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A Comparative Analysis of Exceptional Flood Events in the Context of Heavy Rains in the Summer of 2010: Siret Basin (NE Romania) Case Study

Gheorghe Romanescu [1], Alin Mihu-Pintilie [2,*], Cristian Constantin Stoleriu [1], Donatella Carboni [3], Larisa Elena Paveluc [1] and Catalin Ioan Cimpianu [1]

1 Department of Geography, Faculty of Geography and Geology, Alexandru Ioan Cuza University of Iasi (UAIC), RO-700505 Iasi, Romania; romanescugheorghe@gmail.com (G.R.); cristoan@yahoo.com (C.C.S.); larisapaveluc@gmail.com (L.E.P.); catalin.cimpianu90@gmail.com (C.I.C.)

2 Interdisciplinary Research Department, Field Science, Alexandru Ioan Cuza University of Iasi (UAIC), RO-700107 Iasi, Romania

3 Dipartimento di Scienze Umanistiche e Sociali, Università degli Studi di Sassari, Via Roma 151, 07100 Sassari, Italy; carbonid@uniss.it

* Correspondence: mihu.pintilie.alin@gmail.com; Tel.: +40-741-912-245

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Abstract: The Siret River crosses northeastern (NE) Romania from the north to the south, and it discharges into the Danube, near the city of Galati. Between 17 June and 10 July 2010, significant amounts of precipitations in the mountainous basin of Siret were recorded. The floods comprised two periods with four bimodal cycles, and they were counted as among the strongest on the Romanian territory. The exceptional floods occurred in the rivers of Siret, Suceava, Moldova, Bistrita, Trotus, and so on. The most important compound flood wave was determined by the precipitations, which fell between 29 June and 1 July 2010, when significant amounts of rain were recorded, sometimes exceeding 80 mm/day. The high discharges on the Bistrita River—downstream from the Bicaz Reservoir—were controlled by complex hydro-technical works. The maximum discharge for summer floods in the year 2010 was recorded at the Dragesti hydrometric station: 2884 m^3/s (historic discharge) compared with the preceding historic discharge (2850 m^3/s) of the year 2008. The effects of floods were strongest in the counties of Suceava, Neamt, and Bacau. The floods on the main course of the Siret River were analyzed in correlation with the tributaries within the mountainous sector.

Keywords: continental climate; exceptional floods; historic discharge; hydro-technical works; material damage; Siret catchment basin; NE Romania

1. Introduction

The year 2010 was one of the most dangerous from the perspective of catastrophic floods in Central-Eastern Europe. The months of May–June recorded some of the strongest floods in both central and eastern Europe: Poland, Austria, Czech Republic, Germany, Hungary, Slovakia, Serbia, Ukraine, Slovenia, Bosnia, Herzegovina, Montenegro, Croatia, Romania, and so on [1–4]. On the Romanian territory, exceptional floods occurred in the rivers of Siret, Prut, Tisa, Somes, Olt, and Tarnave [3–7]. In Europe, the number of human losses was significant [8]: Poland—25 victims [44], Romania—six victims [3], Slovakia—three victims, Serbia—two victims, Hungary—two victims, and the Czech Republic—two victims (Figure 1).

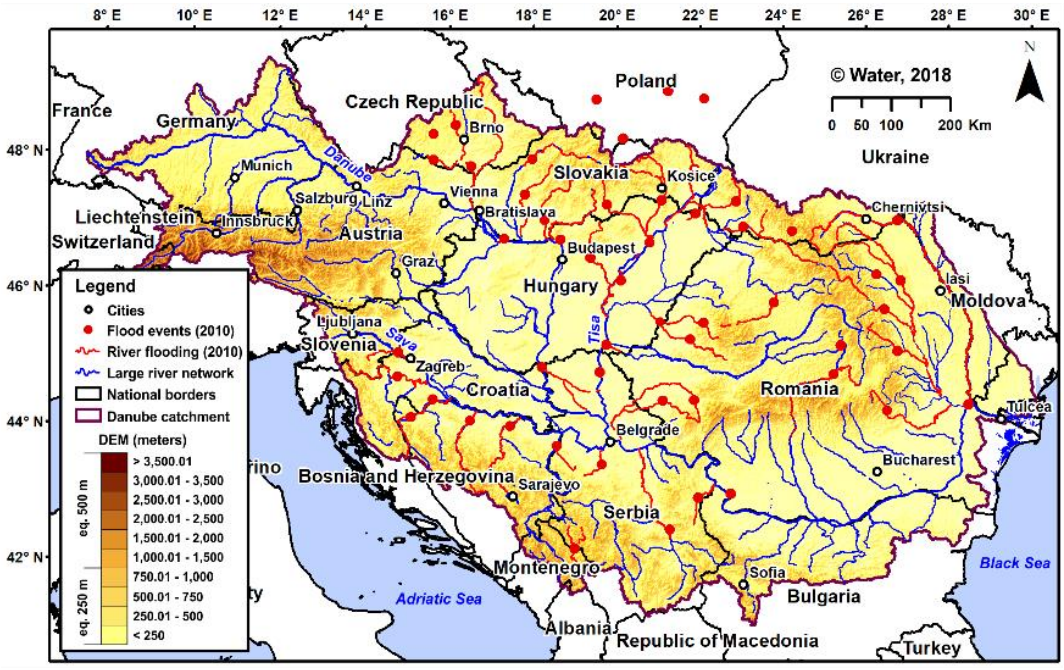

Figure 1. Major floods events within the Danube basin and the surrounding areas that occurred from May to June 2010.

The international literature has analyzed in detail the most important floods that occurred over time around the world [9–16]. From this perspective, the historic floods, or those that produced important material damage or human losses, are worth underscoring [17–30]. The recent catastrophic floods on the Romanian territory—mostly in the east (Moldova region) [3–7]—motivated scientists to pen scientific works that also dealt with the issue of heavy rains [31–33].

The largest catchment basin in the Romanian territory, the Siret catchment basin, comprises the Siret River [2,4], and the mountains and plateaus in the catchment area have showed different patterns of precipitation [31]. At the same time, the Siret catchment basin comprises the highest number of dams in Romania [33].

The Siret River is the most important hydrographic artery in Romania (after Danube): 220 m^3/s, 559 km in length, and 42,890 km^2 on the Romanian territory (44,871 km^2 overall). It springs from the Ukrainian Carpathians, where its upper stream unfolds, and then, its middle and lower streams cut across the east of Romania. It discharges into the Danube south from the city of Galati. It comprises the richest hydrographical network: 1013 rivers, measuring 15,157 km overall, meaning 19.2% of Romania. Its forestry fund comprises 15,882 km^2, which represents 37% of the catchment surface and 25% of the entire forestry fund in Romania [31–33] (Figure 2a).

The Siret basin has the following coordinates: northern limit—47°58′ N; southern limit—45°28′ N; western limit—24°49′ E; eastern limit—28°2′ E. The level difference between the sources and the discharge mouth is 1236 m. The catchment is typically asymmetrical, because it was created on the right (Carpathian Mts. sector), on the basis of mountainous tributaries [2]. The hydrographical network includes the Siret River and its main tributaries, which spring from the mountainous area: Siretul Mic (on the Ukrainian territory), Suceava, Moldova, Bistrita, Trotus, Putna, Ramnicu Sarat, and Buzau. The only important tributary on the left is Barlad (Figure 2b).

This study emphasizes the role played by locally heavy rains at the onset of floods, and the importance of large reservoirs in the mitigation of flood waves (Figure 2c). Another purpose of the article is to evaluate the relationship between mountainous rivers (tributaries of Siret) and water supply during floods. Flood waves are controlled by the reservoirs, which have taken over a part of the excessive discharge in the context of climate change in recent decades.

