Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-289-RC2, 2016 © Author(s) 2016. CC-BY 3.0 License.

Interactive comment on **"Exceptional floods in the Prut basin, Romania, in the context of heavy rains in the summer of 2010"** ***by*** **Gheorghe Romanescu and Cristian Constantin Stoleriu**

Anonymous Referee#1

Dear referee, thank you for your interests about our article,

Referee#1 comment 1: Line 34 "Floods are one of the most important natural hazards on Earth" references are about Europe and not the earth

Authors' answer 1: Concerning line 34 we omitted to detail the phrase from "Floods are one of the most important natural hazards on Earth" to " Floods are one of the most important natural hazards in Europe (Thieken et al., 2016) and on earth as well (Merz et al., 2010; Riegger et al., 2009). They generate major human life losses and property damage (Wijkman and Timberlake, 1984).", and we modified in text's paper.

Referee#1 comment 2: Line 36. "Significant funds...". You may cite the date provided in Merz et al. http://www.nat-hazards-earth-syst-sci.net/nhess- special_issue77-preface.pdf

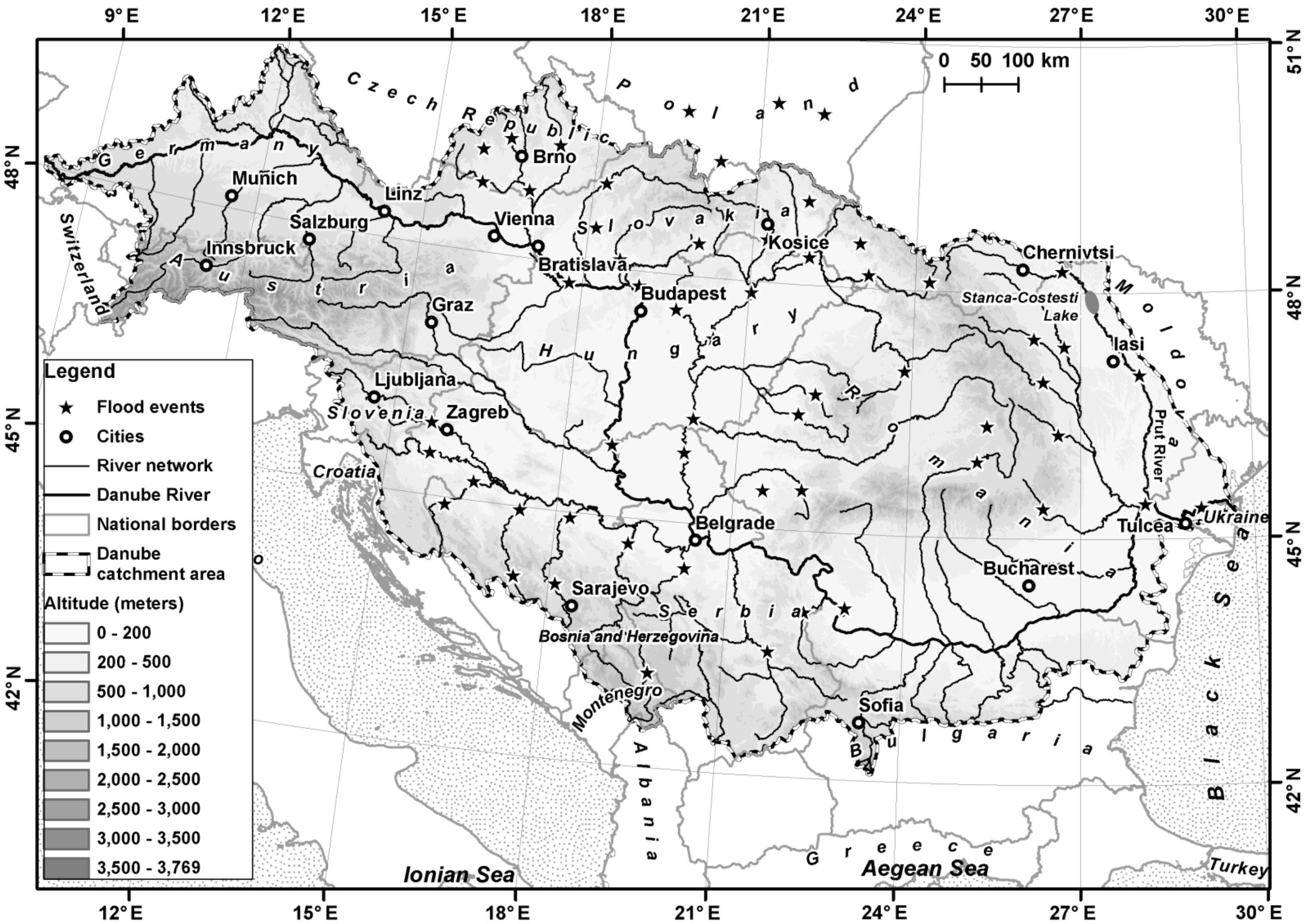
Authors' answer2 : We summarized the ideas specified by Merz et all. Into next paragraph:
"According to Merz et al. (2010) "the European Flood Directive on the assessment and management of flood risks (European Commission, 2007) requires developing management plans for areas with significant flood risk (at a river basin scale), focusing on the reduction of the probability of flooding and of the potential consequences to human health, the environment and economic activity." (p. 511)."

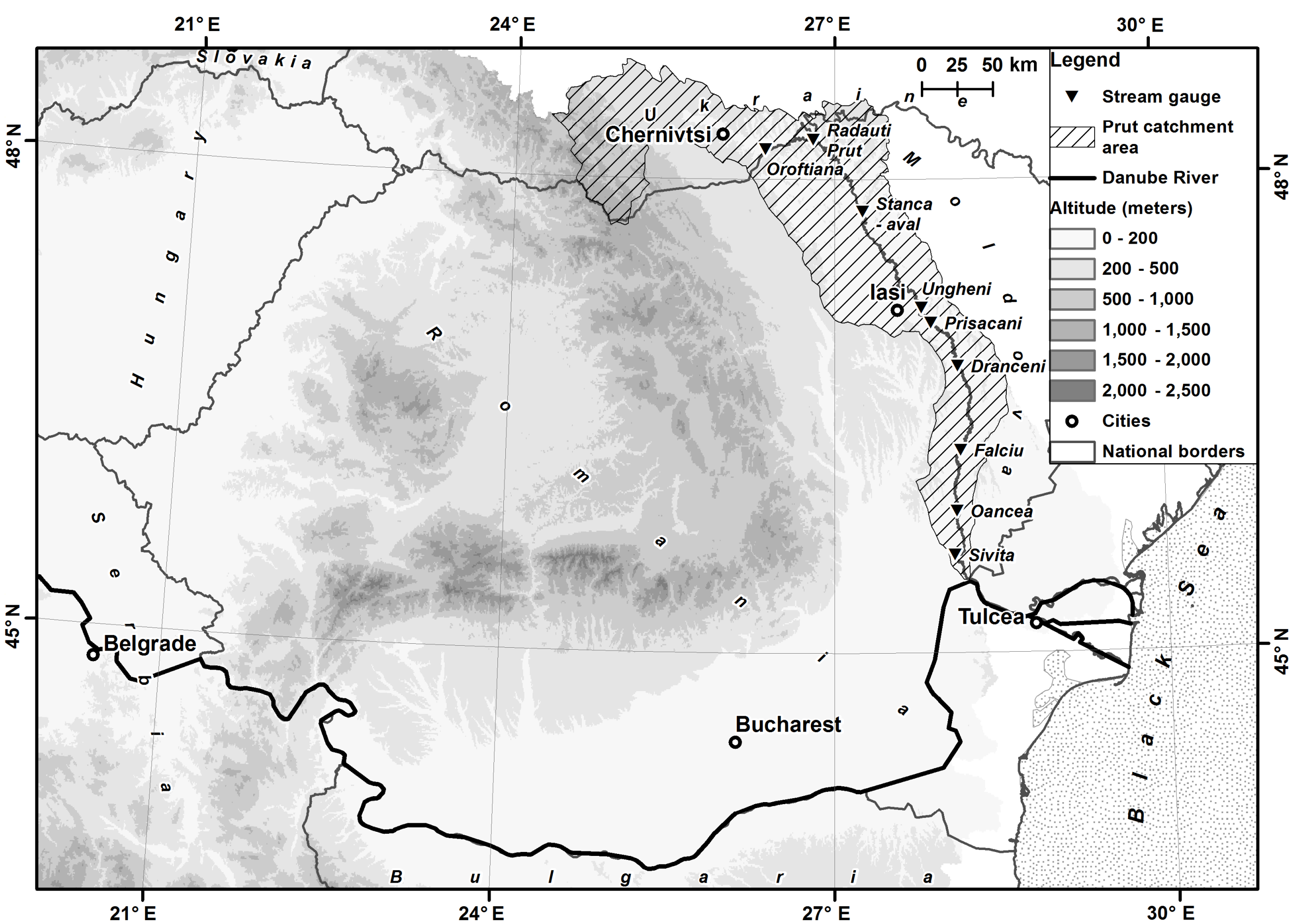
Referee#1 comment 3: The reference in lines 37 to 44 should be documented and separated in different topics. Effectively the list is too long and is a mixing of several subjects. For example: -Ahilan et al. 2012 is about statistical distribution of maximum annual discharge using GEV and relationships with basin geology - Alfieri et al. 2015 is about climate change impacts on floods - Berariu et al. 2015 is about the effects of disasters on infrastructures such as transportation infrastructures and their interdependence, etc...

Authors' answer3: We rephrase the paragraph about references between lines 37-44
Several studies investigated catastrophic floods or the floods that generated significant damage. They focused on: the statistical distribution of maximum annual discharge, using GEV and the links with the basin geology (Ahilan et al., 2012); climate change impacts on floods (Alfieri et al., 2015; Detrembleurs et al., 2015; Schneider et al., 2013; Whitfield, 2012); disasters effects on infrastructures such as transportation infrastructures, and their interdependence (Berariu et al., 2015); historical floods (Blöschl et al., 2013; Strupczewski et al., 2014; Vasileski and Radevski, 2014) and their links to heavy rain (Bostan et al., 2009; Diakakis, 2011; Prudhomme and Genevier, 2011; Retsö, 2015); public perceptions of flood risks (Brilly and Polic, 2005; Feldman et al., 2016; Rufat et al., 2015); land use changes and flooding (Cammerer et al., 2012); the evolution of natural risks (Hufschmidt et al., 2005); geomorphological effects of floods in riverbeds (Lichter and Klein, 2011; Lóczy and Gyenizse, 2011; Lóczy et al., 2009, 2014; Reza Ghanbarpour et al., 2014); the spatial distribution of floods (Moel et al., 2009; Parker and Fordham, 1996); the interrelation between snow and flooding (Revuelto et al., 2013).

Referee#1 comment 4: Line 61: are the Stanca-Costesti reservoir and the Prut reported in Fig. 1?

Authors' answer4: We modified the Figure 1, and also in Fifure 2, in order to appear River Prut, Danube and Stanca-Costesti reservoir.





Referee#1 comment 5: Line 83 altitude in the catchment

Authors' answer5 : The situation observed at line 83 is an unfortunate manner of writing for describing the mean altitude within Prut catchment basin. The phrase was adjusted as follow: "The mean altitude of the midstream sector of catchment area is 130 m, and for the downstream sector is 2 m."

Referee#1 comment 6: Line 90 Jijia basin area is not documented while this basin is important in the last part of the paper.

Authors' answer6 : We introduced some detailed information concerning Jijia River:
"Jijia River has 275 km in length, a catchment area of 5757 km^2 and an annual average flow of 14 m3/s. Its most important tributaries are Miletin, Sitna and Bahlui."

Referee#1 comment 7: Line 94 what is the criteria to define a "large pond"?

Authors' answer7 :
Small ponds are used as drinking water for livestock or to irrigate subsistence rural households. They usually belong to individual households. Large ponds on the other hand have multiple uses, such as: flooding mitigation, irrigation, fish farming etc. They resisted better in time because of their significant surfaces and depths. These large ponds belong to rural or urban communities.

Referee#1 comment 8: Line 111 "measurements were taken to estimate the discharge." It is important to say which kind of measurements.

Authors' answer8:
Mathematical methods were used to reconstitute discharges and terrain measurements using land surveying equipment (Leica Total Station) were used to calculate the surface of the stream cross-section.

Referee#1 comment 9: Lines 113 to 118 Same remark as in lines 37 to 44. It should be clear what type of method is behind a given reference. For example Ali et al. (2012) used tracers while Delli-Priscoli and Stakhiv examined "the performance of existing flood protection systems". Line 132 did CA, CI, CP have been defined before?

Authors' answer9 : We restructured the paragraph such as:
"The recording and analysing methodology used is standard or slightly adapted to local conditions: e.g. the influence of physical-geographical parameters on runoff (Ali et al., 2012; Kappes et al., 2012; Kourgialas et al., 2012; Waylen and Laporte, 1999); the management of risk situations (Delli-Priscoli and Stakhiv, 2015; Demeritt et al., 2013; Grobicki et al, 2015 Grobicki et al, 2015); the role of reservoirs in flood mitigating (Fu et al., 2014; Serban et al., 2004; Sorocovschi, 2011); the probability of flooding and the changes in the runoff regime (Hall et al., 2004, 2014; Jones, 2011; Seidu et al., 2012a,b; Wu et al., 2011); flood prevention (Hapuarachchi et al., 2011); runoff and streamflow indices (Nguimalet and Ndjendole, 2008); morphologic changes of riverbeds or lake basins (Rusnák and Lehotsky, 2014; Touchart et al., 2012; Verdu et al., 2014) etc."

Referee#1 comment 10: Line 148, 149 the methodology should be more detailed.

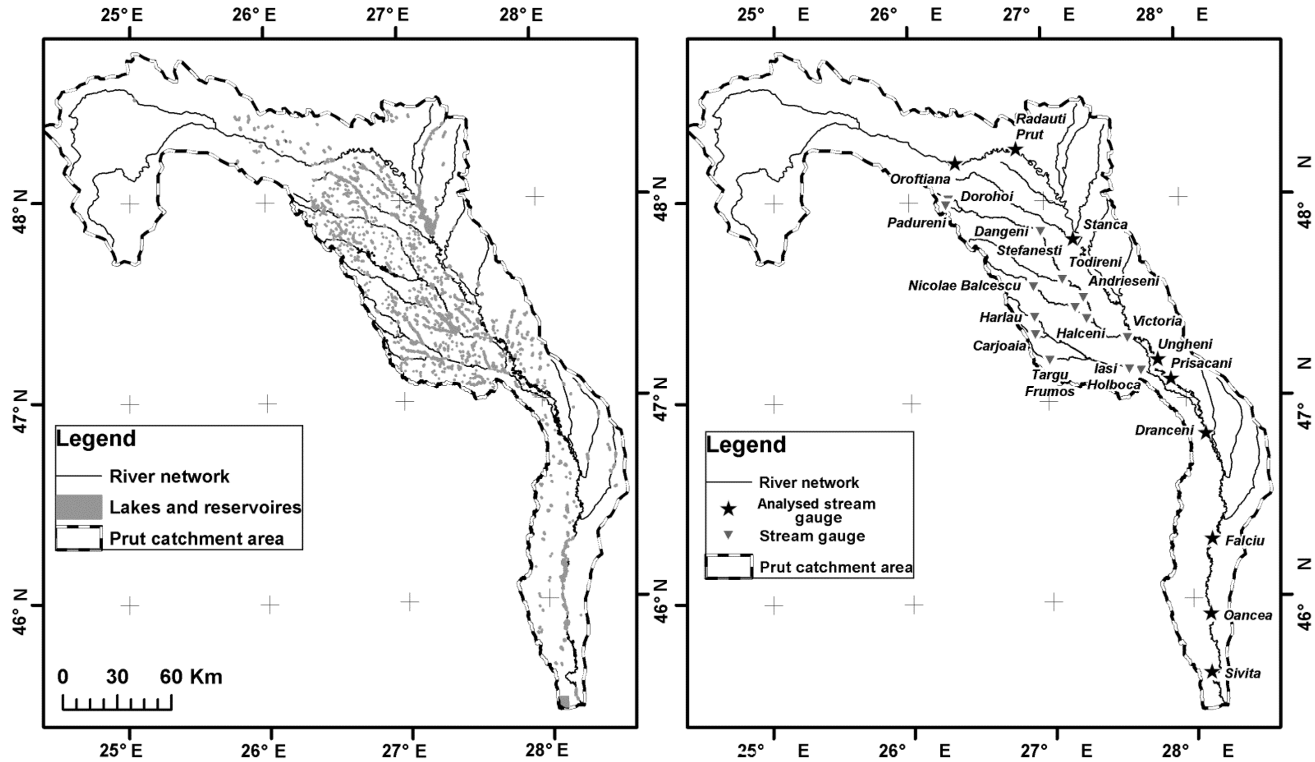
Authors' answer10 :
The cartographic basis used to map altitudes and slopes is Shuttle Radar Topography Mission (Global Land Cover Facility, 2016), at a 1:50000 scale. The vector layers were projected within a geodatabase, using ArcGis 10.1. They include stream lines, sub-catchment basins, and reservoirs and ponds polygons, as well as gauging station points. In order to generate the GIS layers, we applied the following methods: digitisation, queries, conversion, geometries calculation (length, surface) and spatial modelling. Water levels and discharges data were processed and plotted on charts using the Open Office software. We also used the Inkscape software to design the final maps and images.

