UNIT HYDROGRAPH GENERATION FOR UNGAUGED SUBWATERSHEDS. CASE STUDY: THE MONOROŞTIA RIVER, ARAD COUNTY, ROMANIA

***Maria-Mihaela GYÖRI*[1], *Ionel HAIDU*[1,2]**

ABSTRACT:
The present study focuses on the runoff calculation in the Monoroştia Basin, Arad County, Romania, during the historical flash flood in august 2010. On the basis of the collected geospatial data, the hydrologic parameters are computed in a GIS environment, which are subsequently used as input for the rainfall-runoff model. The SCS loss method and the SCS transform method were used for the runoff calculation by the means of a Hydrological Modelling System and the gage weights precipitation method so as to reflect the spatial characteristics of precipitation. The results consist of unit hydrographs for each subwatershed outlet, where monitoring activity doesn't exist.

Keywords: *Curve Number, Monoroştia Basin, Rainfall-runoff Model, Unit Hydrograph.*

1. INTRODUCTION

As streamflow analysis is essential for streamflow predictions, flood control and an even use of water, Geographic Information Systems in combination with rainfall-runoff models have proven to be ideal for runoff estimations.

HEC-HMS (Hydrologic Engineering Centre- Hydrologic Modelling System) rainfall-runoff model was chosen for the discharge calculations in the present study, a model developed by the US Army Corps of Engineers.

The main purpose of the study is the streamflow estimation in subwatersheds where monitoring activity doesn't exist. The Monoroştia basin was chosen as a case study. The rainfall-runoff model allowed the calculation of the discharge values for all the ungauged tributary rivers during the historical flash flood in August 2010. The results led to a better understanding of the surface runoff and rainfall relation in the area.

The HEC-HMS Rainfall-Runoff model was created for flow simulation on the basis of its three composing models: the basin model, the climatic model and the control indeces.

The implemented loss method computes an effective rainfall on the basis of the input hyetograph and the results are passed to a transform function that converts the excess precipitation into runoff at the subwatersheds' outlets, making possible the estimation and creation of hydrographs for the ungauged watersheds.

Among the many existing methods used for the generation of the hydrographs, the SCS (Soil Conservation System) method is widely applied due to its accurate results.

2. METHODOLOGY

The runoff corresponding to the subwatersheds of the Monoroştia Basin were calculated through the SCS CN loss method and the SCS Unit Hydrograph transform method. The meteorological data used was that of the Monoroştia gauging station for the 1st of August 2010 till the 06th of August 2010, when the historical flash flood occurred due to

[1] *Babeş-Bolyai" University, Faculty of Geography, 400006 Cluj-Napoca, Romania.*
[2] *University of Lorraine 57000 Metz, France.*

the 50.5 mm of precipitation recorded during a thirty minutes rain event. The data was inserted into the model through the use of the specified hyetograph method. The Monoroştia Basin (**Fig. 1**) is located in the Inferior Corridor of the Mureş River, in Arad County, Romania. The total drainage area counts 30 km^2 and the length of the river 12 km.

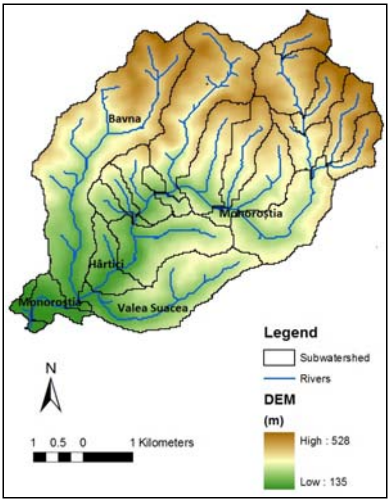


Fig. 1 The Monoroştia Basin and the subwatersheds for which the hydrographs were computed.

2.1. Data preprocessing

ArcGIS 9.3 is used for pre-processing the collected data for the study area: land use data (from the Corine Land Cover 2006 database), soil data (digitised 1: 200 000 pedologic map of the region), DEM for 20 m (raster database).

