"BABEŞ-BOLYAI" UNIVERSITY CLUJ-NAPOCA
FACULTY OF GEOGRAPHY
PHYSICAL AND TECHNICAL GEOGRAPHY

FLASH-FLOOD PREDICTION IN THE CASE OF LIMITED DATA. APLICATION TO THE SMALL RIVERS IN THE ZĂRANDULUI AND SĂVÂRȘINULUI MOUNTAINS

- SUMMARY -

Scientific Supervizor:
Prof. Univ. PhD. HAIDU Ionel

PhD Student:
GYŐRI Maria-Mihaela

Cluj-Napoca
2013

Table of Contents

1. Introduction

The present paper seeks to present the modeling process, extremely useful for hydrograph prediction despite the several acknowledged limiations caused by the measurement techniques and the limited of data temporal for a certain basin. Hence the existing models offer the possibility of extrapolation on the basis of available measurements for small ungauged basins resulting in hydrograph computation and the formulation of predictions (*Beven, 2006*).

As the European Directive 2007/60/EC has been passed, the flooding risk needs to be evaluated. The final result would consist of maps highlighting the flood risk areas as the natural flooding phenomenon are causing yearly, in Romania and in the world death cases and economic disasters.

Flash-floods occur are a consequence of torrential rain that spans for maximum duration of 3 hours, on a basin area up to 200 km^2, a basin travel time smaller than 6 hours and a torrential rain of 100 mm *(Drobot, 2007).*

Hydrologic models help the understanding of natural phenomena, such as the flash-floods, through simulation. The spatial representation of the generating process, the rainfall and that of the hydrological parameters that influence the runoff patterns make it possible to estimate the peak hydrograph for different sections in the basin.

Main research study objectives

The main objectives of the present study are the identification and application of a hydrograph estimation technique for the 100, 50 and 10 year return periods on the small gauged rivers in the Zărandului and Săvârșinului mountains, a second methodology of simulating flash-floods in the small and ungauged basins and third, the elaborating of floodplain maps that are not available in Romania and neither for the study area.

Hence the main working stages were set:

- Probable Maximum Precipitation depths for different return periods and their frequency analysis;
- The building of Intensity-Frequency-Duration Curves for the area of the small Petriș, Troaș and Monoroștia basins;
- The GIS mapping of the study area and the indirect computation of hydrologic parameters necessary for the simulations;

- The building of representative models for the ten basins (out of which seven are ungauged);
- Flash-flood simulation for 100, 50, 10-year return period generated on the basis of the maximum probable precipitation and the SCS method, generated on the gauged basins;
- Simulating flash-floods on ungauged basins using the Cluj Model
- Floodplain delineation for pluvial generated flash-floods with 100, 50, 10 year return periods on the three monitorised basins, by the use of a hydraulic model.

Geographic location and characterization of the study area

The present paper focuses on 10 basins situated in the Zărandului and Săvărșinului mountains (**Fig.1.1**) out of which:

- 3 gauged (Petriș, Troaș și Monoroștia);
- 7 ungauged (Radna, Milova, Conop, Bârzava, Julița, Vinești, Toc).

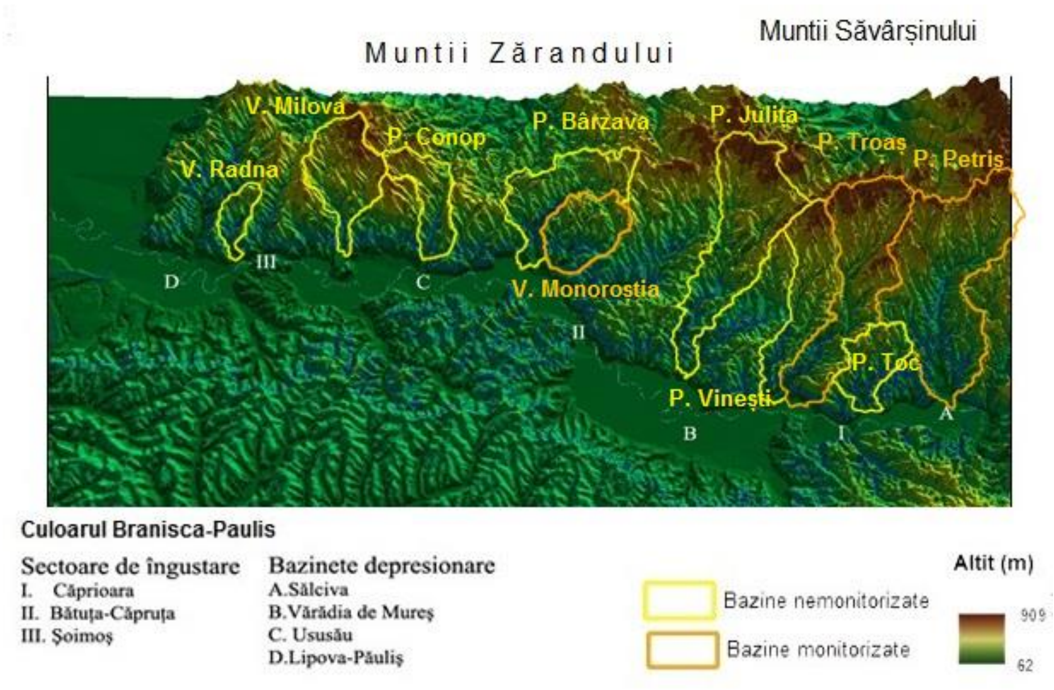


Fig.1.1 Geographic localization of teh 10 study basisns.

Their corresponding drainage areas span from 10 km^2 up to 110 km^2, hence belonging to the small basins' category (*Haidu, 1993*). These river are tributaries to the main river in the area, the Mureș River and are situated in the Zărandului and Săvărșinului mountains (**Fig.1.1**). On their territory a series o human settlements exists as well as a hydrometric and meteorologic network that is offering information on discharge and meteorological conditions:

2. Characteristics of the rainfall-runoff process in small basins

The rainfall-runoff model is investigated at the level of the ten small basins in the study area by the use of hydrologic and hydraulic modeling. These models have the rational and SCS methods implemented in order to represent the unit hydrograph. Hence the present chapter presents the models at the basis of the simulations and follows the evolution of the manner of work in hydrology , the shift that occurred form estimating the effective rainfall quantity to the unit hydrograph estimation using more and more complex models.

3. Frequency analysis, it's role in computing rainfall depth generating flash-floods and Intensity-Duration-Frequency curves for small basins

Frequency analysis of the maximum probable precipitation depths corresponding to different durations will result in input data inserted at the level of the meteorological method in the rainfall-runoff model applied for flash-flood modelling in the small Petriș, Troaș and Monoroștia basins.

At another stage of the study, the frequency analysis is applied to the registered discharge value series (1988-2009) at the hydrometric posts, making use of these results at the calibration stage.

Hydrologic processes need to be explained and analyzed in a probabilistic manner due to their randomness. The hydrologist has to make use of the of the statistical methods at hand so as to organize, present and compress the observed data to a form that facilitates their interpretation and evaluation.

Probability theory and theoretical elements

A fist hypothesis of the frequency analysis is the ***independant character*** of data, stipulating that the magnitude of an event in the future does not depend on the magnitude of former events.

The possible changing of the rainfall patterns, suggesting a change has occurred in the basin or in the regional climate, needs to be taken into account as well. Hence it is only the rainfall quantitative methods of time series analysis that can determine with certainty whether or not non-stationarity applies to the data.

Another aspect that needs to be taken into account is the (in)existence of two or more causing mechanisms for the time series data, termed as a mixed population. For example flash-floods can be rainfall generated, snow generated, or both. In the latter of the cases frequency analysis is run on both the types of data series. (*Bedient, 2002*).

Moments of a distribution and their estimation. Applicability to rainfall analysis and surface runoff

The concept of moments is well known in mechanics engineering. A probability density function or probability mass function is a functional form whose moments are connected to its parameters. Hence by finding the moments, generally the distribution parameters can be found. It is the moments that indicate the form of the distribution.

Determining the moments of annual maximum data series. The Petriş River example

Taking as an example the maximum annual series series of rainfall generated discharges on the Petriş River, on the basis of the equations presented in the preceding sections, the moments can be computed. For the present applications all these computations have been made automatically via the HYFRAN software. (**Tabel 3.3**)

Tabel. 3.3 The computed moments for the maximum rainfall induced discharges on the Petriş River (1988-2009)

Total values	22
Minimum	0.796
Maximum	60.6
Mean	15.4
Median	6.74
Standard deviation	16.8
Coefficient of variation	1.09
Skewness coefficient	1.35

Return period or reccurence interval

The most used method of indicating the probability of an event in hydrology is through the ***return period*** or the ***recurrence interval,***

The exceedance probability (p) and the return period (T) are related as follows (*McCuen, 1982*):

$$p = \frac{1}{T} \tag{24}$$

Mostly used probabilistic models

In hydrologic studies a large variety of discrete probability mass functions and continuous probability density functions are being employed. Nonetheless among the mostly used are the Normal distribution, Log-normal distribution, Gamma (Pearson type III) distribution, and Log-gamma (Log Pearson type III) (*Bedinet, 2002*).

Haidu (2002) mentions as well the Gumbel distribution as being among the most suitable for the maximum data series description and the Log Pearson Type III as giving good results on the Romanian territory

Frequency analysis of generating precipitation of flash-floods registered on the Petriș, Troaș, Monoroștia rivers

The first step in frequency analysis is the data series constitution (*Musy, Higy, 1998, Maidment, 1993*).

In the present study the data series is composed of the annual 24 hour maximum precipitation on the three rivers, with their values registered during April-October, when the mean temperature is positive and the registered flash-floods in the mentioned interval are pluvial in nature.

In our country *Diaconu, Şerban, 1994,* established a manner of computing the maximum probable precipitation of various durations. In order to do this, the 24 hour precipitations have been used, the method being also presented by *Drobot, 2007,* as still valid for the stations where only daily data exist, such as in the case of the present river basins.

The data series have undergone the non-parametric tests in the HYFRAN software for all of the 5 min, 15 min, 1 h, 2, h, 3 h, 6 h, 12 h, 24 h durations, on all of the three rivers:

-the Wald-Wolfowitz independence test;

- the Kendall stationarity test;

- the homogeneity test.

All of the above tests have been accepted.

Subsequently all of the different probable maximum precipitation durations have been a subject of the frequency analysis for the 1%, 2% and 10% for Petriș, Troaș și Monoroștia.

The choosing of the distribution that describes best the data is facilitated by the graphical interface. In the example in (**fig.3.12**) for the 5 minute probable maximum precipitation at Petriș it can be seen that all the distributions (Gumbel; Log Pearson type III) describe sufficiently well the data series, but the best representation belongs to Gumbel, Maximum Likelihood Method.

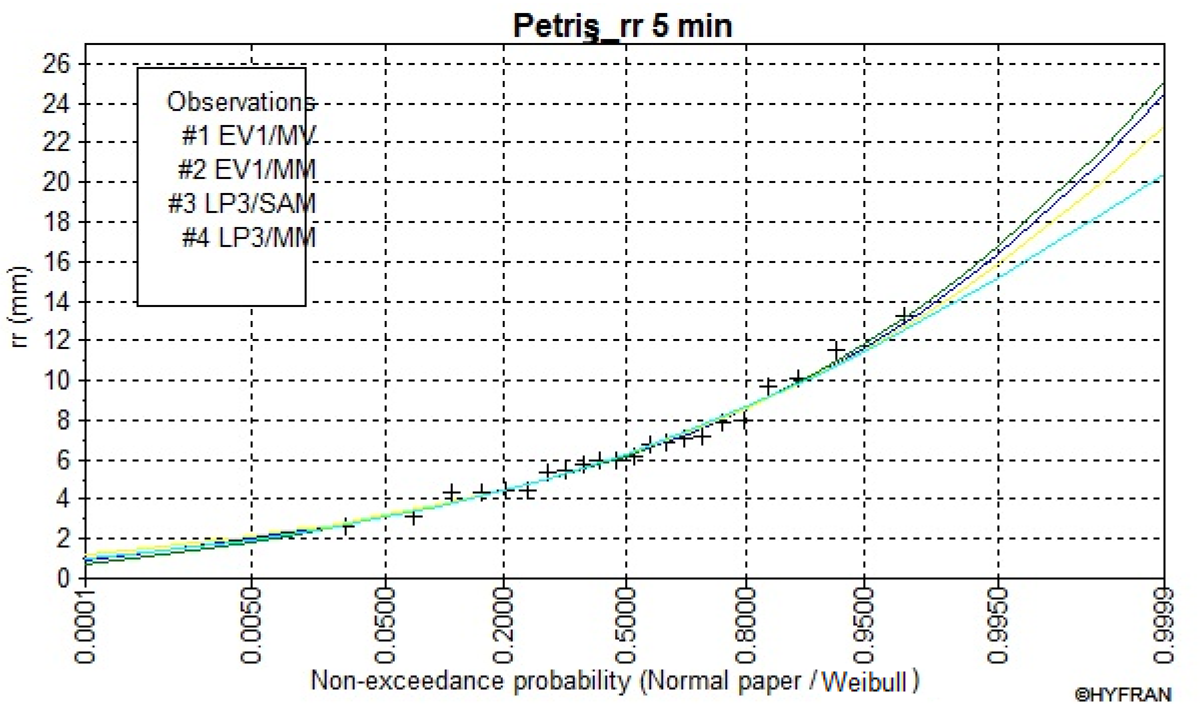


Fig. 3.12.Graphical representation of the probabilistic distributions for the 5 minute probable maximum rainfall duration at the Petriș hydrometric post.

In **tabels 3.8, 3.9, 3.10** the maximum probable precipitation for different durations are given for all of the three rivers.

Tabel 3.8 Probable Maximum Precipitation Petriș. Gumbel Distribution.

p	*T (ani)*	*5 min*	*15 min*	*1h*	*2h*	*3h*	*6 h*	*12 h*	*24 h*
		(mm)	*(mm)*	*(mm)*	*(mm)*	*(mm)*	*(mm)*	*(mm)*	*(mm)*
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

Tabel 3.9 Probable Maximum Precipitation Troaş. Gumbel Distribution.

p	*T (ani)*	*5 min*	*15 min*	*1h*	*2h*	*3h*	*6 h*	*12 h*	*24 h*
		(mm)	*(mm)*	*(mm)*	*(mm)*	*(mm)*	*(mm)*	*(mm)*	*(mm)*
1%	100	15.6	28.1	45.2	52.3	55.4	60.8	68.6	78
2%	50	14.4	25.9	41.7	48.1	51	56	63.2	71.9
10%	10	11.4	20.6	33.2	38.3	40.6	44.6	50.3	57.2

Tabel3.10 Probable Maximum Precipitation Gumbel Distribution.

p	*T (ani)*	*5 min*	*15 min*	*1h*	*2h*	*3h*	*6 h*	*12 h*	*24 h*
		(mm)	*(mm)*	*(mm)*	*(mm)*	*(mm)*	*(mm)*	*(mm)*	*(mm)*
1%	*100*	13.5	29.3	47	54.3	56.7	62.4	70.3	79.9
2%	*50*	12.5	26.7	42.9	49.6	51.8	56.9	64.2	73
10%	*10*	10.2	20.6	33.2	38.3	40.1	44.1	49.7	56.5

These values are essential in the simulation of different exceedance flash-floods simulations, in the intensity calculation of rainfall events and the building of Intensity-Duration-Frequency Curves (**Fig. 3.14, 3.15, 3.16**). Other examples of building the curves that have been taken into account in the documentation stage of the present work are those of *Eman Ahmed Hassan El-Sayed, 2011, Boucher, 2009, WRC Engeneering, 2008, Wolfe, 2006*.

Intensity-Duration-Frequency Curves for the small rivers: Petriș, Troaș, Monoroștia

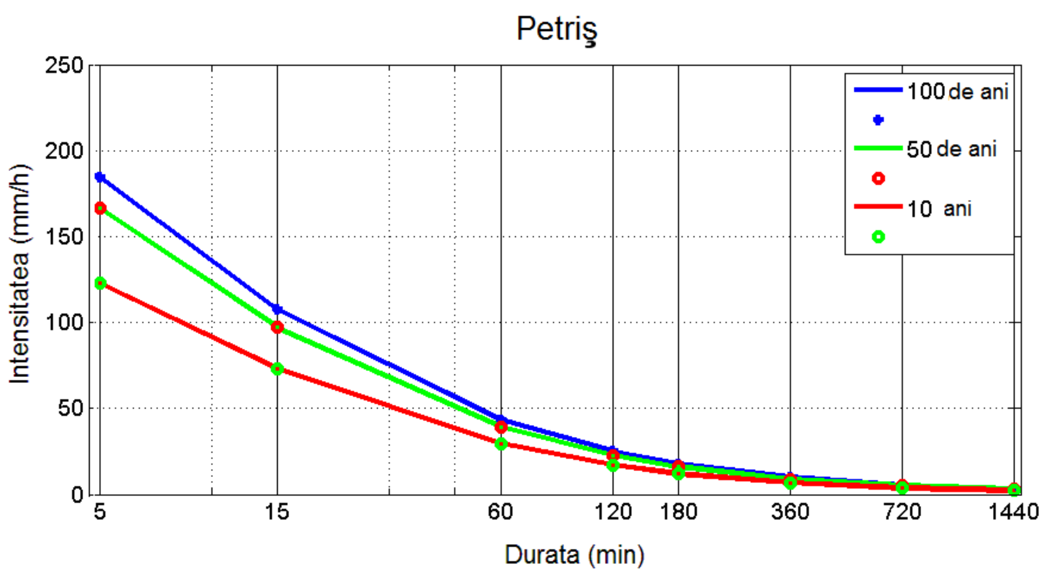


Fig. 3.14 Intensity-Duration-Frequency Curves at the hydrometric post of Petriş (*Győri et al., 2013*).

