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INFILTRATION LOSSES CALCULATED FOR THE FLASH FLOOD IN THE UPPER CATCHMENT OF GERU RIVER, GALAȚI COUNTY, ROMANIA

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Keys words: MIKE software by Danish Institute of Hydraulics, flash flood, UHM, infiltration, radar precipitation

Abstract. MIKE software created by Danish Institute of Hydraulics can be used to perform mathematical modelling of rainfall-runoff process on the hillslopes, resulting in a runoff hydrograph in the closing section of a catchment. The software includes a unitary hydrograph method - *UHM* in the hydrological module Rainfall - Runoff. Excess rainfall is routed to the river and transited through unit hydrograph method. The model divides the flood generating precipitation in excess rainfall (net rainfall) and losses (infiltration).

This paper analyzes data from the flash flood that occurred between the 11th and 13th of September 2013 in the upper catchment of the river Geru. The catchment chosen for study, is controlled by the hydrometric station located in the village Cudalbi. Simulations of this flash flood were performed with MIKE by DHI –UHM software, alternatively using as input data the precipitations recorded by AHSS (Automated Hydrological Sensor Station) Cudalbi and radar precipitations generated by *ROFFG (Romanian Flash Flood Guidance)* software system in ArcGIS module for determining the areas affected by flash floods. The Unitary Hydrograph Method - *UHM* from the hydrological module Rainfall – Runoff calculates excess rainfall and determines infiltration losses by four methods. For each set of input data, the four methods for calculating infiltration losses were subsequently used.

The comparison between the results highlights that the amplitude and phase errors for the maximum discharge are smaller when the model uses for simulation radar

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precipitations as input data, and calculates infiltration losses with the *Proportional Loss method*. This method reproduces with a better accuracy the peaks of the discharge hydrograph. The model can be used in the future to forecast a discharge hydrograph based on estimated radar precipitations in the catchment

Introduction

A storm event causing a flash flood can be simulated with the *Unitary Hydrograph Method*. The *Unit hydrograph* function is the response of the catchment to a 1 mm net rainfall, uniformly distributed on the surface of the catchment and having the duration Δt ; it is defined by the ordinates:

$$U.H.=\{u_i=u(i,\Delta t)\}; i=1,2,\dots,n_u \quad (1)$$

where u_i is the ordinate of the unit hydrograph at the moment of time i ; n_u is the number of ordinates taken into account, so that:

$$\sum_{i=1}^{n_u} u_i \approx \frac{1}{T} \quad (2)$$

where T is the number of hours of time step Δt .

Usually a unit hydrograph is derived from historical rainfall and runoff data. The volume of water produced by the storm (total area under the hydrograph curve) divided by the area of the watershed equals depth of excess precipitation. The ordinates of the storm hydrograph are divided by this depth to obtain the unit hydrograph. If no historical rainfall and runoff data is available the hydrograph can't be obtained in the way presented above. The other methods for the determination of the unit hydrograph that appeared are called *synthetic unit hydrographs*. The two widely known methods for determination of the unit hydrographs are the Snyder method (1938) and the USDA SCS (*United States Department of Agriculture Soil Conservation Service*) method.

The *USDA SCS method* is a method used to create an adimensional hydrograph with ordinate values expressed in a ratio Q/Q_p (flow/peak flow) and containing the values of the ratio t/t_p (time/time to peak) on the abscissa. The dimensionless unit hydrograph can be used later to determine a watershed specific unit hydrograph knowing some characteristics of the watershed.

The data needed to apply the method are: the area of the catchment A , the time of concentration T_c and the duration of the unit excess rainfall D . The concentration time can be calculated using different formulas like the Kirpich/Ramser formula. (Domniţa M., 2012)

The SCS curve number method is a simple method used on large scale for determination of the approximate runoff value corresponding to a certain rainfall quantity in a certain area. Although the method is designed for a single storm, it can be scaled to calculate the annual values for runoff in an area.

The SCS-CN method was developed in 1954 and it is documented in Section 4 of the National Engineering Handbook (NEH) published by Soil Conservation Service (now called the Natural Resources Conservation Service), U.S. Department of Agriculture in 1956.