The HEC-GeoHMS (Geospatial Hydrologic Modelling Extension of US Army Corps Engineering) extension will use this pre-processed data to extract model-specific information from it. On the basis of elevation and geometric algorithms, the hydrologic parameters are computed, such as river length, river elevation, centroid, longest flow path, Curve Number, CN lag time (which serve as input for the Rainfall-Runoff model in HEC-HMS). They are stored in the ArcGIS feature classes "River" and "Subbasin". After converting the ArcGIS model created with HEC-GeoHMS into an HEC-HMS model file, the initial parameters calculated in ArcGIS can be adjusted, updated or removed in HEC-HMS.

Essentially, the process of converting an ArcGIS model into an HEC-HMS project requires four steps (**Fig. 2**):

1) assigning and converting ArcGIS data to a HEC-GeoHMS project (where the whole project is vectorized and concentrated on the basin of choice, with its subbasins);

2) adjusting the model where necessary, and computing parameters used in HEC-HMS based on ArcGIS geographical data, stored in the "River" and "Subbasin" feature classes;

3) converting the model in a HEC-HMS project where geographical data used in ArcGIS is discarded and the only left is the one computed by HEC- GeoHMS;

4) opening and working with the model in HEC-HMS.

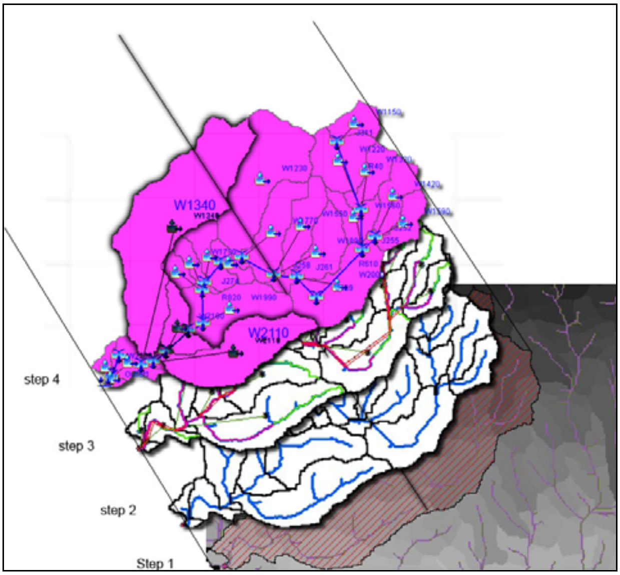


Fig. 2. From an ArcGIS to an HEC-HMS model for the Monorostia Basin.

2.2. The Hydrological Model

The SCS CN Loss method, described by the Soil Conservation Service, US, in 1985 and 1986, is based on an empirical equation that estimates effective precipitation according to the cumulative precipitation, land use and soil type. The SCS CN equation (1) is the following:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \tag{1}$$

where:

P_e = effective precipitation (in) at time "t"
P = accumulated rainfall depth (in) at time *t*
I_a = the initial abstraction (in)
S = potential maximum retention (in)

„ Initial abstraction (I_a) is all losses before runoff begins. I_a is highly variable, but from data from many small agricultural watersheds, it was approximated by the following empirical equation" (*Maidment, 1993*):

$$I_a = 0.2 \times S \tag{2}$$

The potential maximum retention (3) is calculated according to the Curve Number (CN).

$$S = \frac{1000}{CN} - 10 \tag{3}$$

The CN is an empirical parameter used for direct runoff and infiltration prediction in hydrology. A table of the CN values has been developed by the SCS (Soil Conservation Service, US), adapted later for the Romanian territory, by *Chendeş* (*2007*) and used in other recent studies: *I. Haidu, A.I. Crăciun, Şt. Bilaşco, 2007, A.I. Crăciun, I. Haidu, Zs. Magyari-Saska, A.I. Imbroane, 2009*.

The major factors that determine the CN are the hydrologic soil groups, the land use and the antecedent runoff conditions. Within ArcGIS 9.3, on the basis of the aforementioned data, the CN was calculated for every subwatershed. Furthermore, on the basis of the registered rainfall from the previous 5 days of the flash flood (<35,6 mm for the period with vegetation), the CN have been adjusted according to the AMC I (antecedent moisture conditions) (**Fig. 2**).

