# FLOOD ANALYSIS USING Mike 11 by DHI AND ARCGIS. CASE STUDY – THE FLOOD IN THE UPPER CATCHMENT OF RIVER GERU, GALAȚI COUNTY, ROMANIA

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***Abstract**: Between the 11th and 13th of September 2013 large quantities of rainfall occurred in the upper catchment of river Geru. The precipitations have generated a flash flood with three peaks, with the maximum discharges of 118.00 $m^3/s$ recorded on 12th of September 2013, $23^{00}$. Simulations of the flash flood were performed alternatively with Mike 11 by DHI - NAM (Nedbør Afstrømning Modele) and with MIKE by DHI –UHM, using radar precipitations as input data. Radar rainfall values were generated by ROFFG (Romanian Flash Flood Guidance) software system in ArcGIS module for determining the area affected by flash floods.*

*The program Mike 11 by DHI – NAM accounts for the water content in up to 4 different storages. As default, NAM uses 9 parameters to represent the Surface zone, Root zone and the Ground water storages. The program Mike 11 by DHI – UHM calculates excess rainfall and determines infiltration losses by four methods. The discharge hydrographs simulated with Mike 11 by DHI program were compared to the discharge measured at the hydrometric station. The amplitude and phase errors are directly dependent of the accuracy of the input data and chosen parameters.*

***Keywords:** Mike 11 by DHI, ArcGIS, rainfall, runoff, automatic station, radar.*

## 1. Introduction

To evaluate surface runoff in small catchments that are homogeneous from the physico-geographical point of view, only the processes of rainfall transformation in runoff are modeled, without the study of flood routing through the riverbeds. In the formation of network discharges during high intensity rainfalls, the most important weight is held by surface runoff (*Giurma I., 2003*). These types of hydrological models only study the surface runoff component and assume that the parameters used are constant across the entire catchment, so they are models with global parameters. MIKE 11 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. Several types of models are available in the Rainfall-Runoff module: *NAM, UHM, SMAP, Urban, FEH, DRiFt, Combined.*

**1.1. NAM** is the abbreviation of the Danish "Nedbør-Afstrømnings-Model", meaning precipitation-runoff-model. *NAM* is a lumped, conceptual rainfall-runoff model, simulating the overland, inter - flow, and base-flow components as a function of the moisture contents in four different and mutually interrelated storages in the soil. NAM can be prepared in a number of different modes depending on the requirement. As default, *NAM* is prepared with 9 parameters representing the Surface zone, Root zone and the Ground water storages. In addition *NAM* contains provision for: extended description of the ground water component, two different degree day approaches for snow melt, irrigation schemes, and automatic calibration of the 9 most important (default) *NAM* parameters.

The basic input requirements for the NAM model consist of: model parameters, initial conditions, meteorological data, streamflow data for model calibration and validation. The basic meteorological data requirements are: rainfall and potential evapotranspiration. Observed discharge data at the catchment outlet are required for comparison with the simulated runoff for model calibration and validation. The parameters and variables represent, therefore, average values for the entire catchment. As a result some of the model parameters can be evaluated from physical catchment data, but the final parameter estimation must be performed by calibration against time series of hydrological observations. Based on the meteorological input data, *NAM* produces catchment runoff that is split conceptually into overland flow, interflow and base flow components (fig. 1).