Referee#1 comment 11: Line 154 and 164 are not compatible (1 July, 9 July).

Authors' answer11 : In the first case it's about rainfalls registered in Romania (on July 1st) and in the second case it's about those registered in Ukraine (on July 9th).

Referee#1 comment 12: Line 168 You need to specify what is registered in each station. What do you mean by "only water levels"? the stations reported in Table 1 should be easily identified in Fig. 3 (by using a different marker) and what is observed (level or discharge should be mentioned. Fig. 5 is not easy to read Line 199 and line 203. What is meant by "floods were recorded"? Do you mean that a flood gauging was operated instead of using the rating curve?

Authors' answer12 :
Figure 3 was modified by using different marker.



For line 168

"At Oroftiana gauging station, only the water levels data were registered. And for all other gauging stations are registering, in addition to water level, the discharges data."

For line 199 and line 203

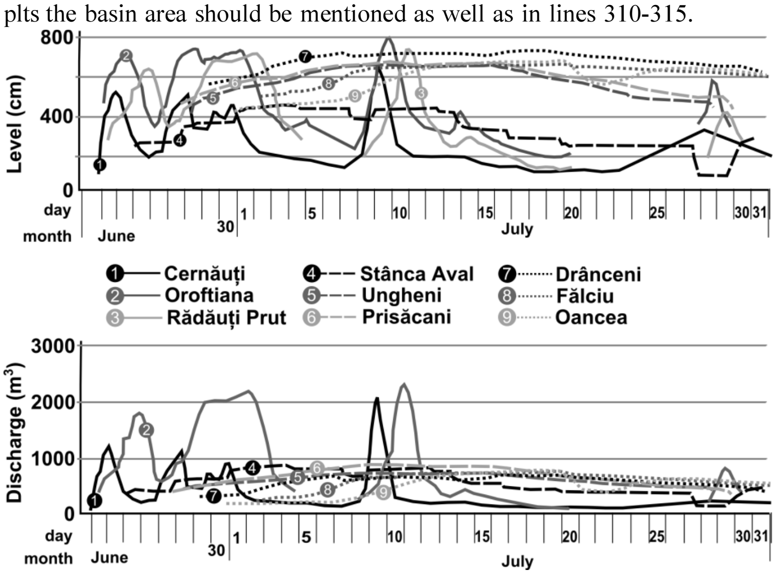
Floods were registered at the gauging station.

Referee#1 comment 13: Line 211 the peculiarity of Oancea gauging station and Sivita station distinguishing tidal effects should be documented.

Authors' answer13:

At line 211 there is an unfortunate translation for the term "backwaters". "Backwaters" is the correct term instead of "tidal bore". Backwaters were caused by increasing water level of Danube River, which influences the measurements results at the gauging stations situated on the downstream sector of Prut River.

Referee#1 comment 14: Line 243 and elsewhere "Fig. 3 and 6" is not clear. Fig 6 is not easy to read. The peculiarity of Stefanesti(?) station should be mentioned and analyzed in the text. (lines 218 to 221) In all figures, with levels and discherges plts the basin area should be mentioned as well as in lines 310-315.



Authors' answer14 :

The figures were modified for a better readability.

Stefanesti gauging station is located in the downstream sector of the dam and itis directly influenced by the discharge water from the Stanca-Costesti Lake (since 1978).

Referee#1 comment 15: Line 316. In is not clear why this mention here "The Oroftiana gauging station only records water level measurements." Idem until line 321. What is the consequence on data accuracy? Line 317. Why this influence?

Authors' answer15 : The water level registered at Radauti Prut gauging station could be influenced by the backwaters caused by Stanca-Costesti Lake. The most obvious case of backwaters was registered during the 2008 historic flood.

Referee#1 comment 16: Lines 329 – 330. Was rainfall observed?

Authors' answer 16 :
200-400 mm of rainfall (ie 50-80% of the annual amount) was recorded between 1 May and 15 July 2010. During the flood manifested in 2008, a historic discharge value was registered for Prut river, but the by-passed water volume was low (in upstream of Stanca-Costesti dam) because the flood duration was short. The 2010 flood registered lower maximum discharges compare to 2008, but it by-passed a larger water volume, as flood lasted longer.

Referee#1 comment 17: Line 331-341 should in the study area section

Authors' answer 17 : the lines 331-341 were moved in Study area.

Referee#1 comment 18: Line 371; When did this record happened?

Authors' answer 18 : (July 5th, 2010)

Referee#1 comment 19: Line 380. Is this increase a result from what was said before?

Authors' answer 19 :
The discharge increase and the historic values registered were caused by several factors, such as: the water input from the upstream sector of Prut River and the water input added by the Danube backwaters.

Referee#1 comment 20: Line 386 Table 2 should be in the study area section.

Authors' answer20 : This table is better in this paragraph location because the text referee to it.

Referee#1 comment 21: Line 412 the backwater phenomena are effectively very difficult to assess and to predict.

Authors' answer21 : We mentioned this phenomenon because it is unique and had a major local impact for Dorohoi city.

Referee#1 comment 22: Lines 427 to 432. The role of the reservoir and its location in comparison to the river stations is not well described in the text.

Authors' answer22 :
The provision of an attenuation water volume (550 million m^3) within the lake basin is efficient in retaining a 1% probability flood (reducing it from 2940 m^3/s to 700 m^3/s). Together with the embankments located on the dam downstream sector, it helps preventing the flooding of 100,000 hectares of meadow. At a normal retention level, Stanca-Costesti lake has a total area of 5900 ha and a water volume of 1.4 billion m^3.

Referee#1 comment 23: Line 449 Fig.12 presents challenging issues for water management.

Authors' answer23 :
In order to avoid such phenomena it is necessary to increase the height of the overflow structure.

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-289-RC2, 2016 © Author(s) 2016. CC-BY 3.0 License.

Interactive comment on **"Exceptional floods in the Prut basin, Romania, in the context of heavy rains in the summer of 2010"** *by* **Gheorghe Romanescu and Cristian Constantin Stoleriu**

Anonymous Referee #2

Received and published: 27 November 2016

General comments

The paper copes with the exceptional floods that hit Central Europe and particularly Romania in summer 2010. The work shows interesting flood data for the examined area (though partially presented by the authors in previous works), but it does not constitute a clear contribution to the understanding of these phenomena in the Prut basin, also for its complicated river network. In fact, though the work contains a lot of information on water levels and discharges observed during huge floods, these are mainly ranked values, roughly compared to similar past events but not statistically defined. In other terms, the paper is too much focussed to the simple inventory of flood values in several gauge stations, and poor attempts to link them to physical reasons or to probabilistic interpretation have been made by authors. Thus, the readability of the paper is not good enough, mainly in the paragraph of the results.

Specific comments

Specifically, though the paper is mainly devoted to flood events, the context of heavy rains of the summer of 2010 (as in the title) is poorly described and could be largely improved. This could be done, for example, by coupling flood diagrams with rainfall histograms, when possible, or by comparing cumulative rainfall values recorded in this event with rainfall that caused other historical floods (also cited in the work). Anyway, the main drawback of the paper is the weak connection between rainfall and floods. In fact, though the period claimed as characterized by intense rainfall is 21 June -1 July 2010, a long set of summer flood (or water level) values is offered to the reader, neither providing any kind of link with triggering precipitation, nor any estimation of the return periods of the rainfall or flood values. Actually, the results are only described by means of simple ranks among critical events. To improve the paper, the paragraph devoted to the results should present at least some evaluations on the estimated frequencies (and not only on critical cases) of the flood values, thus providing more statistical sound to the work. On the other side, the interesting information on water stages and floods overcoming the specific thresholds is described too simply. The valuable data base can be better employed, for example, by combining the temporal overcoming of the higher thresholds in the flood diagrams with the occurrence of the main damages and casualties. This could also provide material for a further interesting discussion on false and missing alarms in the Prut River. Moreover, the work suffers from too much citations, not everywhere appropriate, and from figures affected by some inaccuracies. In brief, though well documented as regards the discharge values, the structure of the work is disorganised enough, with a scarce employment of statistical methodologies and a long section devoted to the results, which consist principally in a list of flood values, with no link to occurrence frequencies. As a result, the scientific approach of the work is not statistically accurate. Thus, a substantial revision of the paper is needed to improve the quality of the work and provide effectiveness to the flood analysis of the 2010 event in the Prut River.

Technical corrections

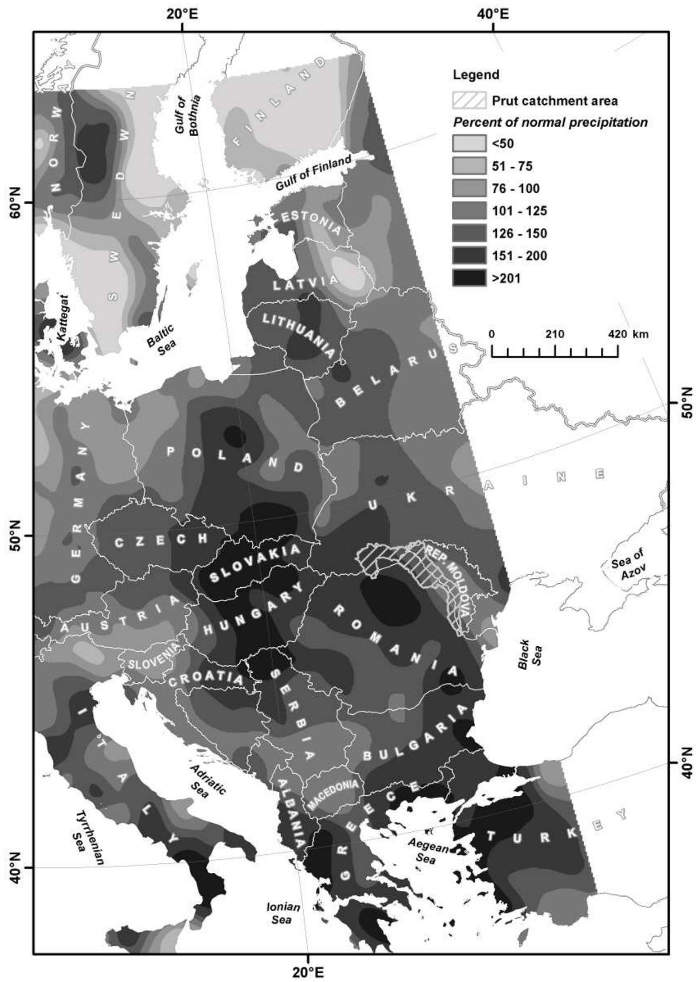
Line 18: avoid the word "etc." in the abstract; line 34: change "Earth" with "earth". Lines 61, 153 (and others): I don't understand if the authors use properly the terms "tidal bore" in rivers, except in the case of backwaters actually induced by reservoirs or confluences. Try to be more accurate. Line 76, Figure 2, legend: change "Km" with "km"; avoid decimal ciphers in elevation values. Line 83: it's not clear why the mean altitude assume different values. Line 84: from the figure, the maximum width of Prut basin seems not to be 30 km (even in the lower reaches). Improve the sentence. Lines 101-103: the sentence is trivial (except, maybe, for the presence of the several ponds, which should be recalled). Anyway, the differences among the discharges for the various sections seem very small for such a large river. Lines 107-118: The cited methodologies are not useful for analysing floods, but for recording and collecting data. The paragraph contains too much references and not all perfectly focussed on the issue. The sentence needs a better explanation. Lines 126: it's not usual the call to the Berg intensity scale. If possible, add a reference. Line 132: the CA, CI and CP flood threshold levels should be clearly defined. Line 141: change "1915" with "1914", as noted in the table 1. Line 144, Table 1: the parameter "0 mira level", and mainly its unit "mrBS", should be better explained (or changed). Line 165: the use of the term "significant" should be associated to statistical analysis. Line 175, Figure 4: the values in the legend should not show decimal ciphers. Line 175, Figure 4: can the areal extension of the rainfall analysis be enlarged to the whole Prut basin? Line 177, Figure 5: it's useless to span the graphs before and after the period 20 June – 31 July, that could be better centered with no temporal amplification. Line 235, figure 6: it's not useful to extend the graphs after 1 July. Line 274, figure 7: the temporal amplification can be easily avoided. Line 303, figure 8: the temporal amplification is useless. The legend ("X scale, 0-24 hours") has no meaning. Line 324: the term "significantly" should be associated to statistical analysis. Lines 325-327: the sentence "This value was recalculated." should be better explained. Line 339: the sentence ".allowing the mitigation of 1%." is not clear. Line 373: there are some words repeated ("was eliminated gradually"). Line 430: it can be used directly the acronym "NRL", previously defined in line 335. References in Romanian language should report the words "(in romanian)" at the end of the citation.

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-289, 2016.

Authors' answer:

The paper represents an analysis of the situation caused by the flood in 2010 within Prut basin. In the future we intend to analyse the hydrological context of the last 50 years for Prut basin. In this moment we do not have all hydrological data (such as levels, flow rates) for the entire Prut basin. We are in discussion with an official institution in order to obtain hydrological data.

The strongest floods from 2010 were registered in the Danube basin (see Table 1). For Romania, we underlined the floods from the basins of Prut, Siret, Moldova and Bistrita rivers.
The majority of floods in Romania are influenced by climate factors, which manifest at local and European level (Birsan, 2015; Birsan and Dumitrescu, 2014; Birsan et al., 2012; Chendes et al., 2015; Corduneanu et al., 2016). During the last decade of June (June 20, 2010) and the end of July (July 30, 2010), a baroclinic area was localized in Northern Moldavia. This favored the formation of a convergent area of humidity. In this case, a layer of humid, warm and instable air was installed between the topographic surface and 2500 m of altitude. The high quantity of humidity has its origins from The Black Sea, situated 500 km away. The warm tropical air is generated by the Russian Plain, overheated by a strong continentality climate. The cold air from medium troposphere, inducted by the cut-off nucleum that generated atmospheric instability, overlapped this structure of the low troposphere (Hustiu, 2011). The synoptic context was disturbed by local physical-geographical factors, especially by the orography of Eastern Carpathians, which led to extremely powerful heavy rains: e.g. 100-200 mm in 24 hours at the sources of Jijia (representing the amount that normally falls during June and July) or 40-60 mm in 24 hours at the Romanian frontier with Ukraine and the Republic of Moldova. The quantity of rainfall during 24 hours were 2-3 higher than the normal values for this period (Hustiu, 2011) (see Figure 4).



