A STATISTICAL AND HYDROLOGICAL ANALYSIS OF THE MAXIMUM FLOW IN THE TERPEZITA RIVER DRAINAGE BASIN

GABRIELA ADINA MOROŞANU[1], *G. VELCU*[2]

ABSTRACT - A statistical and hydrological analysis of the maximum flow in the Terpezița river drainage basin. Starting from the idea that hydrological and hydro-meteorological parameters have a statistical existence over time and a spatial distribution that can be represented by an interaction between the mathematical and geographical elements, the present paper aims to analyze the relationship between maximum flows, hourly rains, flow coefficients and concentration times of the Terpezita Basin. This is the second-largest sub-basin (182km^2) in the basin of Desnatui, which is located in the SW of Romania and is a first degree tributary of the Danube. The assessment of the concentration time, which involves the sizes of the liquid flow and specific liquid flow, was attained according to the physical and geographical characteristics of the basin. Thus taking into account the homogenous character from this point of view and the existence of statistically established hydrological and pluviometric background, we could outline the behavior of Terpezița River Basin during the extreme hydro-meteorological events. The documentation was completed through an exemplification of previously calculated results, using observations and measurements of the river bed in the vicinity of Terpezita village and processing the values that resulted from the hydro-graph of the 2005 flash-flood.

Key-words: Terpezița River, design storms, maximum flows, spatial and temporal statistical method, flash-flood of 2005.

1. INTRODUCTION

The analysis of the maximum flow of water in a drainage basin has become, over the last three decades, an object of research for many geographical studies, both in Romania and abroad. Thus, knowing the maximum flow value is important both for designing, operating and maintaining hydro-technical works and other structures used for protection against flooding and also for limiting the damage caused by floods (Sorocovschi, 2002).

[1] University of Bucharest, Faculty of Geography, Bucharest, Romania, e-mail: beju_gaby@yahoo.com
[2] University of Bucharest, Faculty of Geography, Bucharest, Romania, e-mail: gaby_velcu@yahoo.com

At an international level, the studies concerning the maximum flow generate a special interest, because record water flows that are registered at hydrometric stations generally reflect flash-floods which in turn often lead to flooding. Thus, there are a number of important and ample statistical researches that include aspects of the maximum flow, such as the significance of flash-floods for settlements situated in a drainage basin (Merz et al., 2009) or the understanding of the notion of flood hazard (Sayers et al., 2002; Dawson and Hall, 2004; Rose et al., 2007).

By restricting our field of research to Romanian hydrological scientific papers, we can notice recently a rapid evolution of the studies aimed at water resources located in the south-western part of Romania (Savin, 2008; Pleniceanu, 1999; Boengiu, 2002; Anuța, 2005, Ionuș, 2014), with an increased emphasis on the maximum flow regime (Gyori, 2010; Borcan, 2011).

The methodology employed borrows elements from older hydrological studies (Platagea, Gh., Platagea, M., 1965; Miță, 1992; Diaconu, 1993).

The present study represents a hydrological and statistical analysis of the maximum flow in the Terpezița drainage basin over a period of 27 years (1984-2011), achieved by processing the average flows recorded at Gabru hydrometric station. More specifically, by applying a number of formulas, it was possible to derive the maximum flows from the values of the average flows, by taking into account morphometric and morphographic parameters that define the basin.

It is important to mention that our study aims to prove the applicability of a theory meant to determine the maximum flow, by using statistical means, in small and medium basins, starting from the fact that any preliminary study for determining the potential of a basin to generate within its limits frequent events of maximum flow caused by floods starts from a statistical interrogation of the database containing information on flows and rains recorded in the past.

In order to organize our research, a number of specific objectives were set:

1. Discovering and analyzing the characteristics of those environmental factors that condition the formation of the maximum flow and water movement on the slopes of Terpezița drainage basin and in the river-bed of the same river.

2. Based on information concerning the features of the basin facies, we will try to formulate conclusions on the evolution of global flow coefficients in this basin, on average periods of return in time, which correspond with the probability of matching or surpassing the maximum average flows.

3. The creation of a complex inventory of maximum flow parameters, depending on the average monthly flows between 1984 and 2011, recorded at Gabru gauging station (Terpezița River) and the homogeneity of environmental elements that define the basin facies.