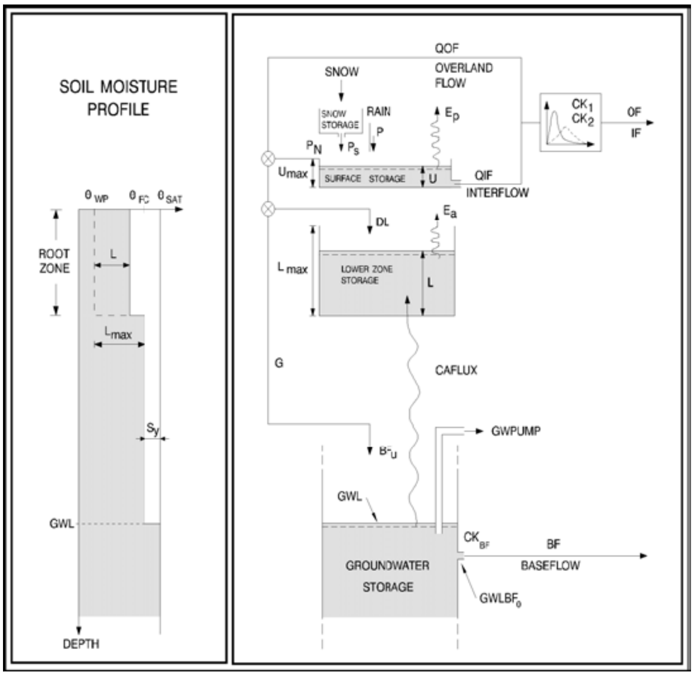

Fig 1. Structure of the NAM model

**1.2. UHM** module simulates the runoff from single storm events by the use of unit hydrograph techniques. 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 $\Delta t$; it is defined by the ordinates:

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

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:

$$\sum_{i=1}^{n_u} u_i \approx \frac{1}{T} \quad \text{where } T \text{ is the number of hours of time step } \Delta t. \quad (2)$$

Usually a unit hydrograph is derived from historical rainfall and runoff data. 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/Qp (flow/peak flow) and containing the values of the ratio t/tp (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 model divides the flood generating precipitation in excess (net rainfall) and losses (infiltration) 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 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 *SCS – NRCS* for estimating the discharge evaluates the effects of the catchment area through land use and the type of treatment applied to agricultural cultures.

## 2. Material and method

### 2.1. The characteristics of the analyzed catchment

The model is applied to the upper basin of the river Geru located in Galati county, in the south of the area operated by the Basinal Water Administration Prut - Bârlad. The upper area of the river Geru catchment was chosen for study. The downstream control section is Cudalbi hydrometric station, located at 22.53 km downstream. The daily transmitted data from the classic hydrometric station with vertical hydrometric surprise are doubled since August 2013 with hourly precipitation data from the AHSS (Automated Hydrological Sensor Station).