Deviation of monthly rainfall amounts (May-July 2010) from the yearly values - CPC (source data NOAA)

There were 6 main periods extremely rainy in Romania, located especially in the Moldavian hydrological basins (Prut and Siret): 21-23 June, 25-26 June, 28-30 June, 3-4 July, 6-7 July and 9 July. Rainfall quantities recorded in June were higher. The flash floods registered in Northern Moldavia in 28-29 June 2010 were generated by convective systems with slow spreading. Even if the rainfalls from June 29th were lower, the floods had devastating effects because they came on the context of the increasing water levels from 28 June 2010. Climate convection was organized as a mesocyclone extended over Northern Moldavia (the departments of Suceava and Botosani) (Hustiu, 2011).
Methodology: Data on the deviation of rainfall quantities were obtained from the Climate Prediction Center NOOA and from the scientific literature (Hustiu, 2011).
Line 18: word "etc." was deleted (Abstract section);
Line 34: it was replaced the letter E with e.
Lines 61, 153 (and others): it was replaced “tidal bore” with “backwaters”.
Line 76, "Km" was replaced with "km"; and the decimals from legend were deleted.
Line 83:
The situation observed at line 83 is an unfortunate manner of writing for describing the mean altitude within Prut catchment basin. The phrase was adjusted as follow: "The mean altitude of the midstream sector of catchment area is 130 m, and for the downstream sector is 2 m.".
Line 84: In Brateș Lake sector is registered 12 km width.
Lines 101-103: It's about the water discharge from affluent basins. In this case, the water volumes were cumulated from all the

accumulations that contributed to diminishing floods.

Lines: 107-118: The paragraph was modified according to the requests of R1.

Line 126: Berg et al., 2009.

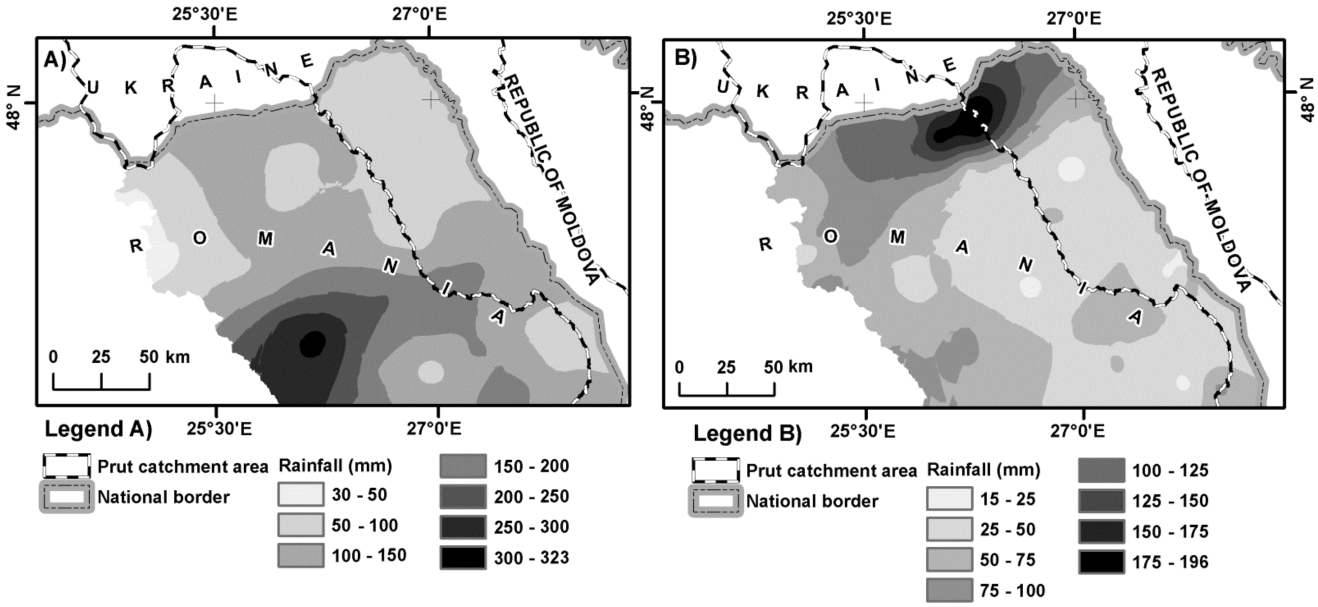
Line 132: These were explained as requested by R1.

Line 141: Changed “1915” with “1914”.

Line 144, Table 1: "0 nivel mira" was translated to 0 meter level of tide pole and "mrBS stand for meters level reported at Black Sea"

Line 165: the term "significantly" was replaced with “high discharge value”.

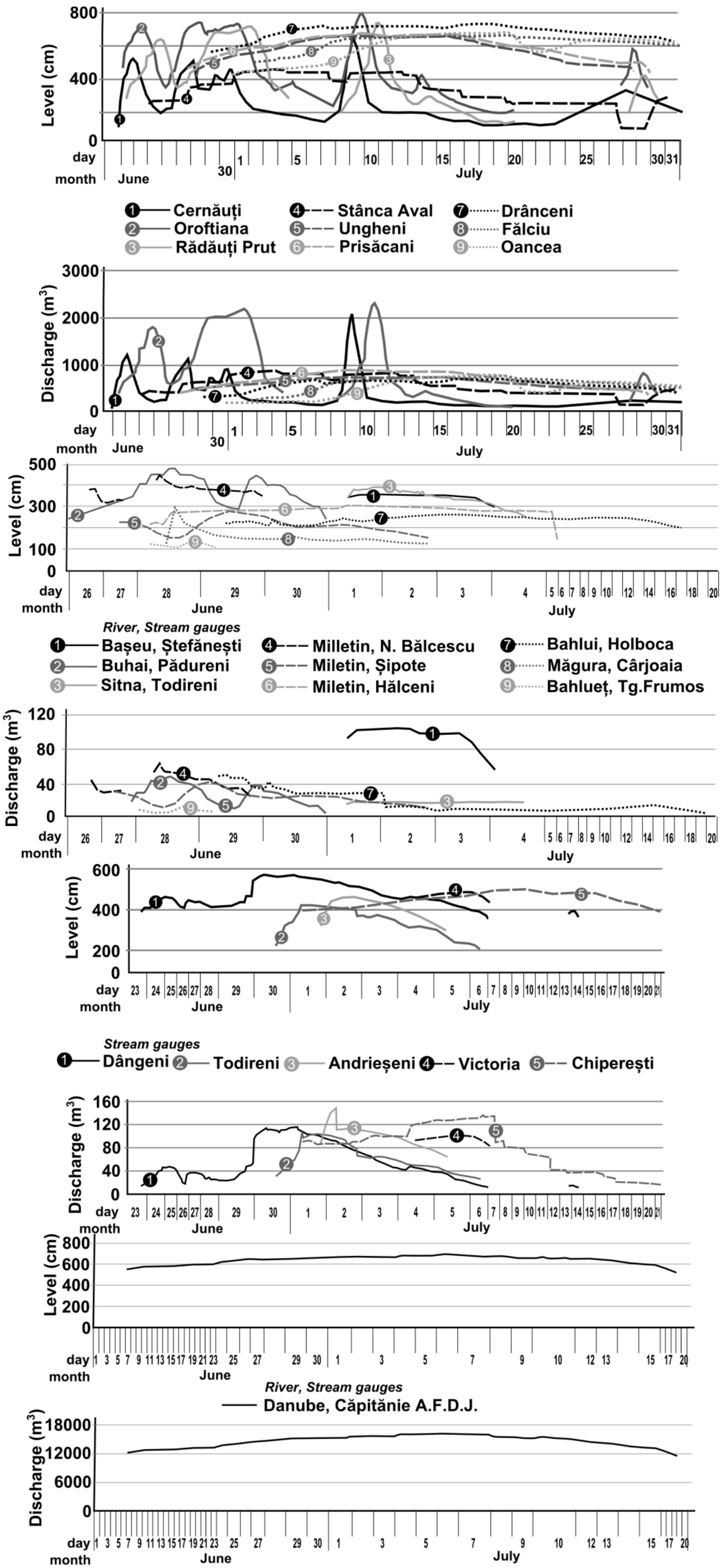
Line 175: The decimals from Figure_4’s legend were deleted. After de correction operated on article’s text and figures, Figure_4 become Figure_5.



Line 175, Figure_4 (now Figure_5) represent a zoom on north-eastern part of Romania, where a large amount of precipitations were registered.

Lines 177, 235, 274, 303: Figures 5-8 (after de correction operated on article’s text and figures, Figures 5-8 become Figures 6-9).

Line 324: the term “significantly” was replaced with term “remarkable”



Lines 325-327: this value was recalculated through reconstitute discharges.

Line 339: The phrase "The reservoir was constructed with a mitigation level of 550 million.m^3, allowing the mitigation of a 1% tidal bore from 2,940 to 700 m^3/s. The damming infrastructure constructed downstream from the hydrotechnical nodes prevents the flooding of approximately 100,000 ha of floodplain area" was replaced with "The provision of an attenuation water volume (550 million m3) within the lake basin is efficient in retaining a 1% probability flood (reducing it from 2,940 m3/s to 700 m3/s). Together with the embankments located on the dam downstream sector, it helps preventing the flooding of 100,000 hectares of meadow."

Line 373: The repeated words were deleted.

Line 430: was used directly the acronym "NRL".

References in Romanian language were specified with "(in romanian)" at the end of the citation.

Exceptional floods in the Prut basin, Romania, in the context of heavy rains in the summer of 2010

Gheorghe Romanescu[1], Cristian Constantin Stoleriu
Alexandru Ioan Cuza, University of Iasi, Faculty of Geography and Geology, Department of Geography, Bd. Carol I, 20 A, 700505 Iasi, Romania

Abstract. The year 2010 was characterized by devastating flooding in Central and Eastern Europe, including Romania, the Czech Republic, Slovakia, and Bosnia-Herzegovina. This study focuses on floods that occurred during the summer of 2010 in the Prut River basin, which has a high percentage of hydrotechnical infrastructure. Strong floods occurred in eastern Romania on the Prut River, which borders the Republic of Moldova and Ukraine, and the Siret River. Atmospheric instability from 21 June-1 July 2010 caused remarkable~~significant~~ amounts of rain, with rates of 51.2 mm/50 min and 42.0 mm/30 min. In the middle Prut basin, there are numerous ponds that help mitigate floods as well as provide water for animals, irrigation, and so forth. The peak discharge of the Prut River during the summer of 2010 was 2,310 m^3/s at the Radauti Prut gauging station. High discharges were also recorded on downstream tributaries, including the Baseu, Jijia, and Miletin ~~and Miletin~~. High discharges downstream occurred because of water from the middle basin and the backwater from the Danube (a historic discharge of 16,300 m^3/s). The floods that occurred in the Prut basin in the summer of 2010 could not be controlled completely because the discharges far exceeded foreseen values.

1 Introduction

Catastrophic floods occurred during the summer of 2010 in Central and Eastern Europe. Strong flooding usually occurs at the end of spring and the beginning of summer. Among the most heavily affected countries were Poland, Romania, the Czech Republic, Austria, Germania, Slovakia, Hungary, Ukraine, Serbia, Slovenia, Croatia, Bosnia and Herzegovina, and Montenegro (Bissolli et al., 2011; Szalinska et al., 2014) (Fig. 1). The strongest floods from 2010 were registered in the Danube basin (see Table 1). For Romania, we underlined the floods from the basins of Prut, Siret, Moldova and Bistrita rivers.~~Cele mai puternice inundații din anul 2010 s-au înregistrat în bazinul Dunării (Tabel 1). Pentru România sunt subliniate inundațiile din bazinele hidrografice Prut, Siret, Moldova și Bistrița.~~ The most devastating floods in Romania occurred in Moldavia (Prut, Siret) and Transylvania (Tisa, Somes, Tarnave, Olt). The most deaths were recorded in Poland (25), Romania (six on the Buhai River, a tributary of the Jijia), Slovakia (three), Serbia (two), Hungary (two), and the Czech Republic (two) (Romanescu and Stoleriu, 2013a,b).

Floods are one of the most important natural hazards in Europe (Thieken et al., 2016) and on earth as well (Merz et al., 2010; Riegger et al., 2009). They generate major losses in human lives, and also property damage (Wijkman and Timberlake, 1984).~~Floods are one of the most important natural hazards în Europa (Thieken et al., 2016) dar și pe Terra (Merz et al., 2010; Riegger et al., 2009). Ele se soldează cu cele mai mari pierderi de vieți omenești și cele mai importante pagube materiale (Wijkman and Timberlake, 1984).~~ For this reason, they have been subject to intense research, and significant funds have been allocated to mitigating or stopping them. According to Merz et al. (2010) "the European Flood Directive on the

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assessment and management of flood risks (European Commission, 2007) requires developing management plans for areas with significant flood risk (at a river basin scale), focusing on the reduction of the probability of flooding and on the potential consequences to human health, the environment and economic activity." (p. 511).”This shift in flood risk reduction policies can be observed in the European Flood Directive on the assessment and management of flood risks (European Commission, 2007). It requires developing management plans for areas with significant flood risk, focusing on the reduction of the probability of flooding and of the potential consequences to human health, the environment and economic activity. Flood risk management plans will be integrated in the long term with the river basin management plans of the Water Framework Directive, contributing to integrated water management on the scale of river catchments.” (Merz et al., 2010). Several studies investigated catastrophic floods or the floods that generated significant damage. They focused on: the statistical distribution of the maximum annual discharge, using GEV and the links with the basin geology (Ahilan et al., 2012); climate change impacts on floods (Alfieri et al., 2015; Detrembleurs et al., 2015; Schneider et al., 2013; Whitfield, 2012); disastrous effects on infrastructures such as transportation infrastructures, and their interdependence (Berariu et al., 2015); historical floods (Blöschl et al., 2013; Strupczewski et al., 2014; Vasileski and Radevski, 2014) and their links to heavy rainfall (Bostan et al., 2009; Diakakis, 2011; Prudhomme and Genevier, 2011; Retsö, 2015); the public perception of flood risks (Brilly and Polic, 2005; Feldman et al., 2016; Rufat et al., 2015); land use changes and flooding (Cammerer et al., 2012); the evolution of natural risks (Hufschmidt et al., 2005); geomorphological effects of floods in riverbeds (Lichter and Klein, 2011; Lóczy and Gyenizse, 2011; Lóczy et al., 2009, 2014; Reza Ghanbarpour et al., 2014); the spatial distribution of floods (Moel et al., 2009; Parker and Fordham, 1996); the interrelation between snow and flooding (Revuelto et al., 2013).Some of the most interesting studies have investigated catastrophic floods or floods that caused significant damage: statistical distribution of maximum annual discharge using GEV and relationships with basin geology (Ahilan et al., 2012); climate change impacts on floods (Alfieri et al., 2015; Detrembleurs et al., 2015; Schneider et al., 2013; Whitfield, 2012); effects of disasters on infrastructures such as transportation infrastructures and their interdependence (Berariu et al., 2015); historical floods (Blöschl et al., 2013; Strupczewski et al., 2014; Vasileski and Radevski, 2014); relații între precipitații torențiale și inundații istorice (Bostan et al., 2009; Diakakis, 2011; Prudhomme and Genevier, 2011; Retsö, 2015); public perception of flood risks (Brilly and Polic, 2005; Feldman et al., 2016; Rufat et al., 2015); schimbări în utilizarea terenurilor și producerea inundațiilor (Cammerer et al., 2012); evolution of natural risk (Hufschmidt et al., 2005); efecte geomorfologice de albie (Lichter and Klein, 2011; Lóczy and Gyenizse, 2011; Lóczy et al., 2009, 2014; Reza Ghanbarpour et al., 2014); distribuția spațială a inundațiilor (Moel et al., 2009; Parker and Fordham, 1996); interdependența dintre stratul de zăpadă și inundații (Revuelto et al., 2013).