4. The elaboration of a hydrographic synthesis on a large scale for the entire drainage Terpezita River basin, in order to verify and correlate the already available synthesis for the entire territory of Romania.

5. Analyzing the flash flood that occurred in August 2005 on Terpezița, as an example of the absolute maximum flow in this basin and as a very devastating hydrological event, which caused significant economical and geographical damage.

Terpezița Basin is a first degree tributary of the Desnățui Basin and covers a surface of 182 km^2. Being located in the South-western part of Romania, in the southern part of the Bălăcița Piedmont, a component of the Getic Plateau (fig. 1), Terpezița Basin, along with the drainage basin of Desnățui, covers the largest hydrographic space that is a direct tributary of the Danube in its south-western section, downstream from Porțile de Fier.

The landscape of this basin is particularized by its wide interfluves, with a tabular character, and the entrenchment of its hydrographic network is asymmetrical (lower on the right side of the valley and more pronounced on the left side), whereas the valley of Terpezita has an average depth of 50-80 meters, and its slopes are affected by dynamical processes that fragment the piedmont into several wide and smooth interfluves, which remain suspended from the flood plain (Anuța, 2005; Savin, 2008).

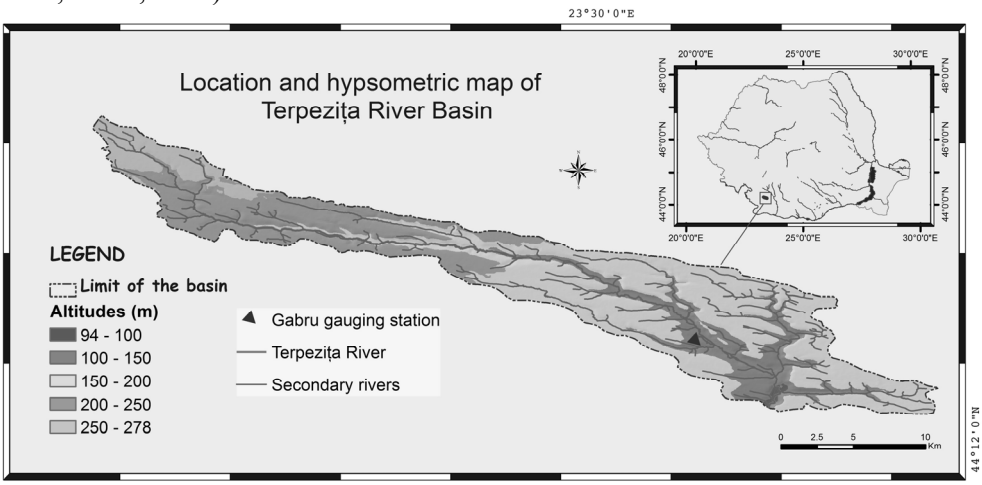

Figure 1. Location and hypsometric map of Terpezița Basin

In terms of delimitations between basins according to their size, Terpezița river basin (182 km^2) belongs to the first class of small basins controlled by a standard hydrographical network, a class where, in special cases (low density hydrographic network, homogeneous slopes on almost the entire surface of the basin, minor differences in land use) basins larger that 100 km^2 but not greater than 300 km^2 can be chosen (Diaconu & Mită, 1995). The basin we are about to analyze is served by just one gauging station – Gabru, situated on the main river, Terpezita, and the data provided on the annual maximum flows was statistically processed, by

following the usual operations presented in the general instructions guide for determining the maximum flows (Miță, 1992).

2. METHODS AND RESULTS

2.1 Insights on the basin facies

The accomplishment of this study entailed a series of steps that had to be followed as prescribed in the methodology presented by the bibliography (Miță, 1992; Diaconu, 1993; Diaconu & Miță, 1995): Determining the watershed and its magnitude order; Calculating the morphometric characteristics of the basin;- Establishing the characteristics of environmental factors; Creating an inventory and analyzing the data; Obtaining and analyzing the information on the dynamics of environmental factors; Calculating and representing the concentration time; Determining the designed storms; Determining the maximum flows; Hypothesis tests through a case study – the 2005 flash flood

In addition to the measurements based on the field's numerical model, our study involved a number of measurements that were made in the field, in order to know the basin's environmental factors, which are important for their influence on the formation of the maximum flow, the movement of water on the slopes and in the riverbed (in addition to the morpho-metrical characteristics listed in Table 1).