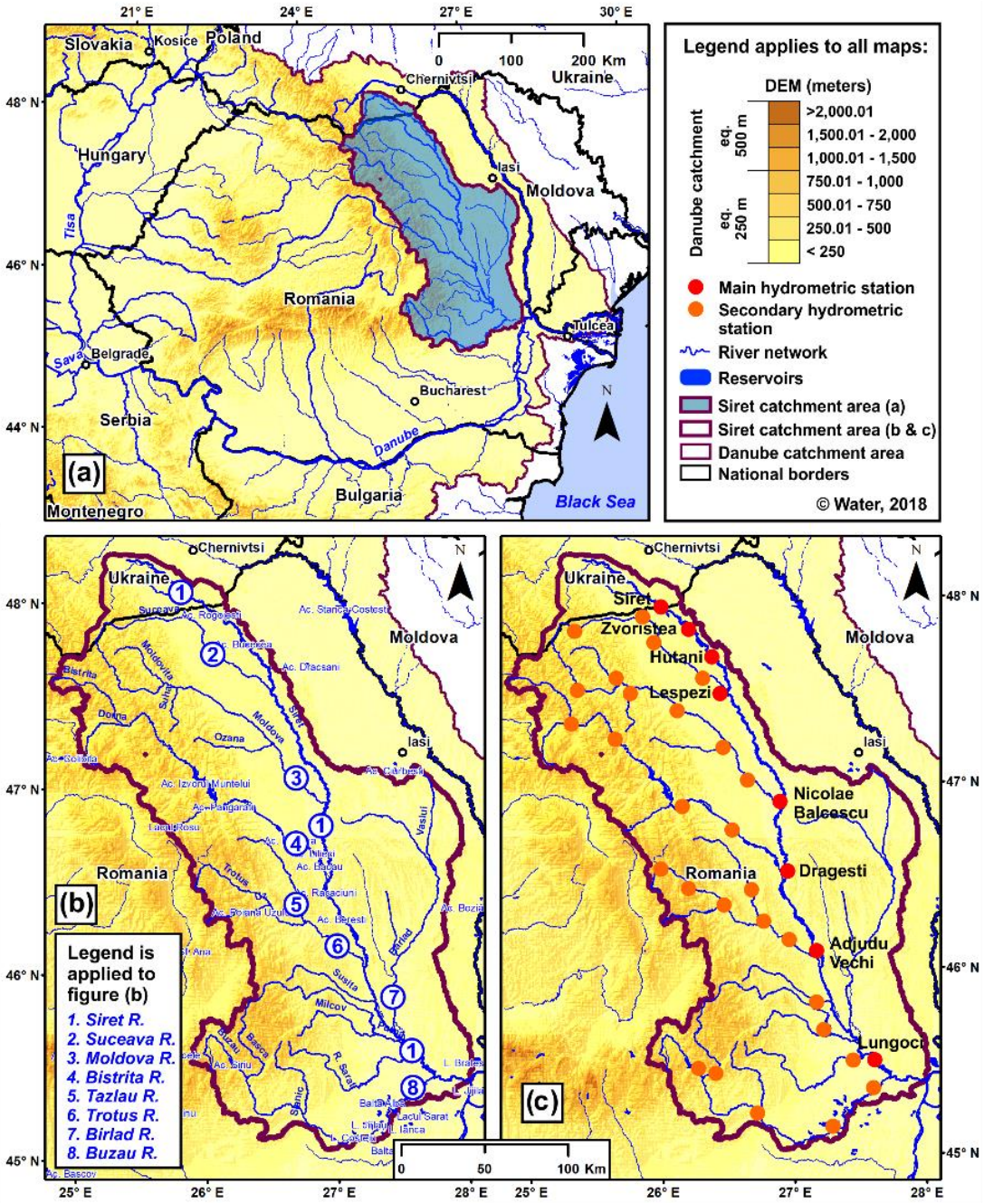

Figure 2. (**a**) Geographic location of the Siret catchment on the Romanian territory; spatial distribution of the (**b**) studied rivers and (**c**) hydrometric stations, with the role of mitigating floods in the Siret catchment area.

The greatest damage was produced in Suceava County by the Suceava River and its tributaries in the Neamt County by Moldova and Siret, and in the Bacau County by Trotus and Siret (Figure 3a). In the localities of Saucesti and Letea Veche (Bacau County), floods damaged 1110 houses, 4000 ha of arable land, and the entire infrastructure. Furthermore, 2137 persons were affected by the floods (Figure 3b–d). The effects of the floods were significant in the counties of Suceava, Neamt, and Bacau (Figure 3e,f). For the purpose of population safety, employees with the Inspectorate for Emergency Situations and the Romanian Army organized an intervention (Figure 3g). The total damage incurred rose to over two billion Euros.

Figure 3. Damage caused by floods within the Siret catchment in the summer of the year 2010: (**a**) houses damaged by the flood on Moldovita, left tributary of the Moldova River (Suceava basin); (**b**) Siret flooded north from the city of Bacau; (**c**) Siret flooded in the Saucesti commune (Bacau County); (**d**) localities, arable land, and infrastructure affected by the floods in the middle sector of the Siret River; (**e**) Roads affected by floods in the lower sector of the Siret River; (**f**) Temporary dams that were resistant to the floods on the Siret River; (**g**) Intervention of employees with the Inspectorate for Emergency Situations, Bacau.

In the Siret hydrographical space, there are 30 reservoirs, 20 of which include more than 50 ha and 144 fish culture developments. The 30 reservoirs make up a volume of 1847.632 million m^3 (a net volume of 1206.121 million m^3). The most important reservoirs are as follows: Dragomirna, Somuz II Moara, Izvorul Muntelui, Uz (Poiana Uzului), and so on on the tributary rivers; and Rogojesti, Bucecea, Galbeni, Racaciuni, Beresti, Calimanesti, and Movileni on the main course of Siret. All of the reservoirs have complex utility, but they do focus on flood mitigation or electric power production (mainly on the Bistrita River).

2. Materials and Methods

In studying catastrophic floods, a globally available methodology was used. Data were obtained from the Siret Water Basin Administration, based in the city of Bacau. For small rivers or places without hydrometric stations, measurements were taken for reconstituting the discharges. The assessment of floods worldwide has been analyzed by competent authorities, using modern, as well as fast, tools and technology [26,27,34–39].

The Siret River has a network of hydrometric stations that have recorded data systematically since the year 1886 (Table 1). The hydrometric stations also benefit from precipitation gauges [40,41] (Figure 2c). Heavy rains fall hourly, and they are recorded within 24 h, according to the Berg intensity scale [42–45]. Some of the data on precipitations were obtained from the regional meteorological stations within the Siret basin. The stations are automatic, and they are centralized by the national monitoring system that is based in Bacau. As for levels and discharges, daily data were analyzed from the period of floods. For the purpose of comparison, data on the mean monthly and multi-annual levels and discharges were also used. The processed data were transposed into histograms that illustrate the evolution of levels (in the time of floods), including danger levels, the levels before and during the flood, and daily and monthly runoff, as well as the hourly variations of runoff during the flood wave.

Table 1. Characteristics of hydrometric stations on the Siret River.