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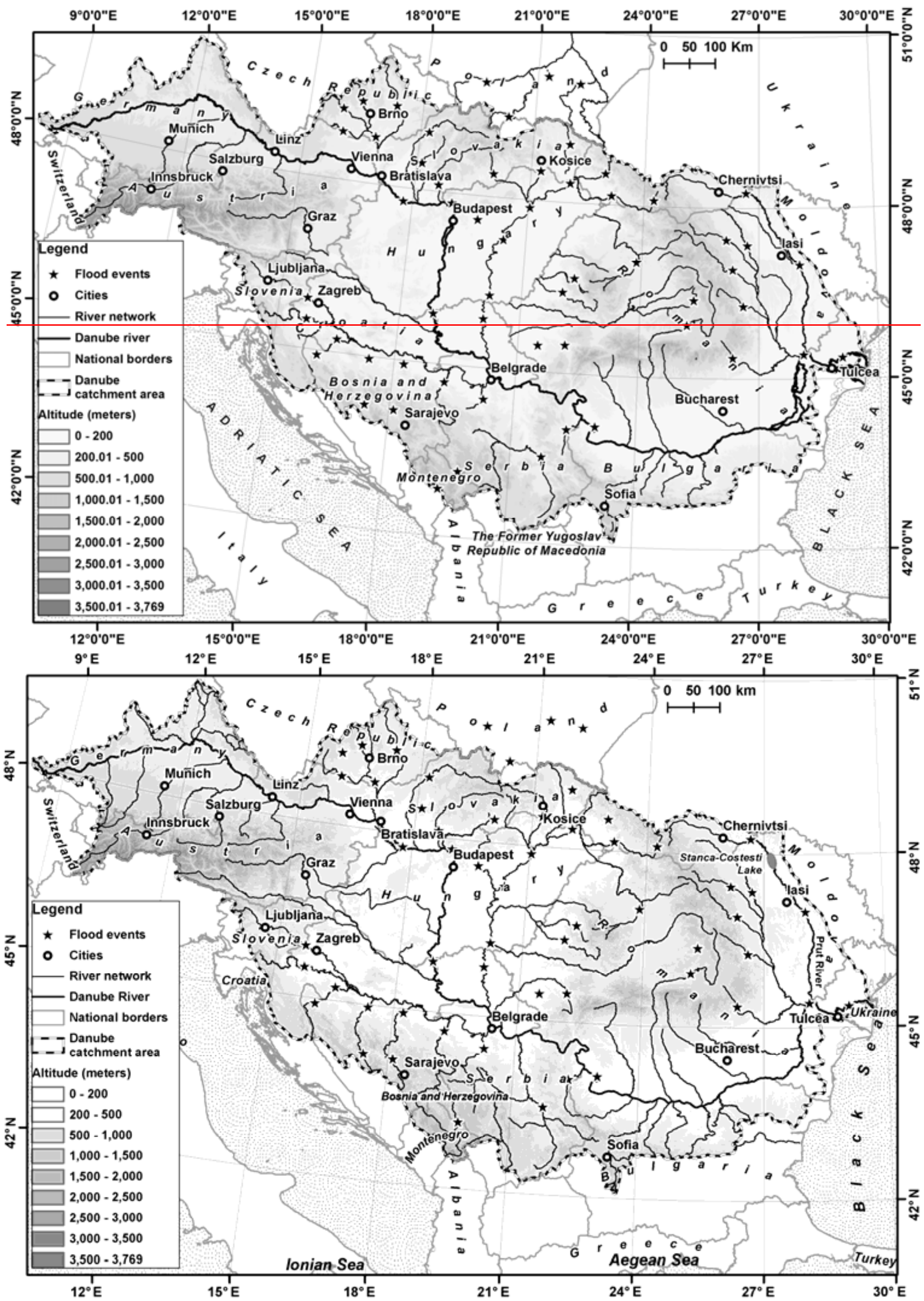

Figure 1. The Danube catchment and the location of the most important floods that occurred from May-June 2010

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Table 1. Overview of main flood events for the Danube river basin in 2010, as forecasted by EFAS and/or reported in international on-line news media (ICPDR, 2010)

From (dd.mm)	To (dd.mm)	River Basin Afected	Country Affected	EFAS Alert Sent?	Date EFAS Alert Sent	Confirmed?	Comment
20 II February	4 March III	Sava	HR/ RS	Yes (Flood Watch)	24 febFeb	Yes	Severe flooding in Central & E. Serbia, and in Sava & Morava river systems.
21 II February	28 II February	Velika Morava	RS	Yes (Flood Watch)	16 Feb	Yes	Severe flooding in eastern Serbia
February Febr	February Febr	Koeroes	RO/ HU	Yes (Flood Watch)	16 Feb	No	(No reports found on on-line news media). Events to be confirmed by partners in next annual EFAS meeting
1 III March	5 March III	Danube	RO/ BG	Yes (Flood Alert)	3 Mar	Yes	Severe flooding in S. Romania and in N.W. & N. Bulgaria.
MarchMarch	March March	Somes/ Mures/ Koeroes	RO/ HU	Yes (Flood Alert)	18 Mar	No	No reports found on on-line news media. Events to be confirmed by partners in next annual EFAS meeting
15 V May	30 V May	Danube/ Oder	SK/ PL/ CZ/ HU	Yes (Flood Alert)	12 May	Yes	Extensive flooding in central & eastern Europe, esp. Poland, Czech Republic, Slovakia, Hungary and Serbia.
Late June	July	Siret/ Prut/ Moldova/ Bistrita	RO/ MD	No	-	Yes	Severe flooding in N.E. Romania kill 25 people, also some counties in Moldova.
15 July VII	15 July VII	Prut/ Olt	RO	Yes (Flood Alert)	7 July	Yes	Maximum flood alert on Prut river in E. Romania, along border with Moldova.
17 IX September	19 IX September	Sava/ Soca	HR/ SL	Yes (Flood Alert)	18 Sept	Yes	Severe flooding in Slovenia kill 3 people. Croatia also affected.
Late NovemberNov	Early DecemberDec	Drina	RS	Yes (Flood Alert)	29 Nov	Yes	Severe flooding in Bosnia, Serbia and Montenegro, with river Drina at highest level in 100 years.
3 XII December	8 XII December	Sava	HR	Yes (Flood Alewrt)	5 Dec	Yes	Heavy rain causes devastating flooding in the Balkans, esp. Bosnia and Herzegovina, Croatia, Montenegro, & Serbia.
9 XII December	9 XII December	Tisza	HU/ RS	No	-	Yes	Snow-melt and swollen rivers flood 3000 km2 of arable land, esp. near Szeged, on Tisza river, in S.E. Hungary.
DecemberDec	DecemberDec	Koeroes	HU/ RO	Yes (Flood Alert)	3 Dec	No	(No reports found on on-line news media. Event to be confirmed by local authorities in annual EFAS meeting)

The Prut catchment basin spans three topographic levels: mountains, plateaus, and plains. The surface and underground water supply to the Prut varies by region and is extremly~~significantly~~ influenced by climatic conditions. This study underscores the role played by local heavy rains in the occurrence of floods, as well as the importance of ponds, mainly the Stanca-Costesti reservoir, in the mitigation of backwater~~tidal bore~~s. We also analyse the local contribution of each catchment basin on the right side of the Prut to the occurrence of the exceptional floods in the summer of 2010. Finally, we consider the upstream discharge and its influence on the lower reaches of the Prut.

2 Study area

The Prut River's catchment is situated in the northeastern Danube basin. It is surrounded by several other catchments: the Tisa to the northeast (which spans Ukraine, Romania, and Hungary), the Siret to the west (which is partially in Ukraine), and the Dniestr (in the Republic of Moldova) to the northeast. The Prut catchment occupies eastern Romania and the western part of the Republic of Moldova (Fig. 2). The Prut River begins in the Carpathian Mountains in Ukraine and empties into the Danube near the city of Galati. The catchment measures 27,500 km^2, of which 10,967 km^2 lies in Romania (occupying approximately 4.6% of the surface of Romania).

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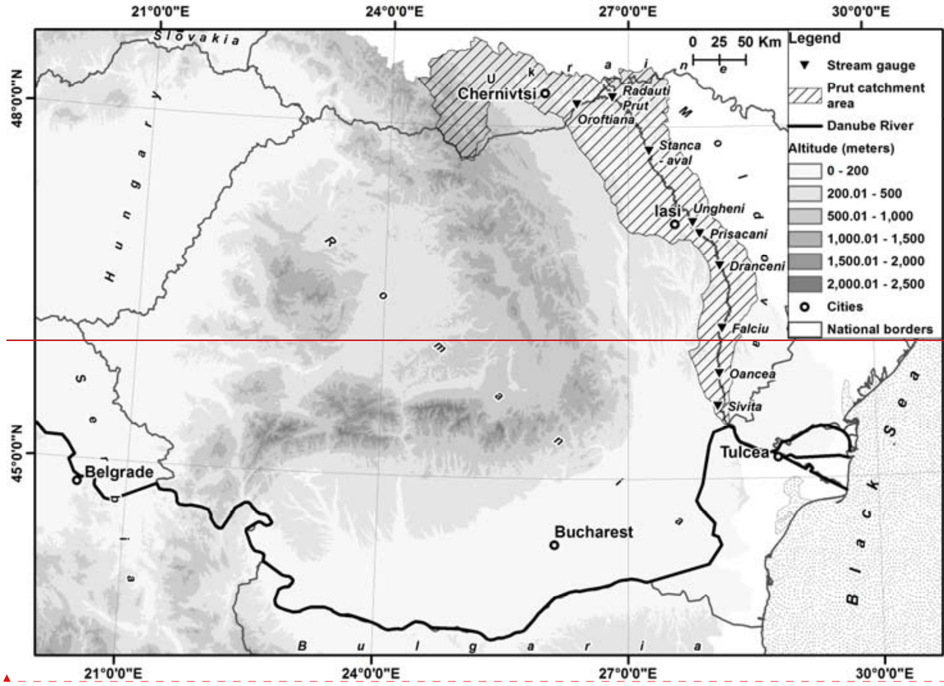

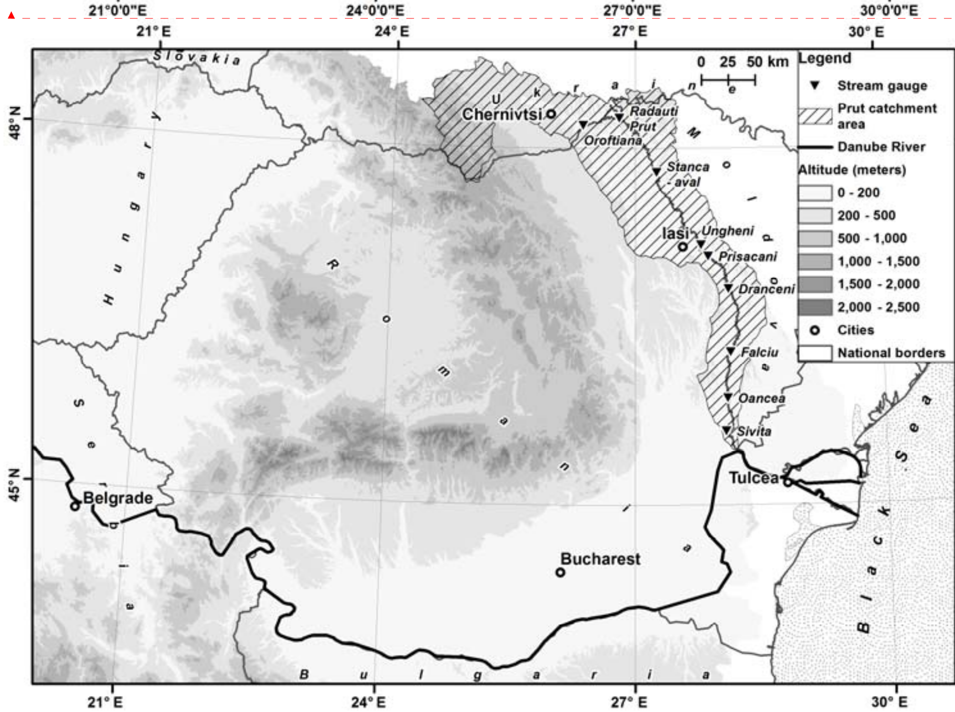

Figure 2. Geographic position of the Prut catchment basin in Romania, Ukraine, and the Republic of Moldova, and distribution of the main gauging stations

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The Prut River is the second-longest river in Romania, at 952.9 km in length. It is a cross-border river, with 31 km in Ukraine and 711 km in the Republic of Moldova. The mean altitude of the midstream sector of catchment area is 130 m, and for the downstream sector is 2 m.~~The mean altitude of the catchment ranges from 130 m in the centre to 2 m at the confluence.~~ The Prut has 248 tributaries. Its maximum width is 12 km (in the lower reaches, Brates ~~lake~~Lake) and its average slope is 0.2%. Its hydrographic network measures 11,000 km in total, of which 3,000 km are permanent streams (33%) and 8,000 km are intermittent (67%). The network has the highest density in Romania at 0.41 km/km^2 (the average density is 0.33 km/km^2).

The Prut catchment is relatively symmetrical, but its largest proportion is in Romania. To the west, it has 27 tributaries, including the Poiana, Cornesti, Isnovat, Radauti, Volovat, Baseu, Jijia (with a discharge of 10 m^3/s, the most important), Mosna, Elan, Oancea, Branesti, and Chineja. The Jijia River is 275 km long, has a catchment area of 5757 km^2 and an annual average flow of 14 m^3/s. Its most important tributaries are Miletin, Sitna and Bahlui.~~Râul Jijia are o lungime de 275 km și bazinul hidrografic deține o suprafață de 5757 km^2. Cei mai importanți afluenți sunt Miletin, Sitna și Bahlui. Debitul mediu multianual este de 14 m^3/s.~~ To the east, it has 32 tributaries, including the Telenaia, Larga, Vilia, Lopatnic, Racovetul, Ciugurlui, Kamenka, Garla Mare, Frasinul, and Mirnova (Romanescu et al., 2011a,b). The catchment basin has 225 small ponds, counting the Dracsani, which is the largest pond in Romania. Small ponds are used as drinking water for livestock or to irrigate subsistence rural households. They usually belong to individual households. Large ponds, on the other hand, have multiple uses, such as: flooding mitigation, irrigation, fish farming etc. They resisted better in time because of their significant surface and depth. Large ponds belong to rural or urban communities.~~Iazurile mici sunt utilizate pentru adăpatul animalelor sau pentru irigatul gospodăriilor. De obicei aparțin unor gospodării individuale. Iazurile mari au întrebuințări multiple: atenuarea inundațiilor, irigații, piscicultură etc. și au rezistat în timp deoarece dețin suprafețe și adâncimi apreciabile. Aparțin unor comunități rurale sau urbane.~~ The river also has 26 large ponds, of which the most important is the Stanca-Costesti reservoir, which has the largest water volume of the interior rivers in Romania (1,400 million m^3).

The topography of the Prut basin includes the Carpathians in the spring area and the Moldavian Plateau and the Romanian Plain near the river mouth. Arable land occupies 54.7% of the Prut catchment, while forests occupy 21.4%, perennial cultures occupy another 13.3%, and the water surface occupies only 1.19%. The mean annual temperature in the Prut catchment is 9°C, and the mean annual precipitation is 550 mm. The mean annual discharge increases downstream, varying from 82 m^3/s at Radauti Prut to 86.7 m^3/s at Ungheni to 93.8 m^3/s at the Oancea gauging station situated near the mouth over the period 1950-2008.

Discharges in the downstream reaches of the Prut are controlled by the Stanca-Costesti reservoir. In the Romanian Register of Large Dams, the Stanca-Costesti dam ranks 49th out of 246 dams in terms of height, but 2nd in terms of active reservoir volume (1,400 million m^3, after the Iron Gates I, with a volume of 2,100 million m^3). It has a surface area of 5,900 ha during a normal retention level (NRL). After construction of the Stanca-Costesti reservoir, floods on the Romanian parts of the Prut diminished considerably. Because the Prut has higher banks in the Republic of Moldova, this area was not affected by dam construction. The reservoir was constructed with a mitigation level of 550 million.m^3, allowing the mitigation of a 1% backwater~~tidal bore~~ from 2,940 to 700 m^3/s. The damming infrastructure constructed downstream from the hydrotechnical nodes prevents the flooding of approximately 100,000 ha of floodplain area (Romanescu et al., 2011a,b).