Table 1. Morphometric characteristics of the main river and its basin

F - (km^2)	**182**
L - length of main riverbed (km)	**38.8**
∑L - sum of the lengths of the main riverbed and the tributary riverbeds (km)	**251**
lv - average length of slopes(km)	**0.4**
Ia - average slope of the main riverbed(‰)	**32**
Iv - average declivity of slopes(‰)	**47**

In terms of cartographic resources, the maps of the basin features (fig. 3), achieved using ArcGIS 10.0, were analyzed so as to extract the values of geological, geomorphological and physio-geographical characteristics. This required the use of an altitudinal numerical model of the ground, and also a 1:25.000 scale topographic map, a 1:200.000 scale geological map, as well as the use of the geospatial databse of Corine Land Cover 2006.

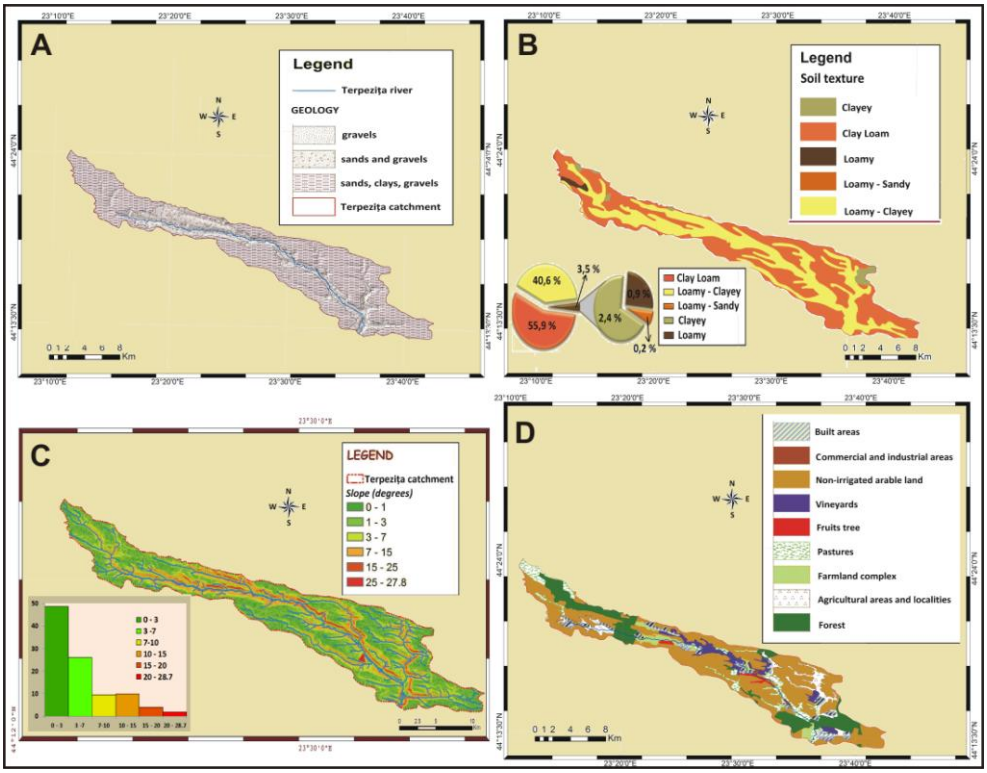

Figure 3. Preliminary maps used for extracting the physiographic, geological, and geomorphologic parameters.
A –Lithological map; B –Soil texture map; C –Slope map; D - Land use map.

In particular, we were interested, due to their important role as conditioning factors, in the following aspects: measuring the width of the thalveg of Lazu Valley near its confluence with Terpeziţa (September 2013), observing the vegetation found in the basin, in terms of spread and types (especially forests), the existence and types of human settlements, the state of Terpeziţa and Lazu riverbeds (the main rivers in the basin and the only ones that have caused flooding and flash-floods).

Thus, the geological structure raised our interest due to the permeability of rocks and their resistance to erosion, and the observational and cartographic study of soils was concerned with the types of soils, their texture (light, medium or heavy) and their erosion status, including their position and spread.

Analyzing the vegetation of the basin meant establishing the degree of forestation which, in turn, gave us the forestation coefficient. We also mentioned the areas covered by orchards, vineyards, cereal crops, pastures and natural grasslands. The establishing of spread (forestation) coefficients proved very useful for evaluating the global water flow coefficient of the basin.