Attributes of Subbasin1

OBJE	Shape *	GRIDCODE	Shape_Lengt	Shape_Area	HydroID	LossMet	TransMet	Name	BasinCN	LagMethod	Tc	BasinLag	Area_HMS
2	Polygon	2	4772.9494	643046.67440	115	SCS	SCS	W1150	45	CNLag	1.2234	0.734097	0.643047
9	Polygon	9	7133.1994	1495857.3523	122	SCS	SCS	W1220	47.09396	CNLag	1.5974	0.958448	1.495857
10	Polygon	10	13741.8986	3525409.0061	123	SCS	SCS	W1230	51.829269	CNLag	2.3236	1.394209	3.525409
20	Polygon	20	6031.7494	755837.68511	133	SCS	SCS	W1330	48.626667	CNLag	1.3025	0.781507	0.755838
21	Polygon	21	20350.5978	6802540.0603	134	SCS	SCS	W1340	58.60474	CNLag	2.8369	1.70215	6.80254
29	Polygon	29	6189.0994	968352.78821	142	SCS	SCS	W1420	47.021053	CNLag	1.4868	0.892115	0.968353
42	Polygon	42	7238.0994	1146480.0794	155	SCS	SCS	W1550	55.324787	CNLag	1.5447	0.926841	1.14648
43	Polygon	43	6346.449	767529.53228	156	SCS	SCS	W1560	55.35294	CNLag	1.0841	0.65047	0.76753
46	Polygon	46	5402.3492	720762.43471	159	SCS	SCS	W1590	52.945946	CNLag	1.0369	0.622185	0.720762
60	Polygon	60	4982.7492	408523.79257	173	SCS	SCS	W1730	56.902439	CNLag	0.9221	0.553263	0.408524
64	Polygon	64	8077.2992	1570822.1364	177	SCS	SCS	W1770	53.473331	CNLag	1.4419	0.865155	1.570822
71	Polygon	71	4668.0494	361069.01518	184	SCS	SCS	W1840	61	CNLag	0.4886	0.293189	0.361069
74	Polygon	74	3986.1994	389266.79605	187	SCS	SCS	W1870	61.533333	CNLag	0.7777	0.466648	0.389267
75	Polygon	75	6556.249	823237.29094	188	SCS	SCS	W1880	59.26506	CNLag	1.0642	0.638525	0.823237
76	Polygon	76	8287.0992	1393382.4122	189	SCS	SCS	W1890	58.565216	CNLag	1.3931	0.835886	1.393382
86	Polygon	86	9073.8486	2078381.9927	199	SCS	SCS	W1990	63.545673	CNLag	1.3090	0.785406	2.078382
87	Polygon	87	9545.8988	2324596.6483	200	SCS	SCS	W2000	62.12254	CNLag	1.4789	0.887351	2.324597
97	Polygon	97	6241.5494	899577.71784	210	SCS	SCS	W2100	66.915253	CNLag	0.9608	0.576537	0.899578
98	Polygon	98	11906.1488	2902994.6721	211	SCS	SCS	W2110	64.650375	CNLag	1.8690	1.121447	2.902995
105	Polygon	105	5192.5492	629291.61994	218	SCS	SCS	W2180	47.897636	CNLag	1.7481	1.048898	0.629292
109	Polygon	109	4091.0994	274412.41807	222	SCS	SCS	W2220	48.942307	CNLag	1.9432	1.165961	0.274412
112	Polygon	112	209.7998	2063.249252	225	SCS	SCS	W2250	46	CNLag	0.3178	0.190732	0.002063

Record: 1 Show: All Selected Records (0 out of 22 Selected) Options

Fig. 3 Hydrologic parameters of the "subbasin" feature class.

The algorithm for the CN calculation implied the creation of several layers (landuse, soil) in order to obtain a map that will display both the landuse and the pedogeographical characteristics of the area. It followed the estimation of the CN index for the different soil types and the assigning of values to the layer's attribute table. (*Haidu, Crăciun, Bilaşco, 2007*).