Hydrometric Station	Inauguration Year	Latitude	Longitude	Altitude (m)	Area (km^2)
Siret	1886	47°56′53″	26°04′34″	572	1637
Zvoristea	1978	47°51′13″	26°18′26″	537	1922
Hutani	1968	47°41′57″	26°28′16″	515	2152
Lespezi	1920	47°21′19″	26°41′48″	513	5899
Nicolae Balcescu	1986	46°55′49″	26°59′21″	479	6906
Dragesti	1961	46°43′46″	26°57′21″	525	11,899
Adjudu Vechi	1986	46°08′22″	27°11′47″	647	20,355
Lungoci	1921	45°33′31″	27°30′45″	539	36,095

Field observations and measurements were also conducted in June and July of the year 2010 floods, on the course of the major floodable riverbed of Siret, Suceava, Moldova, Bistrita, Trotus, Tazlau, and so on [4]. In the areas most affected by floods, where field observations were quite difficult to make, aerial photographs were taken using drones. Daily levels were followed at the most important hydrological stations, and topographic measurements were taken both upstream and downstream from the confluence.

The city halls of localities within the Siret catchment, and the Inspectorates for Emergency Situations in the counties of Suceava, Neamt, and Bacau, provided the reports on damages caused by floods. Some data were taken directly on the field or by consulting the locals. Concerning the roads and railways affected by floods, materials provided by the Ministry of Transport and Communication and city halls were consulted. At the same time, satellite images provided by the Siret Water Basin Administration in Bacau, and by the National Hydrology Institute in Bucharest were also analyzed. Satellite images focused on the periods of the floods. Landsat Thematic Mapper (Landsat TM) and Landsat Enhanced Thematic Mapper Plus (Landsat ETM+) multispectral satellite images were analyzed and interpreted using the Land Cover Classification System developed by Food and Agriculture Organization (FAO-LCCS). Also, to estimate the areas affected by floods, the Sentinel 2 multi-spectral imagery was used, along with Shuttle Radar Topography Mission (SRTM) elevation data, but only the visible floods with cloud coverage less than 30% were selected [3,4] (Figure 4a,b).

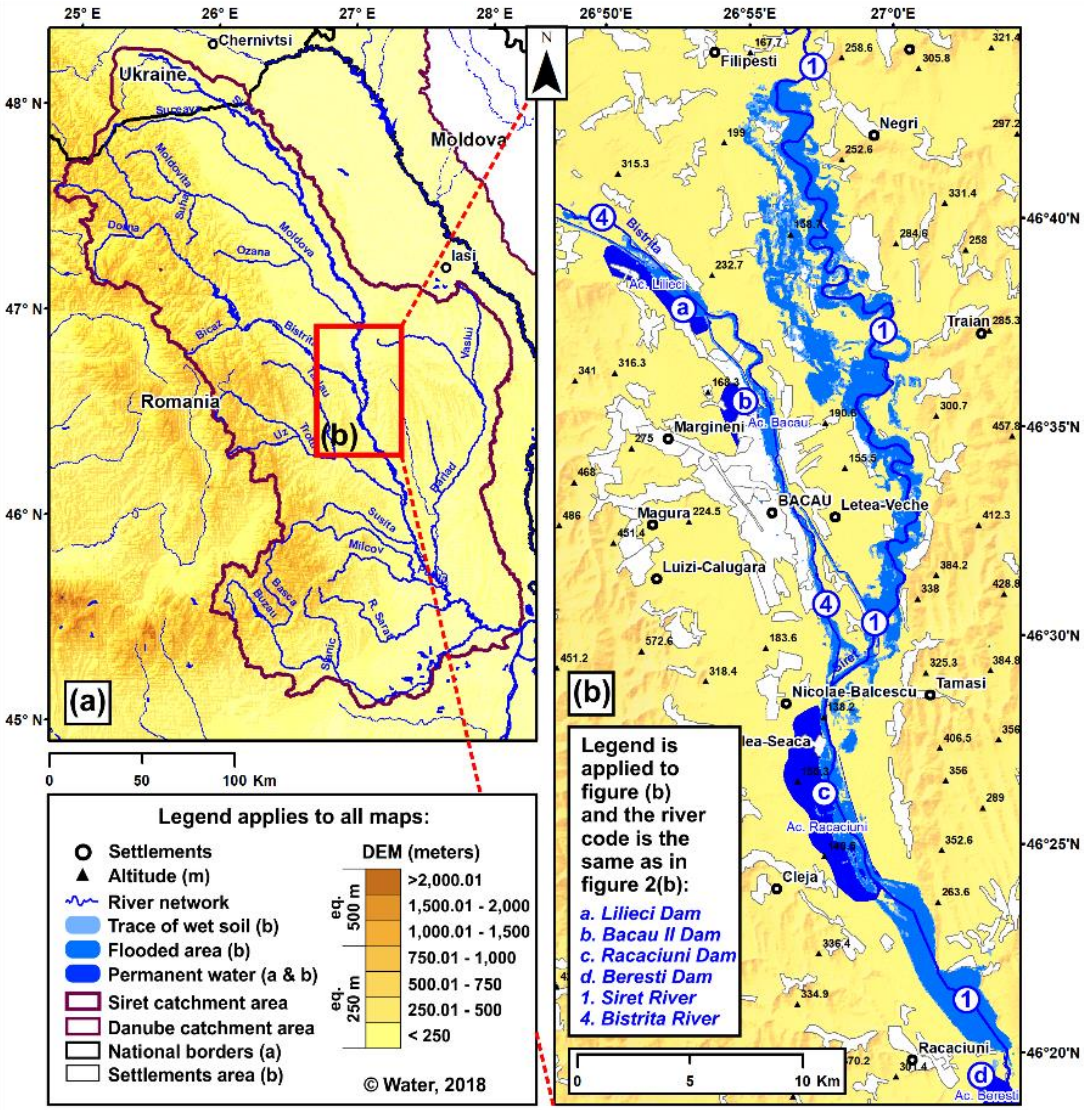

Figure 4. (**a**) Geographic location of the flood events (26 June to 5 July 2010) within the Siret catchment area; (**b**) historical flood on the Siret River extracted from LANDSAT TM and LANDSAT ETM+ scenes from 3 July 2010.

3. Results

Most of the Siret river basin in the mountainous area (Eastern Carpathians and Moldavian Subcarpathians) is developed. From the western sector, the river receives its most important tributaries: Suceava, Moldova, Bistrita, Trotus, Buzau, and so on. From the Moldavian Plateau (east), it receives only one important tributary: Barlad. Therefore, the abundant precipitations of the higher areas maintain a rich and relatively constant flow. From a climate perspective, the Siret catchment belongs to the temperate continental zone, with excessive accents in the east, and Baltic accents in the north. Precipitations range between 800 mm–1000 mm in the mountainous area, 600 mm–800 mm in the subcarpathian area, and 450 mm–600 mm in the Moldavian Plateau sector. Precipitations mainly consist of heavy rains, especially during the summer [6].

Usually, the rain front affects the eastern peri-Carpathian area along its entire length (the year 1991 floods). Rich precipitations may also fall on small surfaces or sectors either downstream (the year 2005) or upstream (the year 2008). Due to climatic layering, the richest precipitations fall in the subcarpathian area, and on the peripheral crests of the eastern Carpathians. Heavier rains may also be determined by the deforestation of significant mountainous forest areas, or by trees put down

during storms. Massive deforestations began in the year 1991, when certain forests were retroceded to individual owners [3–6]. Most of the dams are situated on the Siret watercourse, but there are several dams on mountain tributaries, too. Only two mountain dams play a very important role in flood mitigation: Bicaz (on the Bistrita River) and Uz (on the same river) [3–6,46] (Figure 4b).