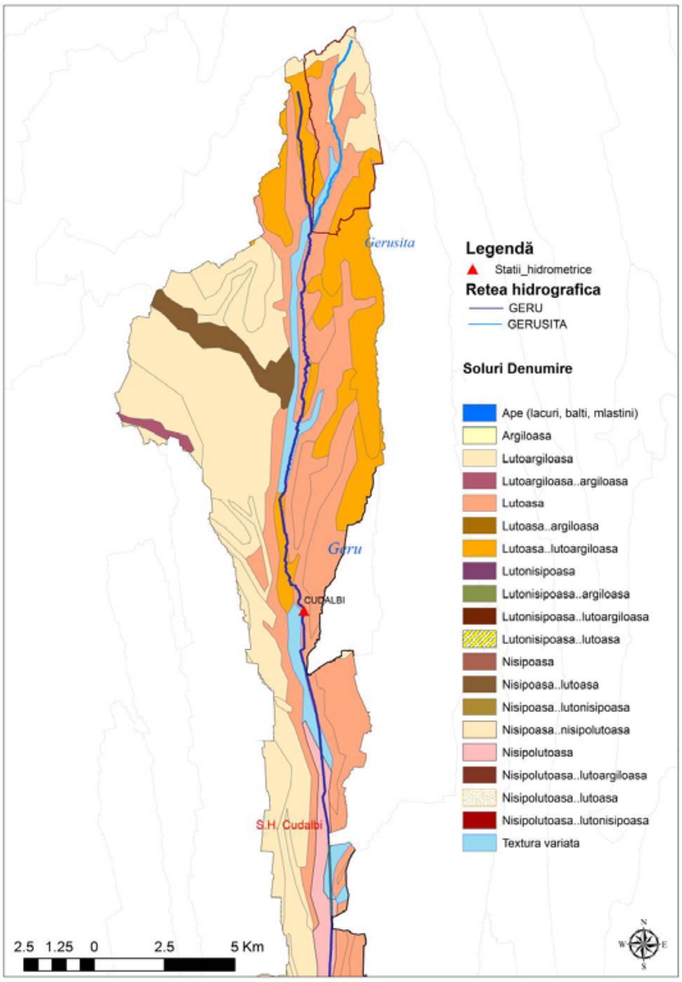


Fig 2. Cartogramme of texture soils in the catchment of river Geru

Cultivated agricultural lands occupied the largest area in the catchment Geru (45%). Then follows meadows (25%), rural localities 15%, and forests (15%). The catchment of river Geru shows very different soil types: river deposits, carbonate silts, colluvial soils, chernozem soils. Grey forest soils occur on the hillslopes and are formed of loess, sand and marl. Fig. 2 presents the textural classes of soils in the catchment of river Geru.

### 2.2. Significant flood that occurred in September 2013

Large quantities of precipitation have occurred between 11$^{th}$ and 13$^{th}$ of September 2013 in the upper catchment of river Geru, Galați county, Romania. The rainfall generated a flow hydrograph with three peaks, with the following maximum discharges: 118.00 $m^3/s$ recorded on 12/09/2013 23$^{00}$, then 75.30 $m^3/s$ recorded on 13/09/2013 02$^{20}$, respectively 10.30 $m^3/s$ recorded on 13/09/2013 10$^{00}$. Following the rapid concentration of runoff on the hillslopes, in the reference period, the defense characteristic threshold DANGER was reached and exceeded at the cross section of the river Geru at Cudalbi hydrometric station (Table 1):

Table 1. Exceedance of DANGER defense threshold at the hydrometric station Cudalbi

| River | Hydrometric station | Maximum Level (cm) | Exceedance of DANGER defense threshold (cm) /date | Maximum Hystoric Level (cm)/Year |
|---|---|---|---|---|
| Geru | Cudalbi | 358 | + 88 cm On 11$^{th}$ of September 2013, 23$^{00}$ | 358/2013 |

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 values of the radar precipitations that occurred between the 11$^{th}$ and 13$^{th}$ 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.

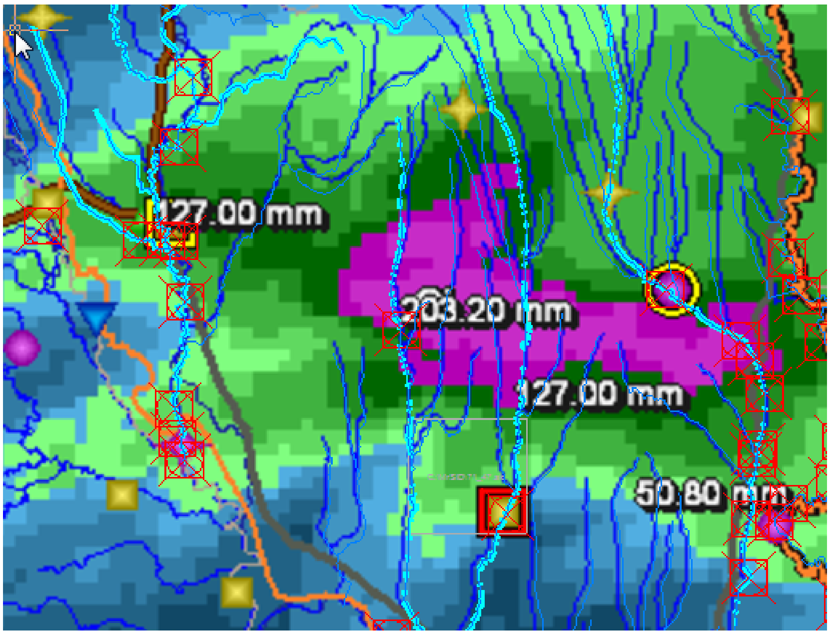


Fig 3. Spatial distribution of the precipitations

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 (fig. 3)

The values of the radar precipitations with an hourly frequency are presented in fig. 4.

