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# DERIVING FLASH FLOODS IN THE CASE OF SIMULATED PRECIPITATIONS

MARIA-MIHAELA GYÖRI<sup>1</sup>, JOËL HUMBERT<sup>2</sup>, IONEL HAIDU<sup>3</sup>

**ABSTRACT.** – *Deriving flash floods in the case of simulated precipitations.*

*The present study sets to determine the historical flash-floods on the Petriș watershed making use of the implemented mathematical models in a Hydrological Modeling System. In order to simulate the 1%, 2% and 10% exceedance probability flash-floods, the Intensity-Frequency-Duration (IDF) curves have been built on the basis of 22 years of precipitation records (1988-2009). They serve as input data together with the hydrological parameters identified by the means of a Geographic Information Systems. The results, computed mainly on the basis of the Soil Conservation Service (SCS) method, consist of hyetographs and hydrographs at the outlet of the main watershed, as well as to that of the ungauged tributaries of the Petriș River.*

**Keywords:** Intensity-Frequency-Duration curves, Hydrological Modeling System, exceedance probability, Soil Conservation Service method, SCS Unit Hydrograph.

## 1. INTRODUCTION

The Hydrologic Engineering Corps Hydrologic Modeling System (HEC-HMS) simulates the fluxes of mass and energy in the hydrological cycle through the mathematical models implemented. The modeling system has a wide range of applicability, being used for balance water equations on large rivers, floodplain studies, or hydrograph estimation studies in natural or urban watersheds (P. P. Mujumdar et al., 2012).

It is due to its distributed-specialized approach that the evolution of the discharge from the most remote corners of the basins, down to the outlet, can be analyzed even though in reality gauged data exists only at a fixed point, namely at the hydrometric post.

The main purpose of the study consists of two parts: the determination of Intensity-Duration-Frequency (IDF) curves for different return periods and the simulation of corresponding hydrographs, both at the gauging post and at the ungauged tributaries' outlets. Many of these outlets are situated in the vicinity of human settlements posing at times problems

related to flooding. The Probable Maximum Precipitation values for the 1988-2009 period and their statistical analysis made it possible to build the IDF curves for the Petriș watershed. The Hydrological Modeling System via the Soil Conservation Service (SCS) method facilitated the transformation of the excess precipitation into runoff, hence computing the 1%, 2%, 10% exceedance probability flash-floods hydrographs.

## 2. METHODOLOGY

The Unit Hydrograph will be generated with the help of the HEC-HMS that transposes the excess precipitation into direct runoff through its transform component. Among the seven transform methods available, the SCS Unit Hydrograph was chosen for the present study, a method that gives good results in scarce data regions, such as the one under investigation.

The meteorological model incorporated makes use of the Frequency Storm method so as to generate the rainfall depths for the 1%, 2%, 10% exceedance probability events. The resulting hyetographs are computed on the basis of data provided by the Agency "Direcția Apelor

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Române” that made possible the computation of Maximum Probable Precipitation depths for various durations (5 min, 15 min, 1 h, etc.)

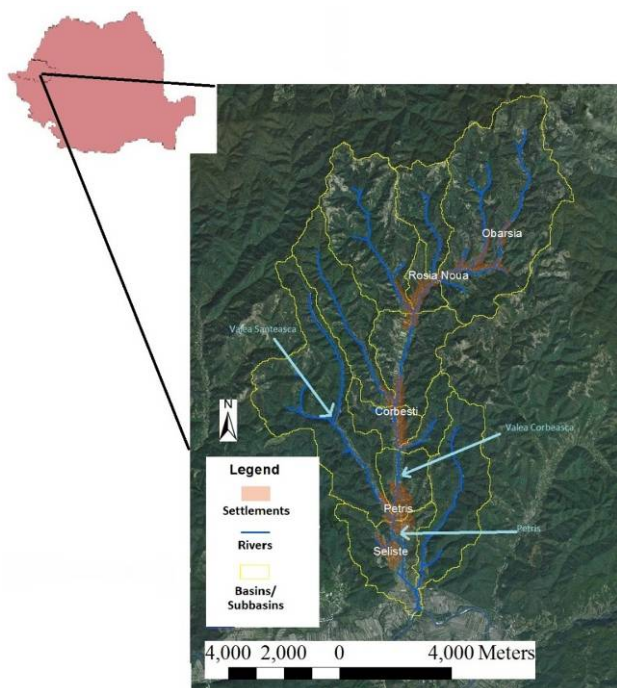


Fig. 1. The Petriș catchment and its main tributary rivers.