The observational and cartographic study of socio-human elements was important because of the settlements, roads and paved areas that exist in the area, and on the basis of these elements, it was possible to calculate the percentage of the basin's surface that is covered by constructions.

When studying the water courses and riverbeds of Terpezita Basin, we took into account the general and dominant characteristics of the water flow, and the main focus of attention was the main river bed, which was analyzed on the ground.

Altogether, along with the inventory, centralization and analysis of the available hydrological and weather data, proved its usefulness during the statistical processing of information, and the most important data elements were the series of average monthly flows (1984-2011) at Gabru Hydrological Station on Terpezita and the flows recorded during the flash flood of August 15-21st 2005, the rains that caused the abovementioned flood (according to information offered by Jiu Basin Administrative Authority from the Dragoia rain gage station – Desnățui Basin, located 15 km. on the eastern side the hydrological station at Gabru), and all these elements were integrated in a series of calculations together with established or designed coefficients that were based on the classifications of the hydrographic

2.2. Concentration time

In small and average-sized basins that are homogenous in terms morphological and geological characteristics, and which have riverbeds that function in a natural regime, it is well established that, when evaluating maximum flows, the significant rains that generate these flows are those whose duration is the same as the concentration time of the discharge. Starting from this time, it was possible to calculate the intensity of the maximum rain as an average "$\mathbf{t_c}$" which leads us to find, after multiplication with the (sub-unitary) flow coefficient of the basin, the maximum intensity of the discharge and the maximum flow (Diaconu & Mită, 1995). The relationships used for evaluating the concentration time in the riverbed ($\mathbf{t_a}$) and on the slopes ($\mathbf{t_v}$) were derived from the following formulae (Diaconu, 1993):

$\mathbf{T_c} = 1{,}2\ t_a^{1,1} + t_v$ **(1)**

$\mathbf{t_a} = 1000 L_a/(m_a I_a^{1/3}\ Q_{max}^{1/4})$

$\mathbf{t_v} = (1000\ l_v)^{1/2}/(m_v I_v^{1/4} h_v^{1/2})$

$\mathbf{Q_{max\ 1\%}} = B_{1\%}\ F^{(1-n)}$ **(2)**;

Where $\mathbf{L_a}$ = length of the main riverbed in kilometers; $\mathbf{m_a}$= coefficient related to the roughness of the riverbed (*In our case, m_a= 9, which corresponds with the riverbed of a river exhibiting sinuous blockages party created by reeds. Water courses that carry a lot of silt during flash floods have a lot of vegetation in their river bed*); $\mathbf{I_a}$= average slope of the main river bed [m/km]; m_v = slope

roughness coefficient (*calculated, according to the methodology, as being between 0.1 and 0,5 – strongly modified surfaces due to plowing and other agricultural works, natural grasslands, cobbled pavement, surfaces which are less than 20% covered by man-made structures*); $\mathbf{I_v}$ = average declivity of slopes [m/km]; $\mathbf{h_v}$ = average intensity of the maximum discharge on the slopes expressed in mm/min (h_v *[mm/min] = 0.06* $B_{1\%}$ *[m³/s.km²]*); $\mathbf{Q_{max}}$= maximum researched flow [m³/s]; $\mathbf{l_v}$ = average length of basin slopes [km]; **F**= basin surface[km²].

2.3. The design storm

The design storm is in accordance with the concentration time o the maximum discharge in the basins. In order to find this parameter, we used concentration times determined as entry values for subsequent calculations **(1)**. The maximum design storm can be established as a local value and as an average value for the basin. Having at our disposal only the hydrological data of the standard hydrometric network (a single station, Gabru, on the main river, Terpezita) this study allowed us to calculate only the local value of the design storm. Therefore, the maximum rain was determined as an intensity "**i**" for the probability of exceeding in time p%, written as $\mathbf{i_{p\%}}$ [mm/min], which corresponded with the concentration time of the water in the basin- $\mathbf{t_c}$ **(1)**. In this undertaking, we employed the following relations (Platagea et al., 1965):