During the first period, from 17 June to 10 July 2010, significant amounts of precipitation were recorded in several cycles (for two or three days). In this case, the retrograde evolution of the Pontic Cyclone was complex, because high atmospheric pressures were recorded above the Russian Plain and in the central–western parts of Europe. Influences of western oceanic masses were also noticed. The first cycle of this complex evolution is represented by the fallen precipitations between 23 and 25 June 2010 on the upper and middle streams of the rivers within the catchment of Suceava and Moldova. Flood waves had an average value. The second cycle occurred between 26 and 27 June 2010; rains and flood waves were recorded on most rivers within the eastern Carpathians. The strongest floods occurred in the Trotus catchment, mostly on its direct tributary, which is called Tazlau. The third cycle occurred between 29 June and 1 July 2010, in the catchment of Suceava, Moldova, and Bistrita (downstream from the Bicaz dam), and in the sub-basins of Bistricioara, Bicaz, Tarcau, and several smaller tributaries. In the Trotus catchment, the third precipitation cycle was weaker, and the flood waves were not important. The flood wave on Tazlau recorded a maximum discharge of 400 m^3/s. The fourth cycle of precipitations was recorded from 2 to 3 July 2010, with considerable amounts in the northern sector of the Siret catchment (Figure 5).

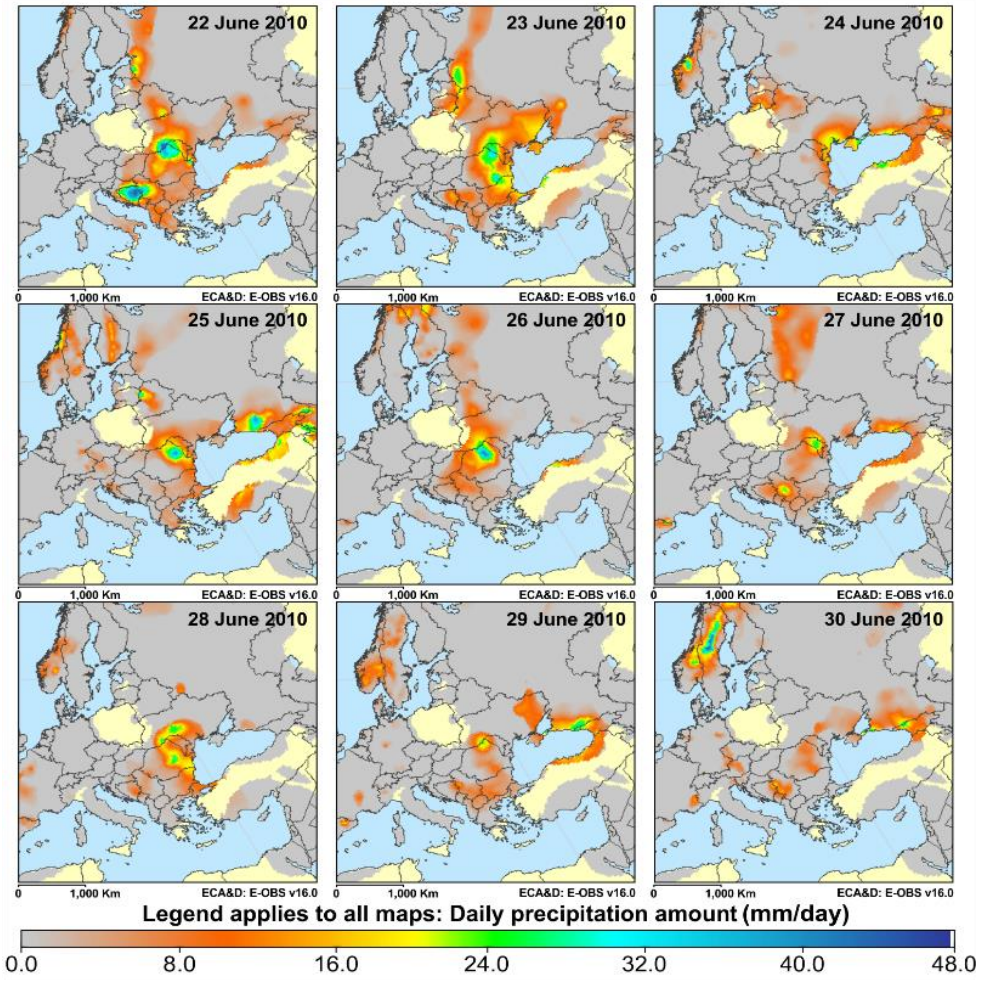

Figure 5. Daily precipitation amounts (mm/day) between 22 and 30 June 2010 in Central-Eastern Europe, based on daily gridded observational dataset (termed E-OBS v16.0).

Historic discharges were recorded for several hydrometric stations on the rivers of Siret, Suceava, Moldova, and on some small tributaries: Solonet, Solca, Sucevita, Horodnic, Patrauteanca, Hatnuta, Horaita, Negostina, Berehia, and so on. Most of the discharges occurred during the second and the third cycles, when the pouring character of rains was determined by the frontal contact between the eastern and western masses. They manifested in the upper course of Siret, and they continued to the Prut basin. The climatic manifestation is similar to that of the year 2008, when historic discharges were recorded in the Prut and Suceava basins.

3.1. Flood Waves in the Catchments of Suceava and Moldova, 22–26 June 2010

Starting from 17 June 2010, a period of atmospheric instability began with the generalized rains (however, the amounts were different). During the period 22–24 June 2010, significant amounts of rain fell in the catchments of Suceava and Moldova. The rain amounts that generated flood waves in the two basins had the following values: Brodina (78.9 mm); Tibeni (72.5 mm); Itcani (107.8 mm); Horodnic (67.5 mm); Parhauti (47.1 mm); Fundu Moldovei (64.9 mm); Prisaca Dornei (88.6 mm); Gura Humorului (54.3 mm); Lungulet (66.2 mm); Dragosa (67.9 mm); and Stulpicani (74 mm). At the hydrometric stations of Brodina, Fundu Moldovei, Dragosa, and Stulpicani, significant amounts of precipitations fell also on 21 June 2010.

The most important flood waves within the first stage (with two peaks) were recorded at the following hydrometric stations: Itcani (364 m^3/s) and Tibeni (266 m^3/s) on the Suceava River (Figure 6); and Roman (500 m^3/s), Tupilati (460 m^3/s), and Gura Humorului (296 m^3/s) on the Moldova River (Figure 7). Punctual flood waves also occurred on the smaller tributaries within the two basins. In the second stage, flood waves were stronger, and they featured two peaks: Itcani (883 m^3/s) and Tibeni (973.2 m^3/s) on the Suceava River (Figure 6); and Roman (870 m^3/s), Tupilati (660 m^3/s), and Gura Humorului (620 m^3/s) on the Moldova River (Figure 7).

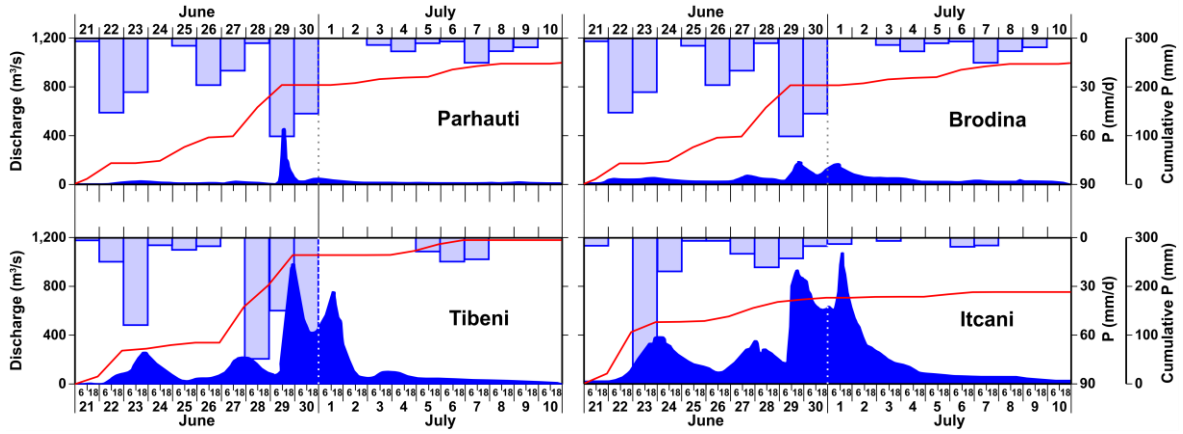

Figure 6. Hydrograph of flood waves and daily intensity of precipitation between 21 June and 10 July 2010, recorded at the hydrometric stations on the Suceava River.

