FLOODS CHARACTERISTIC TO THE PRUT RIVER (ROMANIA) (I)

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ABSTRACT. - Foods characteristic to the Prut river (Romania). The Prut River springs from Ukraine and discharges into the Danube. It covers 952.9 km. It represents the State border between Ukraine, Romania, and the Republic of Moldova. The catchment basin is part of the temperate continental climate of transition, where rains are heavy. The flood waves of the upper sector are caused by the rains fallen in the Forested Carpathians. Because of slopes and high velocities, flood peaks are sharp, levels are very high and they unfold within a very short time frame. Flood waves (Rădăuți Prut) upstream from the Stânca-Costești reservoir and within the lower sector (Prisăcani, Drănceni, Fălciu, Oancea) present natural forms, with steep peaks and slopes. Flood waves downstream from the Stânca-Costești reservoir (Stânca Downstream, Ungheni) are artificial, controlled by the dam. The flood wave of 2008 – the highest in the history of Prut River, with a maximum discharge of 4240 m^3/s (initial calculated discharge 7146 m^3/s) – featured the most interesting characteristics: upstream from the dam, it was sharp, with extremely abrupt slopes; downstream from the dam, the flattened top maintained – with few alterations – as far as the gauging station of Oancea. At the Oancea station, it ended one month after the one corresponding to the Rădăuți Prut station. This study aims at demonstrating the influence of Stânca-Costești reservoir on the manifestation of flood waves within the upper and the lower sector.

Keywords: catchment, floods, heavy rain, management, Prut River

1. INTRODUCTION

Hydrological hazards are specific to areas where heavy rains fall. The most dangerous ones are rains fallen in small, significantly deforested catchment basins. Catastrophic floods are also recorded in moderate climates, with relatively uniform precipitations throughout a year, such as the oceanic climate. In this case, great amount of precipitations fallen over a long period – consequence of global climate changes – are the underlying cause.

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The most damaging floods in Romania occurred in 1970 in Transylvania and Walachia and in 1975 in Moldavia. Starting with 2005, numerous floods have occurred that exceeded the values of those in 1970 and 1975. The most powerful and frequent ones are specific to the catchment basins in Moldavia: Siret and Prut (2005, 2006, 2008, 2010, 2011). Because floods are the natural hazards with the most significant negative impact upon economy and social life, they have been thoroughly studied in all nations on Earth: Brilly & Polic, 2005; Čech & Čech, 2013; Corduneanu & Bucur, 2013; Corduneanu et al., 2014; Furtună, 2012; Gavrilovic et al., 2012; Ion & Ion, 2008; Ionuş et al., 2013; Iosub & Lesenciuc, 2012; Iosub et al., 2014; Loczy, 2012; Loczy et al., Mierlă et al., 2014; Milelli et al., 2006; Plattner et al., 2006; Porcuţan, 2014; Portela & Delgado, 2009; Reti et al., 2014; Revuelto et al., 2014; Romanescu & Romanescu, 2011; Romanescu, 2008, 2013; Romanescu et al., 2010, 2011a,b, 2012a,b, 2013a,b, 2014; Romanescu & Nistor, 2011; Romanescu & Stoleriu, 2013; Salit et al., 2013; Sorocovschi, 2006; Tirnovan et al., 2014; Tutunaru et al., 2013; Yang et al., 2014; Li et al., 2015 etc. The most powerful floods recorded at the gauging stations along the Prut River are outlined. The timing of floods and the shape of the hydrograph are signs of the influences exerted by genetic factors, precipitations and runoff on the river.

Most rivers where catastrophic floods occur benefited from hydrotechnical works. The most important work on the Prut River is represented by the Stânca-Costeşti reservoir. Downstream from it, some sectors on the Romanian banks have been dammed (the left bank – situated in the Republic of Moldova – is high).

