: case study for the Bistrita River from the Eastern Carpathians (Romania)

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Abstract The geographical position of the Bistrita River favours a rich liquid run-off and great hydrotechnical potential. The Bistrita drainage basin is strongly developed from the hydrotechnical point of view. Within the drainage basin, numerous dams and storage reservoirs are installed with the purpose of producing electricity and reducing flood hazards. However, these structures could not stop floods at the drainage basin level. The most powerful floods from Bistrita River basin and the role in flood control of each of the storages are analysed in this paper. The hydrological data have been collected from the monitoring network, where the researchers elaborating this study are performing their daily activity. The most powerful floods in the last century took place in 1970, 1991, 2005 and 2010. An intensification of the floods can be noticed after the year 1990, a period which coincides with large-scale deforestation of the small drainage basins. Disastrous floods occurred as a consequence of summer heavy rains, with amounts of 100–200 mm within 24 h. The most powerful floods were recorded in 2005 and registered discharges up to 1,200 m^3/s. Izvoru Muntelui reservoir, the biggest in the system, can take most of the waters in excess. The reservoirs located downstream are silting up, and the supplementary flows cannot be absorbed entirely by storage. The exact knowledge of flooding phenomena requires studies that can prevent and diminish the damages caused by extreme hydrological events.

Keywords Hydrotechnical development · Floods · Storage reservoirs · Hydrological management · Heavy rains

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1 Introduction

During the last few years, attention worldwide has been focused on discussing the negative effects of economic development on climate, without ensuring proper measures for the protection of the environment. The majority of scientists embrace the idea that worldwide, states have to promote adequate technologies for the sustainable development of society and take firm action towards reducing the pollutant emissions that inevitably lead to "global warming". The increase in mean global temperature is a real phenomenon, proved through numerous scientific researches, and the impact of global warming, according to the thermal increase rates, could be catastrophic. Consequences include flooding of large areas because of the melting of ice caps, prolonged drought and major climate change at a planetary level for many parameters (Al Gore 2006; Feyen et al. 2012; Gaume et al. 2009; Pandi and Mika 2003; Plesoianu and Olariu 2010; Salit et al. 2013; Sankarasubramanian et al. 2001; Zhang et al. 2011; Zhenmei et al. 2008).

Research on global warming has intensified in Romania during the last few years, and numerous studies have been published on modifications in the thermal, pluviometric and hydrological regimes, and their impact upon future hydroclimatic evolution (Arghius 2007; Mihaila et al. 2009; Mustatea 2005; Olaru et al. 2010; Romanescu et al. 2012b; Rotaru and Kolev 2010; Stanciu et al. 2005; Teodosiu et al. 2009).

The Romanian Territory in general and Moldavia in particular are situated in a hydroclimatic transition area, with oceanic influences, wetter and milder than continental climate, and with a discontinuous thermal and pluviometric regime. Under these circumstances, it is assumed that the eastern part of the country will experience the most severe effects of climate modification; the drainage basin of the Bistrita River, administrated by the Siret Water Basin Administration from Bacau, is situated in the eastern sector of the Eastern Carpathians on the junction between two climatic areas (Olariu 2012; Romanescu 2003; Romanescu et al. 2011a; Selarescu and Podani 1993; Serban et al. 2004; Valdes 1995; World Meteorological Organization 2008).

Higher demand for water supplies has stimulated both theoretical and practical hydrological research. From a practical point of view, acknowledgement of the hydrological regime as a whole, and the flash flood regime in particular, is necessary for consolidating the management of quantitative and qualitative parameters of the water resources and for protection against floods. Given that water resources are subject to a complex valorization, this knowledge is of great importance. The multiannual average flows, which are being measured at the hydrometric stations or determined through specific calculations, represent the value of the natural water resources. The minimum flows have to be acknowledged in order to apply restrictions to consumption and for ensuring sanitation and a certain maintenance discharge downstream. Concerning the maximum flows, safety measures are necessary, especially with respect to flood prevention. Between river run-off regime phases and phenomena of great social and economic risk, flash floods, which produce overflows and floods, represent a major natural risk (Affeltranger and Lictorout 2006; Arduino et al. 2005; Arghius 2008; Badaluta-Minda and Cretu 2010; Chiriac et al. 1980; Lóczy 2010; Olang and Fürst 2010; Romanescu 2009; Romanescu and Nistor 2011; Rosu and Cretu 1998).

Within a river basin, flash floods represent the consequence of the effects of discontinued hydroclimatic regime, characterized by extended periods of drought interrupted by significant growths in short-term rainfall amounts and water flows. Flash floods occur on all the water streams, though with different durations, maximum flows and volumes, according to the supply conditions and morphometric parameters of the drainage basin (surface, average height, slopes, relief fragmentation, forest cover) (Atlas of Water Cadastral Survey Romania 1992; Barredo 2007; Berz et al. 2001; Diaconu 1988; Perry and Combs 1998; Podani and Zavoianu 1992; Romanescu 2006; Stefanache 2007; U.S. Army Corps of Engineering 2006).

Because of the deep economic, social and emotional impact created by floods, the issue of protection represents a major theoretical and practical concern, both for acknowledging the phenomenon in itself and for identifying the best precautionary measures. Throughout history, humankind has continuously looked for ways and means to control floods: in the first stage, by avoiding them, where possible, and thereafter continuing with the creation and design of hydrotechnical structures, which have become increasingly sophisticated and complex. In parallel with various uses of water resources, protection against floods has become a concern for modern society (Godlewska et al. 2003; Pircher 1990; Saf 2010). Today, the modern and sustainable management of water resources cannot be developed without the appropriate protection against floods and other meteorological hazards (Konecsny 2005; Förster et al. 2008; Lehner et al. 2006; Mihnea 2008; Romanescu and Lasserre 2006; Romanescu et al. 2011a; Valdes 1995).

An approach towards protection against floods has been made from the perspective of adopting structural measures such as damming, works to improve drainage conditions, water retention and other complex developments. Experience shows that structural measures are expensive and in certain circumstances can generate secondary negative effects such as sedimentation and increased local bed degradation. At the same time, lawsuit cases have been lost, there has been a lack of interest in maintaining the transportation capacities of river channels (in flash flood conditions), and illegal occupation occurs in floodplains (lands frequently flooded). Examples from the last 15–20 years are numerous and the floods in the Bistrita drainage basin (1991, 1998, 2005 and 2010) confirm this situation. Defence against floods is more efficient if non-structural measures are strictly applied, such as the determination of the risk areas and the discouragement by certain means of human occupation of areas that belong to the waters.

It is necessary to have correctly integrated and scientifically based defence works with structural character, for those already constructed, or for those which are to be designed, new models for flood control. Structural and non-structural measures represent a key element in the management of hydrological risk. For the small rivers and torrents, it is necessary to have exact weather forecasts.

Waters from sloping surfaces (mountain areas, transition from hill plateau), where the liquid flows can result in suspension and movement of coarse materials, can have negative unpredictable effects if they are connected with and area that has witnessed massive deforestation (Dorner et al. 2008; Gno et al. 2004; Hoffmann et al. 2010; Iroumé et al. 2006; Konecsny 2005; Solín et al. 2011). The hydrometric and pluviometric stations at the outlet of the basin register only the current state of facts, which often, on the local level is too late. However, this information is very useful for protection downstream, monitoring the spread of flash floods, and informing and warning those concerned. In the case of the Bistrita River, the hydrological situation is modified by the human factor. Eleven dams have been built for the purpose of storing an important quantity of water meant for human use (Siret Water Basin Administration 2009, 2011).

The paper aims to analyse the generation conditions and the evolution of the floods within the Bistrita drainage basin, as well as the causes and effects of the greatest floods registered during the last 40 years. As a consequence of global climate change, a new systematic approach to the hydroclimatic regime at the basin level is needed.

The hydrotechnical structures induce major changes in the stream flow and the suspended sediment load, with repercussions on the whole drainage basin, and especially on economic life (Chen et al. 2007, 2010; Ciaglic 1965; Jolin et al. 2009; Lin et al. 2006; Pinter et al. 2006).

1.1 Geographical setting

The Bistrita River springs from the Rodna Mountains, crosses the Eastern Carpathians, passes through the cities of Vatra Dornei, Bicaz, Piatra Neamt, Roznov, Buhusi and Bacau, and flows into the Siret River, downstream of Bacau city. It is the largest tributary of the Siret River, and it has significant hydroelectric potential. It has a length of 283 km, an area of 7,039 km^2 and 193 tributaries (including Dorna, Neagra Sarului, Neagra Brosteni, Borca, Sabasa, Bistricioara, Putna, Bicaz, Damuc, Tarcau, Cracau, Romani and Trebes) (I. N.M.H. 1971; Romanescu 2005). Considering geographical coordinates, this oblong basin is located between the meridians 24°47´55´´ E longitude and 27°00´49´´ E longitude, and the parallels 46°29´33´´ N latitude and 47°44´42´´ N latitude (Fig. 1).

The physico-geographical characteristics of the Bistrita drainage basin present variations along a west–east axis. Its relief is defined by the mountains (82 %) in the north and central area of the Eastern Carpathians, and the piedmont regions (18 %) of the Moldavian Subcarpathians. The Bistrita River basin has a NNW–SSE orientation. Along its course, it drains several areas with obvious lithological differences. Hydropower installations were constructed after 1950. In 1960, the Izvoru Muntelui accumulation (1.12 billion m^3) was put into operation, one of the largest and most important for energy production (Stejaru plant, 220 MW). Ten reservoirs were developed on the main stream of the Bistrita, and one on the Bicaz River; 14 hydroelectric plants and one reservoir on the Siret, and downstream of the confluence, there were other developments including canals, dams, collectors, transfer flows, protection works on banks and slopes, relocation of human settlements, gravelling (ballast), gallery digging, viaduct location, and means of communication (Romanescu and Bounegru 2012).

The flow of the Bistrita is particularly influenced by rainfall, morphology and type of rocks. The rocks, due to their properties (porosity, permeability, absorption capacity, degree of compaction), influence liquid and alluvial flow. Sediment flow varies according to the liquid flow. The low-flow channel and the flood plain are the result of the flow—structure—prior to the geo-morphological evolution relationship. The new element influencing the flow is induced by the hydrotechnical works performed in the entire basin. The Bistrita basin is the most developed in terms of hydrotechnical structures from the entire chain of the Eastern Carpathians and is the second most important in Romania, after the Arges (Siret Water Basin Administration 2011).