The SCS Unit Hydrograph Method was developed and applied starting with the 1950s in the US, and due to its simplicity, its use has been adopted all around the world. The parameters needed for generating the Hydrograph are the lag time (4), t_L and the watershed areas, both calculated with the help of HEC GeoHMS (**Fig. 3**). On the basis of the lag time ("BasinLag", in hours), the time of concentration, T_c (in hours) corresponding to the subwatersheds was calculated:

$$t_L = 0.6 \times T_c \tag{4}$$

The time to peak component, T_p, expressed in hours (5), and the peak of the Unit Hydrograph, Q_p (6), are calculated according to the following formulas (*ASCE, 1996*):

$$T_p = \frac{D}{2} + t_L \tag{5}$$

where:

D = rainfall duration

$$Q_p = \frac{484A}{T_p} \tag{6}$$

3. RESULTS

During the simulation run, one of the different ways to estimate parameters with HEC-HMS, a Unit Hydrograph was calculated for each of the 22 subwatersheds in the Monorostia Basin.

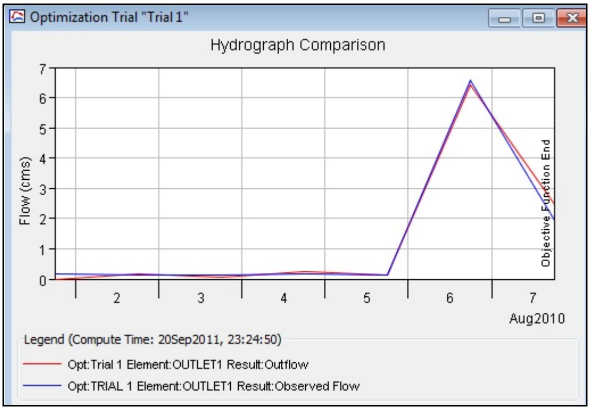
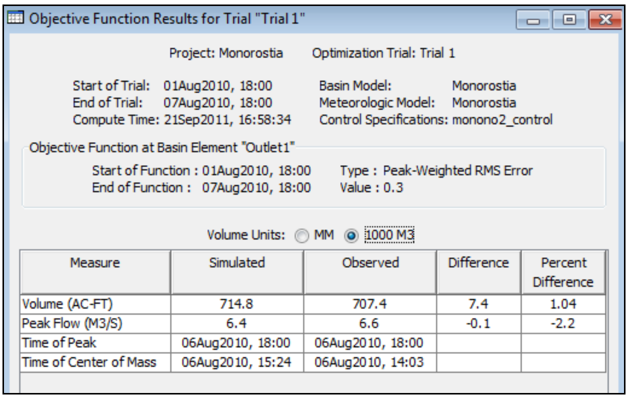


Fig. 4 The observed and the simulated hydrographs at the Monoroştia gauging station, 1-7 August 2010.

Further, the general model with its initial parameters was adjusted during the optimization process so that the simulated hydrograph matches, as closely as possible, the observed one from the Monorostia gauging station, for the study period. The result is based on computations for all of the upstream elements. The simulated and the observed hydrographs at the Monorostia gauging station can be seen in **Fig. 4** and the lowest value of the error function calculated, in **Fig. 5**.


Objective Function Results for Trial "Trial 1"

Project: Monorostia   Optimization Trial: Trial 1

Start of Trial: 01Aug2010, 18:00   Basin Model: Monorostia
End of Trial: 07Aug2010, 18:00   Meteorologic Model: Monorostia
Compute Time: 21Sep2011, 16:58:34   Control Specifications: monono2_control

Objective Function at Basin Element "Outlet1"

Start of Function : 01Aug2010, 18:00   Type : Peak-Weighted RMS Error
End of Function : 07Aug2010, 18:00   Value : 0.3

Volume Units: MM 1000 M3

Measure	Simulated	Observed	Difference	Percent Difference
Volume (AC-FT)	714.8	707.4	7.4	1.04
Peak Flow (M3/S)	6.4	6.6	-0.1	-2.2
Time of Peak	06Aug2010, 18:00	06Aug2010, 18:00		
Time of Center of Mass	06Aug2010, 15:24	06Aug2010, 14:03		

Fig. 5 Data derived from the calibration of the hydrologic model.

As a further example, **Fig. 6** illustrates the hydrograph for the Valea Suacea watershed (W 2110), one of the three tributary rivers of the Monorostia River that have an outlet within the boundaries of the Monoroştia settlement, flooded during the flash flood on the 06th of August 2010. The other two are: Hârtici (W2100) and Bavna (W 1340). As it can be seen from the hydrograph, the streamflow of Valea Suacea is very low, bordering to 0 m^3/s before the above mentioned date, as it happens with many other subwatersheds' discharge values.