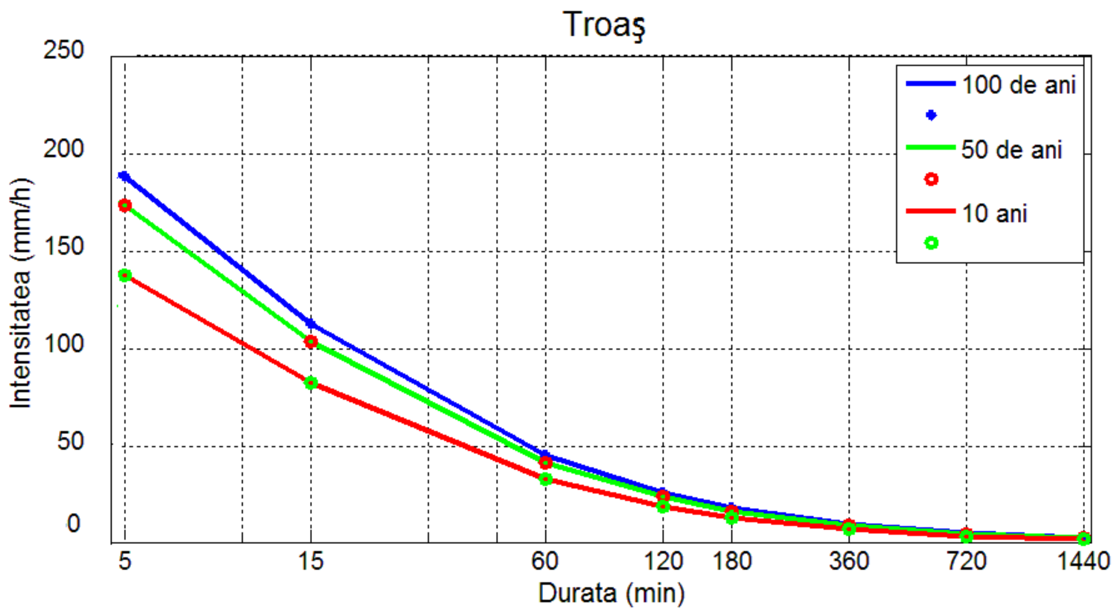


Fig. **3.15** Intensity-Duration-Frequency Curves at the hydrometric post of Troaș.

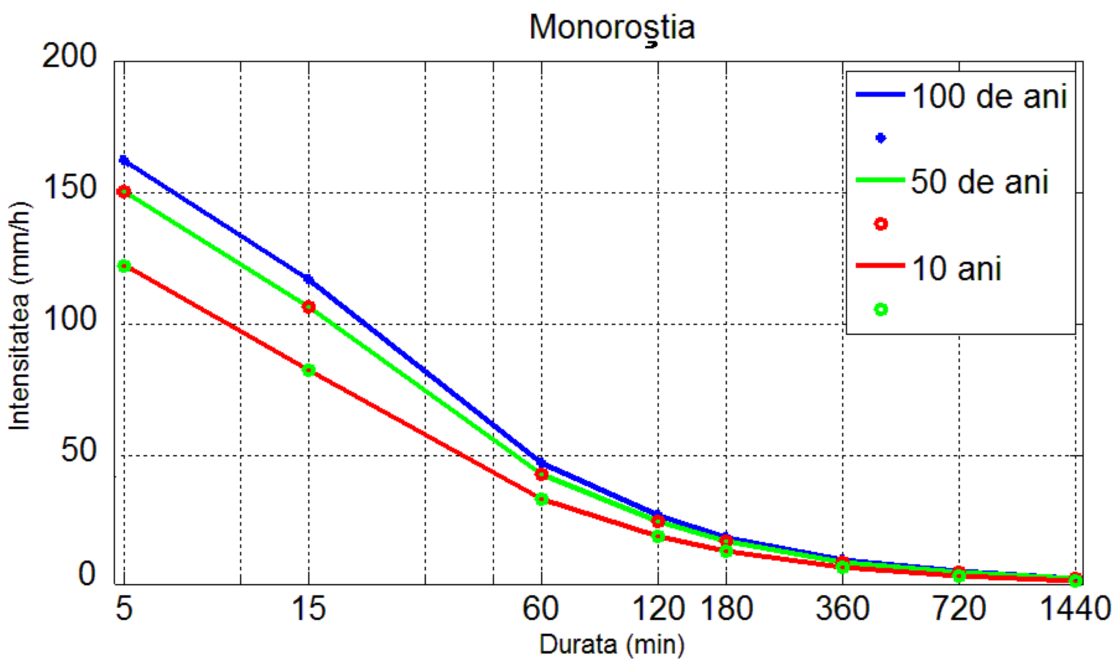


Fig. 3.16 Intensity-Duration-Frequency Curves at the hydrometric post of Monoroștia.

4. The modeling of probabilistic flash-floods. Application on the Petriș, Troaș, Monorostia rivers

Short introduction in the methodology and general presentation of the study basins

The 10, 50 and 100 year return periods are generated on the basis of maximum probable storms of different durations. Thismethod constitutes an alternative that allowed the generation of flash-floods with the HEC-HMS model even though no hourly data was available at the hydrometric posts.

The rainfall-runoff model used has been created in order to simulate the production and transfer functions of runoff in dendritic basins, the energy and mass flux in the water cycle at the basin level being represented by a mathematical mode. The model has a wide applicability, being used for balance applications on large watersheds, flood studies, runoff estimation on small watersheds in the urban area and in basins that keep their natural characteristics.

The three case studies are the Petriș, Troaș and Monoroștia rivers.

Building the database needed for modeling surface runoff

Automatic identification of rivers, basins and subbasins with the ArcHydro model

In order to determine the river courses and their basins, the ArcHydro functions have been used.

CN (Curve Number) parameter

The CN parameter is computed by taking into account the basin characteristics that generate runoff such as soil type, landuse soil surface conditions and antecedent moisture conditions. The CN is the main parameter on the basis of which the SCS method can be applied (*Ponce, Hawkins, 1996)*.

According to the landuse, for the Romanian territory the CN functions have been set by *Chendeş, (2007)*

In a first stage, the index for normal moisture conditions (CN II) are used so that later they are adjusted to the antecedent conditions (AMC I, AMC II AMC III).

GIS Methodology of determining the CN parameter of the basins in the Zărandului and Săvârșinului mountains

For a basin composed of different soil and land use types, a weighted value of the CN can be computed according to formula (31), taking into account the AMC II:

$$CN_{weighted} = \frac{\Sigma A_i CN_i}{\Sigma A_i} \tag{31}$$

-unde: $CN_{weighted}$= weighted CN used in the volume computation in the rainfall-runoff model

i = index of all subdivisions having the same types of soil and landuse

CN_i= CN belonging to the „i" subdivision

A_i= drainage surface of the i subdivision „i" (*USACE, 2000*).

The resulted CN (**Tabel 4.5**) is a weighted value representing the totality of possible combinations between the soil groups and land use types in a sub basin (*Győri et al., 2013*).

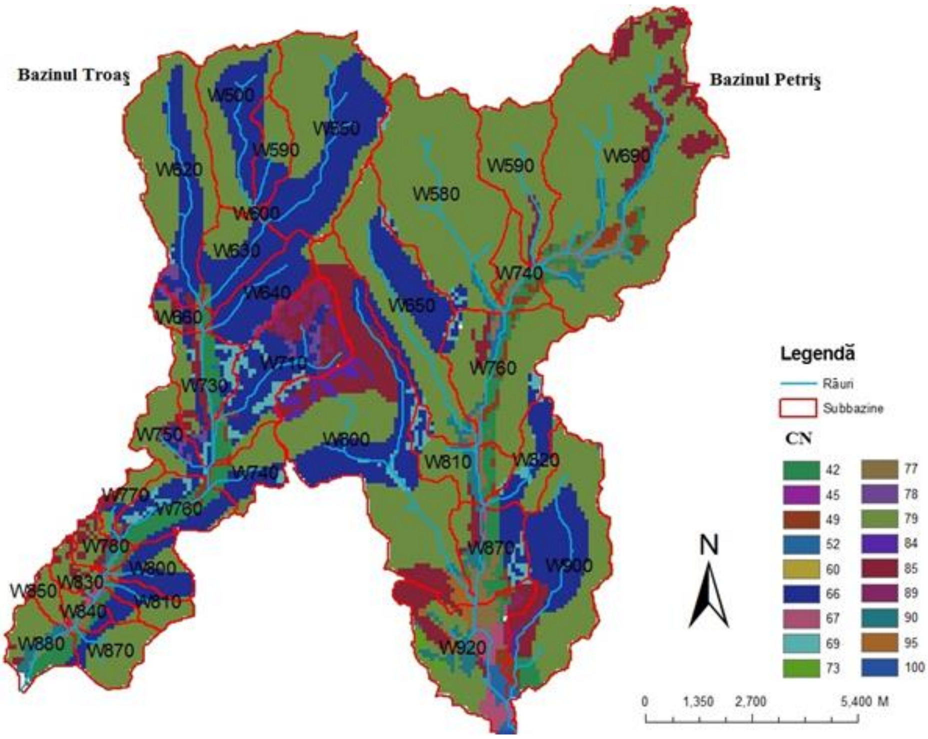


Fig 4.11 CNII Petriș and Troaș basins (*adapted after Győri et al., 2013*)

Tabel 4.5. CN weighted for all on the subbasins of the three rivers.

Petriş		Troaş		Monoroştia	
Subbabsin	*CN*	Subbasin	*CN*	Subbasin	*CN*
W690	*78.498*	**W880**	*71.18*	**W 1090**	*66*
W590	*79.314*	**W870**	*75.88*	**W 1160**	*67.95*
W580	*78.814*	**W850**	*79.61*	**W 1270**	*68.347*
W740	*68.126*	**W840**	*70.882*	**W 1360**	*67.642*
W650	*73.949*	**W830**	*74.734*	**W1500**	*74.603*
W760	*72.506*	**W810**	*72.924*	**W1530**	*72.985*
W810	*74.020*	**W800**	*68.858*	**W1360**	*67.642*
W820	*70.879*	**W780**	*77.194*	**W1490**	*75.028*
W800	*77.363*	**W770**	*79.839*	**W1830**	*76.646*
W870	*67.939*	**W760**	*59.958*	**W1710**	*72.449*
W900	*73.166*	**W750**	*76.902*	**W1170**	*71.449*
W920	*76.240*	**W740**	*69.137*	**W1780**	*79*
		W730	*68.172*	**W1740**	*79*
		W710	*73.418*	**W1820**	*78.156*
		W660	*72.790*	**W1810**	*79.111*
		W640	*68.087*	**W1670**	*75.486*
		W630	*69.517*	**W1920**	*80.536*
		W620	*74.127*	**W2040**	*80.867*
		W600	*70*	**W1380**	*76.287*
		W550	*72.221*	**W2110**	*80.004*
		W590	*72.465*		
		W500	*72.861*		

Time of concentration and Time lag

Once with the apparition of GIS and the possibility of processing spatial data, DEMs and TINs, there has appeared as well the possibility to estimate these two parameters. These determination methods are based on empirical equations and generally need the basin area, medium slope and river length, parameters extracted on the basis of geographic data in a GIS software (*Green, Nelson, 2002, USACE,2011, 2008*)

For the ungauged basins the SCS suggests that the correlation of the lag time ($T_{lag)}$ and the time of concentration (T_c) can be correlated:

$$T_{lag} = 0.6 \times T_c \tag{33}$$

Tabelul 4.6. The T_{lag} and T_c. (*adapted after Győri et al., 2013*)

	T_c *(h)*	T_{lag} *(h)*		T_c *(h)*	T_{lag} *(h)*		T_c *(h)*	T_{lag} *(h)*
Petriş	*5.2*	*3.2*	**Troaş**	*5.3*	*3.2*	**Monoroştia**	*2.9*	*1.74*
Subbabzin W690	*1.77*	*1.06*	**Subbazin W850**	*0.82*	*0.49*	**Subbazin W 1090**	*0.72*	*0.43*

	T_c (h)	T_{lag} (h)		T_c (h)	T_{lag} (h)		T_c (h)	T_{lag} (h)
W590	*1.07*	*0.64*	**W870**	*0.96*	*0.57*	**W 1160**	*0.94*	*0.56*
W580	*1.33*	*0.80*	**W880**	*71.18*	*1.31*	**W 1270**	*0.79*	*0.47*
W740	*1.02*	*0.61*	**W840**	*0.76*	*0.48*	**W 1360**	*0.88*	*0.53*
W650	*1.76*	*1.05*	**W830**	*0.86*	*0.5*	**W1500**	*0.65*	*0.39*
W760	*1.65*	*0.99*	**W810**	*0.96*	*0.58*	**W1530**	*0.62*	*0.37*
W810	*1.14*	*0.68*	**W800**	*1.16*	*0.7*	**W1490**	*0.93*	*0.56*
W820	*1.04*	*0.63*	**W780**	*0.75*	*0.45*	**W1830**	*0.86*	*0.52*
W800	*2.07*	*1.24*	**W770**	*0.97*	*0.58*	**W1710**	*0.89*	*0.54*
W870	*1.27*	*0.76*	**W760**	*1.67*	*1*	**W1170**	*1.4*	*0.84*
W900	*1.85*	*1.11*	**W750**	*1.40*	*0.84*	**W1780**	*0.32*	*0.19*
W920	*1.68*	*1.01*	**W740**	*1.34*	*0.8*	**W1740**	*0.22*	*0.13*
			W730	*1.58*	*0.95*	**W1820**	*0.64*	*0.38*
			W710	*2.05*	*1.23*	**W1810**	*0.48*	*0.29*
			W660	*0.76*	*0.45*	**W1670**	*0.56*	*0.34*
			W640	*1.4*	*0.83*	**W1920**	*0.81*	*0.49*
			W630	*1.17*	*0.7*	**W2040**	*0.64*	*0.39*
			W620	*1.95*	*1.17*	**W1380**	*1.75*	*1.05*
			W600	*0.3*	*0.18*	**W2110**	*1.22*	*0.73*
			W550	*1.97*	*1.18*			
			W590	*1.11*	*0.66*			
			W500	*1.55*	*0.93*			

Modeling the unit hydrograph using the hydrological modeling system HEC-HMS

The modeling performed for the three hydrological models of the basins Petriş, Troaş and Monoroştia using HEC-HMS consists of five components each:

- the basin model;
- the meteorological model;
- control specifications;
- temporal data series.

The unit hydrograph is the model of the direct flow that allows the identification of 1%, 2%, 10% exceedance probability flash-floods that can afterwards be used to evaluate the floodplain areas and to produce the risk maps.