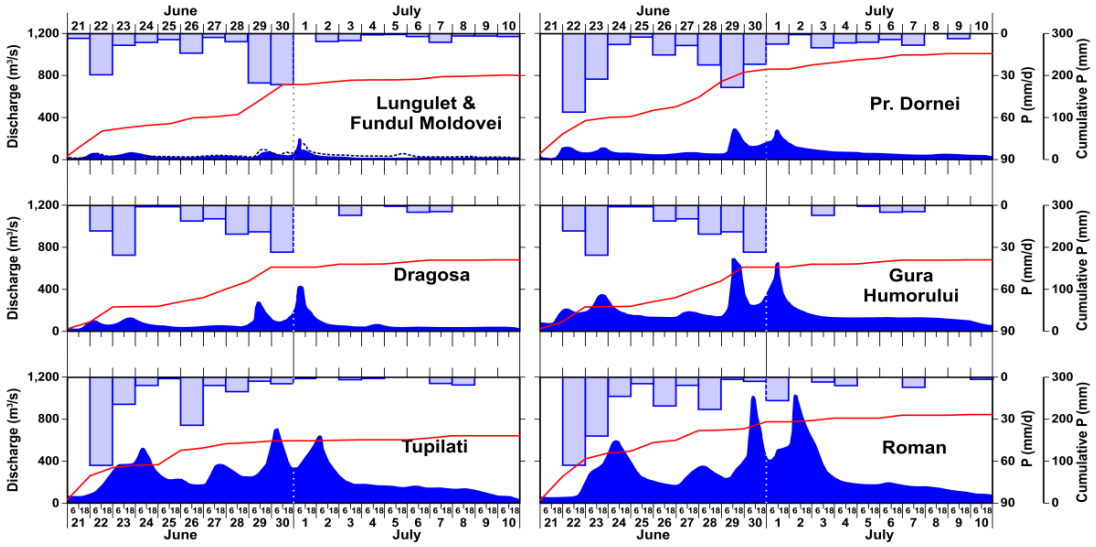

Figure 7. Hydrograph of flood waves and daily intensity of precipitation within the period 21 June to 10 July 2010, recorded at the hydrometric stations on the Moldova River.

3.2. Flood Waves in the Trotus Catchment, 26–28 June 2010

The precipitations that fell between 26 and 28 June 2010 in the Trotus catchment basin resulted in important floods. The entire amount of water ran off the slope, because the soil was already moist, due to the mild rains that fell previously at: Lunca de Sus (59.5 mm), Ghimes Faget (79.6 mm), Goioasa (85.5 mm), Targu Ocna (48.1 mm), Sulta (66.2 mm), Ciobanus (69.0 mm), Asau (85.2 mm), Lucacesti (64.5 mm), Scorteni (112.9 mm), Helegiu (32.0 mm), and so on. Most of the rains (>90%) fell between 26 and 27 June 2010. The floods occurred on the Trotus River and on its main tributaries: Ugra, Garbea, Valea Rece, Ciobanu, Asau, Tazlau, and Tazlau Sarat (Figure 8). Catastrophic floods were recorded on the rivers of Asau, Trotus (at Comanesti), and Tazlau (downstream from Scorteni) (Figure 9). The maximum discharge on Trotus was 1556 m^3/s (Vranceni hydrometric station). The maximum discharge on Tazlau was 780 m^3/s (Helegiu hydrometric station) (Table 2).

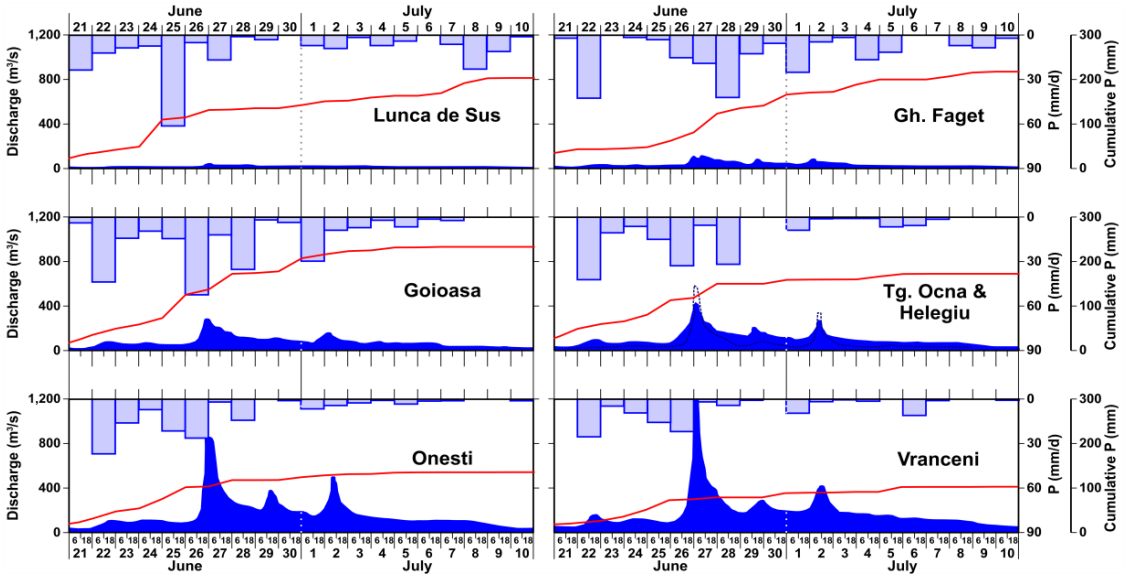

Figure 8. Hydrograph of flood waves and daily intensity of precipitation between 21 June and 10 July 2010, recorded at the hydrometric stations on the Trotus River.

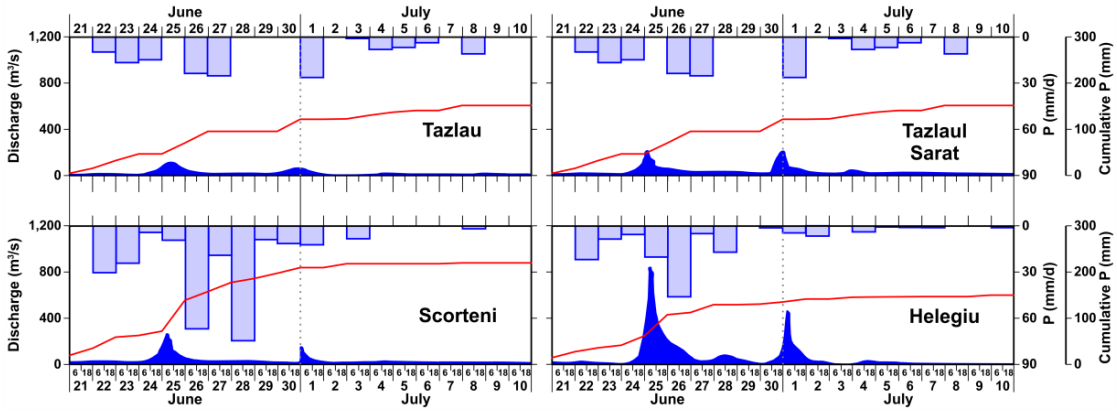

Figure 9. Hydrograph of flood waves and the daily intensity of precipitation between 21 June and 10 July 2010 recorded at the hydrometric stations on the Tazlau River.