1.1. Study area

The Prut River rises on the northeastern slope of the Cernahora Mountain (Carpathian Mountains in Ukraine) – 1580 m high. It empties into the Danube at an altitude of 2 m, near the locality of Galaţi. The catchment basin of Prut unfolds throughout three States: Ukraine, Romania and the Republic of Moldova. As far as Oroftiana, on the territory of Ukraine (entry to Romania), it has a length of 211 km, a longitudinal slope of 6.4%, a sinuosity of 1.18 and a catchment basin of 8241 km^2. It measures a total of 952.9 km and it is the second longest tributary of the Danube, in terms of length. It represents the border between Ukraine and Romania for 31 km

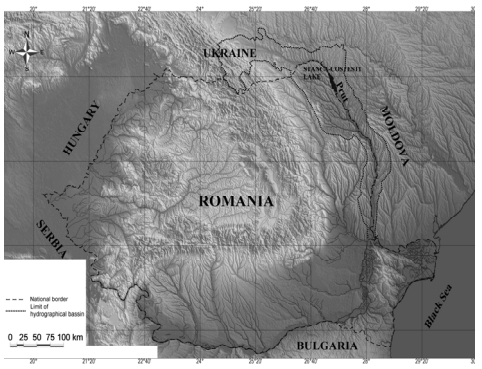

Figure 1. Geographic location of the catchment basin of Prut

and between Romania and the Republic of Moldova for 711 km. It is the last important tributary of the Danube before the latter discharges into the Black Sea (Fig. 1). The mean altitude of the catchment basin ranges between 130 m in the central area and 2 m at the confluence. Its average slope is around 0.2%. It benefits from 248 tributaries, its shape is elongated and its average width is 30 km. The catchment basin of Prut is situated in the temperate continental climate of transition, and it records both underground and pluvial supply. On the entire surface of the catchment basin, heavy rains are registered.

The hydrographical network measures 11000 km, of which 3000 km are permanent (33%) and 8,000 km have intermittent runoff (67%). The network has a density of 0.41 km/km^2, higher than the Romanian average (0.33 km/km^2). The main tributaries on the right are as follows (27): Poiana, Cornești, Isnovăț, Rădăuți, Volovăț, Baseu, Jijia (10 m^3/s – the most important one), Moşna, Elan, Oancea, Brăneşti, and Chineja. On the left side, there are 32 tributaries, among which Telenaia, Larga, Vilia, Lopatnic, Racovețul, Ciugurlui, Kamenka, Gârla Mare, Frasinul, and Mirnova.

2. METHODOLOGY

Hydrological and precipitation data was provided by the Prut-Bârlad Water Administration Basin, Iași. They were analyzed within the Geoarchaology Laboratory of the Faculty of Geography and Geology (Alexandru Ioan Cuza University in Iași). The hours of the most important floods recorded by all the gauging stations on the Prut River (Romanian territory) were taken into account. In Romania, there are eight gauging stations: Oroftiana, Rădăuți Prut, Stânca Aval, Ungheni, Prisăcani, Drănceni, Fălciu, and Oancea (Fig. 2). All data were processed and introduced into tables and graphs as hydrographs. Data from seven stations were used, because Oroftiana had records only for discharges, not for floods.

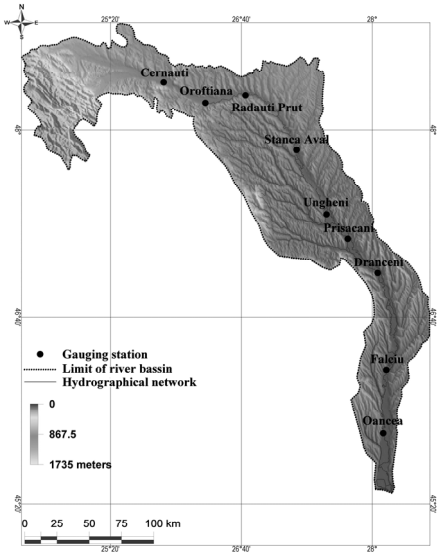

Figure 2. Distributions of gauging stations in the Prut basin

3. RESULTS AND DISCUSSIONS

In 1988, the maximum discharge at the Gauging station of Rădăuți Prut reached 1780 m^3/s. This was a simple flood wave (mono-wave), with an obvious peak, which unfolded over four days (Fig. 3a). The high discharge was the consequence of a serious amount of precipitations, which fell in the interval 2-5 June 1988. In four days, almost a third of the average amount of regional precipitations was recorded (173.2 mm). In fact, in the entire month of June, the maximum value was 253.7 mm, out of a total of 715.4 mm.