The hydrological model

The physical representation of the basins Petriş (**fig. 4.18**), Troaş and Monoroştia was obtained by using the hydrological modeling system HEC-HMS, where, by the use of the component "basin model", the individual hydrological elements can be connected in a network that follows the structure of the hydrological basin. The physical processes specific to each element are included in itself by the use of mathematical models (*Razi et al., 2010, Kafle et. al., 2010, Katani Mehdi, 2011).*

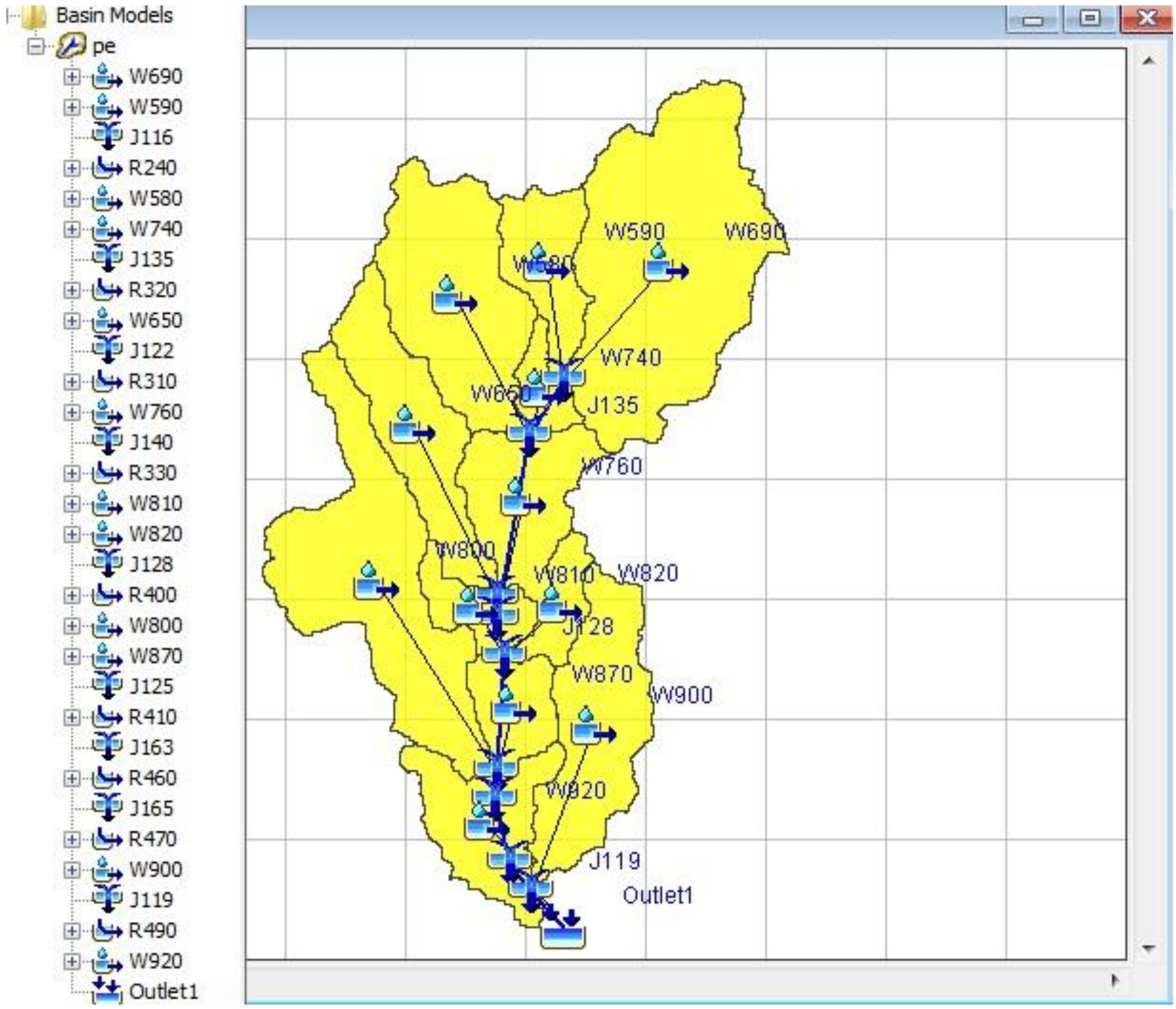


Fig. 4.18 View of the basin model in HEC-HMS for the Petriş basin.

Meteorological model

This component can be used to model the rain and evapotranspiration. For the simulation and modeling of short duration rainfall-runoff events, the evapotranspiration is often neglected.

For this study the method "Frequency storm" was used in order to generate a rain event based on the statistical data obtained from the SGA Arad. This method identifies the rainfall depth for different rainfall durations (5 min, 10 min, 15 min etc.) and their different exceedance probability.

Using the available data from the three gauging stations Petriş, Troaş and Monoroştia (1988-2009), the maximum probable precipitation of different durations were calculated, in order to determine their frequency afterwards.

Calculating the maximum probable precipitation

Maximum probable precipitation of different duration and frequency were calculated based on the precipitation data for the period 1988-2009 and the transformation coefficients, according to the methodology established by *Diaconu and Şerban, 1994, Tabel 3.36, p.251*.

The methodology also appears in *Drobot, 2007*, but it can only be applied for the weather or gauging stations where daily precipitation values are available, as is the case of the gauging stations present on the studied rivers.

The geographic position of the weather stations and gauging stations is depicted in figure **4.19**

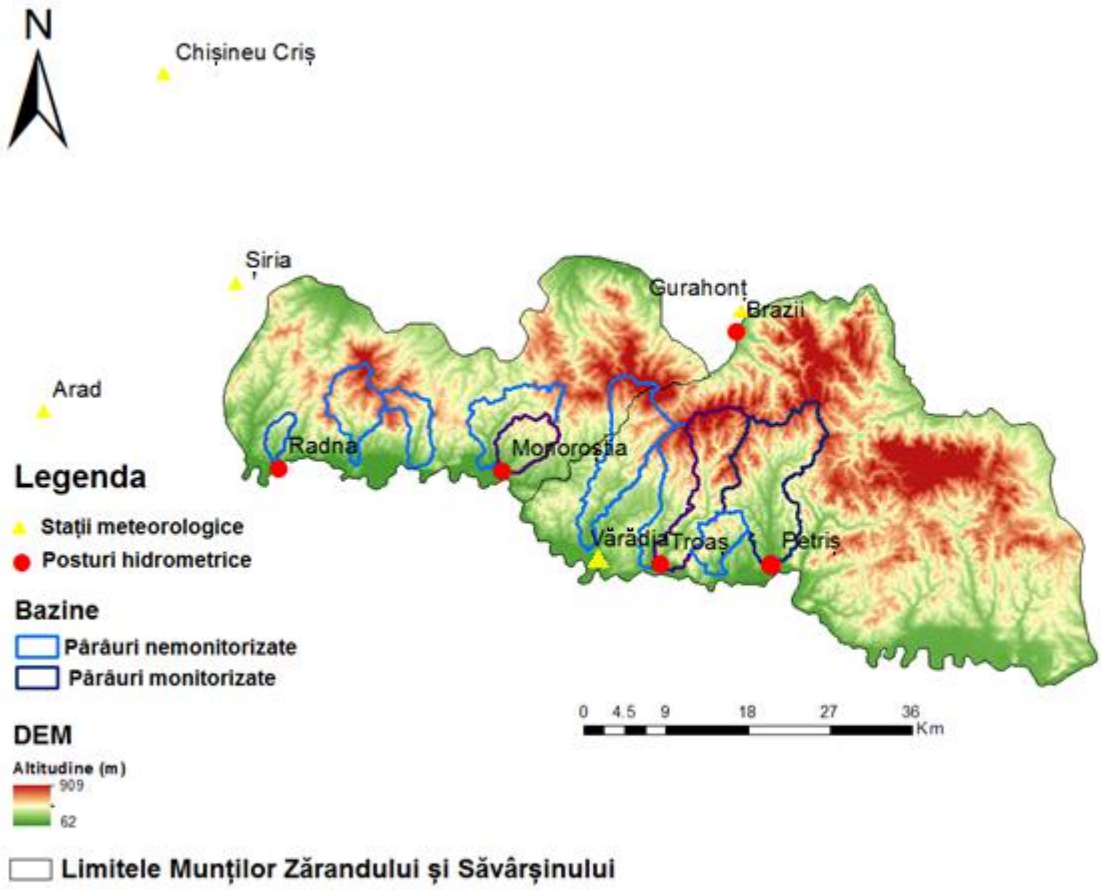


Fig. 4.19 The geographic position of the gauging and weather stations existing in the study area and the surroundings.

The different exceedance probabilities for the maximum probable precipitation were calculated with Hyfran for the three previously mentioned basins. The results were used as input data for the meteorological model.

Loss method

For the hydrological model used, all the water that is collected in a hydrological basin is considered to be reaching a surface that can be pervious or impervious. The precipitation falling on a permeable surface is subjected to some losses (*USACE, 2001)* that are calculated by a component specific to the hydrological model that is called *Loss component.*

For this study, a method that can solve the equations linked to the water losses was chosen, that being the *SCS Curve Number*.

Direct runoff model

In the HEC-HMS model applied to this study, the excessive precipitation is transformed into direct flow by using the method *SCS Unit Hydrograph*.

Therefore, the hydrological model uses all the parameters calculated for all the basins using GIS, but also meteorological data. The parameters were initially calculated for every subbasin of the three basins of the right side tributaries of Mureș river and stored in *feature classes River* and *Subbasin.*

The discharge values of the rain based flash-floods occurring in the three gauged basins of the right side tributaries of Mures river located in the Zarand Mountains, are mentioned in **figures 4.22 to 4.30**.

The maximum discharge of the 100 year-return-period flash-flood in the Petriș basin is 59,6 m^3/s, while the value for the 50 year-return-period flash-flood is 49.9 m^3/s, and for the 10 year-return-period flash-flood the discharge reaches 32.5 m^3/s. The discharge values for the tributaries of Petriș river, were also calculated, for example those for Valea Sântească and Corbeasca are mentioned, the rivers crossing some settlements.

The results can be viewed in different ways. Figures **4.22, 4.23, 4.24** illustrate the hydrographs of flash-floods as they can be seen in HEC-HMS software. USACE also developed a dedicated software HEC-DSS Vue (*USACE, 2009*), that allows data to be exported in tables (discharge, precipitation and infiltration process data for this study). Thus, the comparison of discharges for the subbasins Corbeasca and Sânteasca and Petriș river can be easily made in Excel. Discharge values corresponding to different return periods for the rivers crossing the settlements in Petriș basin are displayed in **fig. 4.27.**

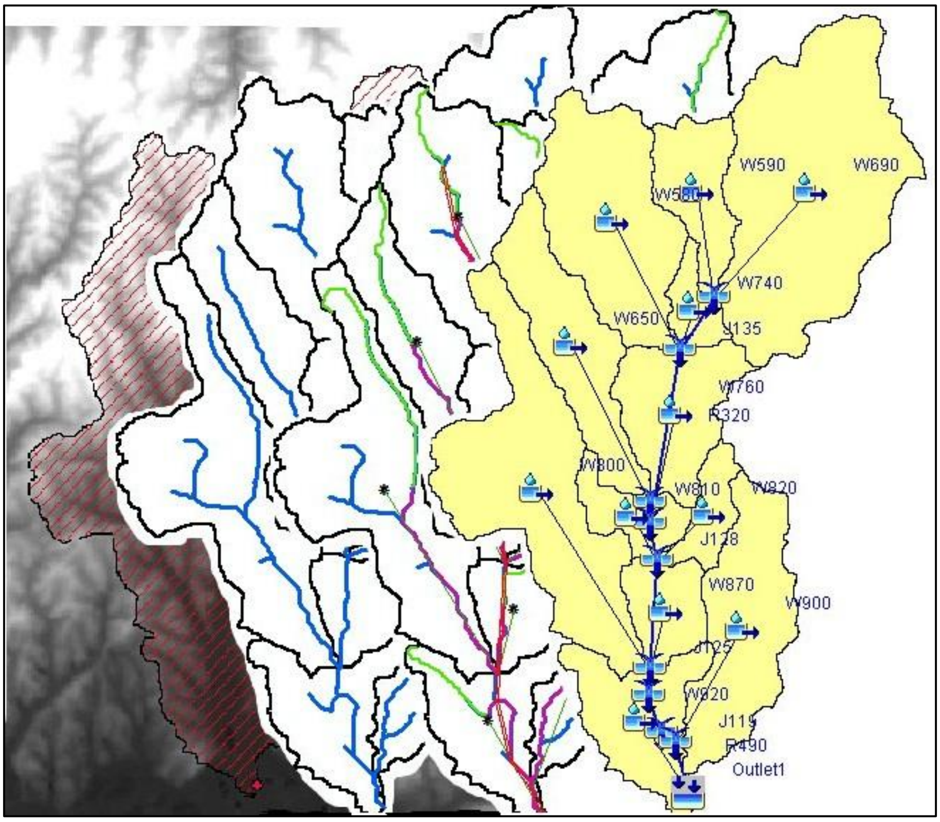


Fig. 4.20 The hydrological parameters of a basin in the *basin model* component of HEC-HMS, example for Petriș basin (*Győri et al., 2013).*

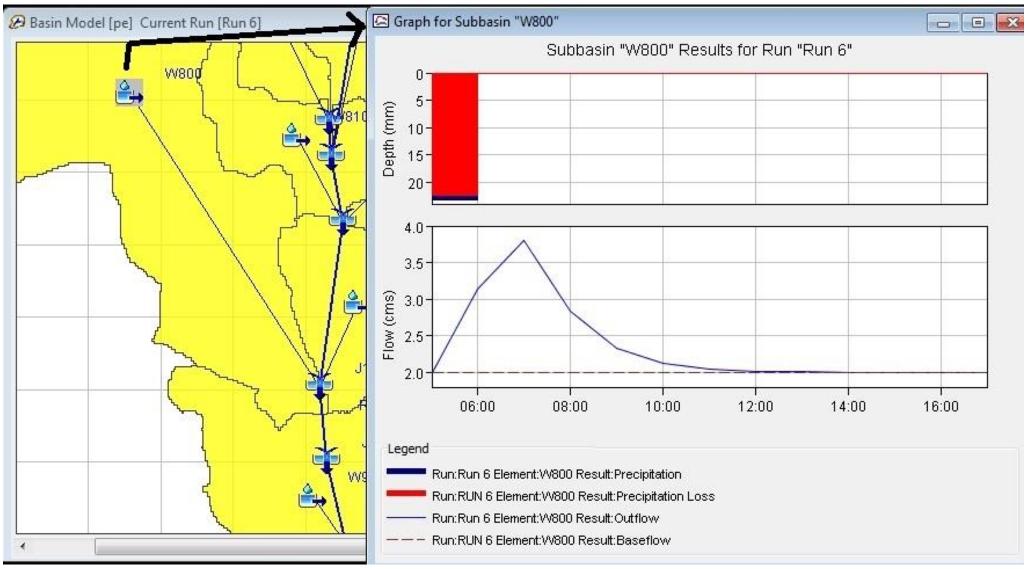


Fig. 4.22 Hyetograph and hydrograph of the 10 year-return-period flash-flood for the subbasin Sânteasca (W 800), tributary of Petriș river.

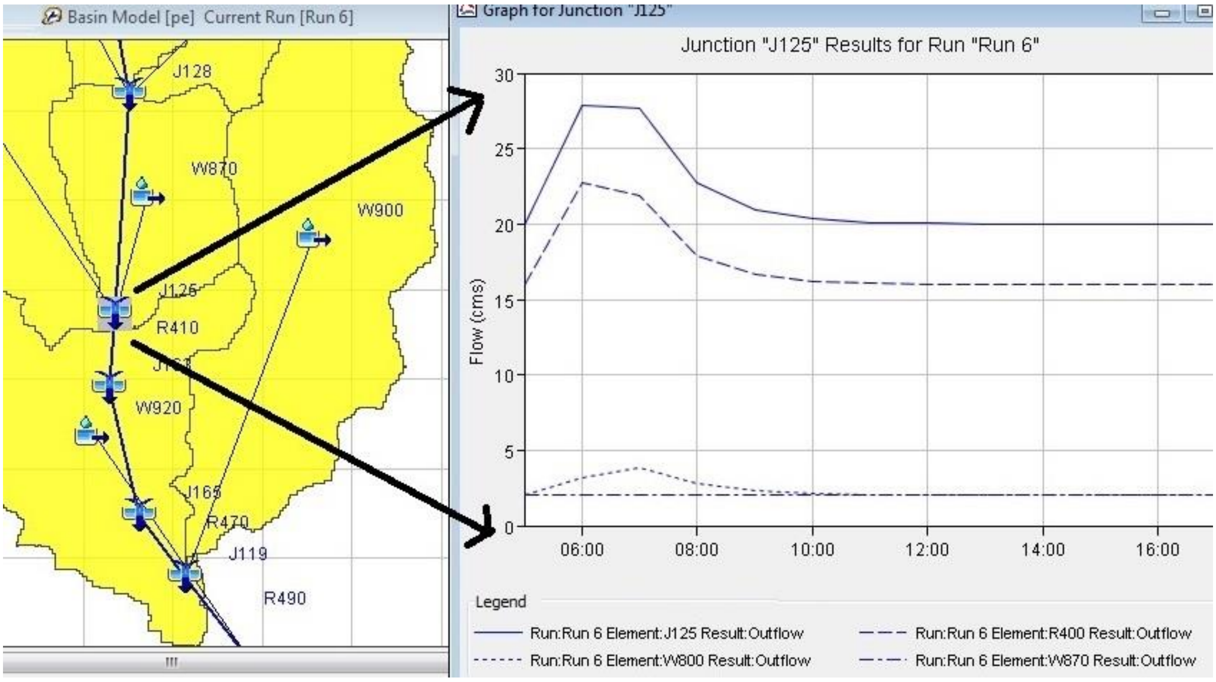


Fig. 4.23 Hydrograph of the 10 year-return-period flash-flood for the junction (J 125) of Sânteasca and Corbeasca, tributaries of Petriș river.

.