Table 2. Maximum levels and discharges of Trotus and of its tributaries during the floods of the summer of the year 2010.

River	Hydrometric Station	$H_{max.}$ (cm)	Compared to Caution Levels (cm)	$Q_{max.}$ (m^3/s)
Trotus	Lunca de Sus	175	+25 *Fl*	20.0
Trotus	Ghimes Faget	174	+24 *Wl*	77.0
Trotus	Goioasa	240	+40 *Fl*	230
Trotus	Targu Ocna	354	+54 *Fl*	586
Trotus	Onesti	400	+50 *Fl*	641
Trotus	Vranceni	408	+58 *Fl*	1556
Valea Rece	Valea Rece	158	+8 *Wl*	54.2
Sulta	Sulta	200	*Fl*	41.3
Ciobanus	Ciobanus	136	+6 *Wl*	8.78
Asau	Asau	260	+10 *Fl*	114
Slanic	Ciresoaia	230	+30 *Fl*	81.6
Tazlau	Scorteni	265	+15 *Fl*	223
Trotus	Helegiu	300	*Dl*	780
Tazlaul Sarat	Lucacesti	215	+65 *Wl*	147

Notes: $H_{max.}$: Height; *Wl*: Warning level; *Dl*: Danger level; *Fl*: Flood level; $Q_{max.}$: Flow rate.

3.3. Exceptional Flood Waves, 17 June to 7 July 2010

The period between 17 June and 7 July 2010 was extremely rainy: two small floods and two significant floods were recorded. The floods occurred in the rivers of Siret, Suceava, Moldova, and Bistrita (downstream from the Bicaz dam), and on their tributaries. The flood waves were also propagated on the middle and lower Siret streams, where historic discharges were recorded at several hydrometric stations. The amount of rainfall recorded between 21 and 30 June 2010—when important amounts of precipitations fell (Table 3)—determined the compound flood wave. Exceptional flood waves occurred in the Patrauti, Darmanesti, Sucevita, Milisauti, Dornesti, Gramesti, and Zamostea rivers (tributaries of Suceava). The high discharges on the Bistrita River, downstream from the Bicaz dam (Izvorul Muntelui Lake), were enhanced artificially through controlled overtopping (Table 4).

Table 3. Daily rainfalls between 21 and 30 June 2010 in the Siret river basin.

River	Pluviometric Station	Daily Rainfalls Amounts (mm)										
		21st	22nd	23rd	24th	25th	26th	27th	28th	29th	30th	Total
Siret	Siret	5.4	4.6	56.7	9.1	3.9	33.6	5.3	2.5	81.7	49.2	252
Siret	Zvoristea	-	33.6	48.1	1.8	18.5	1.6	7.7	115.1	9.9	-	236.3
Siret	Lespezi	-	41.6	19.1	3.7	1.2	14.3	2.2	24.9	7.7	4.5	119.2
Siret	Nicolae Balcescu	-	63	46	13.5	4.5	20.5	6.5	23	2.3	2.5	181.8
Siret	Dragesti	5.6	-	22.6	18.1	-	15.9	20.6	0.4	12.7	-	95.9
Siret	Lungoci	-	0.4	2.3	1.4	8.1	3.7	-	11	-	-	26.9
Suceava	Brodina	1.8	45.7	33.1	-	4.6	28.8	19.9	2.5	60.3	46.3	243
Suceava	Tibeni	1.6	14.7	53.7	4.1	7.4	5.2	-	74.5	44.8	62.6	268.6
Suceava	Itcani	-	86.4	20.7	0.6	1.8	9.3	17.6	12.7	5.1	13.6	167.8
Moldova	Fundu Moldovei	2.9	28.9	7.5	5.9	3.9	13.9	2.7	5.3	35.2	36.3	142.5
Suceava	Prisaca Dornei	-	55.4	31.5	7.1	2.1	14.9	8.4	22.3	37.9	21.8	201.4
Suceava	Gura Humorului	-	18.2	35.5	0.9	0.4	11.1	9.5	20.4	18.8	33.3	148.1
Suceava	Tupilati	-	62.8	19.3	5.8	0.9	34.2	5.8	10	2.4	4.1	145.3
Suceava	Roman	-	63	42	13.5	4.5	20.5	5.5	23	1.3	3	176.3

Table 4. Maximum levels and values exceeding caution levels between 26 June and 5 July 2010 for the main hydrometric stations in the Siret river basin.

River	Hydrometric Station	26–30 June				1–5 July			
		H (cm)	+Caution Levels	*Q* (m^3/s)	Day/Hour	*H* (cm)	+Caution Levels	*Q* (m^3/s)	Day/Hour
Siret	Siret	423	+73 *Dl*	1115	29/13	-	-	-	-
Siret	Zvoristea	602	+266 *Dl*	766	29–30/23	-	-	-	-
Siret	Hutani	588	+138 *Dl*	815	30/8–11	-	-	-	-
Siret	Lespezi	614	+14 *Dl*	1678	29/21–23	662	+62 *Dl*	2049	1/5–8
Siret	Nicolae Balcescu	662	+102 *Dl*	1339	1/1–7	728	+228 *Dl*	1824	2/0–1
Siret	Dragesti	468	+68 *Dl*	2058	30/12	583	+83 *Dl*	2884	2/7–11
Siret	Adjudu Vechi	-	-	-	-	-	-	-	-
Siret	Lungoci	669	+19 *Dl*	2576	1/6	669	+19 *Dl*	2567	3–4/12
Suceava	Brodina	224	+24 *Wl*	151	29/4	215	+15 *Wl*	136	30/15
Suceava	Tibeni	376	+26 *Dl*	973	29/8	332	+32 *Fl*	747	30/20
Suceava	Itcani	619	+169 *Dl*	883	29.3	670	+220 *Dl*	1050	30-20
Solonet	Parhauti	500	+120 *Dl*	346	290	-	-	-	-
Moldova	Fundu Moldovei	130	+30 *Wl*	58.4	29/2–4	180	+30 *Fl*	96.5	30/17–18
Suceava	Prisaca Dornei	325	+25 *Fl*	222	29/0	314	+14 *Fl*	209	30/17–18
Suceava	Gura Humorului	248	+48 *Wl*	617	29/2	240	+40 *Wl*	585	30/20
Suceava	Tupilati	180	<*Wl*	660	29/16	166	<*Wl*	592	1/10
Suceava	Roman	222	<*Wl*	846	29/19	225	<*Wl*	887	1/12
Moldovita	Lungulet	158	<*Wl*	45.4	29/6	255	+5 *Fl*	126	30/13
Moldovita	Dragosa	283	+33 *Wl*	238	29/0	375	+75 *Fl*	368	30/18

Notes: *H*: Height; *Wl*: Warning level; *Dl*: Danger level; *Fl*: Flood level; *Q*: Flow rate.

The high discharges on the mountainous Siret tributaries determined the elevated levels on the main stream. Therefore, the Siret River recorded historic discharges at several hydrometric stations. However, at Lungoci, the maximum discharge of the year 2005 (4650 m^3/s) was not exceeded [6]. The maximum discharge for the year 2010 summer floods was recorded at the Dragesti hydrometric station: 2884 m^3/s (historic discharge), compared to the preceding historic discharge in the year 2008, which was 2850 m^3/s [4] (Figure 10).