The Unit Hydrograph is generated for the Petriș watershed (fig.1), situated in Western Romania, in the Săvârșinului Mountains. In addition, the hydrographs for the tributary rivers have been simulated as well, helping to identify the discharge values in ungauged locations, during historical rainfall events. The main watershed has a surface of 109 km<sup>2</sup> and a river length of 76 km. It is mainly covered by deciduous forests (67%) and the C hydrologic soil group (67.77%), followed by 17.5% belonging to the B group, this being the primary data of outmost importance in the application of the SCS Method.

### 2.1. Meteorological data processing

For the present study case the Maximum Probable Precipitation depths for different durations (12 h, 6 h, 3 h, 2h, 1 h, 15 min and 5 min), shorter than 24 hours will be determined. These values are an essential input element for modeling maximum stream flow and are introduced at the level of the meteorological model, through the Frequency Storm method.

The meteorological model is the component that facilitates rainfall and evapotranspiration modeling in the HEC-HMS. Nevertheless in the simulation and modeling of short rainfall-runoff events the evaporation is considered negligible. The choice to be made for a meteorological model is between the seven existing ones.

C. Diaconu and P. Șerban (1994) have established the manner of computing the Maximum Probable Precipitation on a watershed, using the temporal and spatial analysis of available data for 24 h precipitation provided by the National Institute of Meteorology and Hydrology. The method is recognized by R. Drobot (2007) as being applicable to the stations where only daily precipitation exist, such being the case of the hydrometric post of Petriș, in the study area. The shorter duration rainfall records (6h, 3h, 2h, 1h etc.) are of more recent date, in fewer observation posts and are not available for the catchment under study. On the basis of the available data (1988-2009 annual series) from the pluviometric post Petriș, the Maximum Probable Precipitation for various durations have been computed as a first stage, followed by a frequency analysis.

There exists a link between the rainfall events with duration of 24 h and those with different durations (t) symbolized by  $X_t$ , namely:

$$X_t = \alpha_t X_{24} \quad (1)$$

-where  $\alpha_t$  is a subunit of  $t < 24$  h.

Hence five main areas described by the same temporal-spatial curves have been identified and can be viewed at page 243 in the work of C. Diaconu and P. Șerban (1994). Petriș, a tributary to the Mureș River, situated in the Săvârșinului Mountains is situated in the area number two. The value of the annual maximum precipitation for 24 hours ( $X_{24}$ ) depends on the surface of the catchment ( $F_B$ ).

The relationship between areas described by the same temporal and spatial curves and the temporal percent (p%T) is given by the mathematical expression:

$$\overline{[(X)_{24}]P\%T} = A_p - B_p \log F_B + F_0 \quad (2)$$

-where:  $A_p$  and  $B_p$  are constants depending on  $p\%T$  and area;  
 $F_0$  is a constant depending on the area.

The parameters of the above formula can be identified in the Tabel 3.34, page 249 in the same work of C. Diaconu and P. Şerban (1994). It is worth mentioning that these parameters are valid on the entire Romanian territory. For the computation of rainfall events of smaller duration than 24 hours ( $X_t$ ), the results of the statistical temporal and spatial analysis have been used once more, as well as the data for shorter duration rainfall events ( $X_t$ ) registered at more than 100 rainfall stations that had available data series ( $X_t$ ) for 20-35 years.

The next step is the determination of the  $\alpha$  coefficient as a ratio between  $X_t$  and  $X_{24}$  using the exceedance probabilities of  $X_t$  which have been determined on the basis of the highest rainfall depths registered (a number of 199 rainfall events). Hence in the present paper for the Petriş watershed, the afore-mentioned methodology has been applied. The maximum annual data series of 24 h rainfall events, registered between April and October have been taken into account, when the monthly average temperature is positive and the flash-floods registered in this interval are rainfall induced. Subsequently the computation of the 1%, 5% and 10% exceedance probabilities of the Maximum Rainfall events have been computed with the Hyfran software and the results can be read in Table 2.