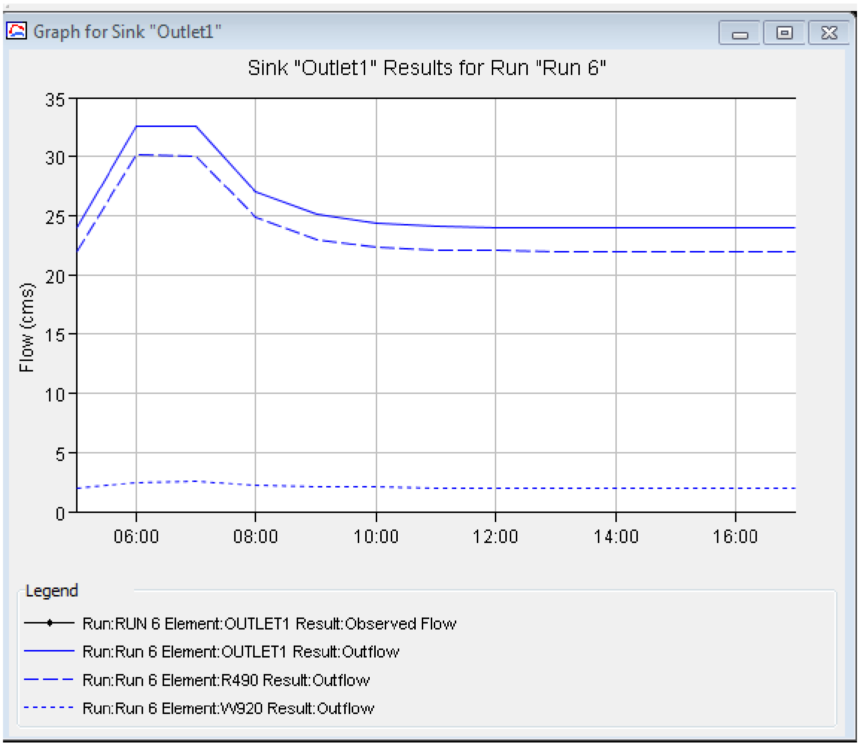


Fig.4.24 The 10 year-return-period flash-flood on Petriș river (Outlet1).

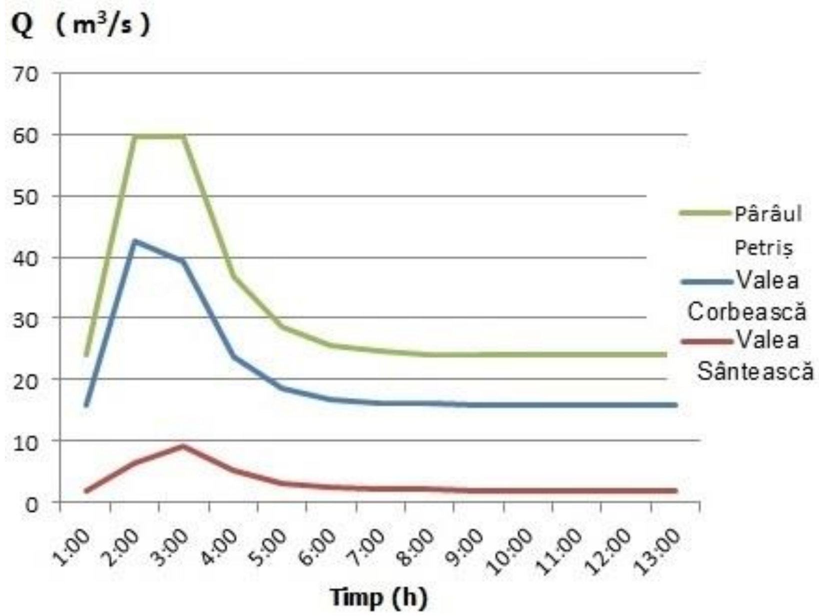


Fig.4.27 Hydrograph of the 100 year-return-period flash-floods *(Győri et al., 2013).*

Tabel. 4.14 Exceedance probability discharges of rivers Petriş, Troaş and Monoroștia.

River	**Return perios (T)**											
	100 years				**50 years**				**10 years**			
	Statistical analysis		**SGA**		**Statistical analysis**		**SGA**		**Statistical analysis**		**SGA**	
	Q m^3/s	q $l/s/km^2$	**Q m^3/s**	q $l/s/km^2$	**Q m^3/s**	**q $l/s/km^2$**	**Q m3/s**	**q $l/s/km^2$**	**Q m^3/s**	**q $l/s/km^2$**	**Q m^3/s**	**q $l/s/km^2$**
Petriş	**58.2**	541.4	**119**	1107	**50.6**	470. 7	**94**	874.4	**32.6.**	303	**39**	362.8
Troaş	**23.7**	311.8	**120**	1579	**20.7**	272.4	**97**	1276	**13.6**	179	**50**	657.9
Mono-roștia	**27.4**	913.3	**130**	4333	**23.9**	796.7	**105**	3500	**15.5**	517	**54**	1800

The discharge values mentioned previously are for rain based flash-floods, therefore they are smaller than the exceedance probability discharges calculated by the SGA Arad. The exceedance probability discharges estimated by the SGA Arad for the gauging stations and the year 2007 are in **table 4.14**, those estimated for 2011 being even greater. The values of the SGA result from analysis that also includes flash-floods of combined factors. The fact that this study focuses on rain based flash-floods explains the difference in values, although the discharge values obtained from the statistical analysis of registered discharges (1988-2009) are very similar to those calculated by the SGA.

The maximum discharge of the 100 year-return-period flash-flood in the Troaș basin is 19.6 m^3/s, while the value for the 50 year-return-period flash-flood is 17.5 m^3/s, and for the 10 year-return-period flash-flood the discharge reaches 8.5 m^3/s (**Fig. 4.29**). The values for Monoroștia river are of 25.9 m^3/s, for the 100 year-return-period flash-flood, 23 m^3/s for the 50 year return period flash-flood, while the 10 year return period flash-flood the discharge reaches 16.7 m^3/s (**Fig. 4.30**). The discharge values for the tributaries of Troaș and Monoroștia rivers that cross settlements can be found in the Appendix.

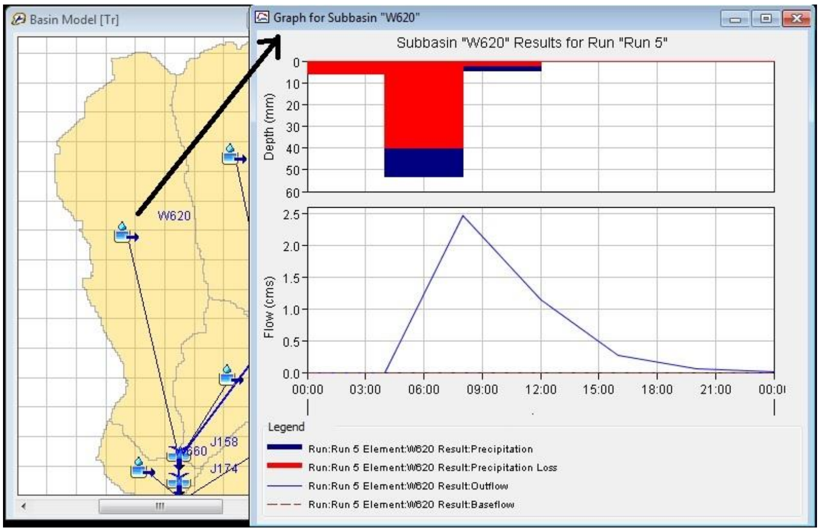


Fig. 4.28 Hyetograph and hydrograph of the 50 year-return-period flash-flood for the river Raiou (W 620), tributary of Troaș river

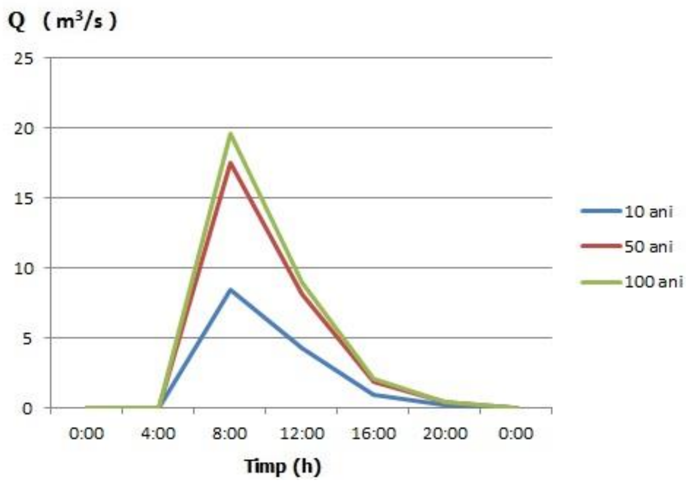


Fig. 4.29 The hydrographs of 100, 50 and 10 year-return-period flash-floods on Troaș river.

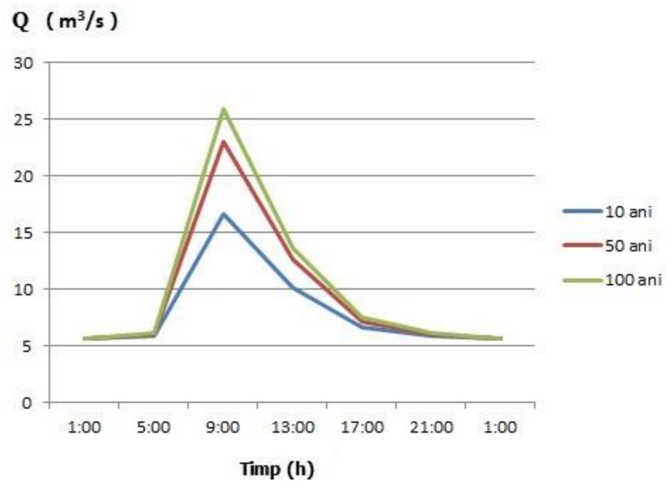


Fig. 4.30 The hydrographs of 100, 50 and 10 year-return-period flash-floods on Monoroștia river.

Model calibration

The model calibration can be made either manually or automatically, as it was performed here, the parameters undergoing an iterative process of adjustment of the values until the selected function offers the smallest of values (*Cunderlik, Simonovic 2004, Oceanit, 2008, Sinclair, 2009, Yener et al.,).*

There are four functions that can be used in the hydrological model:

- The least square method (36) gives a larger weight to the errors close to the maximum discharge of the flash-flood

$$Z = \left\{ \frac{1}{NQ} \left[\sum_{i=1}^{NQ} \left(q_O(i) - q_S(i) \right)^2 \left(\frac{q_O(i) + q_O(mean)}{2q_O(mean)} \right) \right] \right\}^{1/2} \quad \text{...........(36)}$$

Z= the function

NQ= number of calculated hydrographs

$q_s(t)$= data series calculated according to the parameters

$q_0(peak)$= Q_{max} of the observed flash-flood

$q_0(mean)$= mean value of the observed discharges

q_s= Q_{max} of the calculated flash-flood

For the hydrological model used, the calibration was performed by the use of *Peak-weighted RMS Error*.

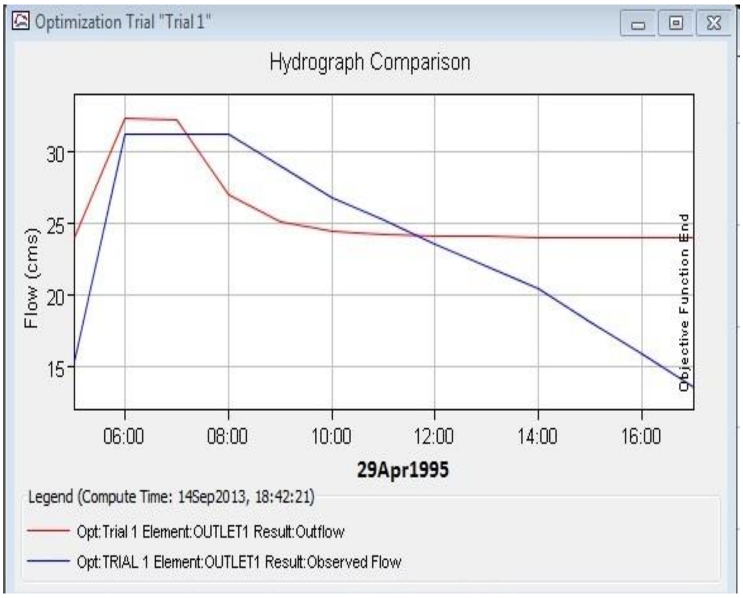


Fig. 4.31 Calibration of a 10 year-return-period flash-flood on Petriș river *(Győri et al., 2013).*

Tabel. 4.15 Simulated and observed discharges on Petriș river. Flash-flood of 29.04.1995.

Time (h)	**Petriș River Q m^3/s (simulated)**	**Petriș River Q m^3/s (observed)**
5:00	24	15.3
6:00	32.2	31.2
7:00	32.2	31.2
8:00	26.9	31.2
9:00	25	29
10:00	24.4	26.7
11:00	24.1	25.12
12:00	24	23.55
13:00	24	21.98
14:00	24	20.4
15:00	24	18.1
16:00	24	15.8
17:00	24	13.5

In the calibration process a RMSE value of 4,8 m^3/s was obtained for the Petriș river (**fig.4.31)**. Therefore the simulated estimation of the discharge is of 99% (**Tabel 4.15**). A small overestimation of the simulated hydrograph peak can be observed, as well as an earlier onset of the time to peak that can be caused by a small underestimation of the basin’s time lag.

The calibration was made between a simulated flash-flood and an observed flash-flood, both pertaining to the same return period as calculated in the statistical analysis of discharges.

The values obtained for the calibration of flash-floods on Troaș and Monoroștia (**tabel 4.16**) indicate a good correlation between the simulated and statistical discharge values.

Tabel.4.16 Maximum simulated and statistical discharge values for the rivers Petriș, Troaș and Monoroștia.

Probability	**Petriş river**			**Troaş river**			**Monoroştia river**		
	Q m³/s simulated	Q m³/s statistical	%	Q m³/s simulated	Q m³/s statistical	%	Q m³/s simulated	Q m³/s statistical	%
1%	**59.6**	58.2	102	19.6	23.7	83	25.9	27.4	95
2%	**49.9**	50.6	99	17.5	20.7	85	21.5	23.9	90
10%	**32.2**	32.6	99	8.5	13.6	63	16.7	15.5	108

5. Flash-flood modeling on the small rivers- gauged and ungauged- in the Zărandului and Săvârșinului mountains

The Cluj model has been developed by the research team from the Faculty of Georgraphy in order to estimate the flash-flood hydrograph and its peak flow, on the small basins where no measurements exist.

It is an event-based simulation model composed of four conceptual models designed with ArcGIS Model Builder and five Python scripts which need to be run in MATLAB.

In the present study we have used the conceptual models designed by using ArcGIS (**fig**. **5.5, 5.6, 5.8, 5.10**) and which can be accessed with ArcToolbox, and after we have run the scripts in MATLAB.

The initial database necessary for flash-flood modeling on ungauged basins

It is necessary to extract a series of primary entry data (**fig**. **5.2)** through the GIS product in order to run the four conceptual models (*Haidu et al., 2007-2010)*:

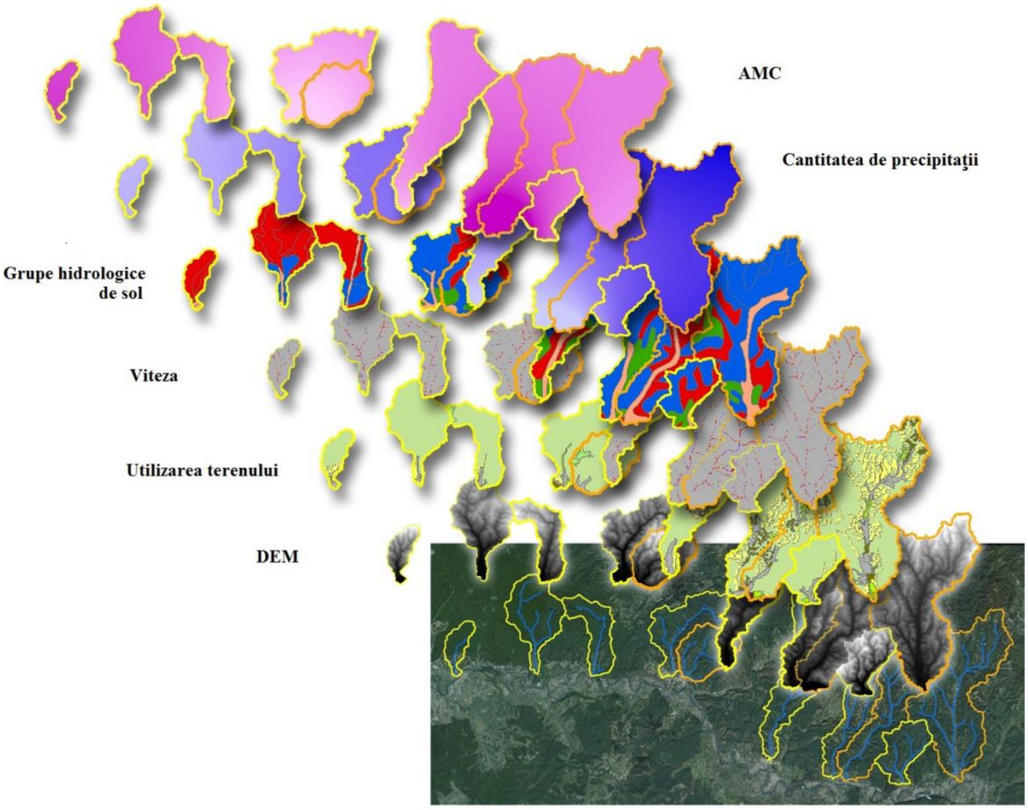


Fig.5.2 Entry data for the Cluj Model.