1.2 Methodology

This research relies on both new and old literature data (Assani et al. 2006; Blynth and Biggin 1993; Cameron 2007; Chidthong et al. 2009; Diakakis 2011; Gabitsinashvili et al. 2007; Gaume and Borga 2008; Gazelle and Maronna 2009; Khatibi 2011; Komma et al. 2007; Neuhold and Nachtnebel 2011; Portela and Delgado 2009; Potcoava et al. 2010; Romanian Space Agency 2008; Schumann and Geyer 1997; Seckin 2007; Strupczewski et al. 2006; Tockner et al. 2000), on the 1970–2011 cadastral documents, developed during investigations into the hydrometric stations (Siret Water Basin Administration) and on

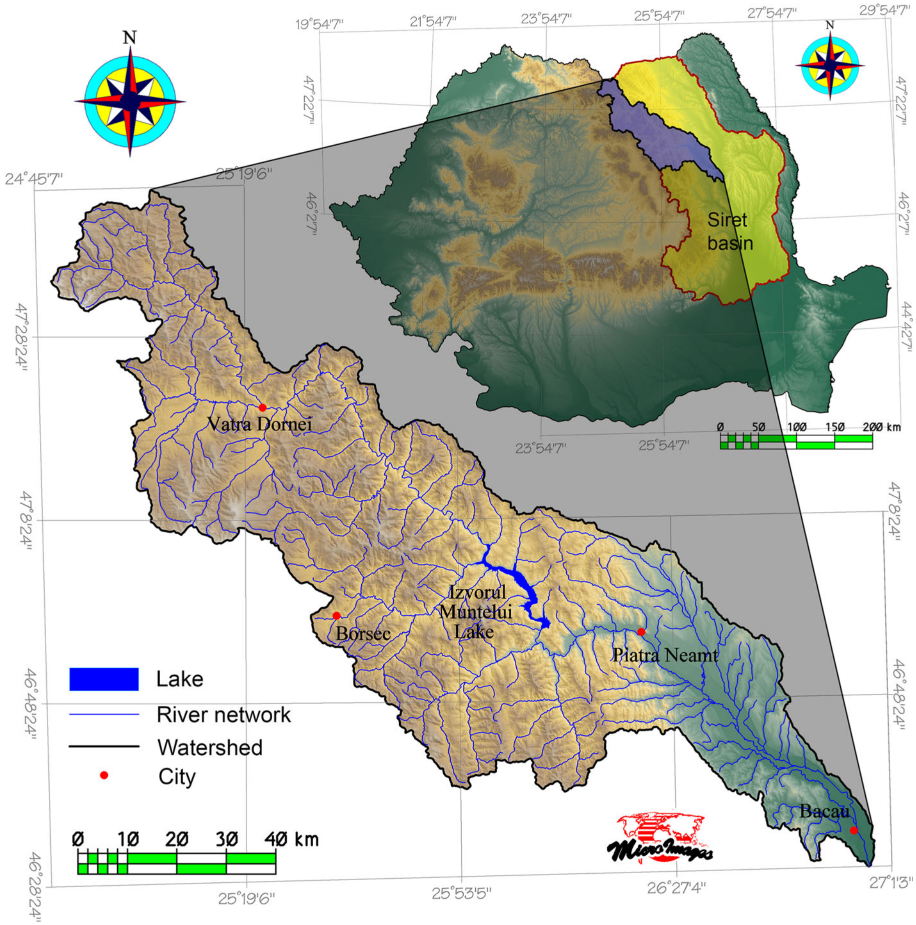


Fig. 1 Localization of the Bistrita drainage basin in Romania and in the Eastern Carpathians

personal field observations made during floods that have occurred between 1990 and 2011. The full ranges of meteorological (rainfall) and water data were obtained from the Siret Water Basin Administration in Bacau. This paper is based on the large amount of hydrometeorological data obtained from the monitoring network and expert information on current trends in the hydroclimatic zone. The database includes level measurements, corresponding flows, water and air temperature values, amounts of annual, monthly and daily rainfall, the minimum and maximum flows from the corresponding periods (contributing to the flow), and the Bistrita basin morphometric data.

The Bistrita basin has 30 hydrometrical stations where the water level, liquid and sediment discharge, water and air temperatures, rainfall, snow and water equivalents, and the evolution of winter phenomena are measured. In order to assess the temporal and spatial distribution of precipitation, data concerning observations on the maximum level of precipitation, recorded at hydrological stations with pluviometers within a 24-h period, have been analysed. Climatic and hydrological data were gathered, taking into account every phase of flooding in the basin.

The geological, geo-morphological, pedological and other data derived from professional literature and personal observations obtained during field trips were used. The cartographic basis was maps prepared by the Military Topographic Directorate of Romania and ANCPI Romania ortophotoplans on a scale of 1:25,000. Forestry data were taken from the Corine Land Cover 2000 (CLC2000) developed in 2004 by the Ministry of Environment and Sustainable Development. Graphic processing was performed using Microsoft Excel and ArcGIS programs in the Geo-Archaeology Laboratory of the Faculty of Geography and Geology from Iasi.

1.3 Results and discussions

Among major hydrological risks, floods are the most dynamic and the most dangerous, causing damage that on most occasions surpasses other phenomena of natural risk (Romanescu 2009). Floods have to be treated and understood both as a physical phenomenon and as a socio-economical phenomenon which both affect and are affected by human activity.

The hydroclimatic characteristics of the Bistrita basin share the East European specificity of a transitional continental climate in mountainous area. These characteristics affect the entire area of Eastern Romania, i.e., east of the Eastern Carpathians and the Moldavian Plateau (Romanescu et al. 2012a, b; Stefanache 2007). This position in the temperate zone produces great seasonal and annual variation of the climatic elements which determine hydrological risks. The limited latitudinal extension has no special hydroclimatic significance. Other physical–geographical factors, local and regional, and the human-activity elements produce significant differences between the areas from N to S, or W to E.

The drainage basin is situated at the interference of two climate provinces: firstly, East European, with major thermal and pluviometric discontinuities, torrential rainfall and frequent drought; secondly, West European, which is moister and more moderate thermally. The Eastern Carpathians represents a significant and complex geographical barrier in the circulation of air masses from west to the east. The air masses from the west that cross the Carpathians produce a slight foehn influence, causing early snowmelt in the Dorna depression (Romanescu and Bounegru 2012). The eastern air masses are forced to ascend and this results in orographic rainfall. Generally, these rains have a torrential character and occur during the summer (Romanescu and Nistor 2011). The continental transitional climate involves frequent and profound discontinuities in the rainfall regime (increase in the torrential degree) and run-off.

In the last two decades, exceptional rainfalls have been recorded on the majority of the hydrographic arteries in Eastern Romania, including the Siret, Trotus, Moldova, Prut and Tazlau. The Bistrita drainage basin cannot be excluded from this trend (Romanescu and Nistor 2011; Romanescu et al. 2011a). At a global level (and even local), the Romanian Territory experiences a process of climate aridization, but in the Siret drainage basin (in which the Bistrita is located), a slight increase in the multiannual average rainfall has been noticed (1990–2010). At the same time, an increase in drought during summer and an increase in the intensity of the rains in the warm season have also been noted. Maximum rainfall intensity is up to 200 mm/24 h, and average rainfall is 600–800 mm/year (Romanescu and Nistor 2011; Romanescu et al. 2012a).

The Bistrita was the first important river utilized for hydroenergetic purposes. Its hydroenergetic potential has drawn the attention of the Romanian hydromechanics pioneers (Leonida 1923; Pavel 1934) from the 1920s. This development involved major modifications in hydrological regime through enhanced regularization of the water flows and through the design of deep discontinuities in suspended load transport.

The Bistrita Valley is considered to be an important touristic landmark, comparable with the Arges where, along with the picturesque landforms, the great “works of art” of the hydropower engineers are found: dams, lakes, channels, viaducts and other such structures. The biggest reservoir by volume, on the interior rivers of Romania, is the Izvoru Muntelui–Bicaz (1,230 million m^3 and a surface of 3,260 ha), with a power plant of 220 MW, up and running since 1960. Eleven reservoirs were constructed downstream (Topoliceni, Izvoru Muntelui, Pangarati, Vaduri, Piatra Neamt—Batca Doamnei, Reconstructia, Racova, Garleni, Lilieci—Bacau I, Bacau II, on the Bistrita and Tasca on the Bicaz) and 14 power plants (Poiana Teiului, Stejaru, Pangarati, Vaduri, Piatra Neamt, Vanatori, Roznov, Zanesti, Costisa, Buhusi, Racova, Garleni, Lilieci, Bacau), with a total of 554 MW installed capacity. In 2004, the Poiana Teiului dam was built with the Topoliceni reservoir as tributary, in order to capitalize the hydroenergetic potential of the upper basin of the Bistrita River (upstream of the Izvoru Muntelui accumulation) but also as protection against ice jam phenomena which lead to catastrophic floods during spring. The 14 power plants have a total of 565 MW installed capacity. On the Bicaz, the main right tributary, the Tasca reservoir was built, which can supply the Izvoru Muntelui reservoir with water (Fig. 2). The 10 dams with reservoirs on the main course of the Bistrita, together with the Tasca dam on the Bicaz River, have as their main objectives the production of hydroelectric energy, the reduction of high floods, the provision of maintenance discharge downstream and aquaculture (Izvoru Muntelui).

The Izvoru Muntelui reservoir with a total water volume of 1,230 million m^3, “head of falls” together with Topoliceni reservoir on the Bistrita River, ensure the mitigation of high-flood waves and therefore protect the localities downstream of the dam, situated in the vicinity of the floodplain (up to the Pangarati reservoir). The useful volume of the reservoir (ranging between normal retention and maximum level of exploitation) is used for the takeover of the overlapping supplementary high floods.