$$\mathbf{I_{p\%}} = (A+B_{log})/\ N(t_C+1)^n = S_{p\%}/\ (t_c+1)^n$$

$$\mathbf{X_{max\ p\%}} = I_{p\%}\, t_c \quad \mathbf{(3)}$$

$$\mathbf{X_{p\%}} = \alpha[A_p - B_p \log(F+F_0)];$$

where, **N** = average reoccurrence in time period corresponding to the p% probability; **A, B, n** = parameters elaborated and spatialized by G.Platagea (1965); $\mathbf{S_{p\%}}$ = parameter that results from A+ $B_{log}N$ (*a value expressed as an average for the basin and measured in mm , maximum rain is determined for the period* t_c *and for various probabilities of exceeding-equalization p%*); **α** = parameter depending on T_c and the area where the basin is situated; $\mathbf{A_p}$, $\mathbf{A_p}$ –parameters depending on p% and the zone; $\mathbf{F_0}$ – parameter depending on the zone.

After completing the calculations for the formulae explained above, we created a first diagram of the probabilities for the return of maximum flows depending on the annual maximum flows processed statistically, taking into account the parameters of the basin facies that were inserted in the set of formulae mentioned previously (fig. 4).

By interpreting the diagram, we can understand the exceptional character of the maximum flows, the probability of return curve being steep between 2 – 6 m³/s (maximum flows with a rather long return time) and very gentle, almost parallel with the abscissa axis when the probability of exceeding is greater. Additionally,

the statistical significance on the tendency introduced in the diagram is rather good when compared to the correlation values from the Bravais- Pearson Table, chosen according to the methodology presented by Diez et al., 2012.

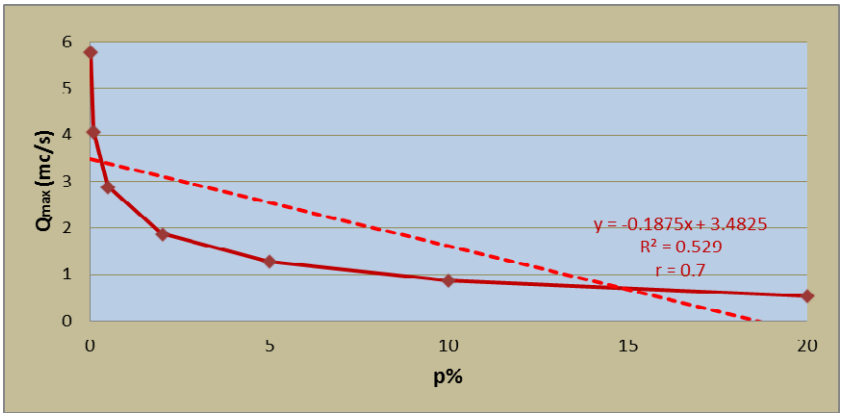

Figure 4. Maximum flow, with different probabilities at Gabru hydrometric station. Data source: ABA Jiu, Craiova

Because we disposed of the necessary hydrometric data from the standard network in the area of Terpezița basin, we used a synthesis of the connection between the specific maximum flows at Gabru Hydrometric station and the areas of the basins where these flows are formed. At this stage in our research, we used the following formula (Diaconu et al., 1995):

$$\mathbf{q}[m^3/s.km^2] = Q_{[m3/s]} / F\ [km^2]\ \mathbf{(4)};$$

where $\mathbf{q_{1\%}}$ = specific liquid flow of the basin, and **F** = area of the basin upstream of Gabru Hydrometric station.

The logarithms for the values of $\mathbf{q_{1\%}}$ **[m³/s.km²]** and **F [km²]** have been determined (Mită, 1992) and the diagram of the correlation between $\log q_{1\%}$ on the axis of ordinates and logF on the axis of abscissa has been created (fig. 5).

For the Terpezița Basin, which is a physio-geographical unit with a homogenous basin facies, and also for its sub-basins, for which we might have future measurements, the points on the diagram allow the expression of a correlation between $\log q1_{\%}$ and logF. The equation of the straight line is (Diaconu & Mită, 1995): $\mathbf{\log q_{1\%}} = a - b*\log F$ **(5)**, which, after being multiplied by F, leads to the following relationship: $q_{1\%} = B_{1\%} / F^n$ (2).