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3 Methodology

Diverse methodology has been used to analyse exceptional floods. Hydrological data, including discharge and the water level, were obtained from the Prut-Barlad Water Basin Administration based in Iasi (a branch of the "Romanian Waters" National Administration). For catchment basins that did not have gauging stations or observation points, measurements were taken to estimate the discharge. Mathematical methods were used to reconstitute discharges and terrain measurements using land surveying equipment (Leica Total Station) were used to calculate the surface of the stream cross-section.S-a apelat la reconstituirea debitelor (metode matematice specifice debitului reconstituit și măsurători de teren pentru determinarea secțiunii active). Most stations within the Romanian portion of the Prut catchment are automatic (Fig. 3). The recording and analysing methodology used is standard or slightly adapted to local conditions: e.g. the influence of physical-geographical parameters on runoff (Ali et al., 2012; Kappes et al., 2012; Kourgialas et al., 2012; Waylen and Laporte, 1999); the management of risk situations (Delli-Priscoli and Stakhiv, 2015; Demeritt et al., 2013; Grobicki et al, 2015 Grobicki et al, 2015); the role of reservoirs in flood mitigating (Fu et al., 2014; Serban et al., 2004; Sorocovschi, 2011); the probability of flooding and the changes in the runoff regime (Hall et al., 2004, 2014; Jones, 2011; Seidu et al., 2012a,b; Wu et al., 2011); flood prevention (Hapuarachchi et al., 2011); runoff and stream flow indices (Nguimalet and Ndjendole, 2008); morphologic changes of riverbeds or lake basins (Rusnák and Lehotsky, 2014; Touchart et al., 2012; Verdu et al., 2014) etc.The recording and analysing methodology used is standard or slightly adapted to local conditions: influența parametrilor fizico-geografici asupra scurgerii (Ali et al., 2012; Kappes et al., 2012; Kourgialas et al., 2012; Waylen and Laporte, 1999); managementul situațiilor de risc (Delli-Priscoli and Stakhiv, 2015; Demeritt et al., 2013; Grobicki et al, 2015 Grobicki et al, 2015); rolul acumulărilor în atenuarea inundațiilor (Fu et al., 2014; Serban et al., 2004; Sorocovschi, 2011); probabilitatea de producere a inundațiilor și schimbările regimului de scurgere (Hall et al., 2004, 2014; Jones, 2011; Seidu et al., 2012a,b; Wu et al., 2011); prevenirea inundațiilor (Hapuarachchi et al., 2011); indicatori ai scurgerii (Nguimalet and Ndjendole, 2008); modificări morfologice ale albiilor de râu sau ale cuvetelor lacustre (Rusnák and Lehotsky, 2014; Touchart et al., 2012; Verdu et al., 2014).

The cartographic basis used to map altitudes and slopes is Shuttle Radar Topography Mission (Global Land Cover Facility, 2016), at a 1:50000 scale. The vector layers were projected within a geodatabase, using ArcGis 10.1. They include stream lines, sub-catchment basins, and reservoirs and ponds polygons, as well as gauging station points. In order to generate the GIS layers, we applied the following methods: digitisation, queries, conversion, geometries calculation (length, surface) and spatial modelling. Water levels and discharges data were processed and plotted on charts using the Open Office software. We also used the Inkscape software to design the final maps and images.

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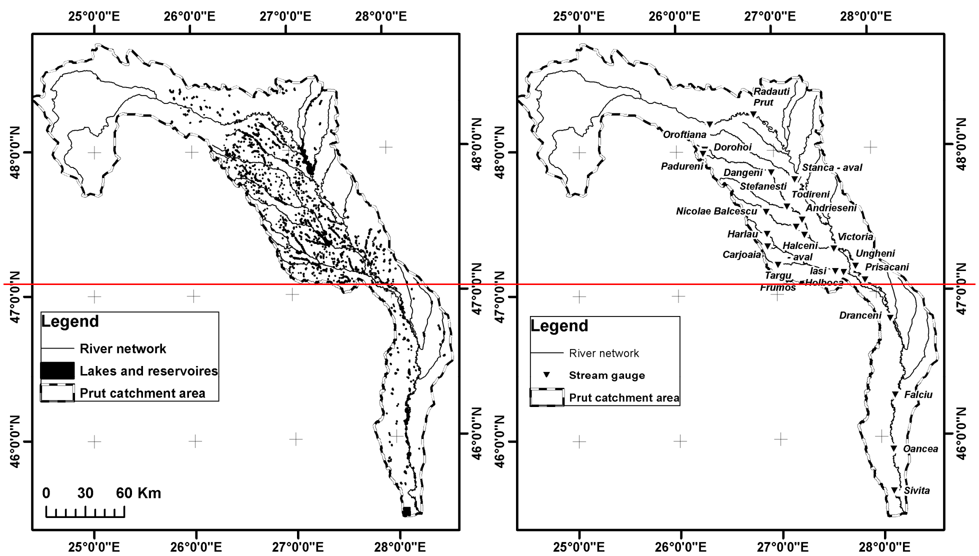

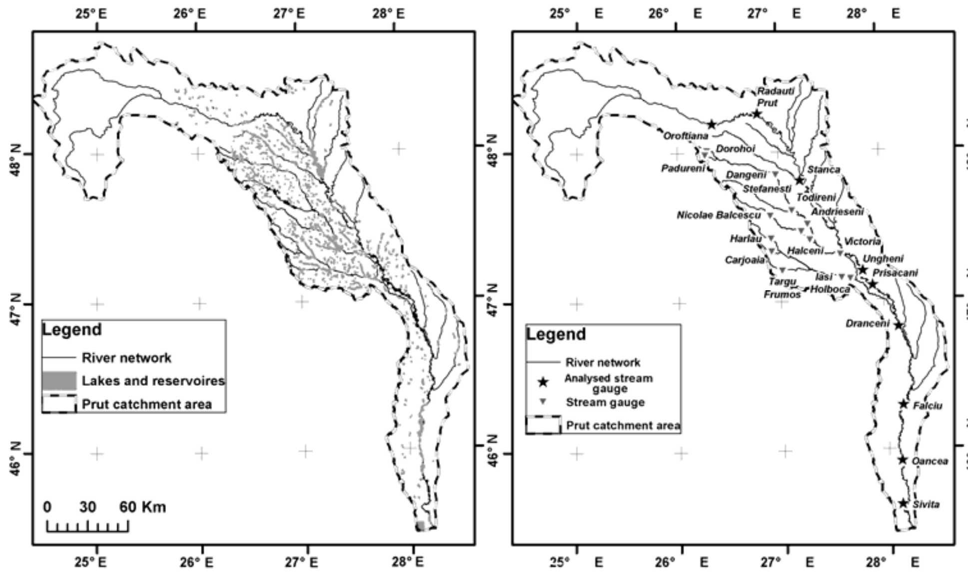

Figure 3. Main tributaries, reservoirs (left), and gauging stations (right) in the Prut River basin

All areas with gauging stations had automatic rain gauges (Anghel et al., 2011; Tirnovan et al., 2014a,b) (Fig. 3, Table ~~1~~2). The heavy rains that cause flooding are recorded hourly over the course of 24 hours according to the Berg intensity scale (Berg et al., 2009). In the areas lacking gauging stations, data were collected from the closest meteorological stations, which are automatic and form part of the national monitoring system. The water level and discharge were analysed throughout the entire flood period. For comparison, the mean monthly and annual data for the water level and discharge were also analysed. The processed data were portrayed as histograms that illustrate the evolution of water levels

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during the floods, including the CA (warning level), CI (flood level), and CP (danger level) flood threshold levels before and after the flood, the daily and monthly runoff, and the hourly variations of runoff during the backwater.The processed data were portrayed as histograms that illustrate the evolution of water levels during the floods, including the CA (warning level), CI (flood level), and CP (danger level) flood threshold levels before and after the flood, the daily and monthly runoff, and the hourly variations of runoff during the tidal bore. For an exact assessment of the damage and the flooded surface area, observations and field measurements were conducted on the major floodplains of the Volovat, Baseu, Jijia, Sitna, Miletin, Bahluet, Bahlui, Elan, and Chineja Rivers (Romanescu and Stoleriu, 2013b).

Nine gauging stations exist in Romanian sections of the Prut River: Oroftiana (near the entry, only including water level measurements), Radauti Prut, Stanca Aval (downstream), Ungheni, Prisacani, Dranceni, Falciu, Oancea, and Sivita (which is directly influenced by the Danube, so no data were collected from this station) (Fig. 3, Table 2). The first gauging station was installed at Ungheni in 1914, and the newest station is Sivita, which was installed in 1978. Much older water level and discharge data are available from stations in other places. The data on the deviation of rainfall quantities were obtained from the Climate Prediction Center NOAA and from the scientific literature (Hustiu, 2011).Datele cu privire la abaterile cantităților de precipitații au fost preluate de la Centrul de Predicție Climatică NOAA și din literatura de specialitate (Hustiu, 2011).

Table 2. Morphometric data for the gauging stations on the Prut River (Romania)

Gauging station	Inauguration year	Geographic coordinates		River length from the confluence	Data on the catchment basin		0 m level of gauging station“0 mira” level
		Latitude	Longitude	km	Surface km²	Altitude m	mrBS (Meters Black Sea)mrBS
Oroftiana	1976	48°11'12"	26°21'04"	714	8020	579	123.47
Radauti Prut	1976	48°14'55"	26°48'14"	652	9074	529	101.87
Stanca Aval (Downstream)	1978	47°47'00"	27°16'00"	554	12000	480	62.00
Ungheni	1914	47°11'04"	27°48'28"	387	15620	361	31.41
Prisacani	1976	47°05'19"	27°53'38"	357	21300	374	28.08
Dranceni	1915	46°48'45"	28°08'04"	284	22367	310	18.65
Falciu	1927	46°18'52"	28°09'13"	212	25095	290	10.04
Oancea	1928	45°53'37"	28°03'04"	88	26874	279	6.30
Sivita	1978	45°37'10"	28°05'23"	30	27268	275	1.66

Flood damage reports were collected from city halls in the Prut catchment and the Inspectorate for emergencies in Botosani, Iasi, Vaslui, and Galati. In isolated areas, we conducted our own field research. We note that some of the reports from city halls seem exaggerated.

4 Results

The majority of floods in Romania are influenced by climate factors, manifesting at local and European level (Birsan, 2015; Birsan and Dumitrescu, 2014; Birsan et al., 2012; Chendes et al., 2015; Corduneanu et al., 2016). During the last decade of June (June 20, 2010) and the

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end of July (July 30, 2010), a baroclinic area was localized in Northern Moldavia. This favoured the formation of a convergent area of humidity. In this case, a layer of humid, warm and unstable air was installed between the topographic surface and 2500 m of altitude. The high quantity of humidity originitated from The Black Sea, situated 500 km away. The warm tropical air is generated by the Russian Plain, overheated by a strong continentality climate. The cold air from medium troposphere, inducted by the cut-off nucleum that generated atmospheric instability, overlapped this structure of the low troposphere (Hustiu, 2011). The synoptic context was disturbed by local physical-geographical factors, especially by the orography of Eastern Carpathians, which led to extremely powerful heavy rains: e.g. 100-200 mm in 24 hours at the sources of Jijia (representing the amount that normally falls during June and July) or 40-60 mm in 24 hours at the Romanian frontier with Ukraine and the Republic of Moldova. The quantity of rainfall in 24 hours were 2-3 higher than the normal values for this period (Hustiu, 2011) (Fig. 4).~~Majoritatea inundațiilor din România sunt influențate de condițiile climatice care se manifestă la nivel european dar și la nivel local (Birsan, 2015; Birsan and Dumitrescu, 2014; Birsan et al., 2012; Chendes et al., 2015; Corduneanu et al., 2016). În ultima decadă a lunii iunie (20 iunie 2010) și sfârșitul lunii iulie (30 iulie 2010) s-a instalat o zonă baroclină în nordul Moldovei. Aceasta a asigurat formarea unei arii convergente de umezeală. În acest caz între suprafața topografică și altitudinea de 2500m s-a instalat un strat de aer umed, cald și instabil. Cantitatea ridicată de umezeală provine din Marea Neagră, situată la 500 km distanță. Aerul cald tropical este generat de Câmpia Rusă, supraîncălzită ca urmare a continentalismului accentuat. Pe această structură a troposferei joase s-a suprapus aerul rece din troposfera medie, antrenat de nucleul cut-off care a dat naștere instabilității atmosferice (Hustiu, 2011). Contextul sinoptic a fost perturbat de factorii fizico-geografici locali, mai ales de orografia Carpaților Orientali, care au dus la formarea unor ploi torențiale extrem de puternice: 100-200 mm/24 ore la izvoarele râului Jijia (cantitate care cade în mod normal în două luni: iunie și iulie) sau de 40-60 mm/24 ore la frontiera României cu Ucraina și Republica Moldova. Cantitățile de precipitații căzute în 24 de ore depășesc de 2-3 ori normele climatice ale perioadei (Hustiu, 2011) (Fig. ?).~~

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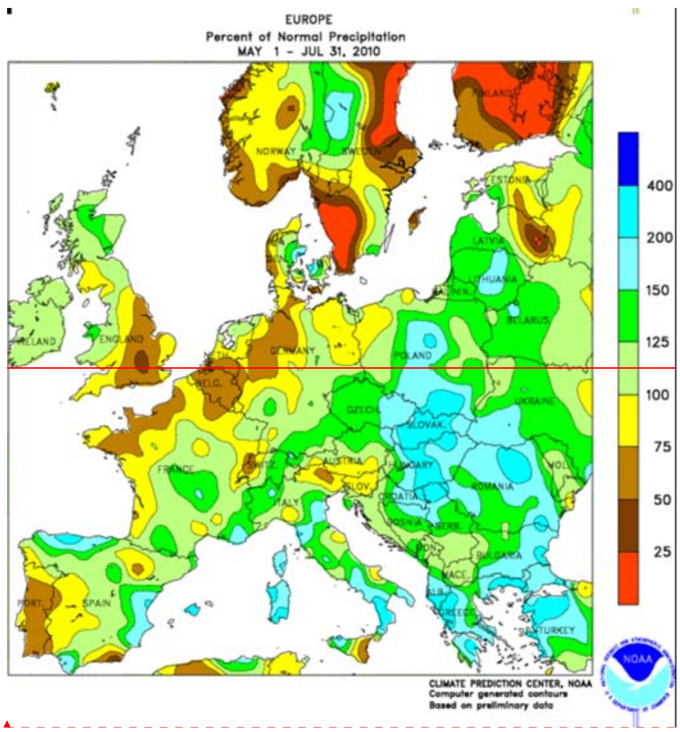

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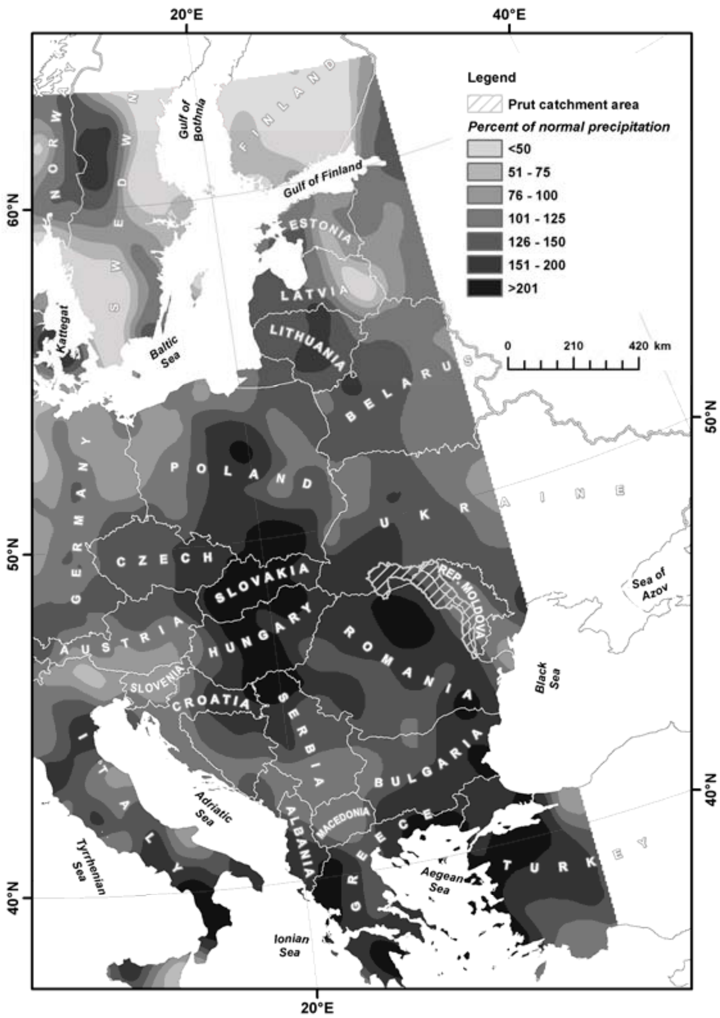