MIKE by DHI software can be used to perform mathematical modelling of rainfall-runoff process on the hillslopes, resulting in a runoff hydrograph in the closing section of a catchment. The software includes a unitary hydrograph method - *UHM* in the hydrological module Rainfall - Runoff. Mathematical modelling of rainfall-runoff process on the hillslopes, resulting in a runoff hydrograph in the closing section of a catchment can be achieved using MIKE by DHI software, which includes in the hydrological module Rainfall - Runoff, a unit hydrograph model (*UHM*).

Excess rainfall is routed to the river and transited through unit hydrograph method. The model divides the flood generating precipitation in excess rainfall (net rainfall) and losses (infiltration).

The *UHM* calculates excess rainfall and determines infiltration losses by four methods:

- *SCS method* using *Curve Number* parameter to characterize the analyzed catchment from the perspective of existing soil type and land use patterns.
- *constant loss method* that sets an initial fixed value and a constant value during rainfall
- *rational method* that describes infiltration as a proportional loss.
- *SCS method generalized* using *Curve Number* parameter and initial infiltration

The runoff curve number (also called a *curve number* or simply *CN*) is an empirical parameter corresponding to different soil-vegetation-land use combinations. The SCS Curve number method only forecasts the quantity of runoff formed in any point of the catchment but does not model the flow routing or the distribution of runoff through time. Because of this reason the requirements of the method are quite low, only the rainfall depth and an empirical parameter named the Curve Number are mandatory. The Curve Number (*CN*) value can be obtained from the hydrologic soil group, landuse and moisture conditions of the soil, the last two values being more important. (Domnița M., 2012)

The SCS-CN method is based on the water balance equation and two fundamental hypotheses (Mishra and Singh, 2003).

The water balance equation states that:

$$P = I_a + F + Q \quad (3)$$

The first hypothesis states that the ratio of the actual amount of direct runoff to the maximum potential runoff is equal to the ratio of the amount of actual infiltration to the amount of the potential maximum retention:

$$\frac{Q}{P - I_a} = \frac{F}{S} \quad (4)$$

The second hypothesis states that the amount of initial abstraction is some fraction of the potential maximum retention.

$$I_a = \lambda * S \quad (5)$$

where: P = total precipitation (mm) ;

I_a = initial abstraction (mm);

F = cumulative infiltration excluding I_a (mm);

Q = direct runoff (mm);

S = potential maximum retention or infiltration;

The values of the CN can be found in chapter 9 of the NEH – National Engineering Handbook for different land uses and soil groups (USDA, 1986). These values were obtained from data on floods, annual rainfall and runoff values taken from scientific literature for a large variety of catchments, usually small catchments under 1 km² (USDA-SCS, 1985).

The $SCS - NRCS$ for estimating the discharge evaluates the effects of the catchment area through landuse and the type of treatment applied to agricultural cultures.

A source of variability is also the antecedent moisture condition (*Antecedent Moisture Condition - AMC*). The SCS methodology represents this parameter based on the cumulated precipitation over the previous five days in the following way (McCuen, 1982):

1. *AMC I* represents dry soil, with cumulated precipitation < 12.7 mm in the dormant season and < 35.6 mm in the growing season.

2. *AMC II* represents medium soil moisture, with cumulated precipitation of 12.7 - 28 mm in the dormant season and 35.6 – 53.4 mm in the growing season.

3. *AMC III* represents moist or saturated soil, with cumulated precipitation > 28 mm in the dormant season and > 53.4 mm in the growing season.

These values of AMC correspond, respectively, to 90, 10, and 50% cumulative probability of exceedance of runoff depth for a given rainfall (Hjelmfelt *et al.*, 1982).

The *Curve Numbers* are calculated for *AMC II* and then adjusted by addition to simulate *AMC III* or subtraction to simulate *AMC I*. (Domnița M., 2012)

1. Material and method

According to the principle of superposition UHM determines a discharge hydrograph for each time step and excess rainfall, according to the method of infiltration losses and then adds the runoff generated in the precedent time step.

Figure 1 presents MIKE 11 by DHI - UHM menu for selecting the parameters.