This indirect correlation graphic between the maximum local flow and the upstream surface of the sub-basins that make up the basin of Terpezita, which have surfaces below 50 km² and do not have standard hydrometrical stations, proves itself useful because the values of B1% of this synthesis are global (mediated) for

basins that are generally larger. The use of these syntheses for smaller basins would only be recommended as an informative value.

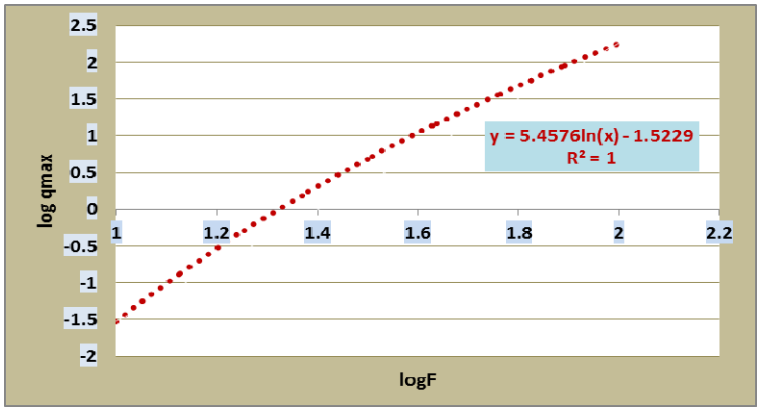

Figure 5 . LogF and log $q_{max1\%}$ correlation graph in Terpezita hydrographic basin. Data source: ABA Jiu, Craiova

The last operation for this part of the research was the creation of a new synthesis, in order to verify the existing syntheses. Thus, starting from the fact that the Gabru station controls the entire hydrographic basin of Terpezița, which has a homogenous basin facies that can clearly reflect the similarities and differences of facies compared to the basin, the series of annual maximum flows were statistically processed by going through the known operations in the general formula used to determine maximum flows in their succession: the downward ranking of sets, the allocation of a percentage of temporal empirical probability for each element and the calculation of the declivity coefficient for the maximum flows on p% = 5, 50 and 95 (Diaconu, 1993):

$$\mathbf{S} = (Q_{5\%} + Q_{95\%} - 2Q_{5\%}) / (Q_{5\%} - Q_{95\%}) \quad \textbf{(6)}.$$

Next, we calculated the variation and asymmetry coefficient, and the transition form Qmax1% to Qmaxp% flows was achieved by using transition coefficients at other assurances, determined after the Pearson III theoretical curves (Diaconu, 1993; Diez et al., 2012). The resulting graphic depiction shows the probabilities of empirical exceeding-equalization of the average annual maximum flows in the Terpezița Basin (fig. 6).

Thus, based on processing the hydrological data from Gabru Hydrological station, on Terpezița River, it was possible to determine more precisely the exceptional nature (in terms of frequency of such an event) and unpredictable character (when it comes to the moment of occurrence and amount of water involved) of the maximum discharge in the Terpezița Basin.

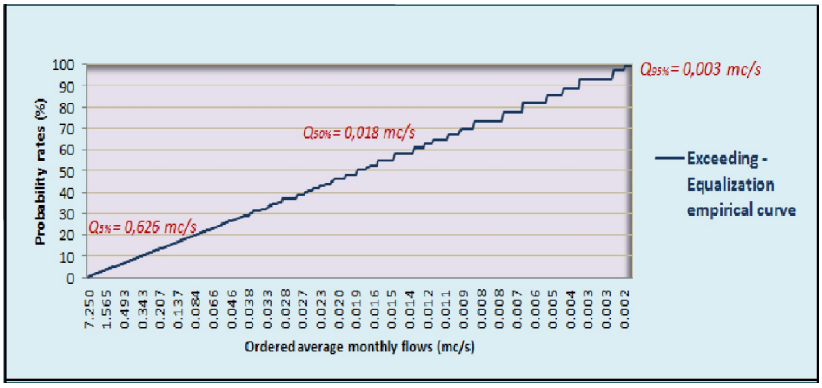

Figure 6. Graphical representation of the empirical exceeding-equalization curve at Gabru Hydrological station (1984-2011). Data source: ABA Jiu, Craiova

Also, one can notice the linear nature of the curve in the years with the greatest flows and the oscillations around the probability value for the years with average maximum flows near the value of 0.