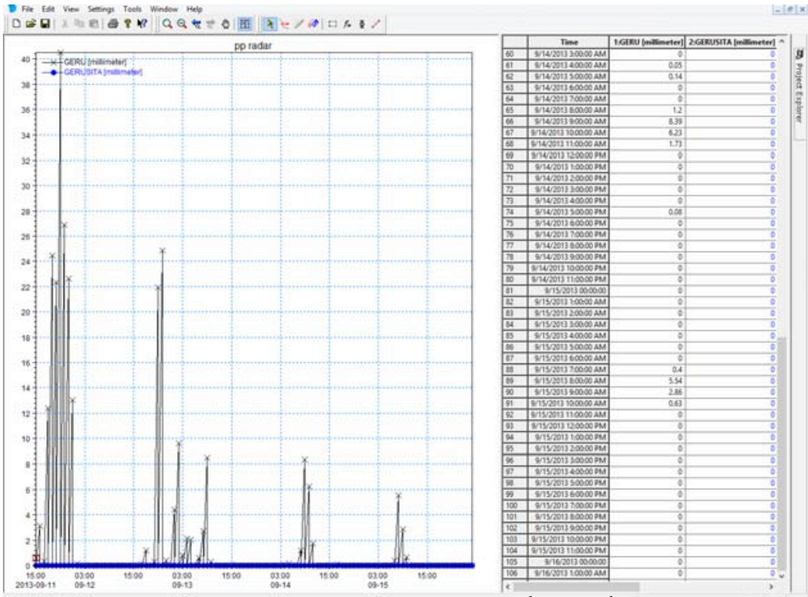


Fig. Radar precipitations radar between the 11th – 15th of September 2013

### 2.3. Mike 11 by DHI -UHM parameters

#### 2.3.1. NAM

To simulate the flood that occurred between 11th and 13th of September 2013 we used a hydrological model for the river Geru that used *NAM (Nedbør-Afstrømnings-Model)* from the Rainfall – Runoff Module, in order to obtain the runoff hydrograph recorded at the hydrometric station.

***Surface storage*** is characterized by the following model parameters: *Umax (*denotes the upper limit of the amount of water in the surface storage) and *U* (the amount of water, in the surface storage diminished by evaporative consumption as well as by interflow).

***Lower zone or root zone storage*** is characterized by the following model parameters: *Lmax (*denotes the upper limit of the amount of water in this storage).

When the surface storage spills, i.e. when $U > Umax$, the excess water gives rise to overland flow as well as to infiltration.

*CQOF* is the overland flow runoff coefficient ($0 \leq CQOF \leq 1$)

*TOF* is the threshold value for overland flow ($0 \leq TOF \leq 1$).

*CKIF* is the time constant for interflow.

*TIF* is the root zone threshold value for interflow ($0 \leq TIF \leq 1$).

*TG* is the root zone threshold value for groundwater recharge ($0 \leq TG \leq 1$).

***The interflow contribution*** *QIF*, is assumed to be proportional to *U* and to vary linearly with the relative moisture content of the lower zone storage.

***The baseflow*** *BF* from the groundwater storage is calculated as the outflow from a linear reservoir with time constant *CKBF*.

#### 2.3.2. UHM

To simulate the flood that occurred between 11th and 13th of September 2013 we used a hydrological model for the river Geru that used the *Unitary Hydrograph Method* from the Rainfall – Runoff Module, in order to obtain the runoff hydrograph recorded at the hydrometric station. 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*. Before the hydrologic event that occurred between the 11$^{th}$ – 14$^{th}$ 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 substraction to obtain the corresponding parameter for *AMC I*. For river Geru catchment the value ***CN* = 74** is obtained**.**

## 3. Results and discussions

### 3.1. NAM

Several trial and error simulations were performed with different values for the calibration parameters till we established a value for the parameters, that led to a discharge hydrograph similar to the measured hydrograph, by phase and amplitude.