The screenshot shows the 'UHM' (Unit Hydrograph Method) menu in MIKE 11. The window title is 'XIII.1_GERU_SHCUDALBI_RA - Modified'. The 'Catchments' tab is selected, showing the 'GERU' catchment. The 'Adjustment and Baseflow' section has 'Area adjustment factor' set to 1 and 'Baseflow' set to 0. The 'Hydrograph' section has 'SCS triangular' selected. The 'Enlargement and Loss Model' section has 'SCS method' selected, 'Curve Number' set to 74, and 'Initial AMC' set to 1. The 'Lag Time' section has 'Curve number method' selected, 'Lag Time' calculated as 5.81, 'Hydraulic Length' as 22.4, 'Slope' as 4.13, and 'Curve Number' as 74. An 'Overview' table is at the bottom.

	Name	Method	AreaAF	Baseflow	InitLoss	ConstLoss	R
1	GERU	SCS tri	1	0	0	0	
2	GERUSITA	SCS tri	1	0	0	0	

Fig. 1. MIKE 11 by DHI - UHM menu

The model is applied to the upper basin of the river Geru located in Galați county. The upper catchment chosen for study, has an area of 99.52 km², and is controlled by the hydrometric station located in the village Cudalbi, located at 22.53 km downstream (figure 2). The daily transmitted data from the classic hydrometric station with vertical hydrometric are doubled since August 2013 by hourly precipitation data from an AHSS (Automated Hydrological Sensor Station).

Between 11th and 13th of September in the upper catchment of river Geru large quantities of precipitation occurred. The storm generated a flow hydrograph with three peaks, with the following maximum discharges: 118.00 m³/s recorded on 12/09/2013 23⁰⁰, then 75.30 m³/s recorded on 13/09/2013 02²⁰, respectively 10.30 m³/s recorded on 13/09/2013 10⁰⁰. The flow hydrograph was extracted from the

rating curve calculated by the Hydrology Department of the Basinal Water Administration Prut - Bârlad for the cross section of the river Geru at Cudalbi hydrometric station.

Fig. 2. Map of the upper catchment of river Geru

It appears that the flood that occurred between 11th and 13th of September 2013 had a maximum discharge of 118.00 m³/s that is very close to the peak of the flood with a 2% probability of exceedance, which is 120.00 m³/s, established by the National Institute of Hydrology and Water Management, for the analyzed section.

To simulate the flood that occurred between 11th and 13th of September 2013 we used a hydrological model that included the river Geru and its tributary, the river Gerușita and used the Unitary Hydrograph Method from the Rainfall – Runoff Module, in order to obtain the runoff hydrograph recorded at the hydrometric station.

The evolution of the runoff was described with the *triangular hydrograph SCS* method (*Soil Conservation Service of USDA*), which established that the moment of occurrence of the maximum flow (peak hydrograph) is considered to be at half the duration of the rain, plus the duration between the nucleus of the rain and the peak of the runoff;

Mostly clay soil and clay loam, with low infiltration are spread in the river Geru catchment. The soils are classified in the *group C* of hydrologic soils. For the analyzed catchment the *CN (Curve Number)* parameter was calculated by the weighted method established in TR - 55 (*Technical Release - 55*) by the *United States Department of Agriculture*. The method is applicable to small basins and *CN* parameter is calculated as a weighted average based on land use and *CN* intermediate surface corresponding to each surface.

For a catchment that is composed of different hydrologic soil groups and different land use, the *Curve Number* parameter can be calculated with the equation (5) for average humidity conditions *AMC II*:

$$CN_{weighted} = \frac{\sum A_i \cdot CN_i}{\sum A_i} \quad (5)$$

where: $CN_{weighted}$ is a weighted *CN* parameter

i = an index of the subdivisions with the same hydrologic soil type and land use

CN_i = *CN* corresponding to the subdivision „ i ”

A_i = draining surface of the subdivision „ i ” (*USACE, 2000*).

CN parameter obtained is a weighted value that represents all the possible combinations of hydrologic soil groups and land use in a catchment. (*Győri et al., 2013*).