2.4. The flash flood of 2005

For exemplifying the applicability of the methodology that was used, we have chosen to graphically represent (fig. 7) and to calculate the elements of the 2005 flash flood which comes from a year with a maximum monthly empirical flow of 0.006 m^3/s and a return probability of 81.9% but which, nonetheless, is a year of reference when it comes to real flows recorded in august.

Furthermore, the hydrograph would not be comprehensive without a representation of the daily amounts of rain (from the Dragoia pluviometric station on Desnățui River), which led to the 25 fold increase in the flow compared to the base value. These high values of the rainfall predated the formation of the flash flood by 3 days, and took place between August 10th and August 16th, totaling 91.9 mm of rain.

By introducing a series of formulas in the Microsoft Excel 2010 Program, applied to the flow and level values recorded during the flash flood, it was possible to determine important parameters for such an event (Pișotă & Zaharia, 2012), and it was also possible to interpret the values thus obtained (Table nr. 2.).

Typical for this kind of flash flood, which occurred in a basin located on a plateau and presenting a homogenous basin facies, with maximum historical annual flows created by a single episode of catastrophic exceeding (such as August 2005, which is one of the only months of that year with average flows above 1 m^3/s), is the moment of occurrence of the first maximum value on the graph, immediately after the last rains that caused the flash flood.

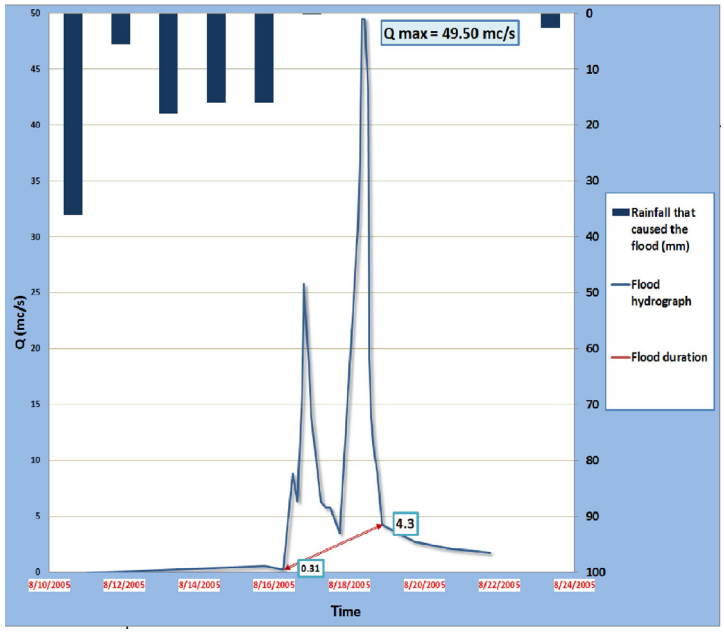

Figure 7. Flash-flood hydrograph from 15-21 August 2005 at Gabru hydrometric station (Terpezița River). Data source: ABA Jiu, Craiova

Table 2. Computed elements for the flash flood hydrograph*

W_t (mil.m^3)	W_b (mil.m^3)	□	T_t (h)	T_c (h)	T_s (h)	H_s (mm)	Q_b (m^3/s)	Q_{max} (l/s.km^2)
3.318	2.795	**0.30**	63	50	13	154	2.305	272

** where Wt – total volume of the discharge; Wb – base volume of the hydrograph;* □ *- shape coefficient of the flash flood; Tt – total time of the flash flood; Tc – flash flood increase time; Ts – flash flood decrease time for the flow; Hs – maximum level reached during the flash flood; Qb – base flow of the flash flood; qmax – specific maximum liquid flow of the flash flood.*

One can also notice that in the case of such a dual-wave flash flood, the maximum flow of 49.5 m^3/s is more than 20 times greater than the base flow of 2.3 m^3/s and around twice as large as the relative maximum flow of 25.8 m^3/s.

Last but not least, it is important to note the moment when the absolute maximum flow is recorded, which is formed by cumulating the amounts of rainfall on the entire area of the basin over the previous days, after an interval of growth of more than two days for the flash flood, and, after that, the flow decreases dramatically in less than one day.

CONCLUSIONS

The methodology employed reveals a good statistical significance, by highlighting the return time and the maximum average flows on Terpezita River, which is representative for the basin bearing the same name.