## 2. 2. Direct runoff generation

Once the rainfall amounts are introduced in the HEC-HMS meteorological component, the excess of rainfall can be transformed in direct runoff. Among the several implemented methods, for the Petriş watershed the SCS Unit Hydrograph Method is selected.

The SCS formula can be expressed as (S. K. Mishra, 1999, 2002, 2003):

$$P_e = \frac{(P - 0.25)^2}{P + 0.85} \quad (3)$$

-where:-  $P_e$ = rainfall excess (mm)  
 -  $S$ = maximum potential of retention (mm),

$$S = \frac{25400}{CN} - 254$$

-  $P$ = total rainfall (mm)

The Curve Number (CN) parameter (fig. 2) is mandatory in the application of the SCS method. It is computed according to the basin characteristics that concur in runoff generation, namely: the hydrological soil group, land use, land cover and antecedent moisture conditions.

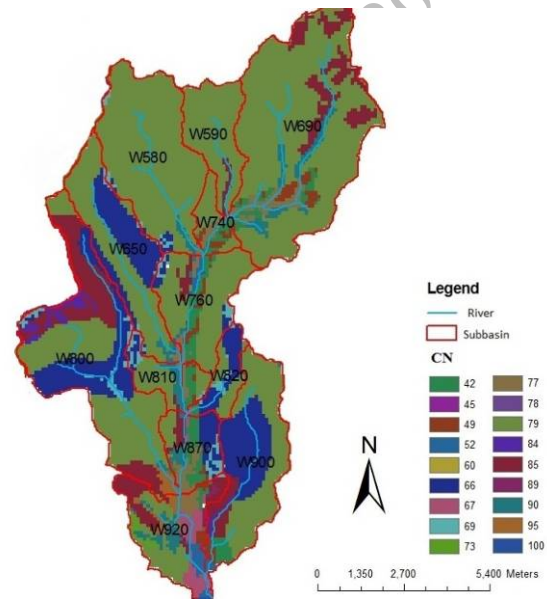


Fig. 2. Spatialization of the CN in the Petriş catchment.

For a catchment composed of different soil and land use types a weighted value of the CN can be computed on the basis of the formula (4) and according to the AMC II (Army Corps of Engineers, 2010, 2000):

$$CN_{\text{weighted}} = \frac{\sum A_i CN_i}{\sum A_i} \quad (4)$$

-where: - the  $CN_{\text{weighted}}$ = the weighted CN used for volume computation in the rainfall-runoff model;  
 -  $i$  = an index of the subdivisions that have the same type of soil and land use;  
 -  $CN_i$ = CN belonging to the  $i$  subdivision;  
 -  $A_i$ = the catchment area of subdivision

The resulted CN is a weighted value that represents the totality of possible combinations between the soil groups and the land use that

exist in a basin. This weighted CN should be computed without including the impervious areas in a basin. These need to be specified separately nonetheless, in the database as percentage from the total of the impervious surface (Army Corps of Engineers, 2010).

**Tab. 1.** Time of concentration ( $T_c$ ) and Lag time ( $T_{lag}$ ) in the Petriş catchment.

	$T_c$ (h)	$T_{lag}$ (h)
<b>Petriş</b>	5.2	3.2
<b>Subbasin</b>		
<b>W690</b>	1.77	1.06
<b>W590</b>	1.07	0.64
<b>W580</b>	1.33	0.80
<b>W740</b>	1.02	0.61
<b>W650</b>	1.76	1.05
<b>W760</b>	1.65	0.99
<b>W810</b>	1.14	0.68
<b>W820</b>	1.04	0.63
<b>W800</b>	2.07	1.24
<b>W870</b>	1.27	0.76
<b>W900</b>	1.85	1.11
<b>W920</b>	1.68	1.01

Knowledge of the time of concentration ( $T_c$ ) is of utmost importance as well and it can be estimated by measuring the time elapsed between the end of the net precipitation and that of the direct runoff. The Lag time ( $T_{lag}$ ) has also been determined for the Petriş subbasin and its subwatersheds, on the basis of a series of automated element extractions from a DEM via GIS. Hence the watershed area, medium slope, river length etc. have been extracted to serve this purpose

$$T_{lag} = \frac{(L^{0.8} + ([S+1])^{0.7})}{1900 \times Y^{0.5}} \tag{5}$$

-where: L= hydraulic length of the sections where the direct runoff is concentrated;  
- Y= basin slope (%).