Before the hydrologic event that occurred between the 11th – 14th of September 2013, the cumulative precipitations in five precedent days were less than 35.6 mm, which is the limit set by *McCuen, 1982* for the spring – summer period, that characterizes a dry soil, close to a wilting point. For the initial moisture condition we used *AMC=1* for dry soil. The parameter *Curve Number* calculated for *AMC II* was adjusted by subtraction to obtain the corresponding parameter for *AMC I*. For river Geru catchment the value $CN = 74$ is obtained.

2. Results and discussion

Simulations of this flash flood were performed with MIKE by DHI –UHM software, alternatively using as input data the precipitations recorded by AHSS Cudalbi and radar precipitations generated by *ROFFG (Romanian Flash Flood Guidance)* software system in ArcGIS module for determining the areas affected by flash floods. The Unitary Hydrograph Method - *UHM* from the hydrological module Rainfall – Runoff calculates excess rainfall and determines infiltration losses by four methods. For each set of input data, the four methods for calculating infiltration losses were subsequently used.

2.1 Precipitations recorded by AHSS Cudalbi as input data

The precipitations recorded by AHSS Cudalbi with a 10 minute time step are presented in figure 3.

Fig. 3 – Precipitations recorded at AHSS Cudalbi during the 11th – 14th of September 2013

After performing several trial-and-error simulations we concluded that the value **0.71** for the **area adjustment factor** parameter represents the real proportion between the rain intensity in the catchment and the precipitations recorded at AHSS Cudalbi.

SCS Method for infiltrations

When we used the value **0.71** for the **area adjustment factor** parameter, in the parameters menu, the simulation led to a peak discharge of 120.10 m³/s (12th of September 2013, 06⁰⁰), with a 1.8% increase compared to the maximum recorded discharge of 118.00 m³/s (11th of September 2013, 23⁰⁰), and a delay of 7 hours.

The comparison of the measured and simulated flow hydrograph highlights that it is possible that some precipitations fell in the upstream side of the analyzed catchment and were not captured by the automated station located downstream. The missing precipitations from the recordings may have in fact contributed to the measured surface runoff that showed three peaks. The simulated hydrograph did not catch the three discharge peaks.

CONSTANT LOSS Method for infiltrations

The **CONSTANT LOSS Method** describes the infiltration through *Initial Loss* parameter (initial infiltration, at the beginning of the rain) and *Constant Infiltration* parameter (constant infiltration throughout the rain).

We calculated the maximum retention potential, which expresses the retention capacity of the soil, S .

$$S = \frac{1000}{CN} - 10 = \frac{1000}{73} - 10 = 3.69 \text{ inch} = 93.94 \text{ mm}$$

Initial infiltration I_a depend directly of the maximum retention, in the equation:

$$I_a = 0.2 \cdot S = 3.69 \cdot 93.94 = 18.8 \text{ mm}$$

Several simulations were performed using the precipitations recorded at AHSS Cudalbi, gradually increasing the constant infiltration throughout the rain, starting with the value Constant loss = 5 mm/h, till we established a value for the parameter, which led to a discharge hydrograph similar to the measured hydrograph, by phase and amplitude. We reached the conclusion that the value **26 mm** for the parameter **Constant Loss** led to a peak discharge of 118.85 m³/s with a 0.7% increase and a 7 hours delay compared to the maximum recorded discharge.

PROPORTIONAL LOSS Method for infiltrations

Several simulations were performed gradually decreasing the value for the parameter **Runoff coefficient**, starting with the value 0.5, till we established a value for the parameter which led to a discharge hydrograph similar to the measured hydrograph, by phase and amplitude. We reached the conclusion that the value **0.27 mm** for the parameter **Runoff coefficient** led to a peak discharge of 117.71 m³/s with a 0.2% decrease and a 6 hours delay compared to the maximum recorded discharge.

SCS GENERALISED Method for infiltrations

The **SCS generalised method** calculates the infiltration losses and water retention in the depressions uses **CN (Curve Number)** parameter and **Initial abstraction depth** parameter.

