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

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ABSTRACT:
The present study focuses on the runoff calculation in the Monoroștia 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, Monoroștia 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 Monoroștia 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 Monoroștia Basin were calculated through the SCS CN loss method and the SCS Unit Hydrograph transform method. The meteorological data used was that of the Monoroștia gauging station for the 1ʳᵗʰ of August 2010 till the 06ᵗʰ of August 2010, when the historical flash flood occurred due to

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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 Monoroștia Basin (Fig. 1) is located in the Inferior Corridor of the Mureș River, in Arad County, Romania. The total drainage area counts 30 km² and the length of the river 12 km.

![Fig. 1 The Monoroștia Basin and the subwatersheds for which the hydrographs were computed.](image)

### 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.
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:

\[ P_e = \frac{(P - I_a)^2}{P - I_a + S} \]

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):

\[ I_a = 0.2 \times S \]

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

\[ S = \frac{1000}{CN} - 10 \]
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. Bilașco, 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).

![Fig. 3 Hydrologic parameters of the “subbasin” feature class.](image)

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, Bilașco, 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:

$$t_L = 0.6 \times T_c$$

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):

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

![Fig. 2 Hydrologic soil groups.](image)
where:
\[ D = \text{rainfall duration} \]

(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.

![Hydrograph Comparison](image)

**Fig. 4** The observed and the simulated hydrographs at the Monoroșția 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'](image)

**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 Monoroștia settlement, flooded during the flash flood on the 06\textsuperscript{th} 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\textsuperscript{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).](image)

This information is accurate as the main river, Monoroștia, with a considerably bigger drainage area, has a multiannual discharge average of 0.1 m\textsuperscript{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.

<table>
<thead>
<tr>
<th>Subwatershed</th>
<th>Hydrologic element</th>
<th>Drainage Area (km\textsuperscript{2})</th>
<th>Peak Discharge (m\textsuperscript{3}/s)</th>
<th>Volume (1000 m\textsuperscript{3})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bavna</td>
<td>W1340</td>
<td>6.8025</td>
<td>1.5</td>
<td>163.5</td>
</tr>
<tr>
<td>Hârtici</td>
<td>W2100</td>
<td>0.89958</td>
<td>0.3</td>
<td>28.7</td>
</tr>
<tr>
<td>Valea Suacea</td>
<td>W2110</td>
<td>2.903</td>
<td>0.8</td>
<td>61.8</td>
</tr>
</tbody>
</table>

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.

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