Table 2 presents the final calibration parameters for *NAM.*

Table 2. Final parameters for *NAM*

| | Initial Value | Lower Bound | Upper Bound |
|---|---|---|---|
| **Umax** | **18.7** | 10 | 20 |
| **Lmax** | **95** | 10 | 300 |
| **CQOF** | **0.27** | 0.1 | 1 |
| **CKIF** | **982** | 200 | 1000 |
| **CK1.2** | **7.5** | 7.5 | 50 |
| **TOF** | **0.36** | 0 | 0.99 |
| **TIF** | **0.45** | 0 | 0.99 |
| **TG** | **0.5** | 0 | 0.99 |
| **CKBF** | **3830** | 1000 | 4000 |
| **CK2** | **7.55** | 7.55 | 50 |
| **CQLOW** | **0** | 0 | 100 |
| **CKLOW** | **10000** | 1000 | 30000 |

The results of the simulations performed with Mike 11 by DHI (NAM) using radar precipitations were analyzed. We reached the conclusions that this method led to a complex discharge hydrograph with two major peaks of 118.37 $m^3/s$, respectively 40.99 $m^3/s$ and a total volume of 6611577 $m^3$ (fig. 5).

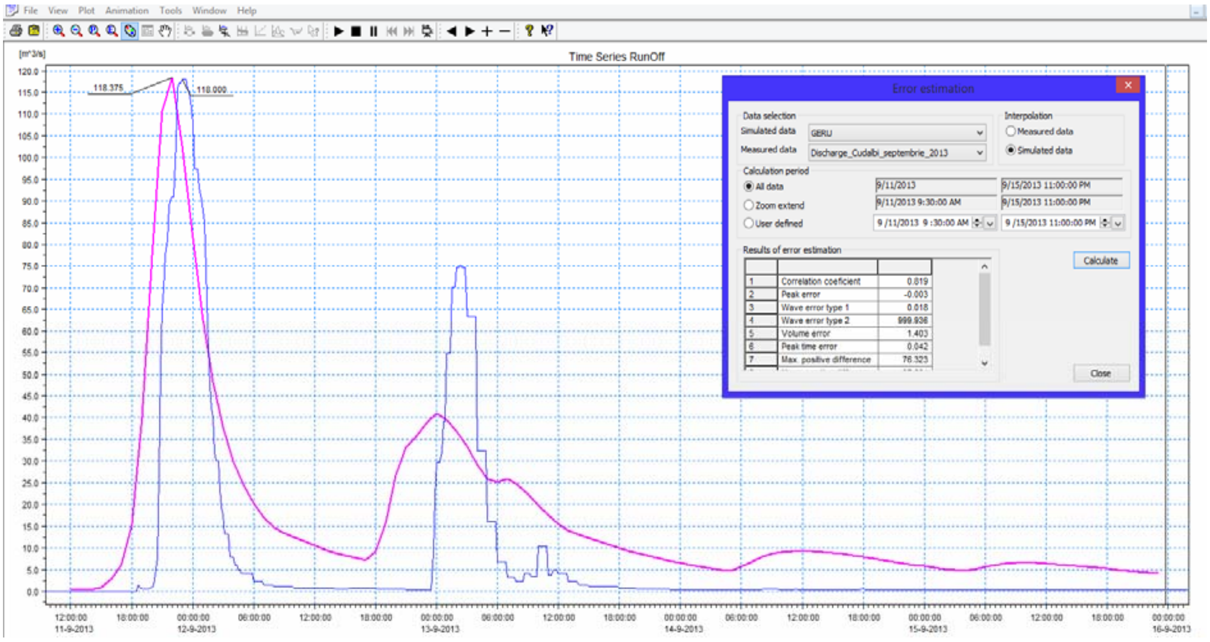

Fig 5. Discharge hydrograph (______simulated with *NAM*, ______recorded)

The parameters *Increase time, Form Coefficient and Volume* for the discharge hydrograph simulated with this method have similar values with the parameters of the measured flood. The correlation coefficient is 0.819.