The high degree of sedimentation for some reservoirs has resulted in the low volume of water taken up during floods (Pangarati 66.5 %; Vaduri 57.3 %; Garleni 54.9 %). The fact

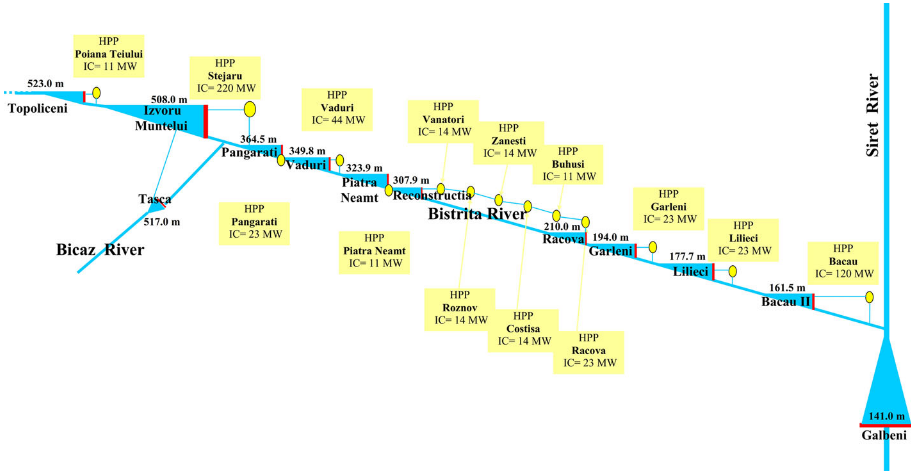


Fig. 2 Hydroenergetic scheme of the Bistrita River

that the Izvoru Muntelui reservoir, the biggest within this system, has a low degree of siltation (8.8 %) ensures that the floods are in major part controlled (Table 1). Rapid siltation occurring in other reservoirs means that on certain sectors downstream, floods have devastating effects.

1.4 Major floods in 1970

In 1970, nine dams and reservoirs were already functional, such as Izvoru Muntelui, Vaduri, Pangarati, Racova, Garleni, Lilieci, Bacau II, on Bistrita River and on the Bicaz River (Table 1). This year recorded the greatest floods on Romanian Territory which affected the entire country. Most of the rivers from Romania, including the Danube, reached historical flows, including the Mures, Somes, Viseu, Iza, Tur, Siret, Tarnava, Trotus, Olt and Crisul Repede. The Bistrita River was no exception (Mustatea 2005; Romanescu 2003). The causes behind the catastrophic floods on Romanian Territory were the heavy spring rains which cumulated in 48 h (12–14 May) to 50–100 mm (Fig. 3).

The heavy rains, with torrential character, overlapped with a long period of precipitation (January 1–May 10, with values between 100 and 400 mm). At the same time, the soil, especially in the mountain areas, was still frozen. As a consequence of the high humidity and extended frost, the largest amount of water (70–80 %) entered directly into the drainage system. In this context, the Eastern Carpathians was holding an important quantity of unmelted snow. Masses of hot tropical air accelerated the melting of the snow provoking catastrophic floods. The floods covered the entire Bistrita drainage basin, even though the hydrosystem was functional. Unfortunately, all the reservoirs were charged at full capacity and the streams downstream had bankfull discharge.

The synoptic situation within the Bistrita drainage basin demonstrated the existence of impressive rainfall quantities which displayed for 2 days. The high flood was triggered by precipitation that surpassed 80–90 mm on many occasions during 10–14 May 1970 (Table 2). The maximum flows recorded at the hydrometric stations in the Bistrita drainage

Table 1 Characteristics of the reservoirs on the Bistrita River

No	Accumulation	Year of commissioning	Height of the dam (m)	Initial volume NRL million (m^3)	Current volume NRL million (m^3)	Basin surface upstream (km^2)	Degree of sedimentation (%)
1	Poiana Teiului–Topoliceni	2004	15.5	0.7	0.7	2,886	0
2	Izvoru Muntelui	1960	127	1,230	1,122	4,022	8.80
3	Pangarati	1964	28	6.00	2.01	5,142	66.5
4	Vaduri	1966	27	5.60	2.39	5,213	57.3
5	Batca Doamnei	1963	22.3	10.0	6.50	5,290	35.0
6	Reconstructia	1963	8.15	0.25	0.23	5,403	8.00
7	Racova	1965	20	4.37	Empty	6,580	–
8	Garleni	1965	19	5.10	2.30	6,758	54.9
9	Lilieci	1966	19	7.40	5.40	6,775	27.0
10	Bacau	1966	18	4.60	4.42	6,814	3.90
11	Tasca	1980	20	0.10	0.09	512	0.01

NRL normal retention level (12. Galbeni reservoir = confluence with Siret River)

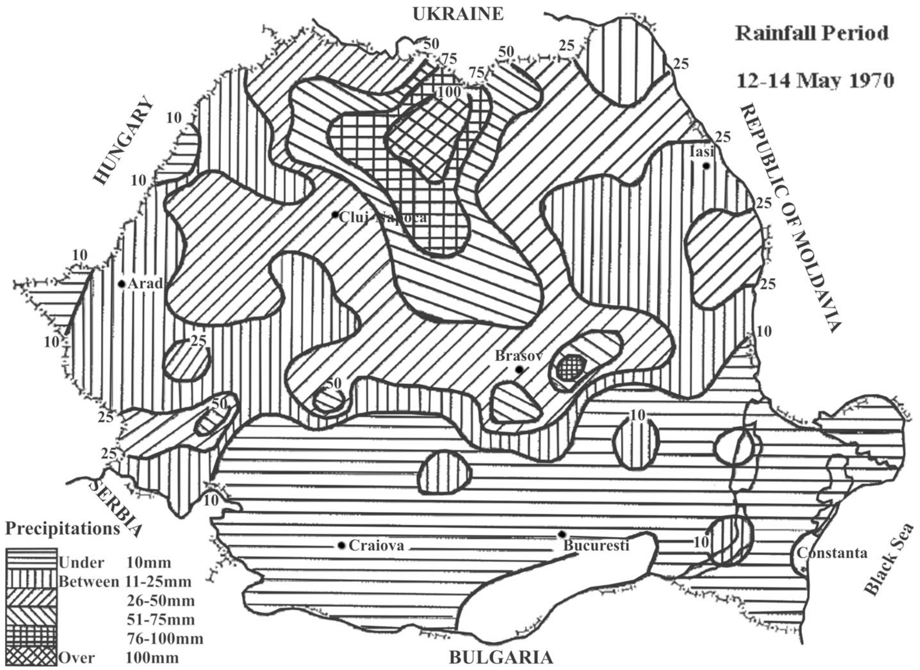


Fig. 3 Rainfalls from 12 to 14 May 1970 (adaptation after Mustatea 2005)

Table 2 Rainfalls from 4 to 16 May 1970 in the high mountain area of the Bistrita drainage basin (mm)

Pluviometric station	4.V	5.V	6.V	7.V	8.V	9.V	10.V	11.V	12.V	13.V	14.V	15.V	16.V	Total
Sesuri	10.5	7.5		4.6	2.9			18.2	18.2	14.7	12.0			72.0
Carlibaba	2.5	3.6		29.8	22.0	3.8	6.7	7.5	30.2	22.0	8.0			136.1
Vatra Dornei	2.6	4.0	6.7	5.0	2.8	1.5	9.0	6.5	13.7	38.8	8.8			99.4
Brosteni	9.2	9.3	22.6	2.5	7.8	7.5	2.5	13.9	12.4	42.2	6.3			121
Crucea	6.4	7.5	11.7	1.8	6.6	0.1	4.4	4.2	11.4	43.5	6.0			103.6
Panaci	14.1	8.0	17.7	6.6	7.6	14.9	4.6	5.0	16.1	24.2	10.9	7.4		137.1
Neagra Sarului	12.5	7.9	17.5	10.8	4.1	9.3	8.4	5.3	9.0	28.8	7.5	0.3		121.4
Paltinis	6.4	4.8	13.3	8.5		2.3	16.0	6.1	10.5	18.9	9.2	2.3	14.6	112.9

basin had registered relatively high historical values up to 1969 (Table 3). The average Bistrita multiannual flow in 1969 was 57.0 m^3/s at the Frunzeni hydrometric station (Table 4). The maximum flow recorded up to 1969 was 353 m^3/s at the Frumosu hydrometric station, on 9 June 1969.

In 1970, most of the hydrometric stations from the Bistrita drainage basin recorded historical flows, with a probability of surpassing over 5 % (Fig. 4; Tables 5, 6). All the localities situated in the river floodplain were flooded. The entire city of Vatra Dornei was flooded including the central part, the mining equipment plant, the forest unit and the cheese factory. In 1970, the flows from the Frumosu (772 m^3/s) and Dorna Arini (580 m^3/s)

Table 3 Maximum flow recorded in 1969

No	River	Hydrometric station	Maximum flow recorded up to 1969 (m^3/s)	Date
1	Bistrita	Carlibaba	78.4	8 June 1969
2	Bistrita	Dorna Giumalau	205	12 May 1958
3	Bistrita	Dorna Arini	327	13 May 1958
4	Bistrita	Frumosu	**353**	9 June 1969
5	Bistrita	Straja	40.0	14 April 1963
6	Bistrita	Frunzeni	No data available up to 1969	

Bold value indicates the maximum flow recorded on Bistrita River

Table 4 Average multiannual flow in 1969

No	River	Hydrometric station	Average multiannual flow 1950–1969 (m^3/s)
1	Bistrita	Carlibaba	7.03
2	Bistrita	Dorna Giumalau	11.9
3	Bistrita	Dorna Arini	23.0
4	Bistrita	Frumosu	34.4
5	Bistrita	Straja	49.9
6	Bistrita	Frunzeni	57.0