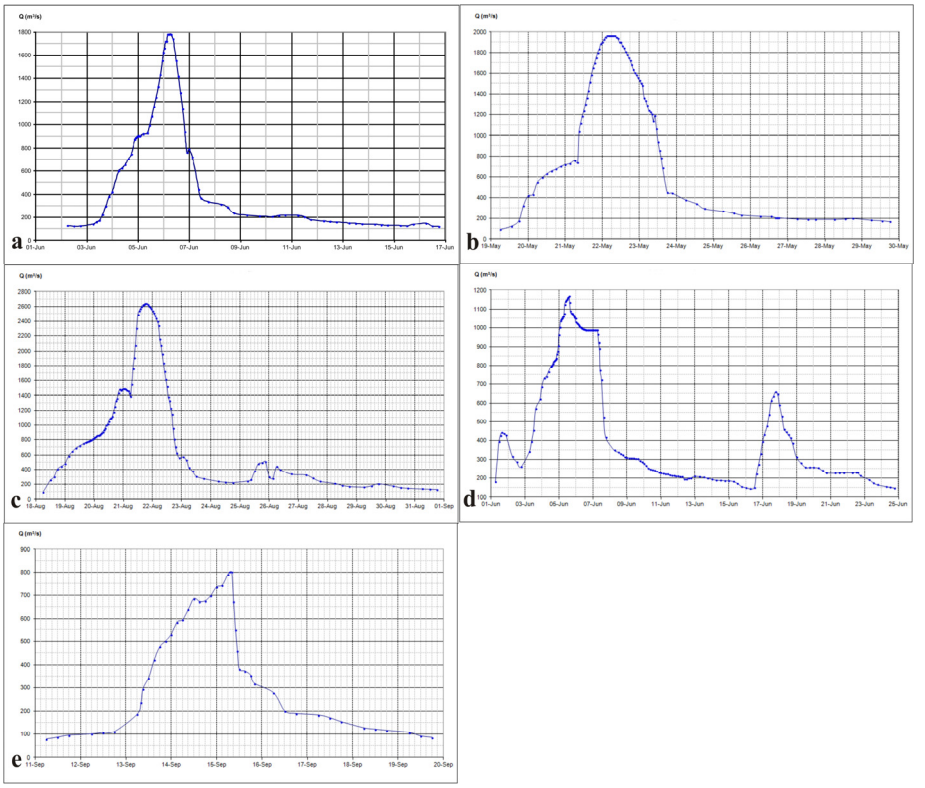

Figure 3. Evolution of the maximum flood at the Gauging station of Radăuți Prut: a-1988; b-1998; c-2005; d-2006; e-2007

In 1998, the maximum discharge at the Gauging station of Rădăuți Prut reached the value 1960 m^3/s. This was a simple flood wave (mono-wave), with an obvious peak, which unfolded over three days (Fig. 3b). The high discharge was the consequence of a serious amount of precipitations, which fell in the interval 20-

23 May 1998. In six days, an amount of 47.6 mm precipitations was recorded. In the entire month of May, a maximum value of 106.1 mm was registered, out of a total of 817.0 mm.

In 2005, the maximum discharge at the Gauging station of Rădăuți Prut reached the value 2640 m^3/s. This compound wave (multi-wave) – with a secondary, weak peak and a principal peak – unfolded over four days (Fig. 3c). The high discharge was the consequence of an important amount of precipitations fallen in the interval 18-20 August 2005. In four days, around 40% of the average amount of regional precipitations was recorded (177.7 mm). Actually, in the entire month of August, the maximum value of precipitations was 247.4 mm, out of a total of 646.9 mm.