The Runoff Module

In order to determine the runoff module (mm) we have used in ArcGIS Model Builder the well-known version of the formula SCS-CN. Its different variants, its usage and the applicability as well as its limitations have been discussed in *Chapter 2*.

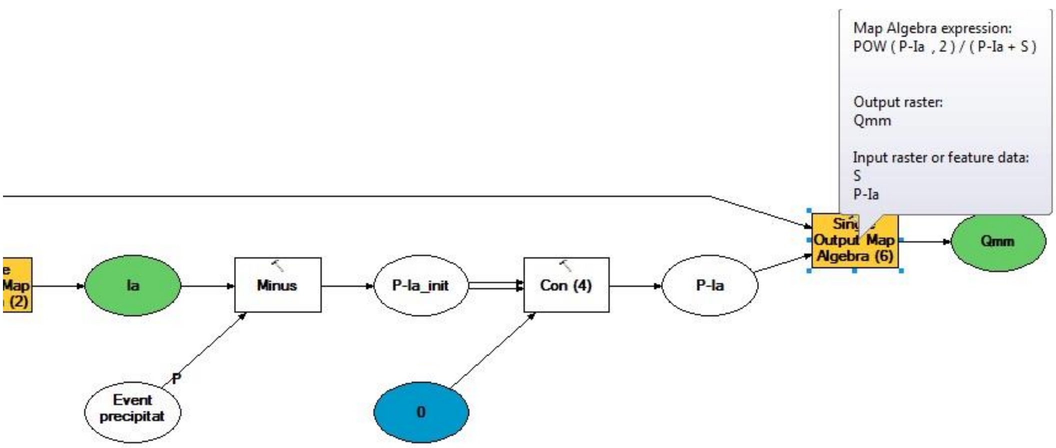


Fig.5.5 The integration of the SCS-CN formula in the Runoff module

The runoff coefficient module

The runoff coefficient module (noted with „α” or „c”) results from the division of the runoff water quantity drained in a certain amount of time and the quantity of precipitations fallen in the reception area which generated the runoff (*Diaconu, Şerban, 1994*) (**fig. 5.6**).

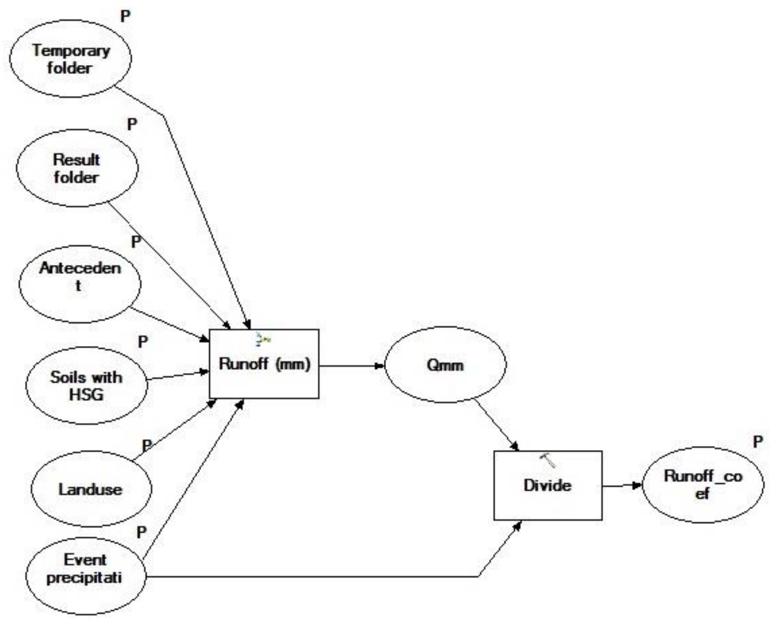


Fig.5.6 Runoff Coefficient Module

Travel Time Module

This model is the third out of the four models which compose the Cluj Model, and calculates the time required by the water particle to get to the outlet point.

The entry data (**fig. 5.8**) is composed of the speed layer and the DEM. The layer representing the speed was created in SAGA GIS by running the following functions: *Sink Removal, Flow Direction, Flow Accumulation, Catchment Delineation* and *Variable Isochrones Speed*. The last operation helps to identify the speed of the water for each isochrones, and for the travel time. This can be done only by using SAGA GIS database.

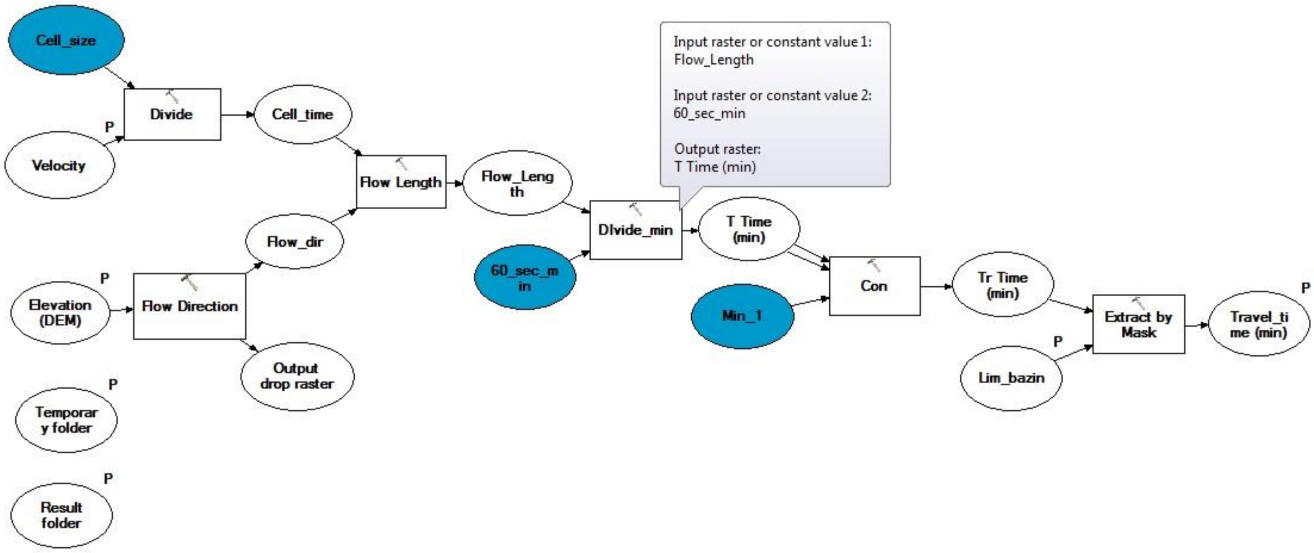


Fig. 5.8 Travel Time model of the basin

By using the velocity raster, the travel time for each cell can be estimated as a ratio between the distance traversed inside a cell and the time needed for it. The travel time for each cell on the drainage path can be calculated by adding the travel time reaction of each cell. This operation implies as well a reclassification of the raster in 1-minute intervals.

Discharge module

All the previous results can be obtained by running one of the previous modules. Nonetheless the user can choose to insert all entry data and run the Discharge module so as to compute all the parameters that are incorporated in this module as well.

This model has embedded the rational method at a cell level in order to calculate the discharge, a formula which is widely used by the Romanian scientific community (*Diaconu, Şerban, 1994).*

Once that the drainage area of an isochrones is computed, the discharge for the respective isochrones results by summing up all the discharge in those cells. The generated values are saved into a table that represents the final result of the model, the *Zonal Statistics.dbf*

In order to transform the tabular discharge data into a hydrograph, the scripts written by *M. Domnița, 2012* need to be run (*Haidu et al., 2007-2010*). The resulted hydrographs based on linear routing have been simulated for the 10 (**fig. 5.11, 5.12**).

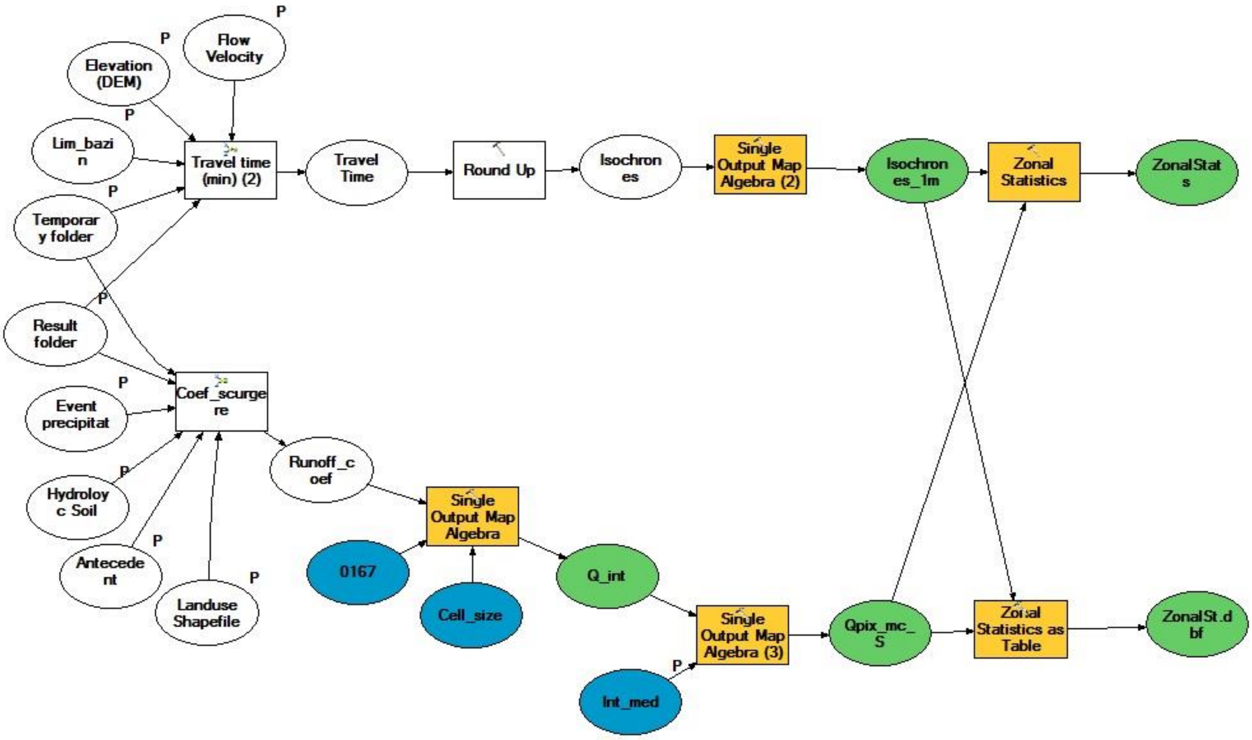


Fig. 5.10 The Discharge Module

In **fig.5.11** and **5.12** the resulted runoff hydrographs are shown. To obtain the hydrograph all the parameters shown in fig. 5.1 have been modeled. The result is for the simulation of the 03.07.2001. The discharge has been reached and the time to peak corresponds to measured data. Hence the maximum peak flows can be considered valued when modeling ungauged rivers.

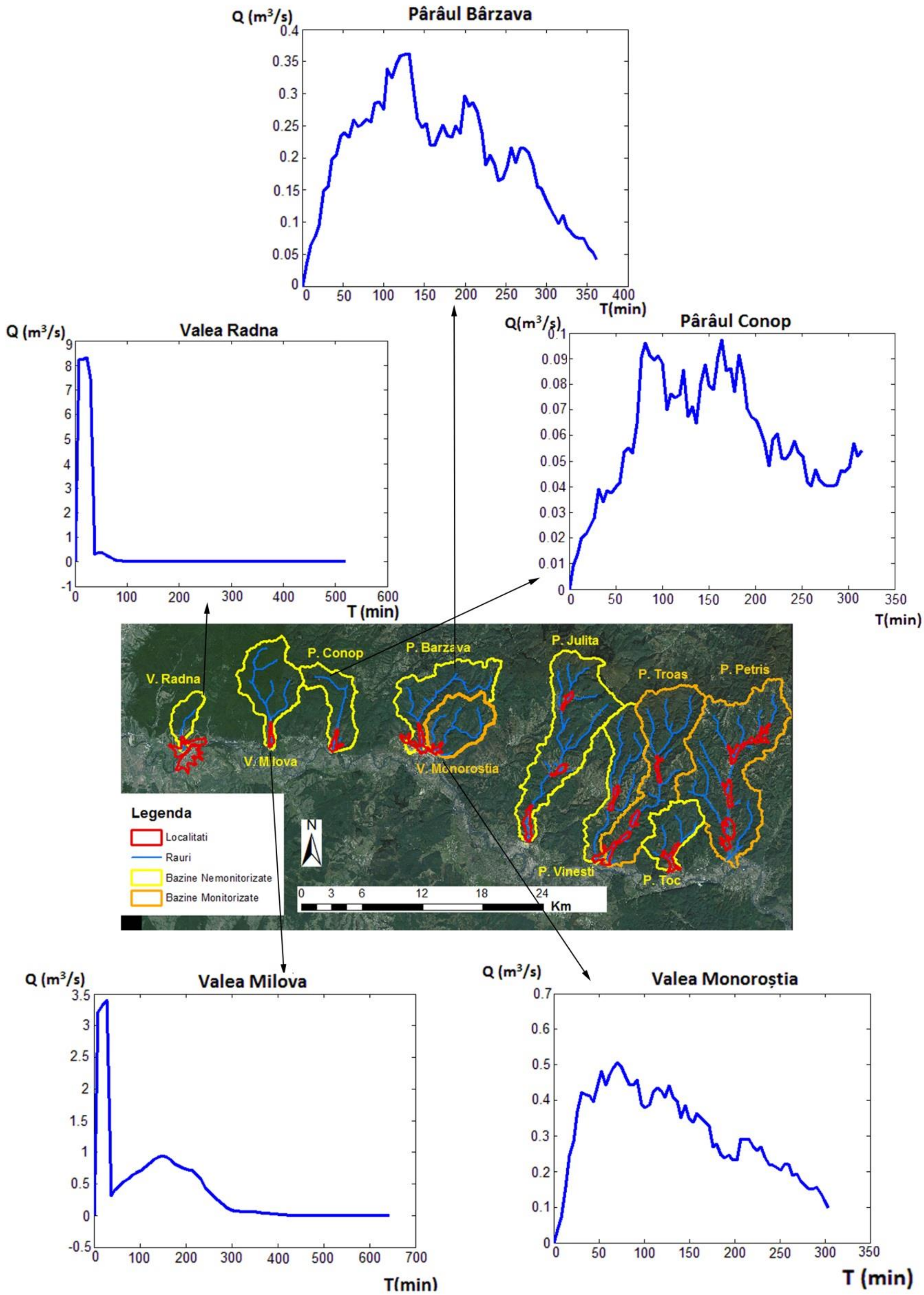


Fig.5.11 Simulated hydrographs for the Zărandului mountains by the use of the Cluj Model.