Figure 4. Deviation of monthly rainfall amounts (May-July 2010) from the yearly values - Climate Prediction Center (source data: NOAA)Fig. ? Abaterea cantităților lunare de precipitații (mai-iulie 2010) față de cantitățile multianuale – CPC (NOAA)

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There were 6 main extremely rainy periods in Romania, especially in the Moldavian hydrological basins (Prut and Siret): 21-23 June, 25-26 June, 28-30 June, 3-4 July, 6-7 July and 9 July. Rainfall quantities recorded in June were higher. The flash floods registered in Northern Moldavia in 28-29 June 2010 were generated by convective systems with slow spreading. Even if the rainfalls from June 29th were lower, the floods had devastating effects because they came on the context of the increasing water levels from 28 June 2010. The climate convection was organized as a mesocyclone extended over Northern Moldavia (the departments of Suceava and Botosani) (Hustiu, 2011).Pe teritoriul României s-au evidențiat 6 perioade extrem de ploioase, care s-au desfășurat, cu precădere, în bazinele hidrografice din Moldova (Prut și Siret): 21-23 iunie, 25-26 iunie, 28-30 iunie, 3-4 iulie, 6-7 iulie și 9 iulie. Cele din luna iunie sunt mai importante din punct de vedere cantititativ. Viiturile care s-au

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~~produs pe 28-29 iunie 2010 în nordul Moldovei au fost generate de sisteme convective cu propagare lentă. Deşi ploile din data de 29 iunie au fost mai reduse inundaţiile au avut efecte distrugătoare deoarece veneau pe fondul creşterilor de nivel din data de 28 iunie 2010. Convecţia climatică s-a organizat sub forma unui mezociclon extins pe suprafaţa judeţelor din nordul Moldovei (Suceava şi Botosani) (Hustiu, 2011).~~

~~Tidal bores~~Backwaters in the upper basins of the Prut and Siret (in northeast Romania) recorded during the summer of 2010 were caused by atmospheric instability from 21 June-1 July 2010. At this time, the flood danger level (CP) was exceeded on the Prut and Jijia Rivers. High amounts of rain fell during three periods: 21-24 June 2010, 26-27 June 2010, and 28 June-1 July 2010. Precipitation exceeding 100 mm was recorded from 21-24 June (105 mm, at the Oroftiana station) and from 28 June-1 July 2010 (206 mm at Padureni and 110 mm at Pomarla on the Buhai River). Very high rainfall rates occurred within a brief timeframe: 51.5 mm/50 min. was recorded at Oroftiana station on the Prut River and 42.0 mm/30 min. at Padureni on the Buhai River (Romanescu and Stoleriu, 2013a,b; Tirnovan et al., 2014b) (Fig. ~~4~~5).

Precipitation in the Carpathian Mountains in Ukraine initiated a series of floods in the upper Prut basin. Among the five flood peaks recorded by the Cernauti gauging station, we noted one with a discharge of 2,070 m^3/s recorded on 9 July 2010 at 12:00. In comparison, another flood recorded in May was not very high discharge value~~significant~~ (308 m^3/s). In the mountainous sector, the flood warning level (CA) was exceeded only twice, with water levels of 523 cm (+25 cm CA) and 645 cm (+145 cm CA) (Fig. ~~5~~6).

At the Oroftiana gauging station, where only the water levels are measured, the flood danger level (CP) was exceeded four times, with levels of 716 cm (+66 cm CP), 743 cm (+93 cm CP), 736 cm (+86 cm CP), and 797 cm (+147 cm CP, on 9 July 2010 at 12:00). The flood warning level (CA) was exceeded throughout the entire flooding period (May-July 2010). In the month of May, the flood levels (CI) were not exceeded (Fig. ~~5~~6). At the Oroftiana gauging station, one registered solely the water levels data. And for all the other gauging stations the discharge data are being registered, in addition to water level.~~La staţia hidrometrică Oroftiana sunt înregistrate doar nivelurile. La celelalte staţii hidrometrice se fac măsurători complexe.~~

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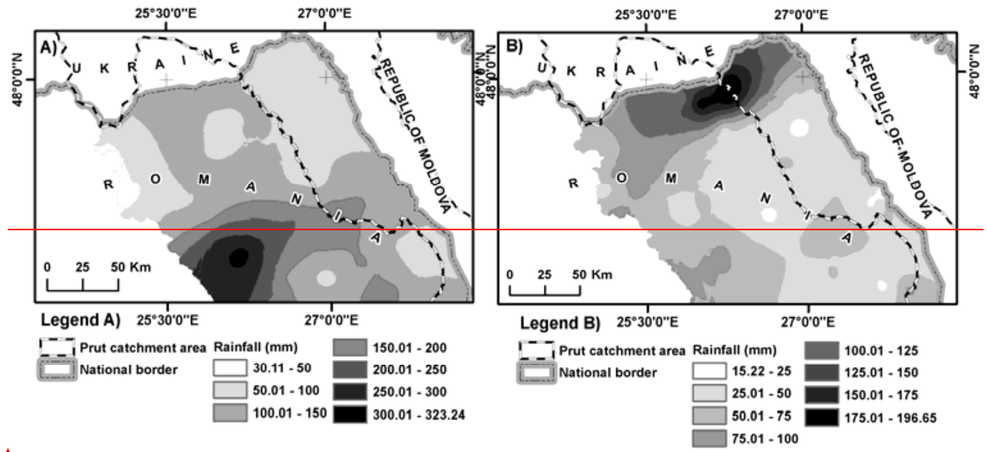

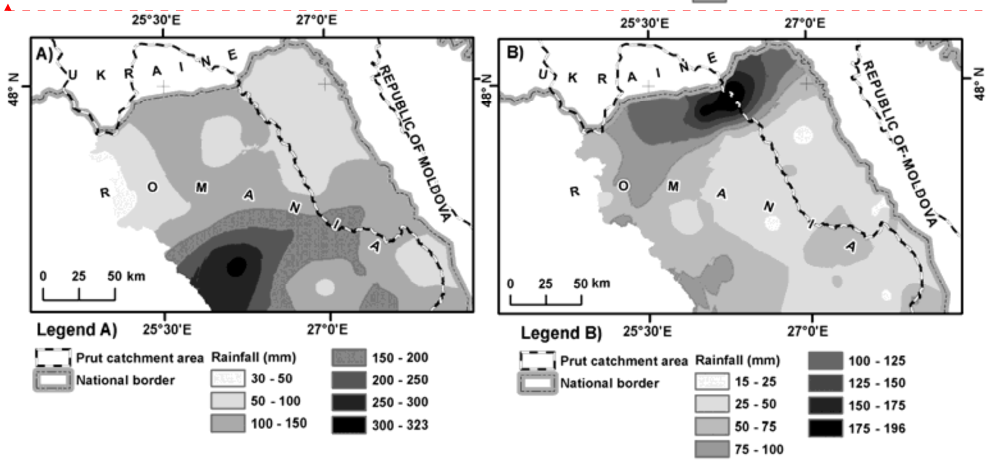

Figure 5. Cumulative precipitation amounts, in northeastern part of Romania, from 21-27 June 2010 (left) and 28 June-1 July 2010 (right)~~**Figure 4.** Cumulative precipitation amounts from 21-27 June 2010 (left) and 28 June-1 July 2010 (right)~~

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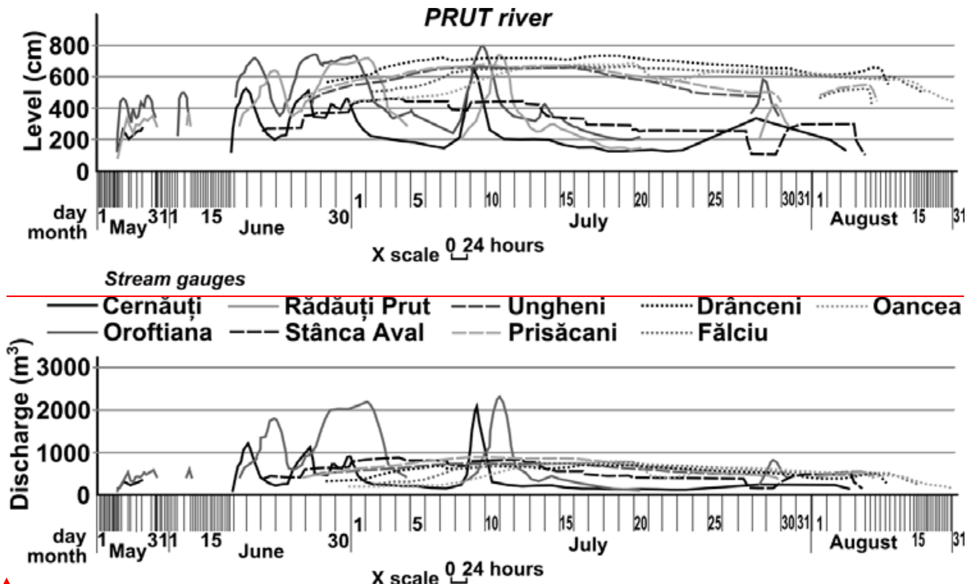

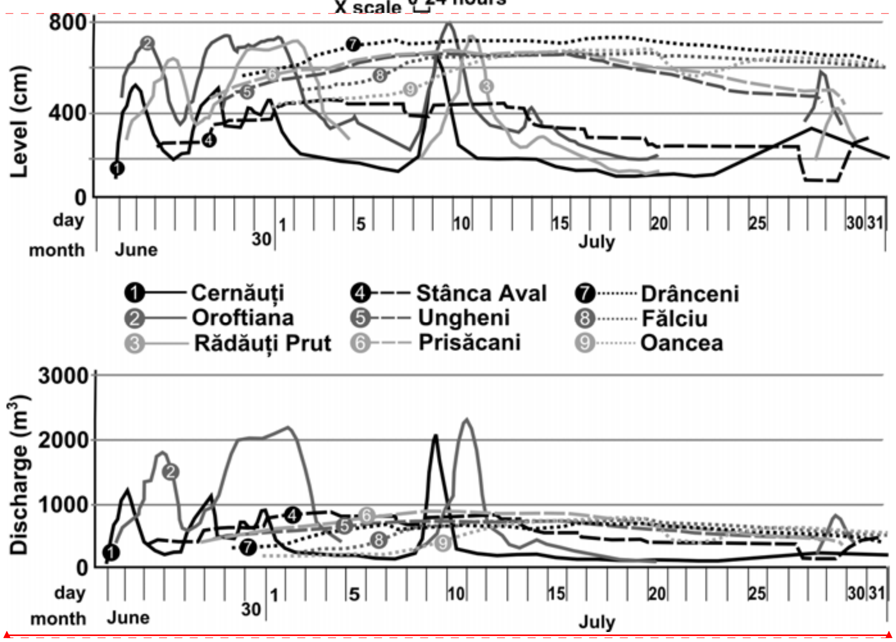

Figure 56. Water levels and discharge on the Prut River at the gauging stations of Cernauti, Oroftiana, Radauti Prut, Stanca Aval (downstream), Ungheni, Prisacani, Dranceni, Falciu, and Oancea during the summer of 2010

At the Radauti Prut gauging station, three important peaks were recorded on 26 June, 29 June-2 July 2010, and 10-11 July 2010. A maximum discharge of 2,310 m^3/s was registered on 10 July 2010 at 9 pm. The flood danger level (CP) was exceeded at four times, with water levels of 643 cm (+43 cm CP, on 25 June 2010), 685 cm (+85 cm CP, on 29 June

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2010), 721 cm (+121 cm CP, on 29 June-2 July 2010), and 744 cm (+144 cm CP, on 10-11 July 2010) (Fig. ~~5~~6).

The Stanca Aval (downstream) gauging station is controlled by overflow from the Stanca-Costesti reservoir. This control mitigates the flood hydrographs. The maximum discharge value at this station was 885 m^3/s on 3 July 2010. The flood level (CI) was exceeded from the beginning to the end of the flooding period. The flood danger level (CP) was exceeded from 1-13 July 2010, reaching a maximum water level of 460 cm (+85 cm CP, on 3 July 2010) (Fig. ~~5~~6).

At the Ungheni gauging station, floods were recorded throughout the entire month of July. The maximum discharge was 673 m^3/s on 8 July 2010. Flooding continued until 5 August 2010. The flood danger level (CP) was exceeded during the 12-day period from 6-17 July 2010. The maximum water level was 661 cm (+1 cm CP) (Fig. ~~5~~6).

Floods were also recorded throughout July at the Prisacani gauging station. The maximum discharge was 886 m^3/s on 9 July 2010. Flooding continued until 5 August 2010. The flood danger level (CP) was exceeded during the 16-day period from 4-19 July 2010. The maximum water level was 673 cm (+73 cm CP) (Fig. ~~5~~6).

At the Dranceni gauging station, floods were recorded over a long period from the end of June until the beginning of August. The maximum discharge was 718 m^3/s on 17 July 2010. The flood danger level (CP) was reached or exceeded during the 18-day period from 4-22 July 2010. The maximum water level was 729 cm (+29 cm CP) (Fig. ~~5~~6).

At the Falciu gauging station, floods occurred throughout July and during the first half of August. The maximum discharge was 722 m^3/s on 19 July 2010. The flood danger level (CP) was reached or exceeded during the 35-day period from 6 July-2 August 2010. The maximum water level was 655 cm (+55 cm CP) (Fig. ~~5~~6).

At the Oancea gauging station, two ~~tidal bores~~backwaters were recorded in July and August. The first ~~tidal bore~~backwaters on 19 July 2010 had a peak discharge of 697 m^3/s and the second on 27 July 2010 had a peak discharge of 581 m^3/s. Both ~~tidal bores~~backwaters exceeded the flood danger level (CP) throughout the month of July. The maximum water level of the first backwater~~bore~~ was 683 cm (+83 cm CP), and the maximum for the second was 646 cm (+46 cm CP) (Fig. ~~5~~6). Backwaters were caused by increasing water level of Danube River, which influences the measurements results at the gauging stations situated on the downstream sector of Prut River.~~Undele de remuu sunt determinate de creşterile de nivel de pe fluviul Dunărea şi influenţează măsurătorile de la staţiile hidrometrice situate în sectorul aval al Prutului.~~

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The western tributaries of the Prut (within the Moldavian Plain) are numerous, but they have only modest mean annual discharges. They are periodically affected by floods following heavy summer rains. At the Stefanesti gauging station, within the downstream sector of the Baseu River, floods were recorded from 1-4 July 2010. The maximum discharge was 107 m^3/s on 6 July 2010. The flood level (CI) was reached or exceeded for two days. The maximum level was 355 cm (+5 cm CI) (Fig. ~~6~~7). The Stefanesti gauging station is located in the downstream sector of the dam and it is directly influenced by the discharge water from the Stanca-Costesti Lake (since 1978).~~Staţia hidrometrică Stefanesti este situată în sectorul aval al barajului si este direct influenţată de descărcarea apei din lacul Stânca-Costeşti (începând cu anul 1978).~~

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At the Padureni gauging station on the Buhai River, two ~~tidal bores~~backwaters were recorded in June and a secondary backwater~~tidal bore~~ in May. The maximum discharge was 470 m^3/s on 28 June 2010. The flood danger level was exceeded during both backwater~~bore~~s, with water levels of 470 cm (+120 cm CP, on 28 June 2010) and 440 cm (+90 cm CP, on 29 June 2010) (Figs. 3, ~~6~~7).