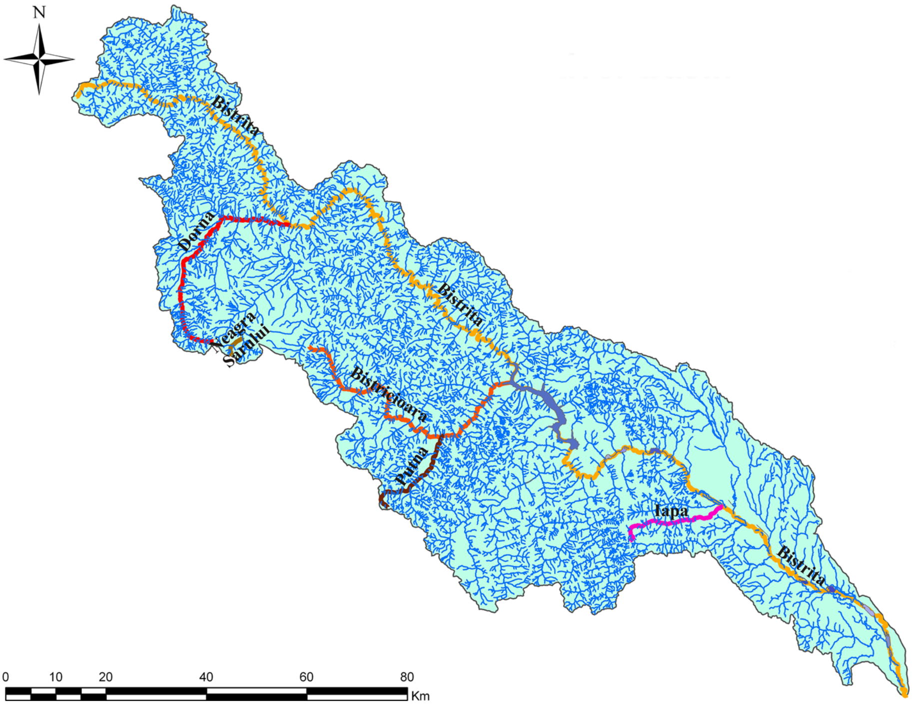


Fig. 4 Rivers affected by the floods of 1970

Table 5 Rainfalls regime monthly average during I–V 1970, comparative with multiannual average

Hydrometrical station	Rainfall during January–May 1970 (mm)									
	I	I[a]	II	II[a]	III	III[a]	IV	IV[a]	V	V[a]
Carlibaba	56.3	34.3	121.8	75.5	100.2	61.7	84.4	48.4	273.0	146.9
Dorna Arini	27.4	19.1	91.4	61.4	44.6	33.5	48.0	31.0	214.6	106.6
Brosteni	14.9	10.8	57.8	36.5	28.3	26.2	47.0	26.5	232.8	105.3
Frumosu	26.2	16.2	48.1	40.8	24.4	25.1	37.2	23.8	163.2	89.8

[a] Multiannual monthly average

Table 6 Maximum flows produced during floods in May 1970 in the Bistrita drainage basin

No	River	Hydrometric station	Maximum flow (m^3/s)	Data	P %
1	Bistrita	Carlibaba	170	13.V	5
2	Bistrita	Dorna Giumalau	310	13.V	10
3	Bistrita	Dorna Arini	580	13.V	5–10
4	Bistrita	Frumosu	772	13.V	5–10
5	Carlibaba	Carlibaba	29.6	13.V	50
6	Dorna	Dorna Candreni	180	13.V	5–20
7	Neagra Sarului	Gura Negri	98.0	13.V	20
8	Neagra Brosteni	Brosteni	50.4	13.V	50
9	Bistricioara	Tulghes	48.4	13.V	Insignificant
10	Putna	Tulghes	13.2	13.V	Insignificant
11	Iapa	Luminis	66.0	13.V	Insignificant

[a] P insurance (%)

stations were higher than those recorded prior to 1969 (Frumosu 453 m^3/s and Dorna Arini 327 m^3/s). These are flows recorded in the superior sector, which cannot be controlled by the reservoirs. At the same time, the construction of the Izvoru Muntelui reservoir has changed the slope of the Bistrita superior sector. The shortening of the route has increased the slope and directly increased current velocity.

1.5 Major floods in 1991

After a relatively dry period (1980–1990), in 1991 torrential rainfall triggered catastrophic floods (July–August). Rainfall collected by the Bistrita River basin during the spring and summer of 1991 exceeded the annual amounts in just 3 months (May, June, July) (Olariu and Nour 1997). In the lower course of the Bistrita, the precipitation amount for the specific 3 months reached 106 % (558.3 mm, whereas the annual average was 526.7 mm) (Mustatea 2005). Even though there had been 9 years of drought, the rainfall recorded in 3 months generated the highest floods causing the greatest damage in the history of the Bistrita basin. At the same time, there were floods in the river basins of Moldova, Trotus, Putna and in the main collector Siret.

Synoptic conditions at the end of July 1991 had resulted in unstable weather with isolated rainfall, overlapping with an excessive rainfall background in the period January–

Table 7 Monthly average levels of precipitations for January–July 1991 in comparison with annual averages

Hydrometrical station	Precipitations during January–July 1991 (mm)													
	I	I[a]	II	II[a]	III	III[a]	IV	IV[a]	V	V[a]	VI	VI[a]	VII	VII[a]
Cuejdiu	14.8	27.4	23.9	29.7	33.8	37.8	52.7	70.4	199.0	109.7	95.0	126.1	346.3	117.7
Luminis	7.3	25.2	24.2	29.0	23.4	30.7	47.6	69.9	187.9	104.6	154.3	117.8	324.5	102.2
Slobozia	8.5	15.4	19.8	17.6	21.8	20.9	44.0	43.9	213.3	76.6	137.0	89.4	369.4	94.1

Table 8 Highest precipitation amounts during 28–29 July 1991

No	River	Hydrometrical station	Precipitation (mm)
1	Ozana (Neamt)	Dumbrava	234.5
2	Cracau	Dobreni	139.4
3	Nechit	Borlesti	156.9
4	Bistrita	Frunzeni	153.6

Table 9 Maximum levels registered on the main rivers in the Bistrita River basin in 1991

River	Hydrometrical station	CA	CI	CP	Level (cm)	Flow (m^3/s)
Bistrita	Frumosu	200	250	300	214	226
Bistrita	Straja	150	250	350	**226**	211
Bistrita	Frunzeni	100	150	200	225	800
Bicaz	Tasca	150	200	250	214	76.5
Cuejdiu	Cuejdiu	130	170	200	141	150
Iapa	Luminis	180	250	350	254	217
Cracau	Magazia	100	170	220	120	34.0
Cracau	Slobozia	250	300	350	**366**	156
Nechit	Borlesti	0	100	150	**200**	66.9

CA–warning level, CI–flood level, CP–danger level

Bold value indicates the maximum level recorded on Bistrita River, Cracau River and Nechit River

July (Table 7). On 28 July 1991, pressure was low, while the temperature and humidity were high. On its course towards NNW, the retrograde front met the peaks of the Moldavian Subcarpathians and of the Eastern Carpathians, where orographic rainfall was very large, in general. These quantities of historical value could not be measured in all places due to the lack of representative pluviometric stations. Precipitation is measured only in Dumbrava hydrometric station on the Ozana River (234.5 mm), in Dobreni station on the Cracau River (139.4 mm), in Borlesti station on the Nechit River (156.9 mm), and in Frunzeni station on the Bistrita River (153.6 mm) (Table 8). At the majority of the meteorological stations and pluviometric stations in the National Administration of Meteorology network, precipitation levels were lower, which emphasizes the local aspect of the precipitation. Moreover, quantitative differences were very high in some cases.

Historical values were recorded on the Iapa River, at the Luminis hydrometrical station (217 m^3/s), and on the Nechit River, at the Borlesti station (66.9 m^3/s) (Table 9). Danger level for the Bistrita was exceeded at Frunzeni (225 cm). The danger level was also exceeded on the Cracau River (Slobozia station) and the Nechit (Borlesti station) (Table 9).

The highest flood levels occurred on small tributaries with watersheds by deforestation and great longitudinal slopes: Cuejdiu, Iapa and Cracau (Figs. 5, 6, 7, 8, 9). The maximum flows recorded in the three stations were 55.7, 217 and 124 m^3/s, respectively. At the Cuejdiu hydrometric station, the recorded flow was also the highest in history. At the other hydrometric stations, historical flow values were recorded in the 1970s. In this case, the alluvial transport was also extremely high. Additionally, anthropogenic activity also led to flooding on the three streams. After 1989 and the overthrow of the Communist regime,

Fig. 5 Monthly flow in 1991, in comparison with Cuejdiu annual average

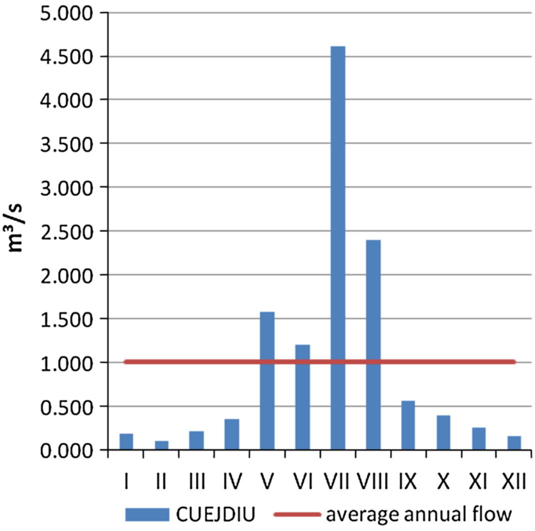


Fig. 6 Monthly flow in 1991, in comparison with Iapa annual average

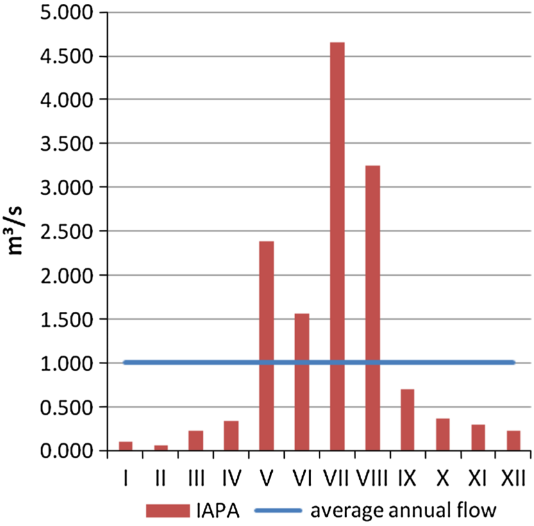
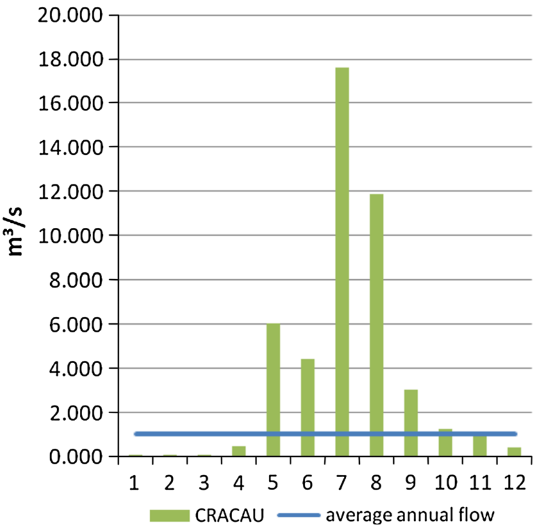