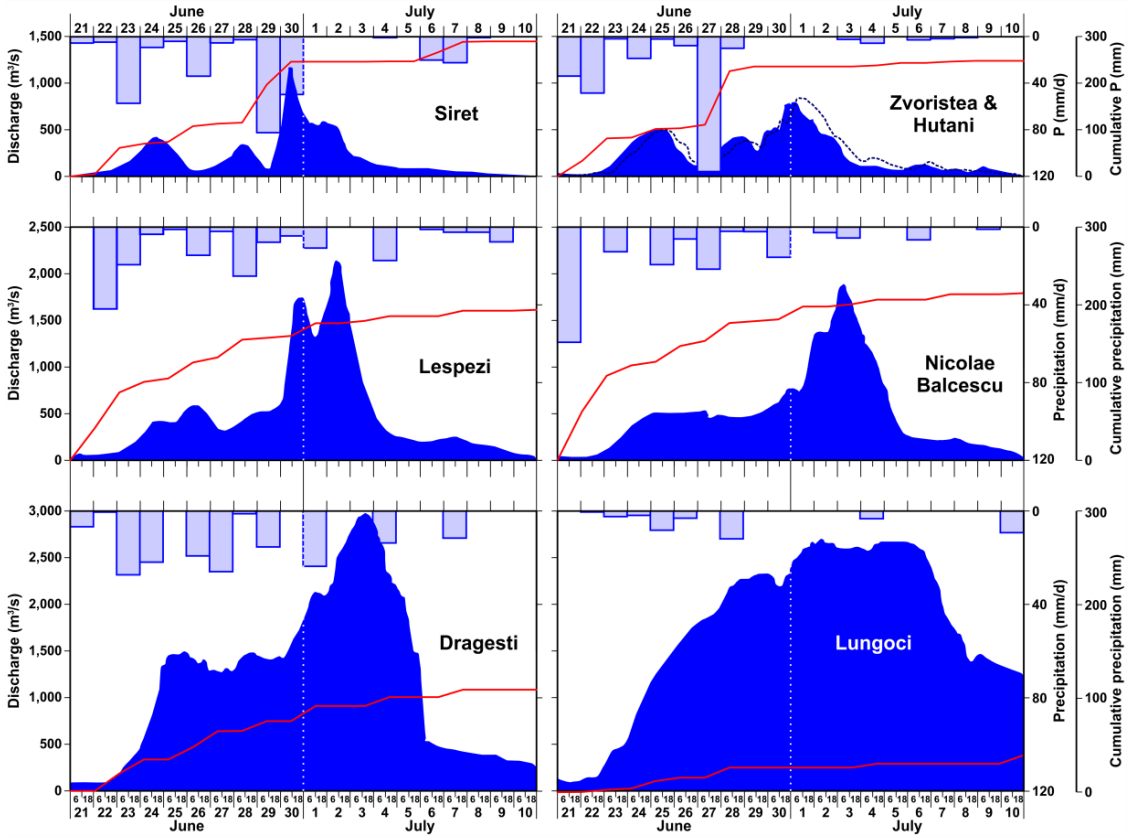

Figure 10. Hydrograph of flood waves and daily intensity of precipitation between 21 June and 10 July 2010, recorded at the hydrometric stations on the Siret River.

4. Discussion

In the last century, an increase of 0.6 °C–0.8 °C of the air temperature has been recorded on the Romanian territory, which are values that are similar to the European tendency [47,48]. This trend is less significant in the west and northwest of Romania, but is notable in the eastern and southeastern regions [42]. The average amounts of precipitations increased slightly between 1990 and 2010, from 630 mm/year to 640 mm/year. At the same time, heavy rains recorded a high value. There is an alternation of droughty years (1961, 1963, 1965, 1986, 1990, 1994, 2000, 2003, and 2007), normal years (1968, 1971, 1976, and 2009), and rainy years (1955, 1969–1970, 1972–1973, 1978–1979, 1981, 1984, 1991, 1996–1997, 2005, 2008, and 2010) [3–7,31–34,46]. The repartition of precipitations per season underscores the extreme values for the Romanian territory, mostly for the Moldova Region, between precipitations that fell in the warm season compared with the hot season: Iasi +2.13 mm/year, Suceava +2.72 mm/year, and Roman +2.74 mm/year. The heavy rain character is highlighted by the precipitation values recorded within 24 h.

For the Siret catchment (at 120 weather stations and posts), an increase in the occurrence of maximum precipitations within 24 h after the year 1960 is worth underscoring. This homogeneity of occurrences was represented by the adjustment of values, which was determined by the multiplication of hydrometric stations. Precipitations that exceed 100 mm/24 h entail significant hydrological effects. The analysis of occurrences of value levels exceeding 100 mm indicates significant increases for the interval between 100 and 160 mm/24 h. The intervals 181–200 mm/24 h or >200 mm/24 h were also taken into account (Table 5). During flood waves on the Siret catchment (the years, 1991, 2004–2006, 2008, and 2010), numerous amount of rainfalls comprising 200 mm/24 h was recorded. Between 2000 and 2010, at least five episodes of catastrophic floods occurred: in the years 2004 and 2005 in the Trotus catchment and on the lower stream of Siret, in the year 2006 in the Arbore area (Suceava), and in the

years 2008 and 2010 in the northern half of the Siret hydrographical space, mainly on the Suceava River, when the historic value of 1946 m^3/s was recorded for discharge (Itcani hydrometric station) on 27 July 2008.

Table 5. Variations in max. rainfall occurrence, exceeding 100 mm/24 h, within the past century.

Intervals	Before 1900	1901–1920	1921–1940	1941–1960	1961–1980	1981–2000
Occurrence of max. rainfalls in 24 h	1.7	1.7	9.9	8.3	30.5	47.9
Occurrence after homogenization	7.7	7.7	15.9	14.3	18.5	35.9

The shape of flood hydrographs is different for every tributary, and for the Siret River per se. Hydrographs are influenced by the value of precipitations and their distribution in space and time. For the Suceava River, two periods comprising four cycles were delimited. The flood wave on Siret—downstream from the confluence, with the Suceava River—featured two peaks, which originated from the tributary. They merged at the Dragesti hydrometric station. An important role was played by the actions taken at the Rogojeşti and Bucecea reservoirs, in the flood waves, and on the upper sector of the Siret River (Table 6).

Table 6. Reservoirs on the Siret River with a role in flood mitigation.

Lake	River	Total Volume (mil. m^3)	Net Volume (mil. m^3)	*S NRL* (ha)	Depth of Dam (m)	*H NRL* (cm)
Rogojesti	Siret	55.8	26.0	930.0	14	300
Bucecea	Siret	25.0	5.86	475.0	20	271
Galbeni	Siret	29.4	9.34	1123.0	29	141
Racaciuni	Siret	123.03	60.67	2004.0	29	129
Beresti	Siret	143.6	74.8	1800.0	29	110.7
Calimanesti	Siret	60.3	15.9	740.0	22	75.0
Movileni	Siret	72.0	46.53	948	13.0	48.50

Notes: *NRL*: Normal Retention Level; *H*: Height.

In the middle and lower sectors of the Siret River (at the Racaciuni, Beresti, Calimanesti, and Movileni reservoirs), correlated actions were taken to prevent the maximum discharge from exceeding 2300–2500 m^3/s in the downstream sector of the Movileni dam. The first period—with two flood cycles (bimodal)—was weak, and it did not have a significant influence on the Siret River. The second period—with two cycles (bimodal)—was strong, and it had significant effects on the Siret River. The sharp peaks show the existence of pouring rain and the shape of the flood wave within the tributary basin.