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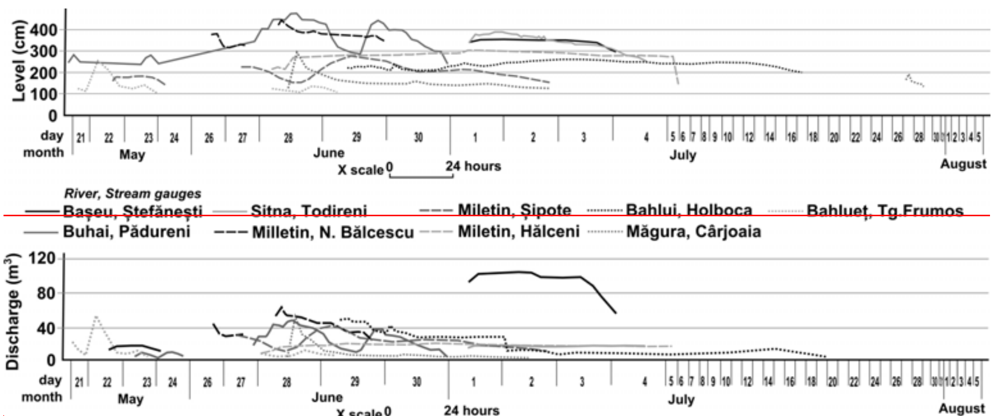
At the Todireni gauging station on the Sitna River (a tributary of the Jijia), floods occurred from 1-4 July 2010. The maximum discharge was 19 m^3/s on 1, 2, and 4 July 2010. The flood level (CI) was exceeded on 1 and 2 July 2010. The maximum water level was 387 cm on 1 July 2010. The flood warning level (CA) was exceeded on 4 July 2010 (Figs. 3, ~~6~~7).

At the Nicolae Balcescu gauging station on the Miletin River (a tributary of the Jijia), floods were recorded from 26-29 June 2010. The maximum discharge was 60 m^3/s on 6 June 2010. The flood level (CI) was exceeded just once, on 28 June 2010. The maximum level was 444 cm (+22 cm CI). The warning level (CA) was exceeded throughout the flooding period (Figs. 3, ~~6~~7).



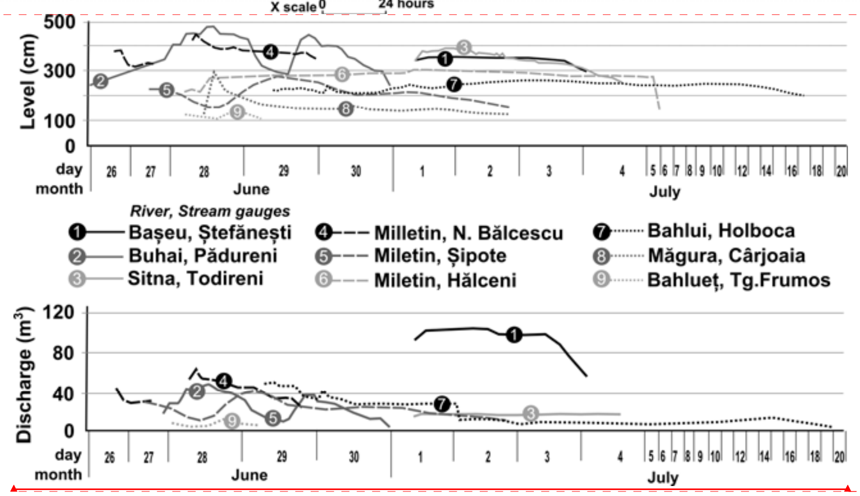


Figure ~~6~~7. Water levels and discharge on the main Prut tributaries during the summer of 2010: the Baseu, Buhai, Sitna, Miletin, Bahlui, Magura, and Bahluiet Rivers

At the Sipote gauging station on the Miletin, four backwaters~~tidal bores~~ were recorded from 22 June-2 July 2010. The maximum discharge was 45 m^3/s on 29 June 2010. The flood level (CI) was exceeded from 29-30 June 2010. The maximum water level was 269 cm (+19 cm CI). The warning level (CA) was exceeded throughout the flooding period (Figs. 3, ~~6~~7).

At the Halceni gauging station on the Miletin, floods were recorded from 28 June-5 July 2010. The maximum discharge was 32 m^3/s on 1-2 July 2010. The flood danger level

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(CP) was exceeded during the peak discharge period, with a water level of 302 cm (+2 cm CP). The flood level (CI) was exceeded throughout the flooding period (Figs. 3, ~~6~~7).

The Carjoaia gauging station on the Magura River (a tributary of the Bahlui), one major backwater~~tidal bore~~ was recorded. The maximum discharge was 73.5 m^3/s on 28 June 2010. The flood level (CI) was exceeded on 28 June 2010. The maximum water level was 280 cm (+90 cm CI) (Figs. 3, ~~6~~7).

At the Targu Frumos gauging station on the Bahluet (atributary of the Bahlui), one major backwater~~tidal bore~~ was recorded on 22 May 2010, with a maximum discharge of 48 m^3/s. The flood danger level (CP) was reached on the same day and the maximum water level was 250 cm (0 cm CP). The flood warning level (CA) was exceeded throughout the flooding period (Figs. 3, ~~6~~7).

At the Harlau gauging station on the Bahlui (a tributary of the Jijia), successive and increasing backwater~~tidal bores~~ were recorded from 22 May-1 July 2010. The maximum discharge was 32 m^3/s on 29 June 2010. The flood level (CI) was exceeded throughout the flooding period. The maximum water level was 552 cm (+132 cm CI) (Figs. 3, ~~6~~7).

At the Iasi gauging station on the Bahlui, floods occurred from 24 June-4 July 2010. The maximum discharge was 44 m^3/s on 1 July 2010. The flood warning level (CA) was exceeded throughout the flood. The maximum water level was 286 cm (+86 cm CA) (Figs. 3, ~~6~~7).

At the Holboca gauging station on the Bahlui, floods were recorded from 29 June-17 July 2010. The maximum discharge was 50 m^3/s on 29 June 2010. The warning level (CA) was reached or exceeded throughout the flooding period. The maximum water level was 259 cm (+59 cm CA) (Figs. 3, ~~6~~7).

At the Dorohoi gauging station on the Jijia, several backwater~~tidal bore~~s were recorded from 21 May-7 July 2010. The maximum discharge was 119 m^3/s on 29 June 2010. The flood danger level (CP) was exceeded from 29-30 June 2010. The maximum water level was 760 cm (+160 cm CP). The flood warning level (CA) was exceeded throughout the flooding period (Figs. 3, ~~7~~8).

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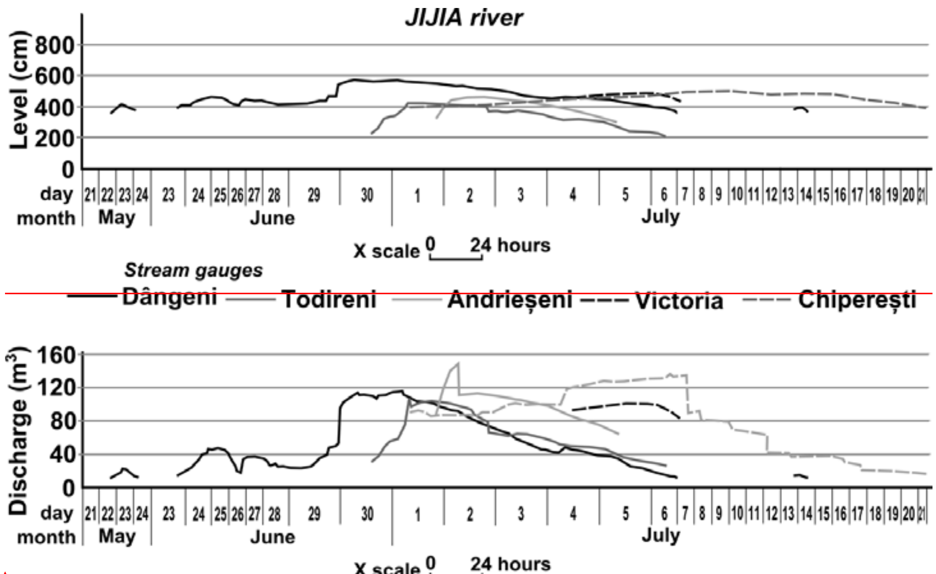

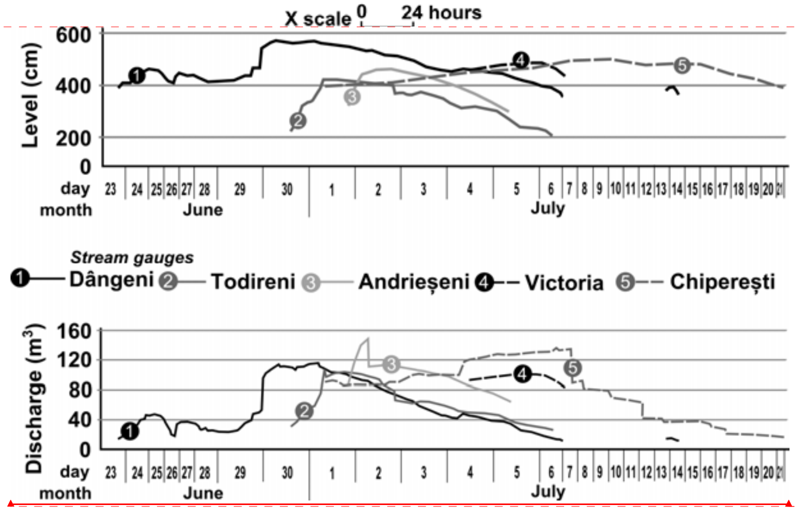

Figure 78. Water levels and discharge on the Jijia River at the gauging stations of Dangeni, Todireni, Andrieseni, Victoria, and Chiperesti during the summer of 2010

At the Dangeni gauging station on the Jijia, several backwatertidal bores were recorded from 22 May-28 July 2010. The maximum discharge was 116 m^3/s on 1 July 2010. The flood level (CI) was exceeded from 30 June-3 July 2010. The maximum water level was 578 cm (+108 cm CI). The flood warning level (CA) was exceeded throughout the flooding period (Figs. 3, 78).

At the Todireni gauging station on the Jijia, flooding occurred from 30 June-6 July 2010. The maximum discharge was 104 cm on 1 July 2010. The flood levels (CI) were exceeded from 1-4 July 2010. The maximum water level was 417 cm (+47 cm CI). The flood warning level (CA) was exceeded throughout the flooding period (Figs. 3, 78).

At the Andrieseni gauging station on the Jijia, flooding was recorded from 1-4 July 2010. The maximum discharge was 148 m^3/s on 2 July 2010. The flood danger level (CP) was

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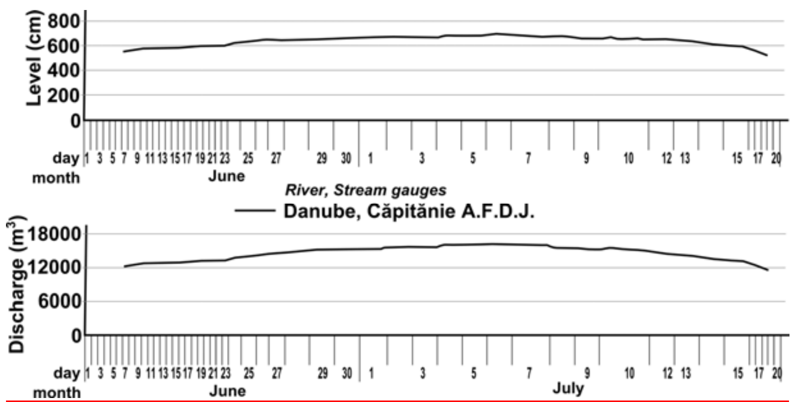
exceeded on 2 and 3 July 2010. The maximum water level was 461 cm (+11 cm CP). The flood warning level (CA) was exceeded throughout the flooding period (Figs. 3, 78).

At the Chiperesti gauging station on the Jijia, successive and increasing backwatertidal boress were recorded from1-19 July 2010. The maximum discharge was 136 m^3/s on 6 July 2010. The flood warning level (CA) was exceeded throughout the flooding period. The maximum water level was 497 cm (+97 cm CA) (Figs. 3, 78).

At the Victoria gauging station on the Jijia, flooding occurred from 4-7 July 2010. The peak discharge was 100 m^3/s on 5 July 2010. The flood warning level (CA) was exceeded throughout the flooding period. The maximum water level was 485 cm (+35 cm CA) (Figs. 3, 78).

At the Capitanie A.F.D.J. gauging station on the Danube, record floods occurred. The maximum discharge was 16,300 m^3/s on 5-6 July 2010, which is a historic discharge for the Galati station. The flood level (CI) was exceeded from 26 June-14 July 2010 (Fig. 89).



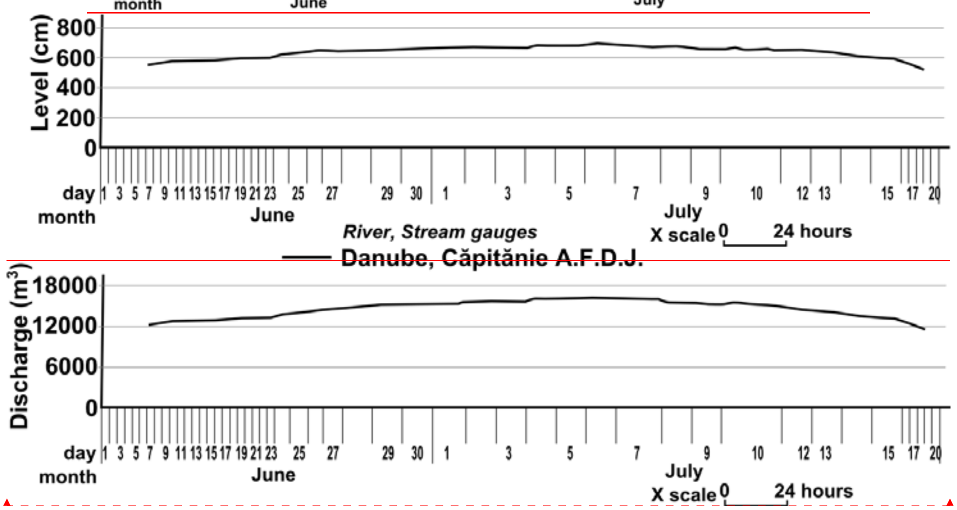


Figure 89. Water levels and discharge on the Danube at the Capitanie A.F.D.J. gauging station in the summer of 2010

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5 Discussion

Cumulative heavy rains from 21-24 June, 26-27 June, and 28 June-1 July 2010 caused water levels to exceed the flood danger level (CP) by 40-150 cm on the Prut in the Oroftiana-Radauti Prut sector and by 30-150 cm in the upper basin of the Jijia. The flood level (CI) was exceeded by 80-110 cm in the middle basin of the Jijia and in its tributaries (Sitna, Miletin, and Buhai). Discharges within the lower Jijia basin were controlled by upstream reservoirs and downstream polders in the lower reaches of the Jijia.

The Oroftiana gauging station only records water level measurements. The Radauti Prut gauging station may be influenced by the water stored in the Stanca-Costesti reservoir (which occurred during the historic flood of 2008) (Romanescu et al., 2011a,b). The Stanca downstream gauging station may be influenced by overflow from the Stanca-Costesti reservoir. The Oancea gauging station, situated near the mouth of the Prut, may be influenced by waters from the Danube. The water level registered at the Radauti Prut gauging station could have been influenced by the backwaters caused by Stanca-Costesti Lake. The most obvious case of backwaters was registered during the 2008 historic flood.

Nivelul apei de la stația hidrometrică Radauti Prut poate fi influențat de remuul provocat în lacul Stânca-Costești. Cel mai evident caz este cel produs în timpul inundațiilor istorice din anul 2008).

High discharge and water levels of 2,310 m^3/s and 744 cm (+144 cm CP), respectively, were recorded at the Radauti Prut gauging station. The 2010 values are remarkablesignificantly lower than the maximum values recorded in 2008 of 7,140 m^3/s and 1,130 cm (+530 cm CP) (the highest value for Romanian rivers). This value was recalculated after two years (through recomposed discharges)(prin intermediul debitelor reconstituite), resulting in a discharge of 4,240 m^3/s, which is the second highest value in Romania (after the historic discharge of 4,650 m^3/s on the Siret in 2005) (Romanescu et al., 2011a,b). The existence of five backwatertidal bore peaks (with the second and third backwatertidal bores being weaker) clearly indicates that they were caused by heavy rains in the Carpathian Mountains in Ukraine. A volume of 200-400 mm of rainfall (ie 50-80% of the annual amount) was recorded between 1 May and 15 July 2010. During the flood manifested in 2008, a historic discharge value was registered for Prut River, but the by-passed water volume was low (in upstream of Stanca-Costesti dam) because the flood duration was short. The 2010 flood registered lower maximum discharges compare to 2008, but it by-passed a larger water volume, as flood lasted longer.În perioada 1 mai-15 iulie 2010 s-au înregistrat precipitații cuprinse între 200-400 mm (adică 50-80% din norma anuală). Viitura din anul 2008 a înregistrat debitul istoric pentru râul Prut dar volumul de apă tranzitat a fost redus (amonte de barajul Stânca-Costești) deoarece durata fenomenului a fost scurtă. Viitura din anul 2010 a înregistrat debite maxime mai reduse dar a tranzitat un volum mai mare de apă deoarece durata fenomenului a fost îndelungată.