Fig. 7 Monthly flow in 1991, in comparison with Cracau annual average



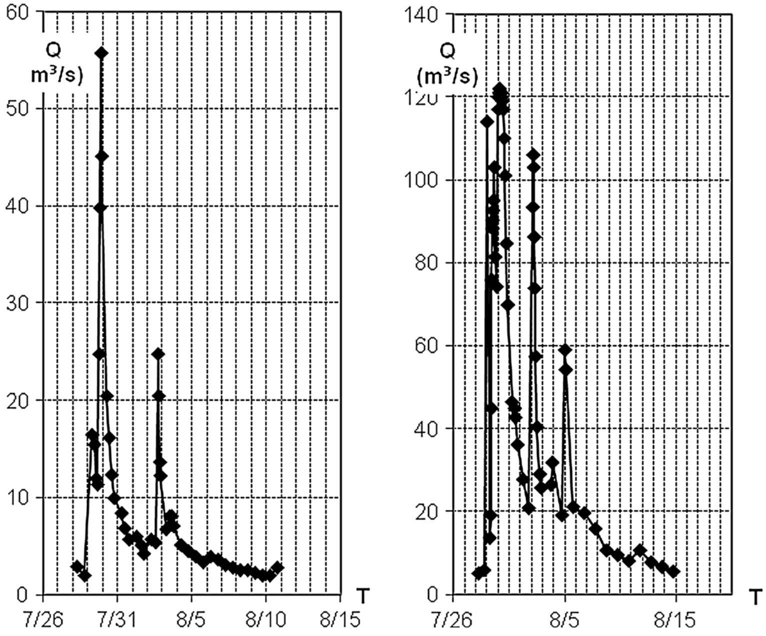


Fig. 8 Flood hydrograph in July–August 1991 for Cuejdiu and Cracau hydrometrical stations

most rural residents illegally occupied the river valleys, building homes or carrying out economic activities (such as wood processing, agriculture and exploitation of the riverbed gravel). This caused the virtual elimination of the floodplain, and flood waters were accommodated within a much reduced section. Most culverts have very small openings with waste blocking the water discharge.

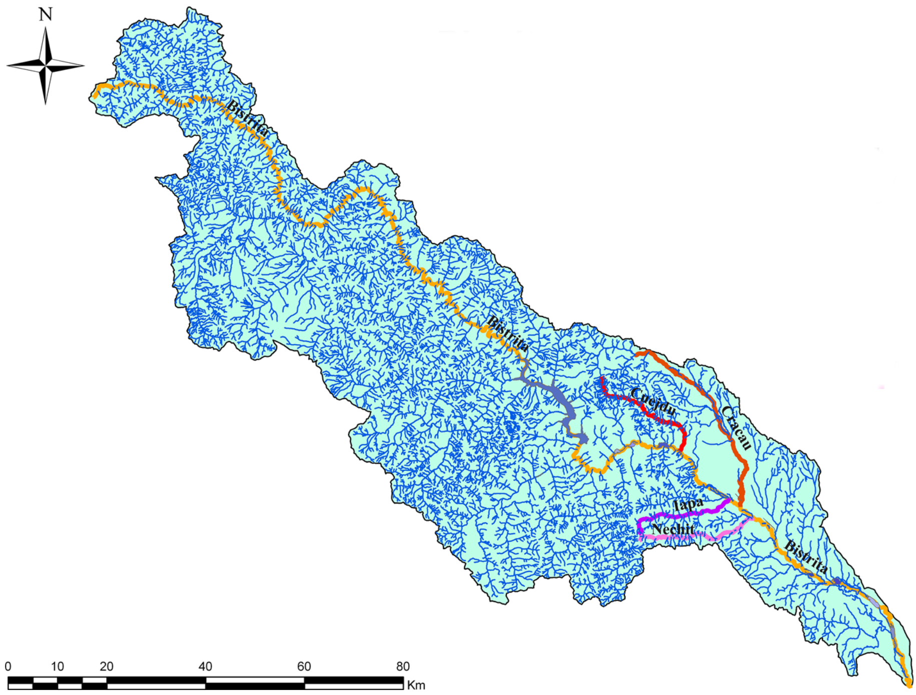


Fig. 9 Rivers affected by floods in 1991

A very important issue determining flooding is represented by the excessive deforestation on very large areas (Table 10). These tend to contribute to torrential precipitation in reservoirs; when they overheat during hot summer days, they consequently cause the rapid lifting of air masses. Heavy advection showers take place, often catastrophic for small reservoirs.

Most secondary river basins have high afforestation levels (Neagra 83.3 %, Dornisoara 82.3 %, Cuejdiu 77.9 %). Unfortunately the extent of deforestation in recent years has been quite high: for example, −9.5 % and −9.1 % for Bistricioara, and −10.6 % for Bicaz (Table 10). Reduced soil depth and impermeable rocks cause rainwater to completely drain the topographic surface.

The damage and loss of life caused by the Bistrita floods in 1991 was extremely high. Houses and annexes, agricultural and socio-economic objectives, roads, county and municipal bridges, culverts and hydrotechnical structures were affected. The total damage was estimated at 95 million USD (for 1991) (Table 11).

1.6 Major floods in 2005

In the summer of 2005, the highest flows on the Siret River were recorded (the main collector of the Bistrita River), with 4,650 m^3/s at the Lungoci hydrometric station, situated in the vicinity of the confluence with the Danube. It has to be mentioned that this flow was the highest of all Romanian inland rivers in 2005 (Romanescu and Nistor 2011). Based on the reconstruction of the flows from the sectors where there are no hydrometric stations, the conclusion has been drawn that in the Cosmesti sector the flow was between 5,000 and

Table 10 Evolution of forest areas during 1991–2006 (after CORINE LAND COVER)

No	River	Hydrometrical station	Reservoir surface (km^2)	Forest surface 1990 (km^2)	Forest surface 2006 (km^2)	Evolution of forest area 1990–2006 (km^2)	Evolution of forest area 1990–2006 (%)	Forest area percentage 2006 (%)
1	Bistrita	Dorna Giumalau	758	572.2	545.9	−26.3	−4.6	72
2	Bistrita	Dorna Arini	1,690	1,005.1	957.7	−47.4	−4.7	56.7
3	Bistrita	Frumosu	2,858	1,994.1	1,941	−53.1	−2.7	67.9
4	Bistrita	Straja	5,118	3,495.9	3,379.1	−116.8	−3.3	66
5	Carlibaba	Carlibaba	111	85.1	80.8	−4.4	−5.1	72.8
6	Dorna	Poiana Stampei	132	111.3	108.5	−2.8	−2.5	82.2
7	Dorna	Dorna Candreni	565	420.3	412	−8.4	−2	72.9
8	Dornisoara	Poiana Stampei	47	41.5	38.7	−2.8	−6.8	82.3
9	Neagra	Sura	48	36	36	0	0	75
10	Neagra	Gura Negri	312	147	136.2	−10.8	−7.3	43.7
11	Haita	Gura Haitei	40	30	29.8	−0.2	−0.6	74.5
12	Sarisor	Panaci	44	15.8	15.3	−0.5	−3	34.8
13	Neagra	Brosteni	292	247.5	243.2	−4.2	−1.7	83.3
14	Bolatau	Poiana Largului	59	39.1	39.1	0	0	66.3
15	Bistricioara	Tulghes	408	252.4	228.4	−24	**−9.5**	56
16	Bistricioara	Bistricioara	760	505.1	459.3	−45.9	**−9.1**	60.4
17	Schit	Ceahlau	40	28.6	28.6	0	0	71.6
18	Bicaz	Tasca	496	235.2	210.3	−24.9	**−10.6**	42.4
19	Cuejdiu	Cuejdiu	65	50.8	50.6	−0.2	−0.4	77.9

Bold value indicates the areas most affected by defforestation

Table 11 Damages recorded in the Bistrita River basin 1991

No	Affected area	Neamt county
1	Localities	66
2	Deceased population	3
3	Houses and annexes	3,447
4	Agricultural area (ha)	–
5	Deceased animals (heads)	172
6	Socio-economical objectives	26
7	National, county and communal roads (km)	115.4
8	Streets (km)	54.1
9	Forest roads (km)	–
10	Railroad (km)	–
11	Bridges and culverts	221
12	Hydrotechnical structures	7

5,500 m^3/s (Romanescu and Nistor 2011; Romanescu et al. 2011a, b). This value has been surpassed by the Prut River, situated in the east of Romania, in 2008 with a historical flow value of 7,146 m^3/s (Romanescu et al. 2011b). The floods from 2005 have recorded maximum flows for most of the water streams from the east of Romania.

For the floods in 2005, a series of natural factors have to be taken into account, as well as the human factors which generated the production of this hydrometeorological phenomenon. Regarding natural factors, the following have to be mentioned: the rainfalls with torrential character, the soil saturation with water, high slope and the nature of the lithology which does not favour infiltration. As far as the human impact is concerned, there are several factors that have to be taken into consideration: the high degree of deforestation, especially in the small drainage basin, the insufficient dimensions of hydrotechnical structures for the transportation of high sediments specific to the mountain areas, the poor maintenance of the minor and major riverbed, over lodging of the major riverbeds with poorly located construction and the high degree of warping of some reservoirs.