In 2006, the maximum discharge at the Gauging station of Rădăuți Prut reached the value 1168 m^3/s. This was a compound wave (multi-wave), with three peaks. The first peak was secondary, weak. The main peak was recorded on 5 June 2006. The second main peak occurred on 18 June 2006, but it was slightly weaker (Fig. 3d). The high discharge was the consequence of an important amount of precipitations fallen in three stages. The largest amount of discharge came from tributaries. In June, the maximum value of precipitations was 133.4 mm, out of a total of 519.7 mm.

In 2007, the maximum discharge at the Gauging station of Rădăuți Prut 2007 reached the value 803 m^3/s. This was a simple wave (mono-wave), with a peak divided into two episodes. The peak was reached on 15 September 2007 (Fig. 3e). The high discharge was the consequence of an important amount of precipitations fallen over three days, when the maximum value recorded was 57.7 mm (out of a monthly total of 58. mm). This type of autumn flood wave rarely occurs on the middle course of Prut.

In 2008, two flood waves were recorded. The first flood wave occurred in the interval 6-11 April 2008; a maximum value 560 m^3/s was recorded. This was a simple wave (mono-wave), with sudden increase and abrupt decrease (Fig. 4a). The high discharge was caused by an important amount of precipitations fallen: 29.1 mm. In the month of April, the total amount of rain was 99.6 mm, out of an annual amount of 559.9 mm. The water runoff took the course of the riverbed because the soil was frozen or moist.

The second flood wave of 2008 unfolded in the interval 24-31 July 2008; it was the most dramatic flood wave in the history of hydrologic records on the Prut River: 4240 m^3/s (re-evaluated data: the initial recorded value was 7146 m^3/s, but it was re-evaluated and changed; Fig. 4b). The underlying cause of the flood wave was the heavy rains fallen in the upstream sector of Prut, to which local rains added (89 mm in the interval 22-26 July 2008). In July, the maximum value was 161.1 mm, considering that the annual amount was 559.9 mm.

In 2009, the maximum discharge at the Gauging station of Rădăuți Prut reached the value 419 m^3/s. This was a compound wave (multi-wave), with two peaks, which unfolded over an entire month (April) (Fig. 4c). The high discharge originated in the upstream sector (situated in Ukraine) and in several tributaries. The gauging station recorded a significantly low amount of precipitations in the month of April: 3.3 mm (considering that the annual amount was 368 mm). The year 2009 was one of the doughtiest years in the middle course of Prut.