For the ungauged basins, the SCS (National Engineering Handbook, 2001) suggests that the  $T_{lag}$  be correlated with the  $T_c$  as follows:

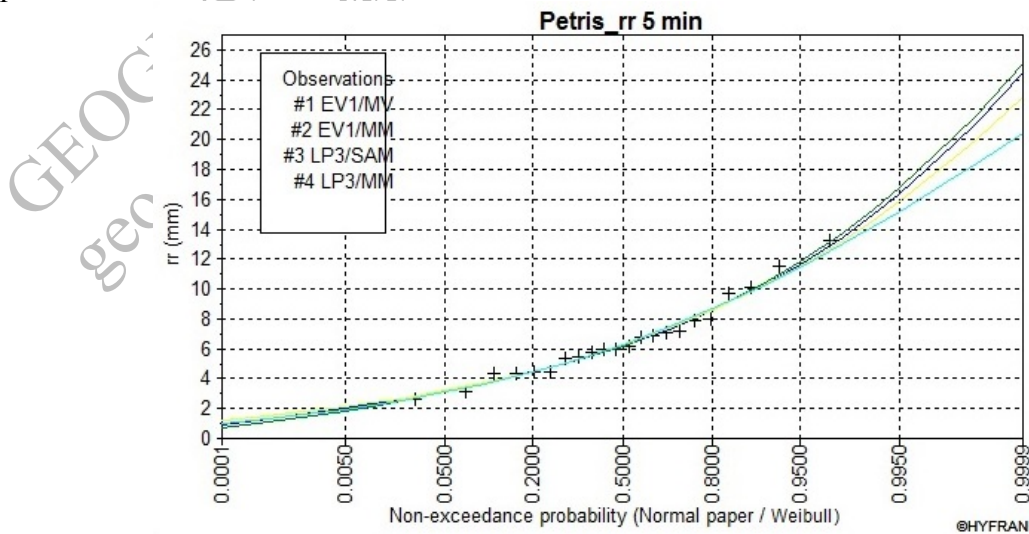
$$T_{lag} = 0.6 \times T_c \tag{6}$$

### 3. RESULTS

The statistical analysis of annual series (1988-2009) for the probable maximum precipitation of different durations shows a good fit to the Gumbel law for the 1%, 2% and 10% exceedance probability computations for the 5 min, 15 min, 1h, 2h, 3h, 6h, 12 h, 24 h.

As an example the frequency determination of the probable maximum precipitation of a 5 a minute duration is shown in fig. 3. It can be seen that both the Gumbel Law and the Log-Pearson Type III fit well the data, nevertheless the best fit is given by Gumbel Maximum Likelihood Distribution.

The values of the probable maximum precipitation for different duration are shown in table 2. They represent input for the meteorological model in HEC-HMS and they make possible the subsequent building of the IDF curves (fig.4).



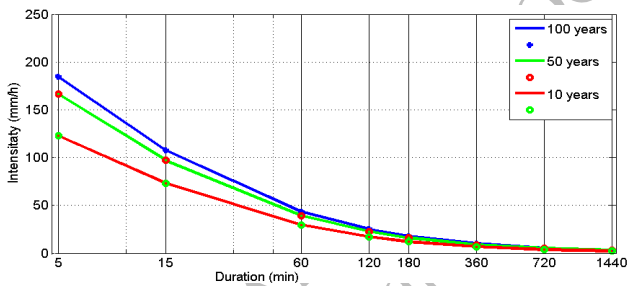
**Fig. 3.** The Gumbel distribution fitting the Petriş Maximum Probable Precipitation data.