The synoptic situations from 10–14 July 2005 show that on Romanian Territory at the soil level, a contact was produced between the Azores maximum baric dorsal, which occupies Central Europe and the lowlands from the south-east of Europe. For the Balkan Peninsula, a well-organized depressionary core was formed, which surpassed the level of 500 hectopascals. This core absorbed the air of tropical origin, which was interfering with the Atlantic mass. Because of the long duration, over 48 h, high quantities of precipitation were produced. The sites most affected by the rainfalls were situated in the middle and the inferior drainage basin of the Bistrita River (subbasins: Bistricioara, Schit, Bicaz, Tarcau, Cuejdiu, Cracau, Nechit and Trebes) (Siret Water Basin Administration 2005).

The first 6 months of 2005 were characterized, in general, by excessive of monthly rates of precipitation. With the exception of March, which was the driest, in other months the precipitation value rates were over the limit in almost all of the areas under discussion. The exceeding character of the precipitation was quite obvious in May and especially in June (Table 12).

The surpassing of the normal values of precipitation in June was, according to the monitoring, over 159 %. The relatively large quantities of precipitation were able to compensate for the soil moisture deficit recorded in the previous years and create humidity

Table 12 Monthly average levels of precipitations for January–June 2005 in comparison with annual averages

Hydrometrical station	Rainfall during January–June 2005 (mm)											
	I	I[a]	II	II[a]	III	III[a]	IV	IV[a]	V	V[a]	VI	VI[a]
Tasca	24.2	17.6	16.2	18.5	22.6	28.8	58.9	57.1	76.5	78.8	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
Luminis	40.4	23.8	42.7	27.1	20.7	34.4	50.7	64.3	74.5	93.5	109.7	112.3
Magazia	44.9	22.8	42.2	27.1	28.5	34.4	67.9	63.8	89.3	73.5	103.0	104.6
Slobozia	21.8	15.1	59.9	16.5	12.5	22.9	46.1	43.5	106.7	69.9	68.0	89.9
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
Bacau	18.0	24.3	0.0	22.4	4.5	26.9	1.6	48.5	18.9	68.7	22.2	82.5

[a] Multiannual monthly average

Table 13 Monthly average levels of precipitations for the first 10 days of July 2005 in comparison with monthly averages

Hydrometrical station	Rainfall during 1–10 July 2005 (mm)											Monthly average of July
	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
Cuejdiu	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
Borlesti	20.9	0.0	1.6	2.2	0.0	0.0	12.8	0.0	0.0	14.4	51.9	108.6

excess in the mountain area. The high humidity had led to a saturation of the soil and the result was more pronounced run-off. The humidity reserves from the mountain area soil, where the recalled hydrological phenomenon took place, were oversaturated. Against this general background, with wet and cool weather, there were some local sequences with strong showers which caused exceptional run-off on the slopes and floods on the small river courses.

The phenomenon was generated by the massive deforestation through the last decades. In the first 10 days of July, daily precipitations were recorded with moderate values, with local intensifications in the middle sector of the Bistrita River (1 July 2005) (Table 13).

It can be noticed that the precipitations in the first 10 days of June were very high, representing 30–50 % of the average values of this month (Table 14). Between 11 and 14 July 2005, the registered maximum values were 172.4 mm at Luminis on the Iapa River, 164.0 mm at Borlesti on the Nechit River and 160.2 mm at Straja on the Bistrita River. On 10 July 2005, rainfalls were general all along in the Bistrita River. These daily rainfalls maintained relatively high flows on the water streams, over the monthly multiannual average values (sometimes double) (Fig. 10). In most hydrometric monitoring stations, the defence limits were exceeded, and some of the high floods had a catastrophic character (Tables 15, 16). The recorded historical flows can be noticed at the Straja station (650 m^3/s) and Frunzeni (1,208 m^3/s) (Figs. 11, 12).

Table 14 Rainfall in the Bistrita drainage basin during 11–14 July 2005

Code	River	Hydrometrical station	Rainfall in July 2005 (Mm)			Total
			July 11–12	July 12–13	July 13–14	
42763	Bistrita	Carlibaba	1.9	11.1	0.0	13.0
42765		Dorna Giumalau	1.0	8.0	0.0	9.0
42766		Dorna Arini	0.6	18.6	0.0	19.2
42768		Brosteni	2.4	16.9	0.0	19.3
42780		Frumosu	6.5	29.3	1.0	36.8
42783		Straja	65.0	92.2	3.0	160.2
42785		Frunzeni	16.2	52.0	3.1	71.3
42787	Carlibaba	Carlibaba	1.9	11.1	0.0	13.0
42790	Dorna	Poiana Stampei	1.5	13.0	2.0	16.5
42791	Dorna	Dorna Candreni	0.8	7.4	1.3	9.5
42769	Dornisoara	Poiana Stampei	1.5	13.0	2.0	16.5
42794	Tesna	Cosna	0.5	2.9	2.4	5.8
42795	Bancu	Cosna	0.5	2.9	2.4	5.8
42801	Sabasa	Sabasa	5.2	37.0	1.2	43.4
42803	Bolatau	Poiana Largului	0.0	35.9	3.2	39.1
42806	Bistricioara	Tulghes	39.2	22.3	2.5	64.0
42808		Bistricioara	19.6	104.0	0.0	123.6
42811	Putna	Tulghes	39.2	22.3	2.5	64.0
42812	Schit	Ceahlau	35.0	74.5	3.0	112.5
42816	Bicaz	Bicaz Chei	42.0	35.5	3.8	81.3
42817	Bicaz	Tasca	43.2	62.2	1.5	106.9
42820	Cuejdiu	Cuejdiu	17.2	83.5	10.2	110.9
42821	Iapa	Luminis	39.4	133.0	0.0	172.4
42822	Cracau	Magazia	8.0	55.0	0.0	63.0
42825		Slobozia	14.0	62.7	14.0	90.7
42826	Nechit	Borlesti	28.6	127.0	8.4	164.0

The precipitation quantities from the middle and lower basin of the Bistrita River were higher than from the upper drainage basin. Thus, between 11 and 14 July, the following values were recorded: 160.2 mm in Straja, 123.6 mm in Bistricioara, 112.5 mm in Ceahlau, 106.9 mm in Bicaz Chei, 119.9 mm in Cuejdiu, 90.7 mm in Roznov-Slobozia, 164.0 mm in Borlesti, 146.3 mm in Buhusi, 168.7 mm in Garleni and 157.4 mm in Luncani. The maximum flow produced at the Straja hydrometric station, which controls 1,051 km^2 out of 3,000 km^2 of the drainage basin to the downstream Bicaz dam, was 650 m^3/s plus the values discharged in the Izvoru Muntelui dam (Table 17). This flow corresponds to the flows from Strejaru hydroelectric plant and to the difference of the drainage basin downstream, leading to the value of 1,400 m^3/s (reconstructed flow), and this had to be crossed through the accumulation system from Pangarati to Bacau. Manoeuvres were warned in advance by SC HIDROELECTRICA SA, and no major event occurred at the confluence with the Siret River.

In the drainage basin of the Trebes River, an intense flash flood of great dimensions took place, which produced further flooding including the northern sector of the Bacau

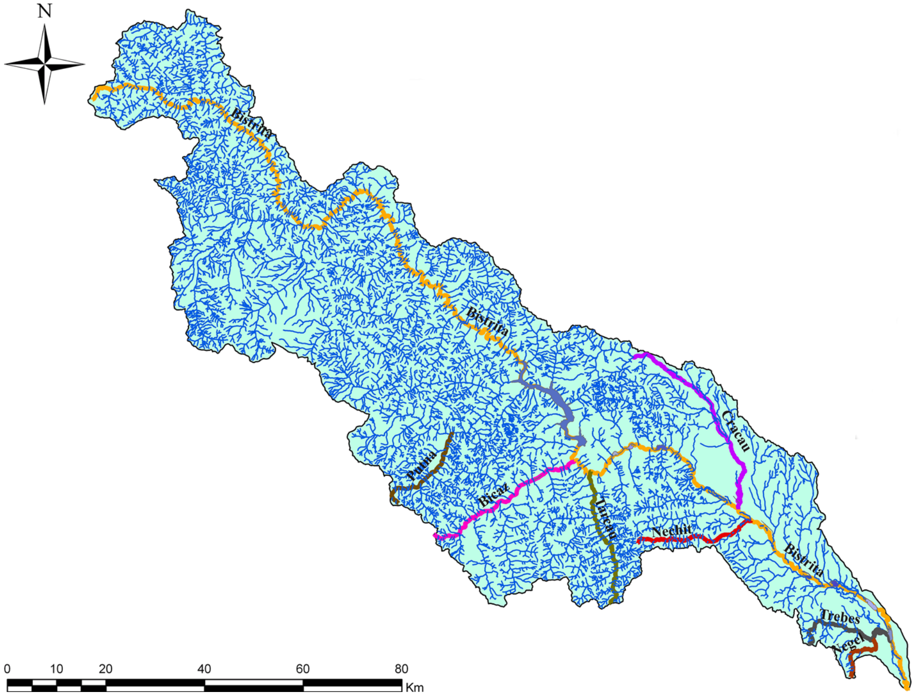


Fig. 10 Rivers affected by floods in 2005

Municipality, due to the dam breach on the Negel River and the lack of protection dams on the Trebes River. The maximum flow recorded on the Negel River, at Magura hydrometric station, was 26.0 m^3/s and on the Trebes River, at Margineni hydrometric station, 130 m^3/s. The high flow on the Trebes River could not be held by the national road bridge, which led to an upstream afflux which flooded the dammed downstream of the Negel River and broke the protection dams. Because of the overflows and floods produced in the north part of Bacau, on the Barnat River (the lower stream of the Trebes River), the recorded value of the maximum flow was 68.0 m^3/s.

The reservoirs on the Bistrita River contributed partially to artificially raised flood levels. Exploited in normal conditions, these reservoirs could have ensured the reduction in the high flood on the Bistrita River. The maximum flows evacuated out of the Bistrita River, on Piatra Neamt sector, exceeded 1,400 m^3/s. Unfortunately, the Galbeni–Racaciuni–Beresti lacustrine complex (downstream of the confluence of the Bistrita and the Siret) could not reduce water volumes. Houses and annexes, infields, social economic objectives, national and county roads, and bridges were affected, and the total value of the damages ran to 169.66 million USD in 2005 (Table 18).