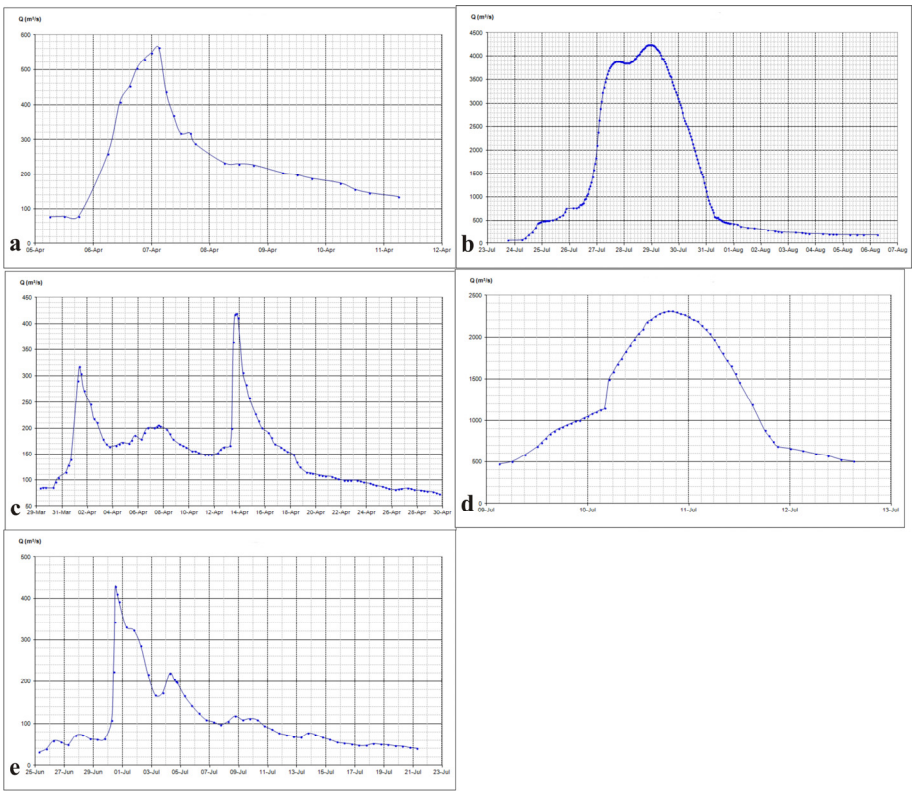

Figure 4. Evolution of the maximum flood at the Gauging station of Radăuți Prut: a-2008(1); b-2008(2); c-2009; d-2010; e-2011

In 2010, the maximum discharge at the Gauging station of Rădăuți Prut reached the value 2310 m^3/s. This was a simple wave (mono-wave), with slightly mitigated peak, which unfolded in the interval 10-12 July 2011 (Fig. 4d). The high discharge originated in the upstream sector (situated in Ukraine) and in several tributaries. Throughout the flood, the gauging station recorded a maximum precipitation amount of 40.3 mm, out of a total of 149.9 mm for the entire month. The annual mean for 2010

was high: 829.2 mm. In July 2010, high amounts of precipitations fell in the north of Moldavia and in Ukraine. In this case, the upper and middle courses of Prut were affected by the flood wave, as far as the Stânca-Costeşti level.

In 2011, the maximum discharge at the Gauging station of Rădăuţi Prut reached the value 428 m^3/s. This was a compound wave (multi-wave), with a multitude of secondary inflexions, which unfolded in the interval 29 June-21 July 2011 (Fig. 4e). The high discharge was the consequence of an important amount of precipitations that originated in the upstream sector. The increase slope was extremely abrupt, because the peak was recorded within minutes. The rain fallen during the flood wave, recorded at the gauging station, was insignificant; hence, it could not have altered the flood wave. In July, the precipitation value was only 62.4 mm, out of an annual mean total of 327.2 mm (droughty year).

In 1988, the maximum discharge at the Gauging station of Stânca Downstream reached the value 651 m^3/s. This was a simple wave (mono-wave), mitigated, with a peak recoded in the interval 3-9 July 1988. The increase and decrease of the flood wave occurred extremely fast. This flood was controlled by the Stânca-Costeşti dam (Fig. 5a). The gauging station recorded a maximum precipitation amount of 96.4 mm, out of an annual mean total of 466.4 mm (Table 1). Heavy rains and controlled spill determined the flood wave to extend over a longer period.

In 2005, the maximum discharge at the Gauging station of Stânca Downstream reached the value 570 m^3/s. This was a simple wave (mono-wave), with a multitude of secondary inflexions, which unfolded in the interval 19-31 August 2005 (Fig. 5b). The increase slope was extremely abrupt, and the peak was recorded on 21 August 2005. The long duration of the flood wave demonstrates that it was controlled by flood diversion from the Stânca-Costeşti reservoir. The flood wave peak was 21-29 August 2005, and it had the same value throughout this period. The amounts of rain fallen during the flood wave, recorded at the gauging station, were significant; hence, they influenced the flood wave. Between 18 and 24 August 2005, 277.2 mm precipitations were recorded, out of a monthly total of 309.7 mm. The year 2005 was rich in precipitations: the mean was 733.6 mm.