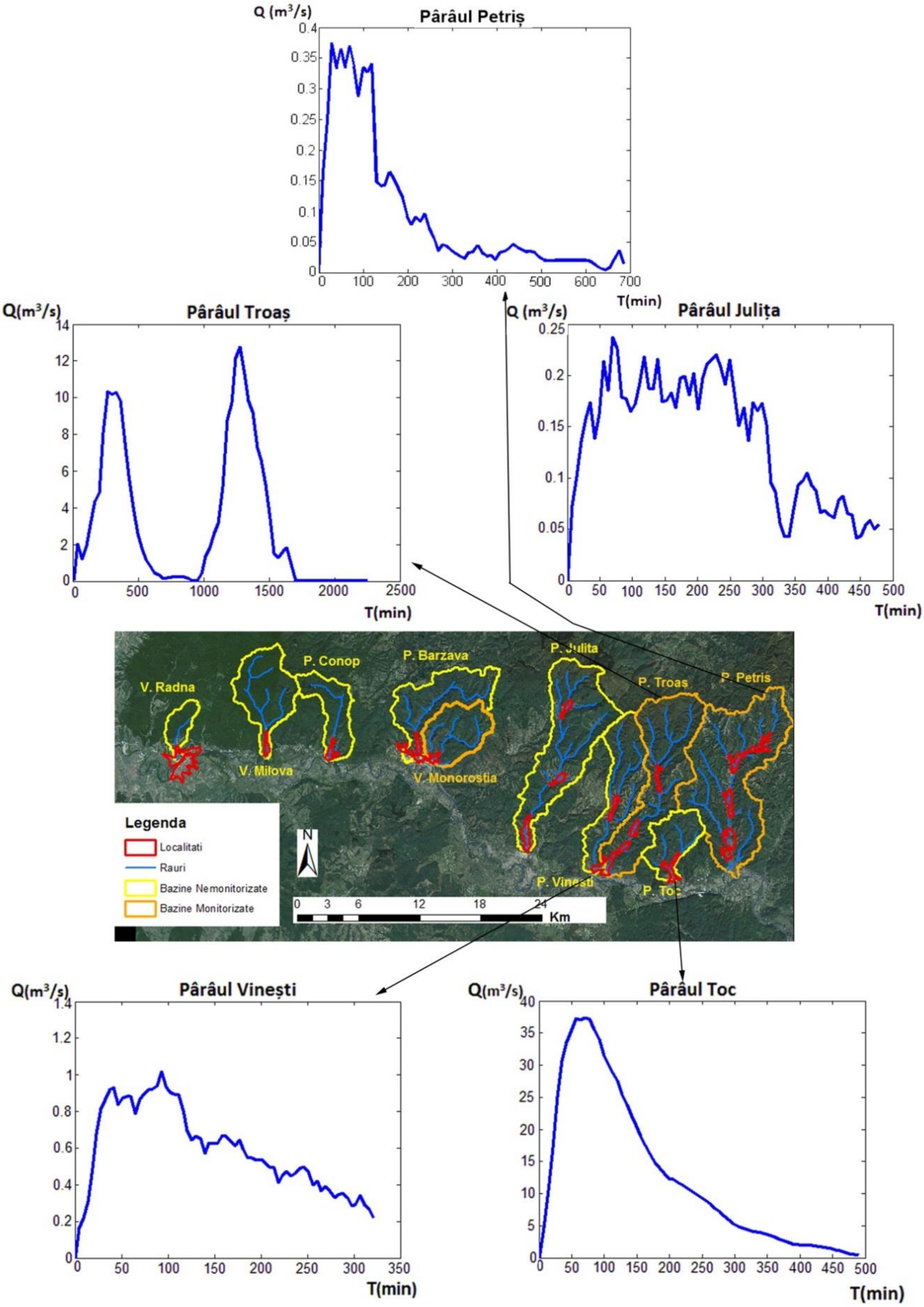


Fig. 5.12 Simulated hydrographs for the Săvârșinulu mountains by the use of the Cluj Model.

Exemplification of the stages for the hydrograph modeling by using the Cluj Model

Validation of the flash-flood on the Troaș River, 03.07.2001

6. Floodplain area delimitation on the basis of probabilistic events. Case study the small rives in the Zărandului and Săvârșinului mountains

The present chapter presents a methodology for floodplain areas at different return periods on the Petriș, Troaș and Valea Monoroștia rivers *(Haidu,Győri, Humbert, 2014)*.

In the last years such studies have been in the center of attention due to their socio-economic relevance and the role they occupy in the risk management to floods, hence there is a wide variety of hydraulic modeling possibilities.

So as to determine the impact of flooding the MIKE 11 modeling system was used.

The model was built by the Danish Hydraulic Institute and for the three gauged rivers the 1D method was used.

The following steps have been undertaken:

- **DEM analysis, river axes and transversal sections establisment in the minor floodplain**.

  In the minor floodplain the transversal sections have been drawn at every 100 m in a perpendicular position on the river course.

- **Building the hydrodynamic model, preliminary estimations of the initial conditions of discharge and water level, preliminary running of the model and the solving of all its resulted instability.**

  The boundary conditions at open-ends elements or point source of the modeled network are now set. For the upper stream boundary conditions the hydrographs obtained in the hydrologic model are used.

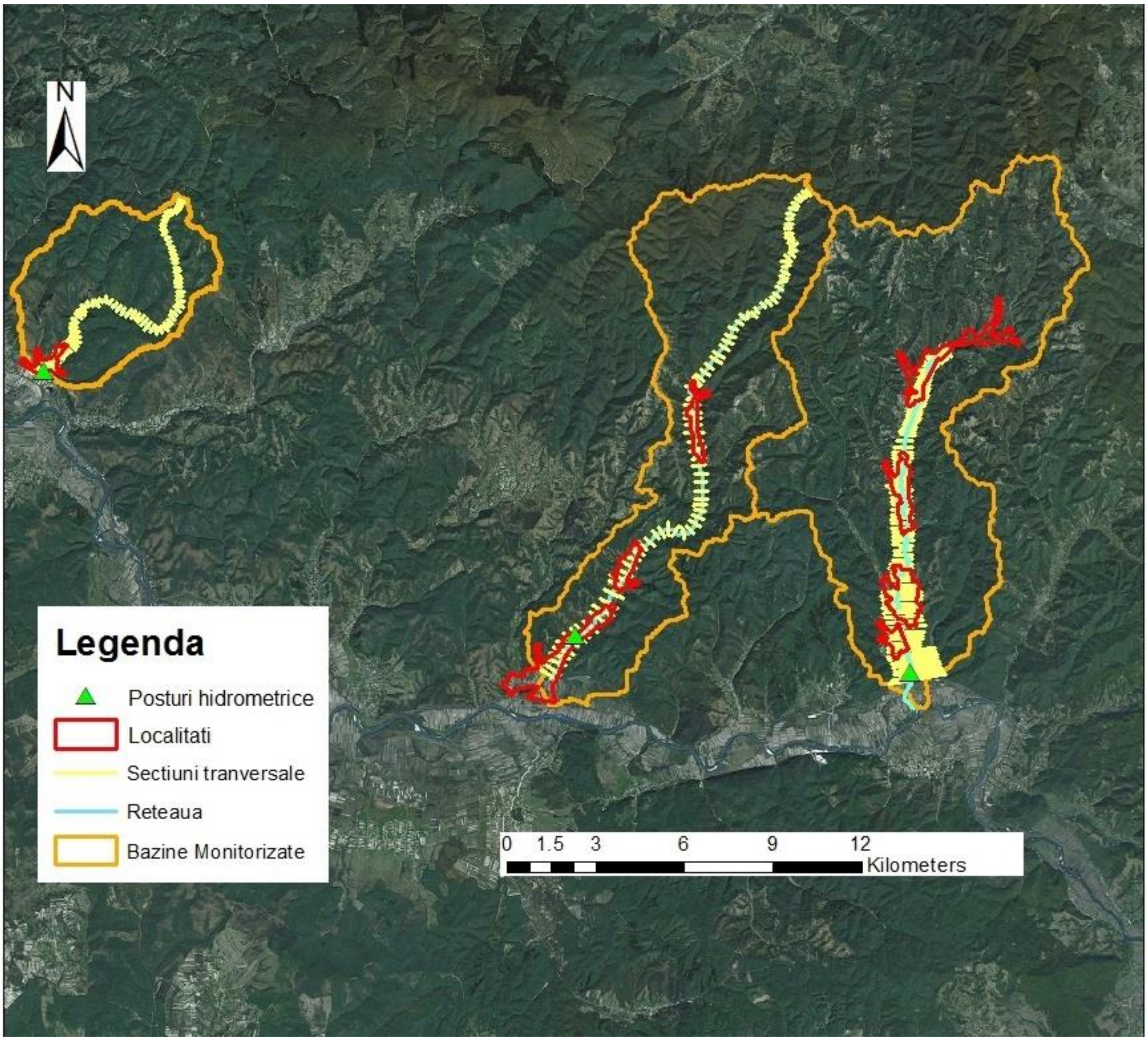


Fig. 6.4 Network schema for the Petriș, Troaș and Valea Monoroștia.

Indentifying the inundation areas of small rivers on the basis of hydraulic models

Once the data base was set, the model was run for :

- A 100 year return period event;
- A 50 year return period event;
- A 10 year return period event

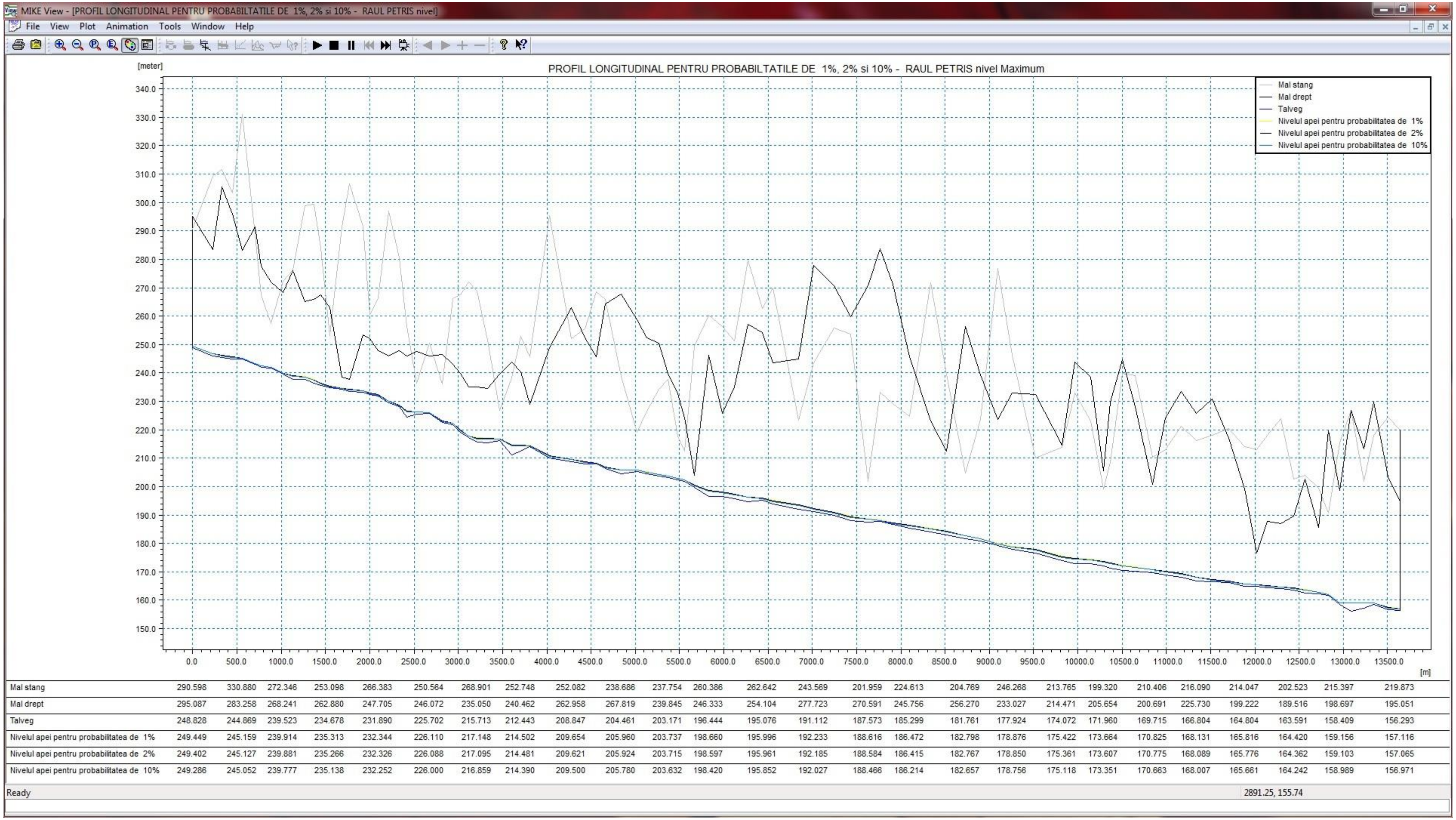
It is the Mike View application that allows access to the graphical and tabelar data on the basis of which the user can extract discharges or water levels at several locations or even see the profiles of the water table. (**Table 6.2**). It can easily be seen that the discharges computed with the hydraulic model at the hydrometric post correspond to those computed by the hydrologic model HEC-HMS.

Tabel.6.2 Computed discharges at the entry and exit of the settlements on the area of the three basins. *(Haidu, Győri, Humbert, 2014).*

Petriș						
Settlement	**Q (m^3/s) entry point**			**Q (m^3/s) exit point**		
	Q 1%	Q2%	Q10%	Q 1%	Q2%	Q10%
Roșia Nouă	-	-	-	27,2	24.9	14.4
Corbești	29.3	26.3	15.4	39.4	35.6	22.6
Petriș	40.5	36.7	23.6	52.8	44.8	28.8
Seliște	52.8	44.8	28.8	55.2	46.7	30.1
Hydrometric post	Q 1%		Q2%		Q10%	
	59.6		50		32.4	

Pârâul Troaș						
Settlement	**Q (m^3/s) entry point**			**Q (m^3/s) exit point**		
	Q 1%	Q2%	Q10%	Q 1%	Q2%	Q10%
Troaș	6.3	5.6	2.5	10.8	9.6	4.7
Temeșești	15	13.6	6.6	16	14.6	7.1
Săvârșin	17.3	15.9	7.8	19.4	17.8	8.8
Hydrometric postc	Q 1%		Q2%		Q10%	
	18.9		17.4		8.6	

Valea Monoroștia						
Settlement	**Q (m^3/s) entry point**			**Q (m^3/s) exit point**		
	Q 1%	Q2%	Q10%	Q 1%	Q2%	Q10%
Monoroștia	17.5	15.6	11.8	27.2	24.2	17.7
Hydrometric post	Q 1%		Q2%		Q10%	
	21.6		19.3		14.5	



Mal stang	290.598	330.880	272.346	253.098	266.383	250.564	268.901	252.748	252.082	238.686	237.754	260.386	262.642	243.569
Mal drept	295.087	283.258	268.241	262.880	247.705	246.072	235.050	240.462	262.958	267.819	239.845	246.333	254.104	277.723
Talveg	248.828	244.869	239.523	234.678	231.890	225.702	215.713	212.443	208.847	204.461	203.171	196.444	195.076	191.112
Nivelul apei pentru probabilitatea de 1%	249.449	245.159	239.914	235.313	232.344	226.110	217.148	214.502	209.654	205.960	203.737	198.660	195.996	192.233
Nivelul apei pentru probabilitatea de 2%	249.402	245.127	239.881	235.266	232.326	226.088	217.095	214.481	209.621	205.924	203.715	198.597	195.961	192.185
Nivelul apei pentru probabilitatea de 10%	249.286	245.052	239.777	235.138	232.252	226.000	216.859	214.390	209.500	205.780	203.632	198.420	195.852	192.027

Mal stang	201.959	224.613	204.769	246.268	213.765	199.320	210.406	216.090	214.047	202.523	215.397	219.873
Mal drept	270.591	245.756	256.270	233.027	214.471	205.654	200.691	225.730	199.222	189.516	198.697	195.051
Talveg	187.573	185.299	181.761	177.924	174.072	171.960	169.715	166.804	164.804	163.591	158.409	156.293
Nivelul apei pentru probabilitatea de 1%	188.616	186.472	182.798	178.876	175.422	173.664	170.825	168.131	165.816	164.420	159.156	157.116
Nivelul apei pentru probabilitatea de 2%	188.584	186.415	182.767	178.850	175.361	173.607	170.775	168.089	165.776	164.362	159.103	157.065
Nivelul apei pentru probabilitatea de 10%	188.466	186.214	182.657	178.756	175.118	173.351	170.663	168.007	165.661	164.242	158.989	156.971

Fig.6.5 Longitudinal profile for the de 10, 2 and 1% exceedance- Petriș.