1.7 Major floods in 2010

Between 17 June and 10 July 2010, a period of atmospheric instability generated frequent showers for 2–3 days. In this case, the Pontic cyclone retrograde evolution was extremely complex. Considering high atmospheric pressure over the Russian Plain and in Central-

Table 15 Maximum flows and levels during the 12–15 July flash flood 2005

Code	River	Hydrometrical station	CA	CI	CP	Maximum level (cm)	Maximum flow (m^3/s)	Data/ Hour	Precipitation (mm)	Multiannual average flow (July)
42763	Bistrita	Carlibaba	150	200	250	–	–	–	13.0	9.15
42765		Dorna Giumalau	200	250	300	–	–	–	9.0	15.1
42766		Dorna Arini	220	300	350	–	–	–	19.2	30.6
42768		Brosteni	150	250	300	–	–	–	19.3	–
42780		Frumosu	250	300	350	–	–	–	36.8	49.3
42783		Straja	300	400	500	440	**650**	12/22	160.2	72.9
42785		Frunzeni	200	250	300	310	**1,208**	12/22	71.3	82.5
42787	Carlibaba	Carlibaba	150	200	250	–	–	–	13.0	2.25
42790	Dorna	Poiana Stampei	100	120	150	–	–	–	16.5	2.85
42791	Dorna	Dorna Candreni	150	200	250	–	–	–	9.5	8.75
42797	Neagra Sarului	Gura Negrii	100	150	250	–	–	–	0.0	5.31
42769	Dornisoara	Poiana Stampei	100	120	150	–	–	–	16.5	0.77
42794	Tesna	Cosna	150	200	250	–	–	–	5.8	3.15
42795	Bancu	Cosna	100	150	200	–	–	–	5.8	1.62
42770	Sarişor	Panaci	80	110	130	–	–	–	–	0.86
42801	Sabasa	Sabasa	80	150	200	–	–	–	43.4	1.36
42803	Bolatau	Poiana Largului	100	150	200	–	–	–	39.1	0.71
42806	Bistricioara	Tulghes	150	200	250	–	–	–	64.0	4.07
42808		Bistricioara	100	180	250	150	102	12/20	123.6	.8.06
42811	Putna	Tulghes	100	200	250	233	51.3	12/14	64.0	1.74
42812	Schit	Ceahlau	–	50	150	25	29.5	12/20	112.5	0.67
42816	Bicaz	Bicaz Chei	150	200	250	195	54.5	12/15	81.3	3.54
42817		Tasca	220	270	320	300	188	12/3.30	106.9	6.17
42820	Cuejdiu	Cuejdiu	100	170	200	–	–	–	110.9	0.60

Table 15 continued

Code	River	Hydrometrical station	CA	CI	CP	Maximum level (cm)	Maximum flow (m^3/s)	Data/ Hour	Precipitation (mm)	Multiannual average flow (July)
	Tarcau	Cazaci	200	250	300	360	217	12/20	–	–
42821	Iapa	Luminis	180	250	350	–	–	–	172.4	0.95
42822	Cracau	Magazia	100	170	220	–	–	–	63.0	1.20
42825		Slobozia	250	300	350	272	86.8	13/12	90.7	2.02
42826	Nechit	Borlesti	–	100	150	–	–	–	164.0	0.88
	Trebes	Margineni	80	150	250	640	130	13/9	–	–
	Negel	Magura	80	150	250	118	8.80	13/6	–	–

CA–warning level, CI–flood level, CP–danger level. There have not been registered maximum flows at the hydrometrical stations with no special relevance

Bold value indicates the most significant flows recorded on Bistrita River

Table 16 Maximum flows registered during the flash flood from 12–17 July 2005

No	River	Hydrometrical station	Average flow VII (m^3/s)	Maximum flow (m^3/s)	P^* %
1	Bistrita	Straja	72.9	626	2
2	Bistrita	Frunzeni	82.5	1,208	5

* P-insurance

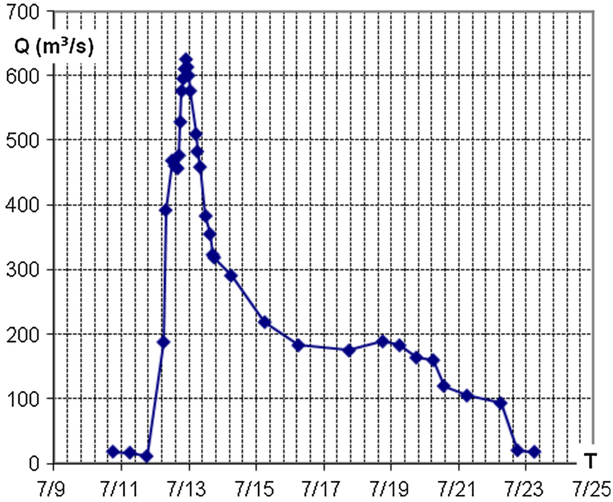


Fig. 11 Flash flood during 9 to 23 July 2005 at the hydrometrical station Straja on the Bistrita River

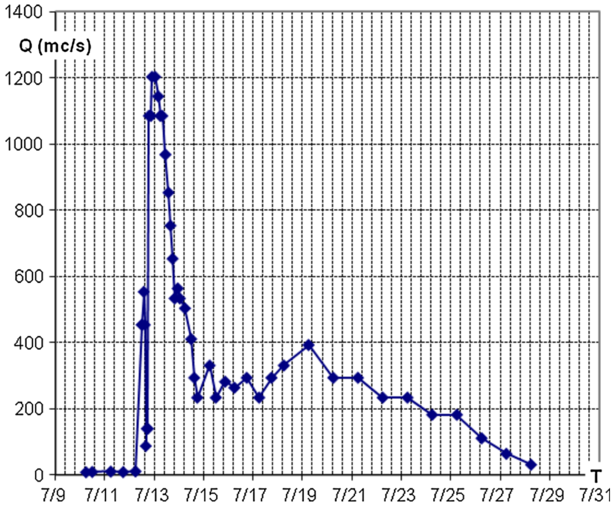


Fig. 12 Flash flood during 7 to 27 July 2005 at the hydrometrical station Frunzeni on the Bistrita River

Table 17 Deffluent flow from Izvoru Muntelui reservoir

No	Data	Level (cm)	Volume million (m^3)	Affluent flow (m^3)	Deffluent flow (m^3)
1	11.07	512.28	1,099.291	96.4	7.30
2	13.07	513.11	1,123.040	317.0	95.8
3	14.07	**513.40**	**1,132.899**	250.0	105
4	15.17	513.28	1,128.819	247.0	180
5	16.07	513.06	1,121.339	184.0	265
6	17.07	512.82	1,116.248	186.0	292
7	18.07	512.47	1,105.258	160.0	285
8	19.07	512.02	1,091.127	144.0	300

[a] FI–513 cm; FII–519.5 cm; FIII–520 cm

Table 18 Damages recorded in the Bistrita River basin 2005

Affected area	Suceava county	Value dollars	Neamt county	Value dollars
Localities	87	40.6 million	54	25.2 million
Deceased population	3	∞	–	∞
Houses and annexes	192	309 thousands	302	486 thousands
Agricultural area (ha)	4123	669 thousands	5012	813 thousands
Socio-economical objectives	23	27.4 million	1	1.19 million
National, county and communal roads (km)	656	38.9 million	79	4.68 million
Streets (km)	–	–	38.5	583 thousands
Forest roads (km)	154	2.67 million	96.2	1.67 million
Railroad (km)	–	–	–	–
Bridges and culverts	785	14.7 million	410	7.70 million
Hydro technical constructions	–	–	20	1.37 million

Western Europe (increased by the general circulation of air masses from the west), the evolution of the cyclone developed through several stages. Between 29 June and 28 July 2010, a third cycle of rainfall affected the Bistrita basin, downstream of the Izvoru Muntelui dam (subbasins Bistricioara, Bicaz, Tarcau and their small tributaries, the Trebes and Negel) (Fig. 13; Table 19). Important exceeding on the monthly average flows for the months of June (184.8 mm) and July (171.4 mm) can be noticed.

All of the floods caused a great deal of damage and casualties. It is necessary to mention that in the third cycle of high rainfall, which caused the biggest flood, the Pontic cyclone air masses, on the east–west direction, met the Western European, heading east, which increased the torrential stream and rainfall quantity. Heavy rains generating significant floods occurred during the night of 27–28 July 2010 in the drainage basin of the Trebes River and in Bacau. Precipitation amounts consisted of 144.3 mm in Podis, 110.7 mm in Luncani, 99.3 mm in Magura, 92.8 mm in Margineni and 108 mm in Bacau. The rainfall intensity is notable, especially at the beginning: Magura—27.5 mm in 50 min (01:00–1:50 AM); Bacau Weather Station—49.2 mm in 50 min (01:05–10:55 AM) and Podis—104.3 mm in 6 h (01:00–07:00 AM). The result of these precipitations consists in quickly

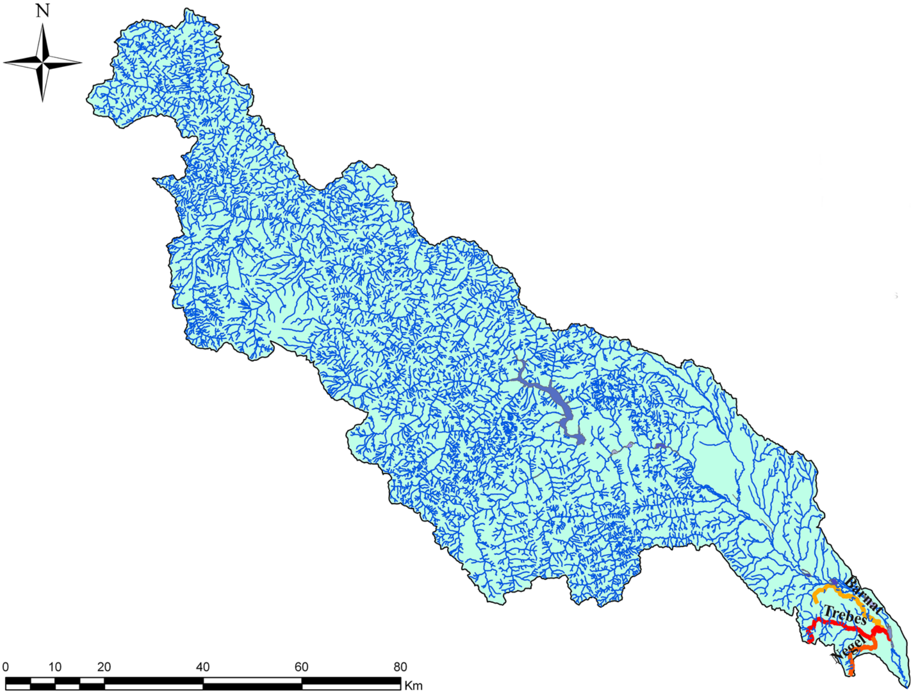


Fig. 13 Rivers affected by floods in 2010

Table 19 Monthly average levels of precipitations for January–July 2010 in comparison with annual averages