In the year 2006, the maximum discharge at the Gauging station of Stânca Downstream reached the value 496 m^3/s. This was a simple wave (mono-wave), with a low secondary inflexion, which unfolded in the interval 3-19 June 2006 (Fig. 5c). The increase slope was extremely abrupt, considering that the peak was reached within hours. The significant duration of the flood wave demonstrates that it was controlled by flood diversion from the Stânca-Costeşti reservoir. The peak of the flood wave unfolded in the period 4-18 June 2006 and it recorded the same value from beginning to end. The amount of rain fallen during the flood wave, recorded at the gauging station, was significant and it influenced, in its turn, the flood wave. Between 1 and 21 June 2006, 121.8 mm of precipitations were recorded, considering that the monthly total was 168.8 mm. The year 2006 was a normal one from the precipitation perspective: 551.2 mm.

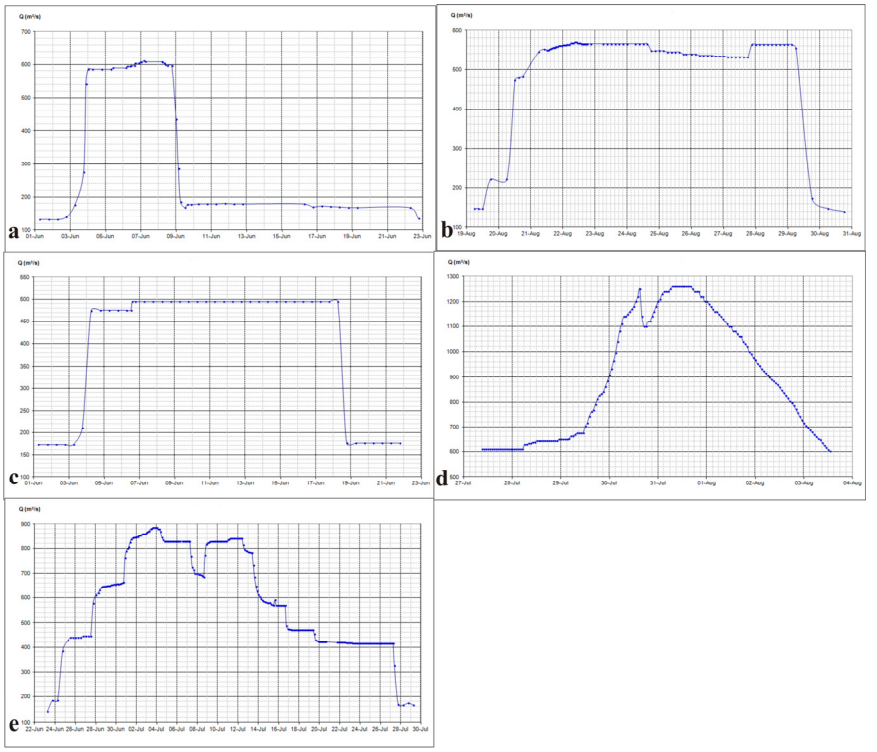

Figure 5. Evolution of the maximum flood at the Gauging station of Stânca Downstream: a-1988; b-2005; c-2006; d-2008; e-2010

Table 1. Mean monthly precipitations recorded at the Gauging station of Stânca Downstream in 1988 (m^3/s)

Day/ Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual
Mean	36.3	8.9	17.1	29.5	83.3	**96.4**	68.6	39.7	41.9	6.3	7.4	31.0	**466.4**

In 2008, the maximum discharge at the Gauging station of Stânca Downstream reached the value 1050 m^3/s. This was a compound wave (multi-wave), with two peaks in the upper part, which unfolded in the interval 28 July-3 August 2008 (Fig. 5d). The increase slope was abrupt, because the peak was reached in 24 hours. The relatively long duration of the flood wave demonstrates that it was controlled by flood diversion from the Stânca-Costești reservoir. In the period 30 July-1 August 2008, water was evacuated in two phases. The flood wave was caused only by the value of the diversion from the Stânca-Costești reservoir. The rain fallen at the Gauging station of Stânca Downstream was insignificant, just like the monthly mean for August.