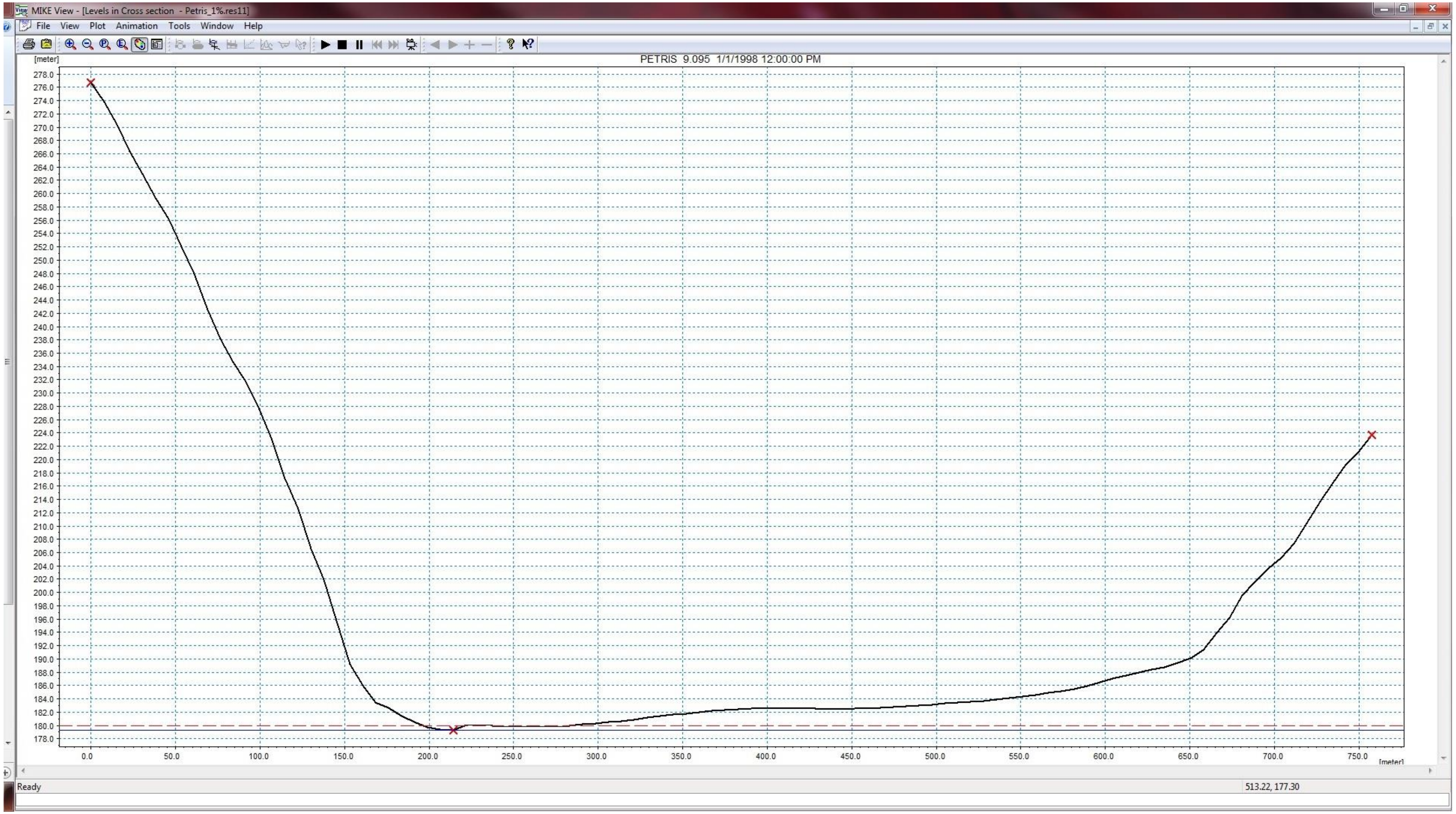


Fig. 6.8 Water table for the 1% exceedance probability at the entry of the Petriş village

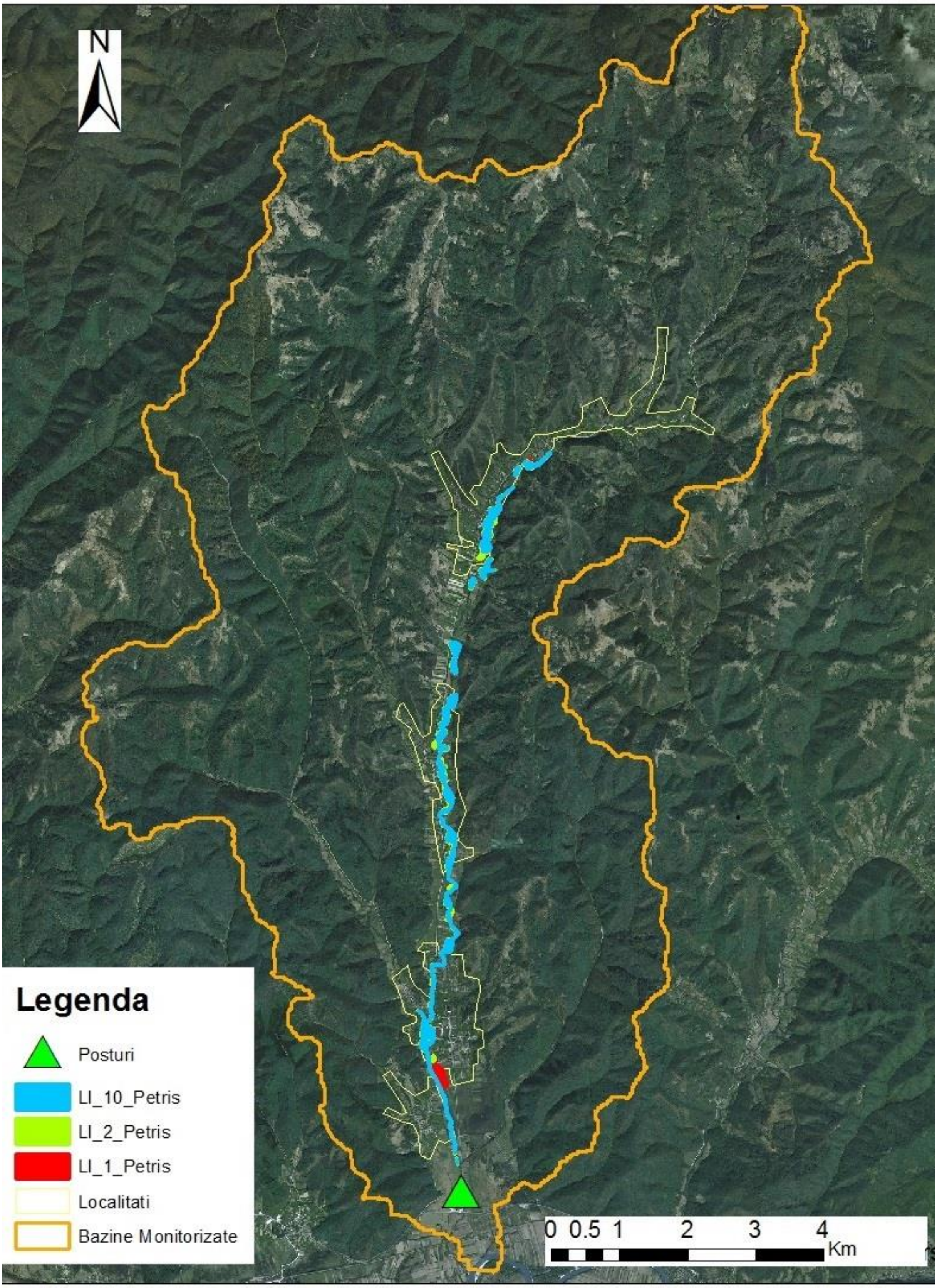


Fig. 6.10 Flood plain map- 1, 2, 10 % exceedance probability on the Petriş *(adapted after Haidu,Győri, Humbert, 2014).*

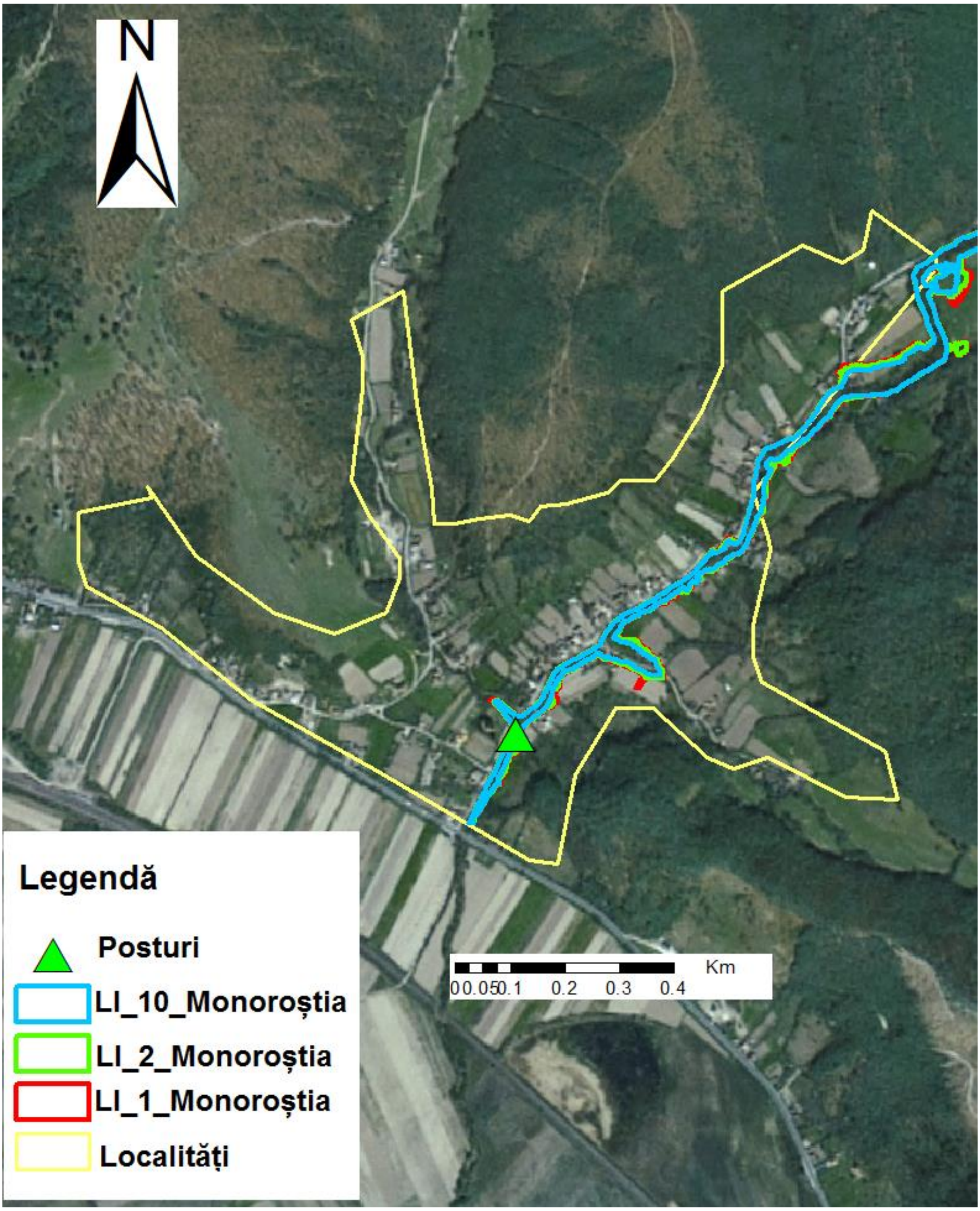


Fig. 6.15 Flood plain map- 1, 2, 10 % exceedance probability on the Monoroștia Detail Monoroștia Settlement *(Haidu,Győri, Humbert, 2014).*

7. Conclusion

A good correspondance between the genberated hydrograph through the hydrologic model and the hydraulic model as compared with the statistical discharges can be seen at the hydrometric postsHence the hydraulic model made it possible to generate the floodplain maps higly necessary for a good managemnt in case of emergency situations.

REFERENCES

- Abbott, M., Refsgaard, J., C., (1996), *Distributed Hydrologic Modelling*, Kluwer Academic Publishers.
- Anderson, D., J., (2000*), GIS-based Hydrologic and Hydraulic Modeling for Floodplain Delineation at Highway River Crossings*, Dissertation, Faculty of the Graduate School of the University of Texas at Austin.
- Arghiuș, V., I., (2007), *Studiul viiturilor de pe cursurile de apă din estul munților Apuseni și Riscurile asociate*,Teză de doctorat, Cluj-Napoca.
- Atkinson, S., Woods, R., A., Sivapalan, M., (2002*), Climate and landscape controls on water balance model complexity over changing time scales*. Water Ressources Research, 38(12), 1314.
- Baltas, E.,A., Dervos, N.,A., Mimikov, M., A., (2007), *Determination of the SCS initial abstraction ratio in an experimental watershed in Greece, Hydrology and Earth System Sciences,* 11, pg. 1825-1829.
- Bedinet, B., P., (2002), *Hydrology and Flood plain Analysis*, Prentice Hall.
- Beven, K., J ., (2006), *Rainfall-Runoff Modelling The Premier*, John Wiley & Sons Ltd.
- Beven, K. J., si Kirkby, M., J., (1979), *A physically based, variable contribuing area model of basin hydrology*, Hydrological Sciences Bulletin, 24(1), 43-69.
- Bilașco, Șt., (2008), *Implementarea SIG în modelarea viiturilor de versant. Studii de caz în bazinul Someșului Mic*. Teză de doctorat, Cluj-Napoca.
- Blaga, Ghe., Filipov, F., Udrescu, S., Vasile, D., (2005), *Pedologie*, Editura AcademicPres, Cluj-Napoca.
- Blöschl, G., (2005), *Rainfall-runoff modeling of Ungauged Catchments*, Encyclopedia of Hydrologic Sciences, pg. 2061-2079, John Willey & Sons Ltd.
- Blöschl, G., Sivapalan, M., Wagener, T., Viglione, A., Savenije, H., (2013), *Runoff Prediction in Ungauged Basins-Synthesis across Processes Places and Scales*, Cambridge University Press.
- Bobee, B., B., Ashkar, F., (1991), *The Gamma Family and Derived Distributions Applied in Hydrology*, Water Ressources Publications, Littleton, CO.

- Borah, D., K., Xia, R., Bera, M., (2002), DWSM- A Dynamic Watershed Simulation Model, în *Mathematical Models of Small Watershed Hydrology and Applications,* Singh, V., P., Frevert, D., K., editori, Water Resource Publications, Littleton, CO., p. 113- 166.
- Boucher, M., (2009), *Rainfall Intensity-Duration-Frequency (IDF) Curves,* Costa County Flood Control&Water Conservation District.
- Burt, J., E., Barber, G., M., (1996), *Elementary Statistics for Geographers,* Guilford Press, New York.
- Chendeş, V., (2007), *Scurgerea lichidă şi solidă în Subcarpaţii de la curbură*, Teză de doctorat, Institutul de Geografie, Academia Română.
- Chow, Ven, T., Maidment, D., R., Mays, L., W., (1998), *Applied Hydrology*, McGraw-Hill International Editions, Civil Engineering Series.
- Chow, Ven, Te, (1964), *Handbook of Applied Hydrology- a compendium of water-resources technology*, McGraw-Hill Book Company, New York.
- Costea, G., (2012), *Using Remote Sensing for deforestation assessment. The deforestation effect over the underlying surface characteristics changes in the upper basins of Someșul Cald and Someșul Rece river*, PhD Thesis.
- Crăciun A., I., Haidu I., Magyari-Sáska, Zs., Imbroane A., I., (2009), *Estimation of runoff coefficient according to soil moisture using GIS techniques*, Geographia Technica, No. 2, 2009, p. 1-10, ISSN 1842-5135.
- Crăciun, A.,I., (2011*), Estimarea indirectă, cu ajutorul GIS, a umezelii solului în scopul modelării viiturilor pluviale. Aplicații în Munții Apuseni*, Teză de doctorat, Cluj-Napoca
- Cunderlik, J., M., Simonovic, S., P., (2004), *Calibration, verification and sensitivity analysis of the HEC-HMS hydrologic model. CFCAS project: Assessment of Water Resources Risk and Vulnerability to Changing Climatic Conditions.* Project Report IV.
- Davie, T., (2002), *Fundamentals of Hydrology*, (2th ed), London and New York: Routledge.
- Dawdy, D., R., O'Donnell, T., (1965), *Mathematical models of catchement behaviour*, Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, 91 (HY4):123-127

- Diaconu C., Şerban P., (1994), *Sinteze şi regionalizări hidrologice*, Editura Tehnică, Bucureşti.
- Di Baldassarre, G., (2012*), Inundation Modelling, Floods in a Changing Climate*, International Hydrology Series, Cambridge University Press.
- Djokic, D., (2008) , *Comprehensive Terrain Preprocessing Using Arc Hydro Tools*, ESRI Press, Redlands, CA.
- Drobot, R., (2007), *Metodologia de determinare a bazinelor hidrografice torenţiale în care se află aşezări umane expuse pericolului viiturilor rapide*, UTCB, Departamentul de cercetare şi proiectare în construcţii, Bucureşti.
- Eman Ahmed Hassan El-Sayed, (2011), *Generation of Rainfall Intensity Duration Frequency Curves For Ungauged Sites, Nile Basin*, Water Science & Engineering Journal, Vol.4, Issue 1.
- Ewen, J., Bathurst, J. Parkin, G., O'Connell, E., Adams, R., Hiley, R., Kilsby, C., Burton, A., (2002), SHETRAN: *Physically-Based Distributed River Basin Modelling System, în Mathematical Models of Small Watershed Hydrology and Applications*, Singh, V., P., Frevert, D., K., editori, Water Resource Publications, Littleton, CO., p. 43-68 .
- Fleming, G., (1975), *Computer Simulation Techniques in Hydrology*, Environmental Science Series, Elsevier.
- Florea, N., Munteanu, I., (2003), *Sistemul român de taxonomie a solurilor (SRTS)*, Editura Estfalia, Bucureşti.
- Florea, N., Munteanu, I., Băcăințan, N., Bălăceanu V., Cârstea Șt., (2000), *Sistemul român de taxonomie a solurilor: SRTS-2000*, Editura Universităţii "Al. I. Cuza".
- Ford, D., T., Hamilton, D., (1996), *Computer models for water-excess management*. Mays L. W. (editor), Water Ressources Handbook, McGraw-Hill, New York.
- Freeze, R., A., Harlan, R., L., (1969), *Blueprint for a physically-based digitally simulated hydrologic response model*. Journal of Hydrology, 9, pg. 237-258.
- Geetha, K., Mishra, S., K., Eldho, T., I., Rastogi, A., K., Pandey, R., P., (2008), *SCS-CN-based Continuous Simulation Model for Hydrologic Forecasting*, Water Resources Management 22: 165-190, January 09, 2008.