The maximum liquid flows and the specific liquid flow, once their return periods were determined, were easy to calculate due to the homogeneity of environmental factors in the basin, slope, geology, forestation coefficient, soil texture, which allowed for the determination of the coefficient used in the formulae. An analysis of the design storms and hydrograph for the 2005 flash-flood underscored the exceptional nature of this event, but in order to have a statistical approach of flash-floods in the studied basin, it is necessary to have a data-base with the largest flash floods recorded so far, and not just an analysis of singular events.

The design storms obtained, and also the theoretical and statistically determined maximum flows, can be used for creating a flood prognosis, by taking into account the numerical model adequate for the type of terrain, which can be acquired both on the basis of topographic plans and also from field measurements. Thus, it was possible to prove the low potential to generate catastrophic maximum flows for this small basin, due to its intermittent regime and subunitary average monthly flows during most of the year.

REFERENCES

1. Anuța, C. (2005), *Resurse în apă ale bazinului hidrografic Desnătui*, Editura Spiritul Românesc, Craiova.
2. Boengiu, S. (2002), *Aspecte hidrogeografice în Piemontul Bălăcitei*, Revista Geografică, VIII, Bucuresti.
3. Dawson, R. and Hall, J. (2004), *Performance-based management of flood defence systems*, Water Management, Issue WMI, 157, 35–44.
4. Diaconu, C. (1993), *Metoda statistico-spatială pentru calculul debitelor maxime probabile*, Hidrotehnica, nr. 3, Bucuresti
5. Diaconu, C., Mită, P. (1995), *Instructiuni pentru calculul scurgerii maxime în bazine mici*, INMH, Bucuresti.
6. Diez, D., Barr, C., Etinkaya-Rundel, M. (2012), *OpenIntro Statistics - Second Edition*, Duke University.
7. Ionuș, O. (2014), *Date preliminare asupra meandrelor râului Jiu din cursul inferior (Sud-Vest România)*, Forum geografic, S.C.G.P.M., vol. XIII (1), Craiova, [Online]. Available from: http://dx.doi.org/10.5775/fg.2067-4635.2014.051.i *[Accessed 26th March 2014]*.

8. Merz, B., Elmer, F. and Thieken, A.H. (2009), *Significance of "high probability/low damage" versus "low probability/high damage" flood events*, Natural Hazards and Earth System Sciences, 9, 1033-1046.
9. Mită, P. (1992), *Precizări la calculul debitelor maxime în bazine mici*, Studii si cercetări – Hidrologie, nr. 61, INMH, Bucuresti.
10. Pisota, I., Zaharia, Liliana, & Diaconu, D. (2010) *Hidrologie (Editia a II-a revizuită si adăugită)*. Editura Universitară Bucuresti, Bucuresti.
11. Platagea, Gh., Platagea, M. (1965), *Calculul debitelor maxime pluviale pe râurile din Republica Populară Română în cazul când lipsesc date din observatii directe*, Studii de Hidrologie, vol. XII, Institutul de Studii si Cercetări Hidrotehnice, Bucuresti.
12. Pleniceanu, V. (1999), *Apele din Câmpia Olteniei*. Editura Universitaria, Craiova.
13. Rose, A., Porter, K., Dash, N., Bouabid, J., Huyck, C., Whitehead, J. C., Shaw, D., Eguchi, R. T., Taylor, C., McLane, T. R., Tobin, L. T., and Ganderton, P. T. (2007), *Benefit-Cost Analysis of FEMA Hazard Mitigation Grants*, Nat. Hazards Rev., 8(4), 97–111.
14. Savin, C. (2008), *Râurile din Oltenia - monografie hidrologică*, volumul I, Editura Sitech, Craiova.
15. Sayers, P. B., Hall, J. W. and Meadowcroft, I. C. (2002), *Towards riskbased flood hazard management in the UK*, Civil Eng., 150(5), 36–42.
16. Sorocovschi, V. (2002*), Hidrologia uscatului*, Edit. Casa Cărtii de stiintă, Cluj-Napoca
17. *** (1981), Topographic map in Gauss-Kruger projection, scale 1:25000, D.T.M., Bucarest.
18. *** Corine Land Cover 2006 [Online] Available from: www.natural-earth.com
19. *** Geological Map of Romania, scale 1:200.000.
20. *** Numerical model of the terrain (MNAT) [Online] Available from: www.geo-spatial.org.