In 2010, the maximum discharge at the Gauging station Stânca Downstream reached the value 885 m^3/s. This was a compound wave (multi-wave), with two main inflexions and secondary levels, which unfolded in the interval 23 June-30 July 2010 (Fig. 5e). The flood wave increased by levels until it reached the maximum value 885 m^3/s, after which it decreased and then increased again to 830 m^3/s. It featured a descending slope by levels, depending on the volume of water diverted from the Stânca-Costeşti reservoir. The significant duration of the flood wave demonstrates that it was controlled by the dam. The amount of rain recorded during the flood wave at the gauging station was reduced (0 mm). This flood wave was influenced only by the upstream factors

In the year 2005, the maximum discharge at the Gauging station of Ungheni reached the value 537 m^3/s. This was a simple wave (mono-wave), with rapid decrease. It unfolded in the period 20 August-5 September 2005 (Fig. 6a). The maximum value extended over a long interval: 23-31 August 2005. This flood

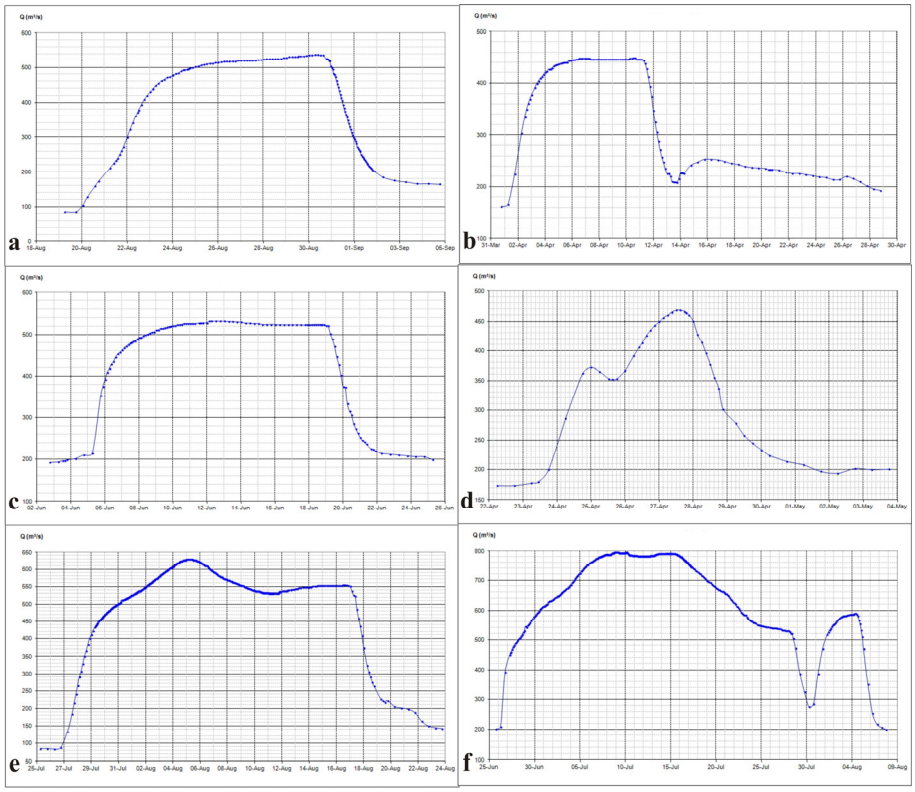

Figure 6. Evolution of the maximum flood at the Gauging station of Ungheni: a-2006; b-2006(1); c-2006(2); d-2008(1); e-2008(2); f-2010

wave was influenced by upstream factors. The amount of rain recorded during the flood wave at the gauging station was reduced (33.7 mm, out of a monthly total of 45.7 mm). The annual mean for 2005 is within the normal range: 557.1 mm. The maximum value reached at the Gauging station of Ungheni is significantly lower than the ones recorded at stations within the sector upstream from the Stânca-Costeşti reservoir. The dam works on the Prut stream protected inhabited territories against floods.