### 3.2. UHM

Simulations of this flash flood were performed with MIKE 11 by DHI – *UHM*, using as input data radar precipitations generated by *ROFFG (Romanian Flash Flood Guidanc*e) software system in ArcGIS module for determining the areas affected by flash floods. The four methods for calculating infiltration losses were subsequently used.

#### *3.2.1. SCS* Method for infiltrations

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 120.72 $m^3/s$ (the $12^{th}$ of September 2013, $02^{00}$), with a 2.3% increase and 3 hours delay, compared to the maximum recorded discharge. The simulated hydrograph reproduced 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.

#### *3.2.2. CONSTANT LOSS* Method for infiltrations

Several simulations were performed, 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 119.81 $m^3/s$ with a 1.5% increase and 1 hour 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 filtration throughout the storm. The increase of the ***Constant Loss*** parameter doesn't influence the moment of occurrence of the hydrograph peak.

### *3.2.3. 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 ***0.27 mm*** for the parameter ***Runoff coefficient*** led to a peak discharge of 121,06 $m^3/s$ with a 2,6% increase and 1 hour 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.

### *3.2.4. 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 ***115 mm*** for the parameter ***Initial abstraction depth*** led to a peak discharge of 119.98 $m^3/s$ with a 1.67% 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 following results were obtained with Mike 11 by DHI (UHM) simulations, using radar precipitations *(table 2):*

Table 3. Simulation results with the radar precipitations as input data

| **Infiltration losses - Method** | **Parameters** | **Maximum simulated discharge** | **Errors compared to the maximum discharge recorded** | |
|---|---|---|---|---|
| | | | **amplitude** | **phase** |
| SCS | *CN*=74<br>*Initial AMC* (Antedecent Moisture Coefficient)=1<br>*Area adjustment factor*=1 | 120.72 $m^3/s$ | + 2.3% | + 3 hours |
| Constant Loss | *Initial Loss*=18.8 mm<br>*Constant Loss*=18.7 mm/hour<br>*Area adjustment factor*=1 | 119.81$m^3/s$ | + 1.5% | + 1hour |
| Proportional Loss | *Runoff coefficient*=0.28<br>*Area adjustment factor*=1 | 121.06 $m^3/s$ | +2.6% | + 1 hour |
| SCS generalised | *CN*=74<br>*Initial abstraction depth*=95 mm<br>*Area adjustment factor*=1 | 119.98 | +1.67% | +26.5 hours |

The results of the simulations performed with Mike 11 by DHI (UHM) using radar precipitations and the four methods for determining the infiltration losses were analyzed. We reached the conclusions that the ***Constant Loss*** method led to a discharge hydrograph with two peaks of 119.81 $m^3/s$, respectively 29.23 $m^3/s$ and a total volume of 4882693 $m^3$ (figure

6). The parameters *Total time, Increase time, Decrease time, Volume* for the discharge hydrograph simulated with the ***Constant Loss*** method have similar values with the parameters of the measured flood. The correlation coefficient is 0.782.