The hydrography of flood waves on the Moldova River is similar to that on the Suceava River, which proves that they come from the same pluvial origin. This time around, the increase on Siret was greater, because it cumulated partly with the controlled spill from upstream. The strong precipitations on the Bistrita River did not lead to flooding, because of the catchment benefits from the hydro-technical works. The 11 reservoirs controlled the Bistrita flow (Figure 11).

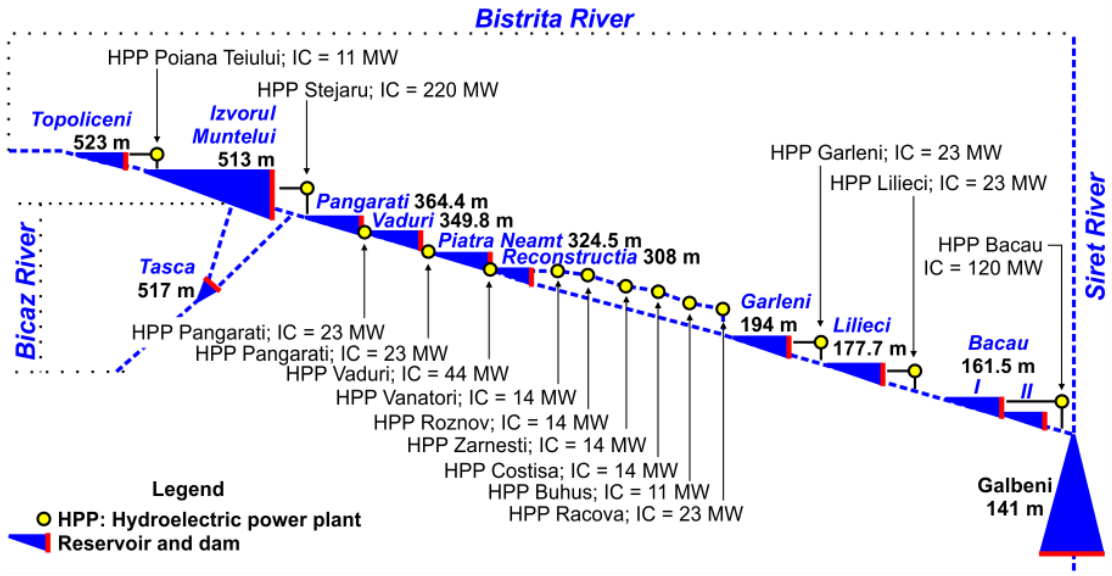

Figure 11. The complex works on the Bistrita River.

The floods in the Trotus catchment are reversed compared with the two aforementioned basins. The first (unimodal) flood was strong. The second period was bimodal, and significantly weaker. They both influenced the Siret flow, because they overlapped the upstream waters. In the case of Tazlau (left tributary of Trotus), the situation is the same as that of the main river. The Siret watercourse, in this case, may be divided into two distinct sectors: the northern one, without floods at the hydrometric stations of Siret, Zvoristea, and Hutani; and the southern one, with floods at the hydrometric stations of Lespezi (because of the Suceava River), Nicolae Balcescu (because of the Moldova River), Dragesti (weaker because of the Bistrita River, and stronger, because of the upstream waters), and Lungoci (because of the Trotus River and the upstream waters).

The mountainous rivers that recorded floods in the summer of the year 2010 have more constant multi-annual discharges compared with plateau or plain rivers: Suceava—16.1 m^3/s; Moldavia—26.2 m^3/s; Bistrita—62.8 m^3/s; and Trotus—34.7 m^3/s. Siret is also the largest river in terms of flow on the Romanian territory: 210 m^3/s at the Lungoci hydrometric station (in the year 2000), and 254 m^3/s at the discharge point into the Danube (Sendreni). As a result of the very high discharges recorded in the years 2005–2006, 2008, and 2010, the mean multi-annual discharge of Siret, at the Lungoci hydrometric station, rose to 220 m^3/s. The high continentality index of the mountainous rivers is also due to the Foehn effect.

The two significant peaks of the compound flood wave of the summer of the year 2010 were recorded only in the catchment of Suceava and Moldova. On the upper course of Siret, there were not two peaks, but only one simple peak, that is, the single-wave variation. The passage of the flood wave through the Rogojesti and Bucecea reservoirs was strictly controlled. Therefore, the evacuated discharges were significantly mitigated downstream from the Bucecea dam. The second flood wave peak of the Suceava River (with higher flow than the first peak) added the flows evacuated from the Bucecea dam (mitigated through human intervention) and propagated downstream, on the Siret River. At the hydrometric station of Lespezi, the two peaks were apparent. The second flood wave peak—downstream from Lespezi—advanced on the trail of the first, and it propagated faster. Therefore, the first flood wave peak at the Nicolae Balcescu hydrometric station manifested itself only as a mitigated inflexion. The second peak was similar (in terms of moment) to the first peak recorded at the Dragesti hydrometric station. Downstream from the confluence with the Moldova River, only one peak emerged as a result of a slow and continuous growth. The high discharges on the Siret River—downstream from Bacau—also occurred due to the waters of the Bistrita River (natural

flows, as well as turbine and spilled flows), with values up to 900 m^3/s. The entire amount of water transited the reservoirs.

Taking into account the high Danube flows (accompanied by the backwater phenomenon), and certain issues with the lower stream of Siret, the discharges evacuated from the Movileni dam were initially limited to 2300 m^3/s. Subsequently, the value of this discharge increased to 2500 m^3/s, and the maximum value reached 2567 m^3/s. Since the waters transited the reservoirs situated on Siret (on the middle and lower sectors), there was no significant discharge recorded. An additional advantage was that the Trotus flows were low during the high discharges on the rivers of Siret (upstream) and Bistrita.

5. Conclusions

The mountainous rainfalls between 17 June and 10 July 2010 led to exceptional floods, compared to those in the years 2005 and 2008. The mountainous tributaries of Siret have relatively constant and high flows. They are responsible for some catastrophic floods, because they are supplied by pouring rains during the summer. The torrential character is induced by the influence of the temperate continental climate of transition, with excessive nuances.

The Siret basin comprises the highest number of dams in Romania, which play a complex role, including flood mitigation. The Bistrita River holds the highest hydropower potential, and for this singular reason, it benefits from 11 reservoirs that totally control the natural runoff. The floods in the Siret catchment were determined by heavy rains that fell in the mountain area. In this case, flood waves occurred on the rivers of Suceava, Moldova, and Trotus (to which Bistrita must be added, though its runoff was controlled).

The hydrometric stations of Siret, Zvoristea, and Hutani, which are situated north of the confluence with the Suceava River, recorded only small floods. On the Siret River, floods occurred in the middle and lower sector, mostly in the localities of Saucesti and Letea Veche (Bacau County). In the Trotus basin, strong floods also occurred on its main tributary: Tazlau.

In the smaller catchments (Patrauti, Darmanesti, Sucevita, Milisauti, Dornesti, Gramesti, and Zamostea—all tributaries of Suceava), exceptional floods occurred, with negative effects locally. The historic discharge for the year 2010 floods was recorded at the Dragesti hydrometric station (2884 m^3/s), and it was higher than the one of the year 2008 (2850 m^3/s). The counties of Suceava, Neamt, and Bacau were gravely affected. The floods on Siret, which occurred in the summer of the year 2010, ranked third on the list of hydrological risk phenomena in the history of the catchment, after the similar events of the year 2005 and the year 2008.

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