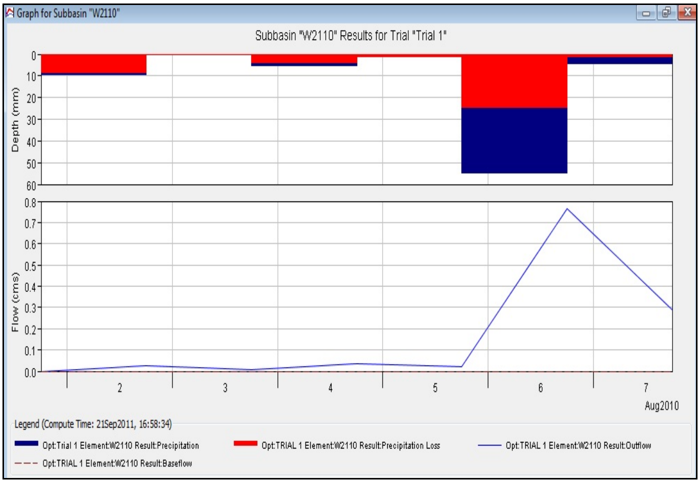


Fig. 6 The hydrograph for the Valea Suacea watershed (W 2110).

This information is accurate as the main river, Monoroştia, with a considerably bigger drainage area, has a multiannual discharge average of 0.1 m^3/s. The hydrograph shows that during the rain event, the small tributary rivers exceed the average discharge of the main river in the basin. Other information available after the optimization process completion is given in **Table 1**.

Table 1. ***Summary results.***

Subwatershed	**Hydrologic element**	**Drainage Area (km^2)**	**Peak Discharge (m^3/s)**	**Volume (1000 m^3)**
Bavna	W1340	6.8025	1.5	163.5
Hârtici	W2100	0.89958	0.3	28.7
Valea Suacea	W2110	2.903	0.8	61.8

4. CONCLUSIONS

HEC HMS is a simulation driven model that can calculate different conditions on the go, giving the user the possibility to compare certain parameters, and possibly to change them. For instance, we computed the hydrograph for certain subwatersheds and could compare the theoretical with the measured data. Hence, regardless of the relative small size of HEC HMS, the versatility of the software and the ability to influence the outcome on the basis of changed parameters gives the software a flexibility perhaps not found in ArcGIS.

This is illustrated as well again through the 'results' chapter. For each of the 22 subwatersheds a specific hydrograph was calculated, hence giving the user the ability to compare and visualise effective rainfall-runoff model results. Conclusions on the simulation run have been drawn in the article, however, the conclusions on the comparable possibilities of HEC-HMS demonstrate the immense possibilities of this software.

AKNOWLEDGEMENTS

This work was possible with the financial support of the Sectoral Operational Programme for Human Resources Development 2007-2013, co-financed by the European Social Fund, under the project number POSDRU/107/1.5/S/76841 with the title „Modern Doctoral Studies: Internationalization and Interdisciplinarity".

REFERENCES

American Society of Civil Engineers, (1996), *Hydrology Handbook (Manual No.28).*

Chendeş V., (2007), *Scurgerea lichidă şi solidă în Subcarpaţii de la curbură*, Teză de doctorat, Institutul de Geografie, Academia Română.

Chow Ven Te, (1964), Handbook of Applied Hydrology- a compendium of water-resources technology, McGraw-Hill Book Company, New York.

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, pag. 1-10. ISSN 1842-5135.

Florea N., Munteanu I., (2003), *Sistemul român de taxonomie a solurilor (SRTS),* Editura Estfalia, Bucureşti.

Haidu I., Crăciun, A. I., Bilaşco Şt., (2007), *The SCS-CN model assisted by G.I.S – alternative estimation of the hydric runoff in real time*, Geographia Technica, ISSN 1842-5135, No.1, 2007, p. 1-7.

Katani Mehdi, Nasri, Masoud, Soleimani Sardoo Farshad, (2011), *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, pg 548- 551.

Maidment D., R., (1993), *Handbook of Hydrology*, McGraw-Hill.

US Army Corps of Engineers, (2010), Hydrologic Modeling System HEC-HMS, User's Manual, Version 3.5.

*** CLC 2006 http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-clc2006-100-m-version-12-2009.