Several simulations were performed using different values for the **Initial abstraction depth** parameter, till we established a value for the parameter, which led to a discharge hydrograph similar to the measured hydrograph, by phase and amplitude. We reached the conclusion that the value **73 mm** for the parameter **Initial abstraction depth** led to a peak discharge of 118.09 m³/s with a 0.08% increase and a 7 hours delay compared to the maximum recorded discharge.

2.2 Precipitations radar as input data

RADAR technology represents a fixed installations that uses electromagnetic waves and their reflection from different objects, to determine their relative position towards the antenna. The meteorological radar can be used to determine location, movement and type of the precipitations and to estimate the future changes of position and intensity. The modern Doppler radar can not only detect the intensity of the rain, but also can detect the movement of the precipitations. The

information provided by the radar is analyzed in order to identify the structure of the rainfall and the possibility of weather changes. The weather stations have their own data base with climate variables, that are stored in specific tables constantly update by the National Administration of Meteorology.

Fig. 4. Spatial distribution of the precipitations

The values of the radar precipitations that occurred between the 11th and 13th of September 2013 were generated by the ROFFG (*Romanian Flash Flood Guidance*) software system in ArcGIS environment used to determine the areas affected by flash floods in small catchments throughout Romania.

From data processed by the ROFFG system, we used the product *Merged Map – medium precipitation accumulated in an hour*, based on the spatial and temporal estimations of the precipitations, corrected and/or based on the precipitations recorded on the ground, by the automated station (*figure 4*).

The values of the radar precipitations with an hourly frequency are presented in figure 5.

SCS Method for infiltrations

For the simulations performed using the radar precipitations we used **area adjustment factor=1**, because we considered that the data input accurately characterizes the catchment, and the file show a temporal distribution close to reality.

The simulations led to a maximum peak of 128.25 m³/s (the 12th of September 2013, 05⁰⁰), with a 8.7% increase and 6 hours delay, compared to the maximum recorded discharge.

The second peak of 89.82 m³/s (the 13th of September 2013, 0716) has a 19% increase and a 5 hours delay, compared to the second recorded peak of 75.30 m³/s (the 13th of September 2013, 0220).

The third peak of 7.47 m³/s (the 14th of September 2013, 1630) has a 27% increase and a 30 hours delay, compared to the third recorded peak of 10.30 m³/s (the 13th of September 2013, 1020).

Fig. 5. Radar precipitations produced between the 11th – 15th of September 2013

The simulated hydrograph catches the three peaks of the hydrograph, with different phase and amplitude errors for each of them. The first peak has small phase and amplitude errors.

CONSTANT LOSS Method for infiltrations

Several simulations were performed using the radar precipitations, gradually decreasing the constant infiltration throughout the rain.

We reached the conclusion that the value **18.7 mm** for the parameter **Constant Loss** led to a peak discharge of 117.99 m³/s with a 0.01% decrease and a 2.5 hours delay compared to the maximum recorded discharge.

The analysis of the results showed that the maximum peak simulated is an inverse ratio of the **Constant Loss** parameter. The excess rainfall that produces the surface runoff is diminished by the constant infiltration throughout the storm. The increase of the **Constant Loss** parameter doesn't influence the moment of occurrence of the hydrograph peak.

PROPORTIONAL LOSS Method for infiltrations

Several simulations were performed gradually increasing the value for the parameter **Runoff coefficient**, starting with the value 0.12, till we established a

value for the parameter which led to a discharge hydrograph similar to the measured hydrograph, by phase and amplitude.

We reached the conclusion that the value **0.28 mm** for the parameter **Runoff coefficient** led to a peak discharge of 118.68 m³/s with a 0.57% increase and a 2.5 hours delay compared to the maximum recorded discharge.

The analysis of the results showed that the maximum peak simulated is an inverse ratio of the **Runoff Coefficient** parameter that diminishes the excess rainfall and therefor the surface runoff. The increase or decrease of the **Runoff Coefficient** parameter doesn't influence the moment of occurrence of the hydrograph peak.

SCS GENERALISED Method for infiltrations

Several simulations were performed using different values for the **Initial abstraction depth** parameter, till we established a value for the parameter, which led to a discharge hydrograph similar to the measured hydrograph, by phase and amplitude.