Hydrometrical station	Rainfall during January–July 2010 (mm)													
	I	I[a]	II	II[a]	III	III[a]	IV	IV[a]	V	V[a]	VI	VI[a]	VII	VII[a]
Bacau	34.7	22.3	43.2	21.7	29.2	32.5	43.0	50.5	92.2	59.3	184.8	92.1	171.4	108.0

[a] Multiannual monthly average

Table 20 Maximum levels recorded in the drainage basin of the Bistrita River in the summer of 2010

No	River	Hydrometrical station	Defence level (cm)			Maximum level (cm)	Time frame
			CA	CI	CP		
1	Trebes	Podis	250	300	350	375	7^{50}–9^{30}
2	Trebes	Luncani	350	400	500	495	8^{10}–9^{20}
3	Trebes	Valea Budului	200	300	400	426	9^{50}–10^{30}
4	Trebes	Margineni	350	400	500	726	13^{05}–14^{20}
5	Barnat	Bacau	200	250	300	326	14–15
6	Negel	Magura	80	150	250	275	8^{50}–9^{20}

CA–warning level, CI–flood level, CP–danger level

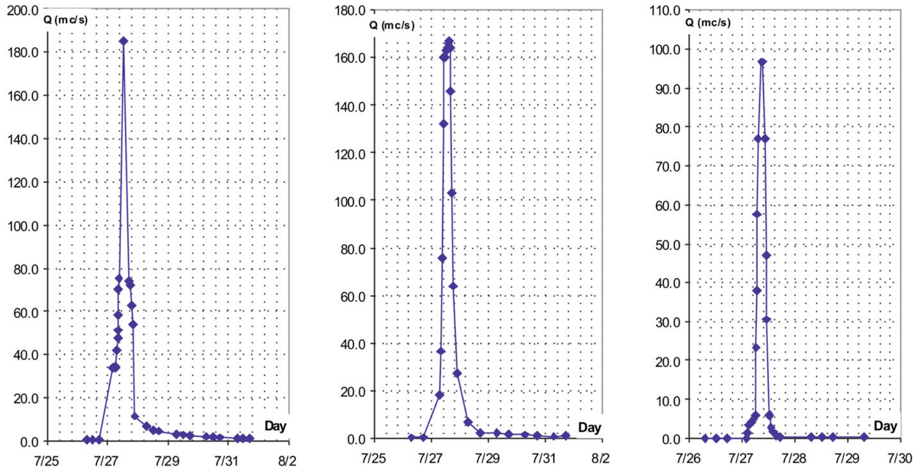


Fig. 14 Flash floods hydrographs from July 2010 on the Trebes River, the Barnat River and the Negel River

Table 21 Damages recorded in the Bistrita River basin in 2010

No	Affected area	Suceava county	Value dollars	Neamt county	Value dollars
1	Localities	108	64.9 millions	77	46.3 millions
2	Deceased population	10	∞	–	–
3	Houses and annexes	6,272	791 thousands	518	653 thousands
4	Agricultural area (ha)	12,573	1.76 millions	7,274	1.02 millions
5	Socio-economical objectives	23	207 thousands	6	540 thousands
6	National, county and communal roads (km)	1,185	15.0 millions	283.4	3.59 millions
7	Streets(km)	–	–	237.4	1.36 millions
8	Forest roads (km)	6.5	3 thousands	213	101 thousands
9	Railroad (km)	0.15		–	–
10	Bridges and culverts	894	7.51 millions	689	5.79 millions
11	Hydrotechnical constructions	5 dams, 38.8-km bank protection and damming	8.21 millions	44	28.1 millions

developed floods with high levels, which tend to form every 50 or even 100 years. The maximum values of the recorded (reconstructed) levels in comparison with the protection rates of the Trebes River are significantly higher (Table 20).

The danger level was exceeded for five hydrometric stations, out of six in total. Only at the Luncani hydrometric station the rates were not exceeded. The most dramatic increase occurred in Margineni, at a rate of 726 cm, considering the established 500 cm as danger level. Maximum flow rates corresponding to the high levels recorded in the hydrometric stations in Bacau area had the following values (Fig. 14):

1. Trebes River—Margineni hydrometrical station: Qmax $= 185$ m^3/s ($P = 2$ %);
2. Barnat River—Bacau hydrometrical station: Qmax $= 167$ m^3/s, ($P = 2$–5 %);

3. Negel River—Magura hydrometrical station: Qmax = 96.7 m^3/s, ($P = 0.2$–0.5 %).

Maximum flows on the Trebes (about 130 m^3/s) and the Negel (about 55 m^3/s) reached the 2G national road bridge and exceeded its capacity, causing significant increases in the upstream level following the afflux phenomenon. The Margineni Bridge (on the 2G national road) is placed before the Negel River confluence with the Trebes River. Its opening is reduced by a pipe line, so it cannot allow higher rates than 75 m^3/s (in free flow up to the deck line) and 100 m^3/s (under pressure), with a 1 meter nappe from upstream. On the Barnat River, in the Bacau hydrometric station, the riverbed capacity is 120–130 m^3/s. The dam on the left side of the river has several areas that do not operate at the same rate. The afflux phenomenon at the Negel and the Trebes confluence followed an upstream spread, causing rate increases which overflowed the defence dam.

The maximum flow recorded for the Negel River is 121 m^3/s (in the dammed area at the entrance of the CFR neighbourhood). The flow exceeded by far the calculated values for the dams on both banks because it was higher than the overflow probability of 1 % (90.0 m^3/s). In the dammed area of the Negel River (the lower course), the maximum flow calculated values with different overflow probabilities which had the following values: Qmax 1 % = 90.0 m^3/s, Qmax 2 % = 72.0 m^3/s and Qmax 5 % = 49.0 m^3/s. Floods in the summer of 2010 affected houses and annexes, agricultural and socio-economic objectives, national, county, communal and forestry roads, bridges, culverts, etc. The total damage was estimated at 185.84 million USD (for 2010) (Table 21).

2 Conclusion

Knowledge of the variation of levels and flash flood flows, defence levels, the correlation between the maximum rates and the height of the banks, and the areas and objectives likely to be flooded is required for designing protection measures. Lately, increased attention has been given to non-structural measures of defence against flooding. Development of hydrological forecasts in the event of flooding should be based on a good knowledge of the hydrological regime. A qualitative hydrological forecast must be substantiated from a hydrometrical point of view.

The presence of the Black Sea in the south-eastern sector of Romania determines important influences in the moisture content of the air masses in the Bistrita drainage basin. Generally, the air masses coming from west and southwest reload with moisture above the Black Sea coast and under the impetus of the high atmospheric pressure of the Russian Plain are deflected towards the northwest. When escalating the Moldavian Subcarpathians and the Eastern Carpathians, the air masses can generate particularly rich and intense precipitation causing major floods. The most exceptional floods are induced by these causes.

Hydrotechnical works carried out on the main course of the Bistrita River and main tributaries are intended for flood mitigation, water supply and electricity. Most of the floods, which have been propagated on the main course, have been alleviated. As a result of specific local conditions, or changes in the morphology of the riverbed or lacustrine basin, some floods could not be mitigated. For this reason, it is necessary to design a new strategy at the level of the river basin.

The floods during the 1970s could not be alleviated because the spring rainfall had filled the reservoir basins and the riverbeds had bankfull discharge. In this case, the floods manifested as in a landscape with no developments. The latest floods, in 1991, 2005 and

2010, generally occurred on tributaries. Flood waves were also propagated on the main course of the Bistrita River since some reservoirs had a high degree of siltation. In this case, they could not take up the excess water, and waves had a devastating effect. In the small affluent drainage basins, floods may have occurred due to the existent conditions of deforestation, inappropriate anthropic structures (such as dams, bridges and culverts) and low-flow channel occupancy due to location of economic objectives (such as softwood, operation of gravel and sand) or housing.

Excessive deforestation, practiced on very large areas in water course basins, gave rise to torrential rainfall. This is due to overheating during hot summer days, which favours the rapid uplift of air masses to high altitudes. Strong advection rainfall is often disastrous for the small river basins. Lack of development structures, the heavy erosion and the mismanagement of soil erosion lead to a sharp increase in the alluvial flow. This causes rapid sedimentation of the reservoirs and reduces storage capacity for excess waters. Extension of the annexes and enclosures in household beds, the storage of waste such as sawdust, or undersized bridges, footbridges and culverts lead to the reduction in transport capacity on rivers.

Household rubbish or wood left on the illegally deforested slopes are transported and accumulated during floods in meandered sections or on the narrow openings of the bridges. Under these conditions, the cork waste favours the appearance of the backwater areas, with temporary character. The backwater phenomenon determines floods upstream, but if the artificial waste barrier breaks it will produce floods downstream.

Although the floods in the Bistrita River basin have a high frequency and are sometimes exceptional, they are more moderate and rarer than those in the undeveloped rivers (such as the Trotus, the Suceava and the Moldova). Through the DESWAT (Destructive Waters) programme, the mitigation and warning of flood occurrence has been implemented through installation of automatic tracking stations for levels and flows. In these circumstances, the volumes of water passing through the reservoirs can be adequately adjusted.

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