**Tab. 2.** Probable Maximum Precipitation (mm) in the Petriş catchment.

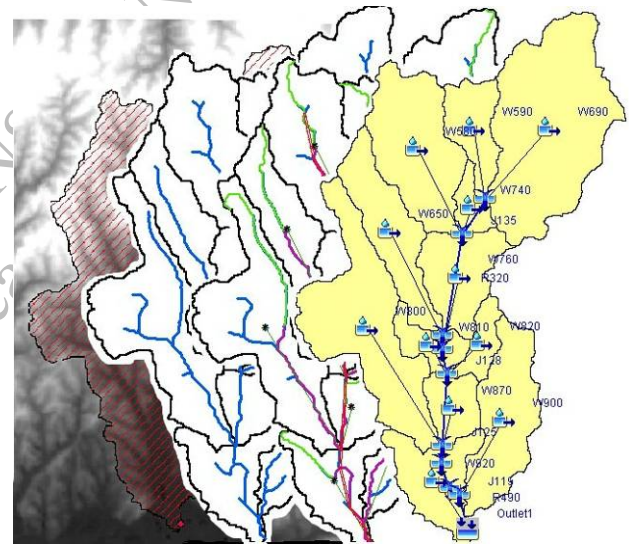
<b>p (%)</b>	<b>T (years)</b>	<b>5 min</b>	<b>15 min</b>	<b>1h</b>	<b>2h</b>	<b>3h</b>	<b>6 h</b>	<b>12 h</b>	<b>24 h</b>
1	100	15.3	26.9	43.4	50.1	53.1	58.4	65.8	74.8
2	50	13.8	24.3	39.3	45.3	48	52.8	59.5	67.6
10	10	10.2	18.3	29.5	34	36	39.6	44.7	50.7

The IDF curves express the existing relationship between rainfall intensity (i), duration (d) and the return period (T). The steps for the determination of the IDF curves are the preparation of the maximum precipitation series, the fitting of a probability distribution and determining of the rainfall depths (P. P Mujumdar et al., 2012). The results for the study catchment can be seen in figure 4 and represent the relation between maximum rainfall depth for each duration and an exceedance probability. There are numerous probability distribution functions that can be used (R. H. McCuen, 2003, S. McKillup, M. D. Dyar, 2010), the Gumbel being the best distribution for the Petriş data set, as indicated by the HYFRAN software.

**Fig. 4.** Intensity-Duration-Frequency curves for the Petriş catchment.

The meteorological data will be processed at the level of the meteorological component of HEC-HMS, within the Frequency storm model. Values of the 5 min up to 1 hour probable maximum data are used, on the grounds that 33.6 mm of rain have been registered on the 29<sup>th</sup> of April 1995 a value that falls within the confidence interval 23.6 mm- 35.3 mm of the 1 h maximum probable precipitation with a 10% exceedance probability. The SCS-CN method advises on the best way of determining the total duration for the rainfall based on the empirical studies made across time (namely a duration of

24 h for urban watershed, or 4 times the time of concentration), nonetheless the abundance of studies shows that it is the hydrologist's reasoning that have the last saying related to the matter. The storm duration is established after having analyzed several result hydrographs and their correspondence with the gauged data. For the present study case, a good correspondence exists for a 1 hour duration storm.

**Fig. 5.** Stages in the building of a HEC-HMS model.

Once the meteorological model has been established, the hydrological parameters of the Petriş basin and its subbasins need to be determined. They are represented under the feature classes River and Subbasin in the ArcGIS geodatabase (fig. 6). Once the model and its parameters have been transformed in a type of file that can be read by HEC-HMS, the initial parameters can be adjusted or changed completely.

The transforming process of an ArcGIS model into a HEC-HMS (fig.5) project includes: the identification of subbasins, of the main catchment, river courses; determining

hydrologic parameters such as river and basin slope, longest flow path, basin CN, Basin Lag; it follows the transforming of the ArcGIS data structure in a model that can be read and used within HEC-HMS; the final step is composed of computations made in the HEC-HMS model in order to obtain the hydrograph.

A similar study and database has been built

on another small watershed nearby, from the Zărandului Mountains, for the historic flash-flood registered on the 06<sup>th</sup> of August 2010 (M. M. Györi, I. Haidu, 2011). A good fit between the registered and the simulated hydrograph was noticed, hence the underlying methods for building the hydrologic model have been employed in the present study as well.