We reached the conclusion that the value **95 mm** for the parameter **Initial abstraction depth** led to a peak discharge of 124.48 m³/s with a 5.49% increase and a 26.5 hours delay compared to the maximum recorded discharge.

The analysis of the results showed that the simulated hydrograph has four peaks and the first peak has a diminished value, compared to the maximum recorded discharge. The second simulated peak is the maximum peak and has an increased value, compared to the maximum recorded discharge. The volume of the simulated flood is 11796236 m³, compared to the volume of the recorded flood of 3138318 m³, with a 276% increase.

The analysis of the results showed that the hydrological modeling that used radar precipitations led to a discharge hydrograph with smaller phase and amplitude errors, compared to hydrograph simulated with the precipitations recorded at AHSS Cudalbi.

The radar precipitations describe the storm with a high accuracy, so the simulations performed using this input data led to a discharge hydrograph with a sequence of peaks which is close to the real discharge hydrograph. The delay between the moment of occurrence of the maximum simulated peak is of 2.5 hours, when using the radar precipitations for the simulations.

The following results were obtained using precipitations recorded by AHSS Cudalbi (*table 1*) and radar precipitations (*table 2*):

Tab. 1. Simulation results with the precipitations recorded by AHSS Cudalbi as input data

Infiltration losses - Method	Parameters	Maximum simulated discharge	Errors compared to the maximum discharge recorded at AHSS Cudalbi	
			amplitude	phase
SCS	<i>CN=74</i>			
	<i>Initial AMC (Antecedent Moisture Coefficient)=1</i>	120.10 m ³ /s	+ 1.8%	+ 7 hours
	<i>Area adjustment factor=0.71</i>			
Constant Loss	<i>Initial Loss=18.8 mm</i>			
	<i>Constant Loss=26 mm/hour</i>	118.85 m ³ /s	+ 0.7%	+ 6 hours
	<i>Area adjustment factor=0.71</i>			
Proportional Loss	<i>Runoff coefficient=0.27</i>			
	<i>Area adjustment factor=0.71</i>	117.71 m ³ /s	- 0.2%	+ 6 hours
	<i>CN=74</i>			
SCS generalized	<i>Initial abstraction depth=73 mm</i>	118.09 m ³ /s	+0.08%	+7 hours
	<i>Area adjustment factor=0.71</i>			

Tab. 2. Simulation results with the radar precipitations as input data

Infiltration losses - Method	Parameters	Maximum simulated discharge	Errors compared to the maximum discharge recorded at AHSS Cudalbi	
			amplitude	phase
SCS	<i>CN=74</i>			
	<i>Initial AMC (Antecedent Moisture Coefficient)=1</i>	120.72 m ³ /s	+ 2.3%	+ 3 hours
	<i>Area adjustment factor=1</i>			
Constant Loss	<i>Initial Loss=18.8 mm</i>			
	<i>Constant Loss=18.7 mm/hour</i>	117.99 m ³ /s	- 0.01%	+ 2.5 hours
	<i>Area adjustment factor=1</i>			
Proportional Loss	<i>Runoff coefficient=0.28</i>			
	<i>Area adjustment factor=1</i>	117.71 m ³ /s	- 0.57%	+ 2.5 hours
	<i>CN=74</i>			
SCS generalized	<i>Initial abstraction depth=95 mm</i>	124.48	+5.49%	+26.5 hours
	<i>Area adjustment factor=1</i>			

Conclusions

It seems that among the four methods for determining the infiltration losses, the **Proportional Loss** method leads to a discharge hydrograph with a sequence of peaks which is close to the real discharge hydrograph, and has smaller phase and amplitude errors (figure 6).

Fig. 6. Simulated and recorded discharge hydrograph (— simulated, — recorded)

Fig. 7. Statistical analysis for the simulated results

The correlation coefficient between the simulated hydrograph and the recorded hydrograph at AHSS Cudalbi is 0.498 (figure 7).

For similar catchments where automated station are installed, the model can be adapted using the same concept, to forecast discharge hydrographs, based on estimated radar precipitations.

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