In 2006, the maximum discharge at the Gauging station of Ungheni – flood wave 1 – reached the value 450 m^3/s. This was a compound wave (multi-wave), with rapid increase and decrease in the first part and a weak inflexion during the second part. It unfolded in the period 1-30 April 2006 (Fig. 6b). The first wave unfolded in the period 1-14 April 2006, when the maximum value was recorded. The second wave, significantly less powerful, occurred in the period 14-30 April 2006. This flood wave was influenced by upstream factors. The amount of rain recorded during the flood wave at the gauging station was reduced (57.4 mm). The annual mean for 2006 is within the normal range (522.4 mm).

The second important flood wave of 2006 unfolded in the period 3-26 June 2006 (Fig. 6c). This was a simple wave (mono-wave), with flattened peak, specific to dam-controlled floods. The maximum value reached 532 m^3/s. Insignificant amounts of rain fell at the gauging station, reason for which they did not influence the flood wave.

In 2008, two major floods occurred at the Gauging station of Ungheni. The maximum discharged of 2008 – flood wave 1 – reached the value 470 m^3/s. This was a compound wave (multi-wave), with rapid increase and decrease in both peaks. The maximum value was reached during the second wave. It unfolded in the period 23 April-4 May 2008 (Fig. 6d). This flood wave was influenced by upstream factors. The amount of rain recorded during the flood wave at the gauging station was reduced. In the months of April and May, the amounts of rain ranged within normal values: 53 mm and 54 mm. The annual mean for 2008 is within the normal range – 517 mm. It does not coincide with the maximum flood waves recorded on the Prut, upstream from Stânca-Costeşti reservoir. This flood wave was influenced by the tributaries located upstream from the gauging station.

The maximum discharge of 2008 – flood wave 2 – reached the value 630 m^3/s. This was a simple wave (mono-wave), with rapid increase and decrease. It featured a weak inflexion during the second wave. It unfolded in the period 27 July-24 August 2008 (Fig. 6e). This flood wave was influenced by upstream factors. It corresponds to the historic flood waves recorded on the Prut River, upstream from the Stânca-Costeşti reservoir. This flood wave was controlled by the dam. The amount of rain recorded during the flood wave at the gauging station was reduced (38 mm). The annual mean for 2008 is within the normal range (517 mm).

The maximum discharge of 2010 reached the value 795 m^3/s. This was a compound wave (multi-wave), with two peaks. The maximum flood wave was recorded during the first wave, when a massive, long-term runoff occurred. The entire flood wave unfolded in the period 25 June-9 August 2010. It was one of the longest flood waves on the Romanian territory, similar to the one of 2008 (2) (Fig. 6f). This flood wave was influenced by upstream factors. It corresponds to the serious flood waves recorded on the Prut River, upstream from the Stânca-Costeşti reservoir. This flood wave was controlled by the dam. Precipitations fallen during the flood wave, at the gauging station, were significant only in the month of June (115.4 mm). The annual mean for 2010 is within the normal range: 545.7 mm.

The maximum discharge of 1988, at the Gauging station Prisăcani, reached the value 742 m^3/s. This was a simple wave (mono-wave), with two mild inflexions during the increase and decrease periods. The flood wave occurred in the period 28 May-1 July 1988 (Fig. 7a). This flood wave was influenced by upstream factors and by precipitations fallen at the local gauging station. It corresponds to the serious flood waves recorded on the Prut River, upstream from the Stânca-Costeşti reservoir. Precipitations fallen during the flood wave, at the gauging station, had a high value in June (102.3 mm). The annual mean for 1988 is within the normal range: 513.6 mm.The maximum discharge of 1991, at the Gauging station of Prisăcani, reached the value 755 m^3/s. This was a simple wave (mono-wave), with two mild inflexions during the increase and decrease periods. The flood wave occurred in the period 27 July-24 August 1991 (Fig. 7b).

This flood wave was influenced by upstream factors and by precipitations fallen at local gauging station. It corresponds to the serious flood waves recorded on the Prut River, upstream from the Stânca-Costeşti reservoir. Precipitations fallen during the flood wave, at the gauging station, had a high value in July (128.1 mm), while in August they did not exceed 97.9 mm. The annual mean for 1991 is high: 734.7 mm.

Acknowledgments

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