Bazin Petris																
OBJECTID*	Shape*	grid_code	Shape_Length	Shape_Area	HydroID	DrainID	LossMet	TransMet	Name	BasinSlope	BasinCN	LagMethod	Tc	BasinLag	Area_HMS	Area_SqKM
10	Polygon	10	78098.0418	109134309.986143	59	59	SCS	SCS	W590	13.954364	75.981186	CNLag	5.17363	3.104178	42.136993	109.13431

SubbasinPetris																
FID	Shape	GRIDCODE	Shape_Leng	Shape_Area	HydroID	DrainID	LossMet	TransMet	Name	BasinSlope	InitAbst	BasinCN	LagMethod	Tc	BasinLag	Area_HMS
0	Polygon	9	22605.9472	13613333.0652	58	58	SCS	SCS	W580	29.193705	0	78.813934	CNLag	1.331508	0.798905	5.256137
1	Polygon	10	15630.0982	5305994.86553	59	59	SCS	SCS	W590	25.955421	0	79.313766	CNLag	1.072862	0.643717	2.048656
2	Polygon	16	24126.9972	9259872.54778	65	65	SCS	SCS	W650	29.530329	0	73.949364	CNLag	1.759306	1.055584	3.575257
3	Polygon	20	30578.3472	24926828.5045	69	69	SCS	SCS	W690	25.839815	0	78.498276	CNLag	1.771487	1.062892	9.624302
4	Polygon	25	9073.8488	2073567.70166	74	74	SCS	SCS	W740	21.616587	0	68.126312	CNLag	1.024827	0.614896	0.800609
5	Polygon	27	17937.8982	7677358.71632	76	76	SCS	SCS	W760	19.820776	0	72.50631	CNLag	1.649265	0.989559	2.964245
6	Polygon	31	35561.0962	18270091.658	80	80	SCS	SCS	W800	26.781404	0	77.362564	CNLag	2.069083	1.24145	7.054122
7	Polygon	32	13112.4986	3220047.71031	81	81	SCS	SCS	W810	21.528019	0	74.020065	CNLag	1.13694	0.682164	1.243267
8	Polygon	33	11434.099	2615515.03681	82	82	SCS	SCS	W820	28.138159	0	70.87854	CNLag	1.04503	0.627018	1.009856
9	Polygon	38	10332.6492	3878225.11875	87	87	SCS	SCS	W870	18.806084	0	67.938889	CNLag	1.271954	0.763172	1.497391
10	Polygon	41	23812.2974	10995067.0259	90	90	SCS	SCS	W900	26.050297	0	73.165695	CNLag	1.85261	1.111566	4.245219
11	Polygon	43	20193.2482	7342424.0754	92	92	SCS	SCS	W920	16.786163	0	76.240448	CNLag	1.678545	1.007127	2.834926

Fig. 6. Example of the GIS database for the Basin feature class, including hydrological parameters of the SCS method

The final results, the hydrographs of the probabilistic flash-flood events of 1%, 2% and 10% for the Petriş catchment and its tributaries are determined. A 10% exceedance probability event was generated and calibrated with the 1995 event, which according to the statistical analysis of 22 years of streamflow data (1988-2009), belongs to the 10% exceedance class. The calibration value resulted in a value of 4.8 m<sup>3</sup>/s, on the basis of the Peak Weighted Root Mean Square Error (RMSE) (fig. 7). We can observe a small overestimation of the peak of the simulated hydrograph and an earlier apparition of the Time of rise which can be due to a slight underestimation of the basin Lag time.

After calibration, the 1% and 2% exceedance probability flash-floods hydrographs have been simulated, reaching peak values of 59.6 m<sup>3</sup>/s (fig.10) and 49.9 m<sup>3</sup>/s (fig. 9): The main tributaries that form the Petriş river are Valea Corbească and Valea Sântească.

As their flow path crosses a series of human settlements, their exceedance probability values represent a high interest as no gauging data exists.

Their exceedance values (fig. 8, 9, 10) surpass the multi annual discharge values of the gauged river Petriş (Q = 0,913 m<sup>3</sup>/s), representing a threat of flooding.