- Green, J. I., Nelson, E.,J., (2002), *Calculation of time of concentration for hydrologic design and analysis using geographing information system vector objects*, Journal of Hydroinformatics, 04.2, IWA Publishing.
- Gumbel, E.,J., (1958), *Statistics of Extremes*, Columbia University Press, New York.
- Győri, Maria-Mihaela, Humbert, J., Haidu, I., (2013) *Deriving flash floods in the case of simulated precipitations*,Geographia Napocensis, VII, No. 2 (acceptată pentru publicare).
- Győri, Maria-Mihaela, Haidu, I., (2011), *Unit Hydrograph Generation for Ungauged Subwatersheds. Case Study: the Monoroştia River*, Arad County, Romania, Geographia Technica, No. 2, pg. 23 – 29.
- Haan, C., T., (1977), *Statistical Methods in Hydrology*, Iowa State University Press, New York.
- Haidu, I., (1993), *Evaluarea potentialului hidroenergetic natural al râurilor mici din Carpatii Maramuresului si Bucovinei*, Editura GLORIA Cluj-Napoca & RENEL, Bucuresti.
- Haidu, I., (2002), Analiza de frecvență și evaluarea cantitativă a riscurilor. *Riscuri și catastrofe*, Editura Casa Cărții de Știință Cluj-Napoca, Vol. 2, pg. 180-207.
- Haidu, I., (2006), *Elemente de hidrologie*, Edit. Academicpres, Cluj-Napoca.
- Haidu, I., Crăciun A.,I., Bilaşco, Şt. (2007), *The SCS-CN model assisted by GIS-alternative estimation of the hydric runoff in real time*, Geographia Technica, ISSN 1842-5135, No. 1, 2007, pg. 1-7.
- Haidu I., Crăciun A., Domnița M, Magyari-Saska Zs., Győri M. (2007-2010). AŞEZĂRI MONTANE AMENINŢATE DE TORENŢI PLUVIALI – METODOLOGIE G.I.S. PENTRU ESTIMAREA VULNERABILITĂŢII ŞI RISCULUI. APLICAŢII LA MUNŢII APUSENI., Grant CNCSIS_PN-II-ID-PCE_RO - Cod.517, Raport final. ***http://geografie.ubbcluj.ro:8010/Idei_517/.***
- Haidu, I., Győri, Maria-Mihaela, Humbert, J., (2014), *Deriving the floodplain of small basin having limited data. Case study: Zărandului Mountains, Romania.* Geographia Technica, 18, No.1 (acceptată pentru publicare).
- Hapuarachchi, H., A., P., Wang, Q., J., Pagano, T., C., (2011), A review of advances in flash flood forecasting, Hydrological Processes, 25, pg 2771–2784, Published online 15 March 2011 in Wiley Online Library.

- Imbroane, A.M., Moore, D., (1999*), Inițiere în GIS și teledetecție*, Edit. Presa Universitară Clujeană, Cluj-Napoca.
- Ionescu, V., Giurma, I., Popovici, G., (1975), *Calcule și modele matematice pentru combaterea eroziunii solului*, Institutul Național de Informare și Documentare, București.
- Kafle, T., P., Hazarika, M., K., Karki, S., Sshrestha, R., M., Sharma, R., Samarakoon, L., (2010), *Basin Scale Rainfall - Runoff Modeling for Flood Forecasts*, http://www.cct.edu.np/uploads/result/flood%20hazard.pdf
- Katani, Mehdi, Nasri, Masoud, Soleimani Sardoo, Farshad, *Simulation of the Rainfall-Runoff Process Using of HEC-HMS Hydrological Model (A Case Study of Sheikh Bahaei Dam Basin*), World Academy of Science, Engineering and Technology 78 2011, 2011, pg 548- 551.
- Keller E., (2008), *Evaluarea şi simularea fluxului de apă în situaţii de risc cu ajutorul S.I.G. : aplicaţie la municipiul Baia Mare*, Teză de doctorat, UBB Cluj.
- Kreis, N., (2004), *Modélisation des crues des rivières de moyenne montagne pour la gestion intégrée du risque d'inondation- Application à la Valée de la Thur (Haut-Rhin)*. Thèse. ENGEES.
- Kritski , S.,N., Menkel, M., F.,(1950),*The Hydrological Basis of River Hydro-Techique*, Moscow: Academy of Sciences Publishing.
- Lang, M., Lavabre, J., (2007), *Estimation de la crue centennale pour les plans de prévention des risques d'inondations*, Editions Quae.
- Magyari-Saska Zs., (2008), *Dezvoltarea algoritmilor S.I.G pentru calculul riscurilor geografice naturale: aplicaţie la Bazinul Superior al Mureşului*, Teză de doctorat, UBB, Cluj-Napoca.
- Maidment, D., R., (1993), *Handbook of Hydrology*, McGraw-Hill.
- Maidment, D., R.,(2002a), *Arc Hydro: GIS for Water Resources*, ESRI Press, Redlands, CA.
- Marian, R., A.,(2013) *Geoinformatics Study Regarding the Hydrological Impact of the Damage to Water Supply Networks in Rural Areas.Application to Baia Mare Depression*, PhD Thesis.
- McCuen, R., H., (1982), *A guide to Hydrologic Analysis Using SCS Methods,* Prentice-Hall, Inc., Englewood Cliffs.

- McCuen, R., H., (2003), *Modeling Hydrologic Change: Statistical Methods*, Lewis Publishers, CRC Press LLC.
- McKillup, S., Dyar, M., D., (2010), *Geostatistics Explained- An Introductory Guide for Earth Scientists,* Cambridge University Press.
- Meyer, S., Olivera, F., (2007), *Floodplain Mapping & Hydraulic Analysis with HEC-GeoRAS 4.1.1 and ArcGIS 9.1*, Texas A&M University – Zachry Department of Civil Engineering.
- Mishra, S., K., Singh, V., P., (1999) *Another look at the SCS-CN method*, Journal of Hydrologic Engineering, 4(3): 257–264.
- Mishra, S., K., Singh, V., P., (2002), SCS-CN-Based Hydrologic Simulation Package, în *Mathematical Models of Small Watershed Hydrology and Applications*, Singh, V., P., Frevert, D., K., editori, Water Resource Publications, Littleton, CO., p. 391- 464.
- Mishra, S., K., Singh, V., P., (2003), *Soil Conservation Service Curve Number (SCS-CN) methodology*, Kluwer, Dordrecht, The Netherlands.
- Moore, I.,D., Grayson, R., B., Ladson, A.,R., (1991), *Digital terrain Modelling: A review of hydrological, geomorphologicaland biological applications, Broadway*, N.S.W.: Water Research Foundation of Australia.
- Moore, R., J., Clarke R., T., (1981), *A distribution function approach to rainfall-runoff modelling*, Water Ressources Research 17, pg. 1367-1382.
- Mujumdar, P. P., Nagesh Kumar, D., UNESCO, (2012), *Floods in a Changing Climate, Hydrologic Modeling,* International Hydrology Series, Cambridge University Press.
- Musy, A., Higy C., (1998), *Hydrologie appliquée*, Editions H.G.A., Bucureşti.
- Oceanit, (2008), *Final Hydrology Report- Ala Wai Watershed Project.*
- Ogden, F., L., Julien, P., Y., (2002), *CASC2D- A Two-Dimensional, Physically-Based, Hortonian Hydrologic Model, în Mathematical Models of Small Watershed Hydrology and Applications*, Singh, V., P., Frevert, D., K., editori, Water Resource Publications, Littleton, CO., p. 69-112.
- Patriche, C.V., (2003*), Evaluarea biofizică și tehnică a terenurilor agricole,*Editura Terra Nostra, Iași.
- Păcurar, V. D., (2005), *Utilizarea Sistemelor de Informaţii Geografice în modelarea şi simularea proceselor hidrologice*, Editura Lux Libris, Braşov.

- Ponce V.M., Hawkins R.H., (1996), *Runoff curve number: Has it reached maturity*? , Journal of Hydrological Engineering, ASCE, Vol. I, No1, pg. 11-19.
- Pop, P., Gr., (2006), *Carpații și Subcarpații României*, Ediția a II-a, Presa Universitară Clujeană.
- Raman, H., S., M., Padalinanthan, P., (1995*), Models for extending streamflow data: a case study*, Hydrological Sciences Journal, 40 (3), pg. 381-393.
- Ramesh, S., Teegavarapu, V., (2012), *Floods in a Changing Climate, Extreme Precipitation*, International Hydrology Series, Cambridge University Press.
- Razi, M., A., M., Ariffin, J., Tahir, W., Arish, N., A., M., (2010), *Flood Estimation Studies using Hydrologic Modeling System (HEC-HMS) for Johor River, Malaysia.* Journal of Applied Sciences, 10: 930-939, 2010.
- Refsgaard, J., C., (2007), *Hydrological Modelling and River Basin Management*, Doctoral Thesis, Geological Survey of Denmark and Greenland, Danish Ministry of the Environment.
- Rosso, R., Rulli, M., C., (2002), *An integrated simulation method for flash-flood risk assessment: Frequency predictions in the Bisagno River by combinig stochastic and deterministic methods*, Hydrology and Earth System Sciences, vol. 6, 2002.
- Rus, D., (2006), *Culoarul Mureşului, sectorul Brănişca – Păuliş - studiu geografico-uman*, Casa Cărţii de Ştiinţă, Cluj-Napoca.
- Sabourin J., F., and Associates Inc., (2009), *Floodplain Mapping Report for the Van Gall and Arbuckle Municipal Drains in the Village of Richmond.*
- SGA Arad, (2006), *Planul de apărare împotriva inundaţiilor*.
- Shantosh Karki, (2011*), A Final Report on: GIS Based Flood Hazard Mapping and Vulnerability Assessment of People due to Climate Change: A Case Study from Kankai Watershed, East Nepal*, National Adaptation Programme of Action (NAPA), Ministry of Environment.
- Sinclair Knight Merz, (2009) *Impact of Land Use Change on Floods in the Upper Waikato, Phase 2: model calibration and flood hydrograph generation*, Auckland, New Zealand.
- Singh, V., P., (1995), *Computer Models of Watershed Hydrology*, Water Ressources Publications, Highlands Ranch, CO.

- Singh, V., P., Frevert, D., K., (2006) *Watershed Models*, CRC Press, Taylor & Francis Group.
- Skøien, J., O., Bloschl, G., (2007) *Spatiotemporal topological kriging of runoff times series*, Water Ressources Research, 43(9), 1-21, doi 10.1029/2006WR005760
- Smith, M., J., Asal, F.,F.,F., Priestnall, G., (2004), *The use of Photogrammetry and lidar for landscape roughness estimation in hydrodynamic studies*, in M. Altan Orhan (Ed.), International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 35, pg 714-719.
- Kollet, S., J., Maxwell R. M., (2008), *Capturing the influence of groundwater dynamics on land surface processes using an integrated, distributed watershed model*, Water Ressources Research, 44(2), 1-18 doi:10.1029/2007WR006004.
- SMIVAL (2011), *Etude Hydraulique de la Leze Phase 2 : Simulation des Crues Synthétiques*, CACG.
- Sommeijer, M. J., (2010), *Sensitivity analysis of the Curve Number method For the Assesment of hydrological impacts of hill slope revegetaion in the Baviaaanskloof, South Africa*, Thesis report, Wageningen University.
- Stedinger, J., R., Vogel, R., M., Foufoula-Georgiou (1993), *Frequency analysis of extreme events*, in D., R., Maidment (Ed.), Handbook of Hydrology, New York: McGraw-Hill, pg.18.1-18.66.
- Șerban, P.,(1995), *Modele Hidrologice Deterministe*, Editura Didactică și Pedagogică, București.
- Ujvari, I., (1972*), Geografia Apelor României*, Editura Ştiinţifică, Bucureşti.
- USDA, (1997), *Hydrology Handbook*, No.28.
- US Army Corps of Engineers USDA, (2000) *Hydrologic Modeling System HEC-HMS,* Technical Reference Manual.
- US Army Corps of Engineers USDA, (2001), *Hydrologic Modeling System HEC-HMS*, User's Manual, Version 2.1.
- US Army Corps of Engineers USDA, (2008), *Urban Flooding Studies, Chapter 2 of Hydrologic Modeling System HEC-HMS* Application's Guide.
- US Army Corps of Engineers USDA, *Hydrologic Modeling System HEC-HMS*, (2008), Applications Guide.
- US Army Corps of Engineers USDA, (2009), *HEC-DSS Vue- HEC Data Storage System Visual Utility Engine*, Users'Manual.

- US Army Corps of Engineers USDA, (2010) *Hydrologic Modeling System HEC-HMS*, User's Manual, Version 3.5.
- US Army Corps of Engineers USDA, (2010), *Geospatial Hydrologic Modeling Extension,* User's Manual, Version 5.0.
- US Army Corps of Engineers USDA, (2010), *HEC-RAS River Analysis System,* User's Manual, Version 4.1.
- US Army Corps of Engineers USDA, (2010), *Hydrologic Modeling System HEC-HMS*, User's Manual, Version 3.5.
- US Army Corps of Engineers USDA, (2011), *HEC-GeoRAS, GIS Tools for Support of HEC-RAS using ArcGIS*, Version 4.3.93.
- Ven Te Chow, (1964), *Handbook of Applied Hydrology- a compendium of water-resources technology*, McGraw-Hill Book Company, New York.
- Vespremeanu E. (1998), *Pedimente, Piemonturi şi glacisuri în Depresiunea Mureşului Inferior*, Editura Universitară, Bucureşti.
- W.J.R. Alexander, (2002), *Statistical Analysis of extreme Floods.*
- Wigmosta, M., S., Nijssen, B., Storck, P., Lettenmaier, D., P., (2002): *The Distributed Hydrology Soil Vegetation Model, în Mathematical Models of Small Watershed Hydrology and Applications*, Singh, V., P., Frevert, D., K., editori, Water Resource Publications, Littleton, CO., p. 7-42.
- Wolfe, D., L., (2006), *Hydrology Manual*, Los Angeles County Department of Public Works, Water Resources Division.
- WRC Engeneering, (2008), *Floodplain and Stormwater Criteria Manual*, Vol 1 & 2, (PDF's only).
- Yener, M., K., Şorman, A., Ü., Şorman, A., A., Sensoy, A., Gezgin, T., *Modeling studies with HEC-HMS and runoff scenarios in Yuvacik Basin, Turkiye*,(2006), International Congress on River Basin Management, pg 621- 634.
- *** Anuar APM Arad (1998).
- *** Arc Hydro Tools – Tutorial Version 1.3 (2009), ESRI.
- *** ArcGIS Desktop I- Getting Started with GIS, ESRI România.
- *** ArcGIS Desktop II- Tools and Functionality, ESRI România.
- *** ArcGIS Desktop III- GIS Workflows and Analysis, ESRI România.
- *** Atlasul Cadastrului Apelor din RPR, (1964), Bucureşti.
- *** Atlasul Geografic al RSR, (1974), Editura Academiei, Bucureşti.

- *** CLC 2006 http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-clc2006-100-m-version-12-2009.
- *** Geografia României vol. III, (1963), Editura Academiei, Bucureşti.
- *** Geografia României, Geografia Fizică, Editura Academiei R.S.R., (1983).
- *** Studii hidrologice anuale pe râul Mureş şi afluenţi, (1973-1998), SGA Arad.
- *** Using ArcGIS Spatial Analyst, (2001-2002), ESRI Press, Redlands, CA.

WEBOGRAFIE

- http://en.wikipedia.org/wiki/Hydrology#Hydrologic_modeling.
- http://forums.esri.com/Forums.asp?c=93
- http://giswin.geo.tsukuba.ac.jp/sis/tutorial/koko/zonalstatistics/ZonalStatistics.pdf
- http://hydrologicmodels.tamu.edu/models.htm, accesat la 15 Decembrie 2011
- http://support.esri.com/index.cfm?fa=downloads.datamodels.filteredgateway&dmid=15
- http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=welcome
- http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=welcome
- http://www.ce.utexas.edu/prof/maidment/ce374k/hms/hms_ex.htm
- http://www.cplusplus.com/doc/tutorial/variables/
- http://www.crwr.utexas.edu/gis/archydrobook/DataModelFiles/Tutorial/ArcHydroPart1.htm
- http://www.crwr.utexas.edu/gis/archydrobook/DataModelFiles/Tutorial/ArcHydroPart2.htm
- http://www.crwr.utexas.edu/gis/archydrobook/DataModelFiles/Tutorial/ArcHydroPart3.htm
- http://www.crwr.utexas.edu/gis/gishydro05/Time/RepresentingSpaceAndTime.htm
- http://www.crwr.utexas.edu/giswr/events/091999giswr/
- http://www.crwr.utexas.edu/giswr/hydro/ArcHOSS/model/index.cfm
- http://www.gsd.harvard.edu/gis/manual/raster/index.htm
- http://www.library.yale.edu/MapColl/gis_workshop_materials.html
- http://www.sinotechcc.co.za/Software/UPFLOOD/SDF1.pdf