The flood hydrographs recorded at the Stanca Aval (downstream) gauging station features flattened and relatively uniform backwatertidal bores, mostly in the central part of the river. This behaviour is due to the influence of Stanca-Costesti reservoir, which significantly reduced the maximum discharge at Stanca Aval (885 m^3/s) compared to the Radauti Prut gauging station upstream of the reservoir. The water level was maintained within the upper limit recorded by longitudinal protection dams.

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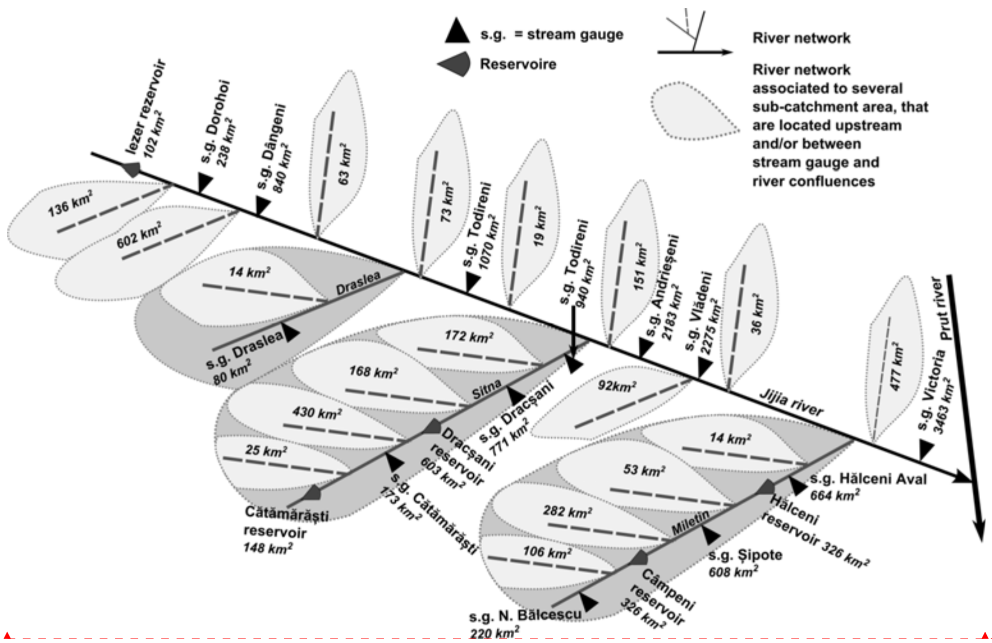

Figure ~~9~~10. Distribution of sub-basins within the Jijia catchment and placement of the main ponds

The Ungheni, Prisacani, Dranceni, and Falciu gauging stations had a flattened and uniform backwater~~tidal bore~~, which signifies upstream control, including some of the tributaries. The flood danger level (CP) was exceeded by a few centimetres and the floodplain was partially flooded in these areas. The high discharges recorded at the Prisacani station occurred because of waters in the upper Prut basin, including controlled spills from the Stanca-Costesti reservoir. Downstream of the Prisacani station, the influence of the Jijia becomes obvious: it increases the water level and lengthens the duration of floods.

Stronger floods within the middle reaches of the Prut occur because of its tributaries. Flooding on the Baseu, Sitna, Miletin, Jijia, Bahluet, and Bahlui Rivers was strong, but it was mitigated for the most part by the existence of ponds (Fig. ~~9~~10). Therefore, the excess water entering Romania from Ukraine entered the Stanca-Costesti reservoir. The excess water downstream of the Stanca-Costesti reservoir came from tributaries. Discharge from the tributaries is controlled by hydrotechnical works within each tributary's catchment. The Jijia and Bahlui catchments are 80% developed. The water levels downstream of these tributaries, in the lower reaches of the Prut, are mitigated by the extreme width of the Prut floodplain (the most important wetland of the interior Romanian rivers).

The system of polders in the lower reaches of the Jijia served as an effective trap for surplus water. High discharges on the Danube, which reached a historic maximum of 16,300 m^3/s at Galati (July 5th, 2010), would have flooded the city centre without the precincts constructed on the Jijia that stopped a portion of the floodwaters. When the floods on the Danube ceased, the water was gradually eliminated from the polders~~ was eliminated gradually~~, which explains why high water levels persisted in the lower Prut for a long time (Fig. ~~10~~11).

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Figure ~~10~~11. Polders on the Jijia and the floods recorded in the summer of 2010: storage of excess water (left) and its elimination (right)

Discharge at the Oancea gauging station increased dramatically from 4-5 July 2010, coinciding with the increased discharge on the Danube at Galati. The backwater~~tidal bore~~ at Oancea was also enhanced by backwater from the Danube. The second backwater~~tidal bore~~ was caused by upstream contributions. The flood danger level (CP) at Oancea was exceeded by +83 cm (CP) during the first backwater~~tidal bore~~ and by +46 cm (CP) during the second backwater~~tidal bore~~ (Table 3). The discharge increase and the historic values registered were caused by several factors, such as: the water input from the upstream sector of Prut River and the water input added by the Danube backwaters.~~Creșterea debitului și înregistrarea unui nivel record se datorează cumului de factori: aport de apă din sectorul amonte al râului Prut; aport de apă prin intermediul remuului provocat de Dunăre.~~

Table 3. Values of CA, CI, and CP for the Oancea (Prut) and Galati (Danube) gauging stations.

Gauging station	CA (Warning level)	CI (Flood level)	CP (Danger level)
Oancea (Prut)	440	550	600
Galati (Danube)	560	600	660

The city of Galati is situated at the confluence of the Prut and the Danube Rivers. Thus, water at the Oancea station may be influenced by the Danube and the Prut. In the summer of 2010, the highest values of discharge and water level at Galati were recorded (Tables 4, 5). The control of flooding on the Prut meant that floodwaters in Galati reached the sector of banks where flood infrastructure had been developed (the sea-cliff) as well as the lower areas of the city (Fig. ~~11~~12).

Table 4. Maximum water levels during flooding in the summer of 2010 for the Danube compared to values from other flood years.

River	Gauging station	Maximum levels in the year (cm)				
		2010	2006	2005	1981	1970
Danube	Galati	678	661	600	580	595
	Isaccea	537	524	481	490	507
	Tulcea	439	437	399	415	429

Table 5. Maximum discharges during flooding in the summer of 2010 for the Danube compared to the maximum values from 2006.

River	Gauging station	Maximum discharges in the year (m^3/s)

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		2010	2006
Danube	Galati	16300	14220
	Isaccea	16240	14325
	Tulcea	6117	5768

Discharges and water levels in the middle sector of the Prut River (recorded at the Oroftiana, Radauti Prut, and Stanca Aval stations) rank third in the hierarchy of floods (after 2008 and 2005). Values for the tributaries (particularly the Jijia, Buhai, Miletin, and Sitna) rank first in the hierarchy of floods (Table 6).

Table 6. Maximum water levels during flooding in the summer of 2010 compared to 2008 and 2005.

River	Gauging station	Maximum level cm	Day	Hour	Difference from the three levels of danger Cm	Maximum level 2008 cm	Maximum level 2005 cm
Prut	Oroftiana	717	24.06	11	+67 CP	867	703
		744	28.06	11-12	+94 CP	-	-
		737	1.07	04	+87 CP	-	-
		797	9.07	17-18	+147 CP	-	-
		425	13.07	20	+75 CA	-	-
Prut	Radauti Prut	643	25.06	18-19	+43 CP	1130	680
		686	29.06	17	+86 CP	-	-
		722	1.07	23	+122 CP	-	-
		744	10.07	19-20	+144 CP	-	-
Prut	Stanca Downstream	461	3.07	15-22	+86 CP	512	331
Jijia	Dorohoi	750	29.06	09	+150 CP	558	646
		722	30.06	05	+122 CP	-	-
		630	30.06	17	+30 CP	-	-
Jijia	Dangeni	575	30.06	08	+105 CI	449	512
		579	1.07	05	+109 CI	-	-
Jijia	Todireni	417	1.07	08	+77 CI	123	420
Buhai	Padureni	470	28.06	19-20	+120 CP	292	-
Miletin	Nicolae Balcescu	444	28.06	15	+24 CI	286	334
Miletin	Sipote	226	27.06	12	+76 CA	198	236
		269	29.06	18	+19 CI	-	-
Miletin	Halceni	302	1.07	15-18	+2 CP	226	238
Sitna	Todireni	378	1.07	17	+28 CI	-	-

The floods recorded in the summer of 2010 in the Buhai catchment (a tributary of the Jijia, which is a tributary of the Prut) caused backwaters to emerge at the mouth of the river. The manifestation of this backwater phenomenon is unique because the floodwaters of the Buhai River climbed the Ezer dam (on the Jijia River) and flooded its lacustrine cuvette. The phenomenon was named “spider flow” (Romanescu and Stoleriu, 2013a,b) (Fig. ~~12~~13).

Figure ~~11~~12. Flooding of the sea-cliff and the NAVROM headquarters in Galati

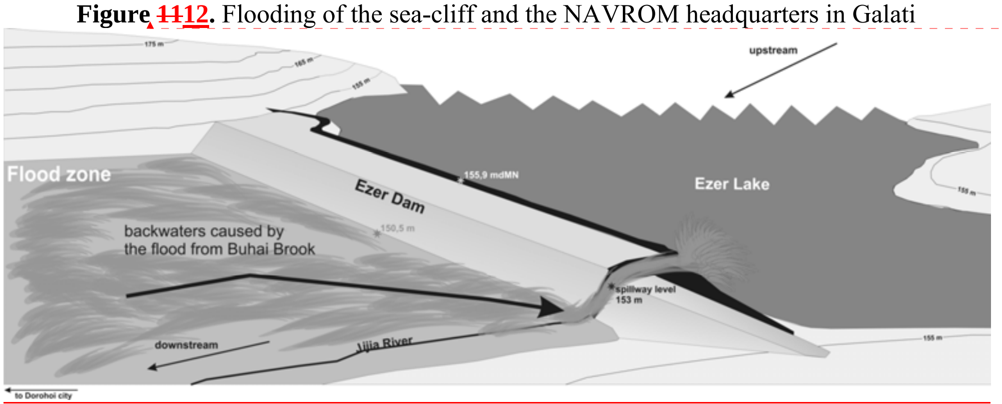

Figure 13. The "spider flow" phenomenon in which the Buhai waters climbed the Ezer dam on the Jijia, in the area of confluence of the two rivers

6 Conclusions

In the summer of 2010, large amount of~~significant~~ precipitation occurred in Central and Eastern Europe. Heavy rains in northeast Romania caused devastating floods in the Prut and Siret basins. Romania incurred huge economic damages. The flooding in 2010 was comparable with previous strong flood years in 2005, 2006, and 2008 in Romania. The greatest damage occurred in, and the most arable area was destroyed in, the middle Prut basin in the Jijia-Bahlui Depression- of the Moldavian Plain.

Discharge in the downstream sector of the Prut was controlled by the Stanca-Costesti reservoir, which ranks 2nd in Romania in terms of active reservoir volume (1,400 million m^3, after the Iron Gates I, with 2,100 million m^3). It has a surface area of 5,900 ha for a ~~normal retention level (~~NRL~~NR)~~. Under normal circumstances, the Stanca-Costesti reservoir can retain enough water to control the downstream discharge and water level. The

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provision of an attenuation water volume (550 million m^3) within the lake basin is efficient in retaining a 1% probability flood (reducing it from 2,940 m^3/s to 700 m^3/s). Together with the embankments located on the dam downstream sector, it helps preventing the flooding of 100,000 hectares of meadow. At a normal retention level, Stanca-Costesti Lake has a total area of 5,900 ha and a water volume of 1.4 billion m^3.Prevederea unui volum de apă de atenuare (550 milioane m^3) în cadrul lacului face ca viitura cu probabilitate de 1% să fie atenuată de la 2940 m^3/s la 700 m^3/s. Împreună cu îndiguirile efectuate în aval de baraj se evită inundarea a 100000 ha de luncă. La Nivelul Normal de retenție lacul însumează o suprafață de 5900 ha și un volum de apă de 1400 milioane m^3.

Discharges downstream of the Stanca-Costesti reservoir are controlled by reservoirs and retention systems constructed on the main tributaries of the Prut. We emphasize that the Jijia and Bahlui catchments have hydrotechnical works on 80% of their surface areas. The system of polders in the downstream sector of the Jijia River was used extensively to mitigate discharge and prevent the city of Galati from flooding (Galati is the largest Danubian port, situated at the confluence of the Prut and the Danube Rivers).

The gauging stations in the lower sector of the Prut recorded high discharges and water levels because of excess water coming from upstream (the middle sector of the Prut). At the Oancea gauging station, however, which is situated near the discharge of the Prut into the Danube, there is a significant backwater influence. The Danube had historic discharge at Galati, which affected the water level at Oancea station on the Prut.

Floods during the summer of 2010, in northeast Romania, rank third among hydrological disasters in Romanian history after the floods of 2005 and 2008, which also occurred in the Siret and Prut catchments. The 2010 floods caused grave economic damage (almost one billion Euros in just the Prut catchment) and greatly affected agriculture. Furthermore, six people died in Dorohoi, on the Buhai River.

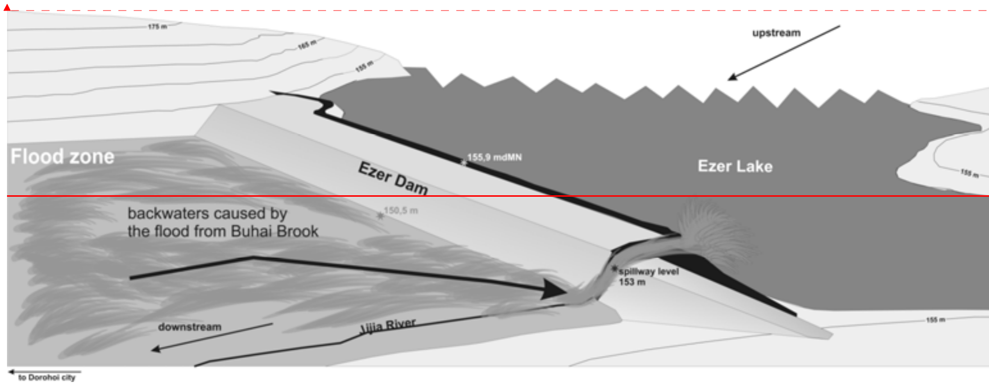

Figure 12. The "spider flow" phenomenon in which the Buhai waters climbed the Ezer dam on the Jijia, in the area of confluence of the two rivers

The 2010 floods caused a unique backwater phenomenon at the mouth of the Buhai River. Floodwaters from the Buhai climbed the Ezer dam (situated on the Jijia River) and flooded its lacustrine cuvette. The phenomenon was called "spider flow". In order to avoid such phenomena it is necessary to increase the height of the overflow structure.The phenomenon was called "spider flow". Pentru evitarea unor asemenea fenomene este necesară supraînălțarea deversorului de ape mari.

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Acknowledgments. This work was supported by the Partnership in Priority Domains project PN-II-PT-PCCA-2013-4-2234 no. 314/2014 of the Romanian National Research Council, called "Non-destructive approaches to complex archaeological sites. An integrated applied research model for cultural heritage management" – arheoinvest.uaic.ro/research/prospect. The authors would like to express their gratitude to the employees of the Romanian Waters Agency Bucharest, Siret Water Administration Bacau, particularly to Jora Ionut, PhD, a hydrologist within this research and administration agency, who was kind enough to provide a significant part of the data used in the present study.

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