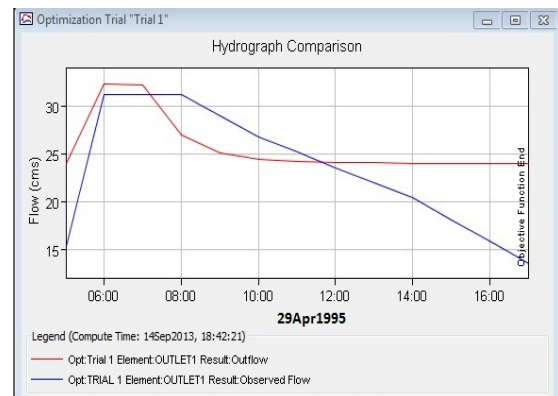
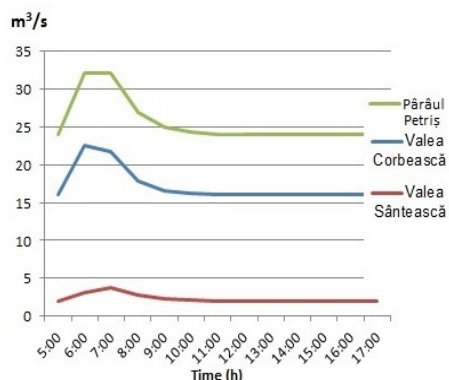
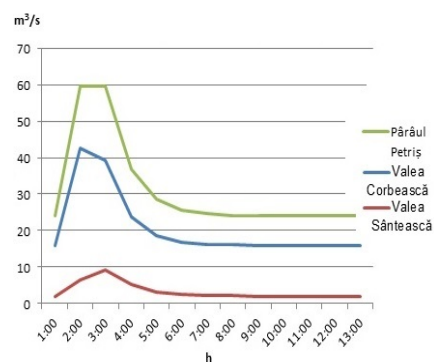


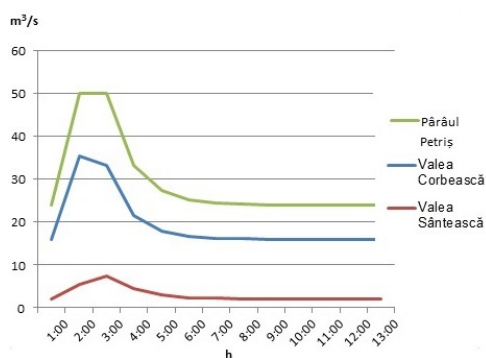
Fig. 7. Calibrating the 10% exceedance probability event.



**Fig. 8.** Flash-floods hydrographs for the 10% exceedance probability.



**Fig. 10.** Flash-floods hydrographs for the 1% exceedance probability



**Fig. 9.** Flash-floods hydrographs for the 2% exceedance probability

The present discharge values, as stipulated in the above sections, are rainfall generated, hence their discharge values are situated under the warning discharge values issued by the local authorities habilitated such as SGA Arad. As it can be seen from table 3, the SGA Arad issues for the year 2007 higher discharge values of different exceedance probabilities than those modeled, as the discharge taken into consideration by the authorities is caused by mixed precipitation. The values for the year 2011 for the same exceedance probabilities are even higher than those of 2007.

All the modeled discharge values are very close to those obtained from a statistical analysis of the discharge measured values between 1988-2009, as illustrated in table 3.

**Tab. 3.** Discharges of different exceedance probabilities for the Petriș River;  $Q$ ,  $m^3/s$ ;  $q$ ,  $l/s/km^2$

Basin	Exceedance probability											
	1%		2%		10%		1%		2%		10%	
	Statistical Analysis	SGA	Statistical Analysis	SGA	Statistical Analysis	SGA	Statistical Analysis	SGA	Statistical Analysis	SGA	Statistical Analysis	SGA
	Q	q	Q	q	Q	q	Q	q	Q	q	Q	q
Petriș	58.2	541	119	1107	50.6	470.7	94	874	32.6	303	39	362

#### 4. CONCLUSION

A physically-based model has been applied on the Petriș catchment despite several shortcomings related to data availability in the region

Hydrologic modeling plays an essential role in hydrograph forecasting once that

precipitation due to fall is known, or even more when meteorological precipitation warnings ( $15.0 l/m^2/h$ ;  $25.0 l/m^2/3 h$ ;  $30.0 l/m^2/6 h$ ) have been issued. Hence possible trajectories of flash-floods and the affected areas can be easily be delineated in the form of maps.



This cartographic material would be especially handy for all city halls as they have under their command the local committees for emergency situations. From flood plain maps one can realize the damage a high quantity of rain, transposed in surface runoff and flash floods, can produce. By having the flood plain maps and taking seriously into account the meteorological warnings flash flood damage can be reduced to a minimum.

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