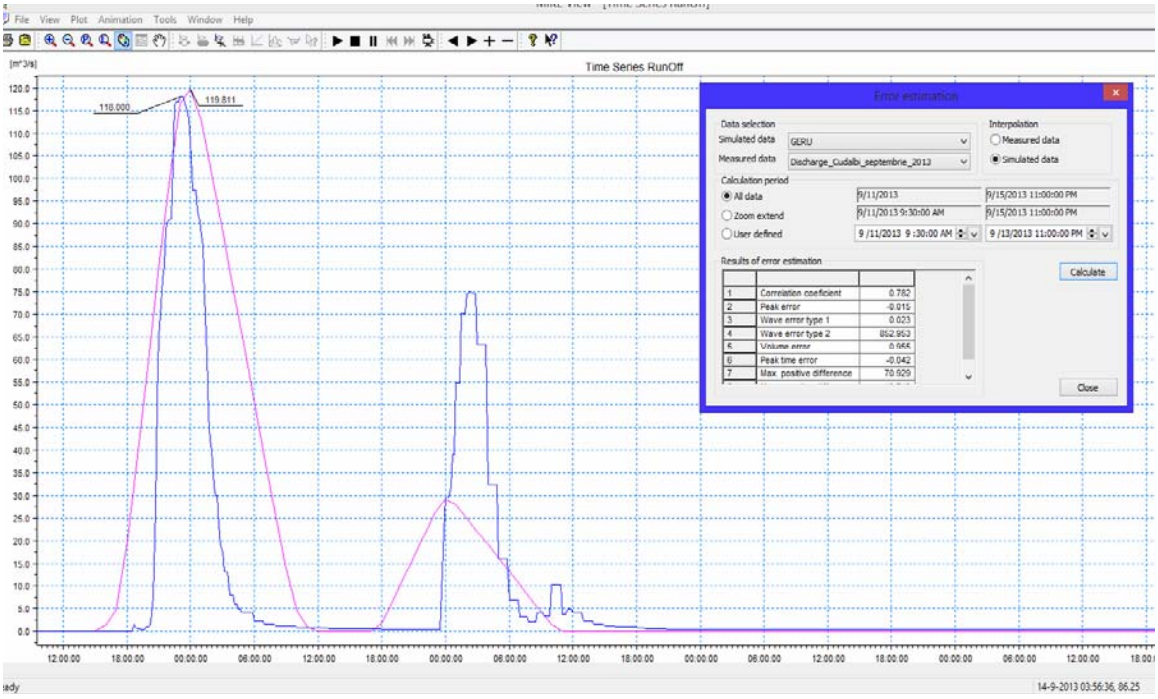


Fig 6. Discharge hydrograph (______simulated with *UHM*, ______recorded)

**4. Conclusions**

Table 3 presents the values of the parameters that characterize the flood recorded at AHSS Cudalbi, compared to the ones that characterize the discharge hydrographs simulated with Mike 11 by DHI (*UHM*) and Mike 11 by DHI (*NAM*).

Table 3. Comparison of the flood parameters

| **Discharge hydrograph** | | **Maximum discharge ($m^3/s$)** | **Total time (hour)** | **Increase time (hour)** | **Decrease time (hour)** | **Form coefficient** | **Volume ($m^3$)** |
|---|---|---|---|---|---|---|---|
| Recorded at A.H.S.S. Cudalbi | | **118.00** | 56.5 | 14 | 42.5 | 0.13 | 3070280 |
| Simulated with ***NAM*** | | **118.37** | 111 | 13 | 98 | 0.14 | 6611577 |
| Simulated with ***UHM*** | SCS | 120.72 | 108 | 15 | 93 | 0.21 | 9660080 |
| | Constant Loss | **119.81** | 50 | 13 | 37 | 0.23 | 4882693 |
| | Proportional Loss | 121.06 | 108 | 13 | 95 | 0.17 | 7171875 |
| | SCS generalised | 118.82 | 108 | 38 | 70 | 0.21 | 9710951 |

Figure 7 presents the comparison between the discharge hydrographs simulated with MIKE 11 by DHI, both NAM and UHM and the hydrograph measured at the hydrometric station Cudalbi. The graphic visualisation complets the analysis of the data and it shows that:

- *NAM* leads to a discharge hydrograph with a longer *total time* and a *form coefficient* almost equal to the one of the measured hydrograph. The value of the second peak (41 $m^3/s$)

is closer to the second peak of the measured hydrograph (75.30 $m^3/s$). The simulated hydrograph overlaps the measured hydrograph.

- *UHM - Constant Loss* leads to a discharge hydrograph with a shorter *total time* and a *volume* that is the closest to the one of the measured hydrograph.

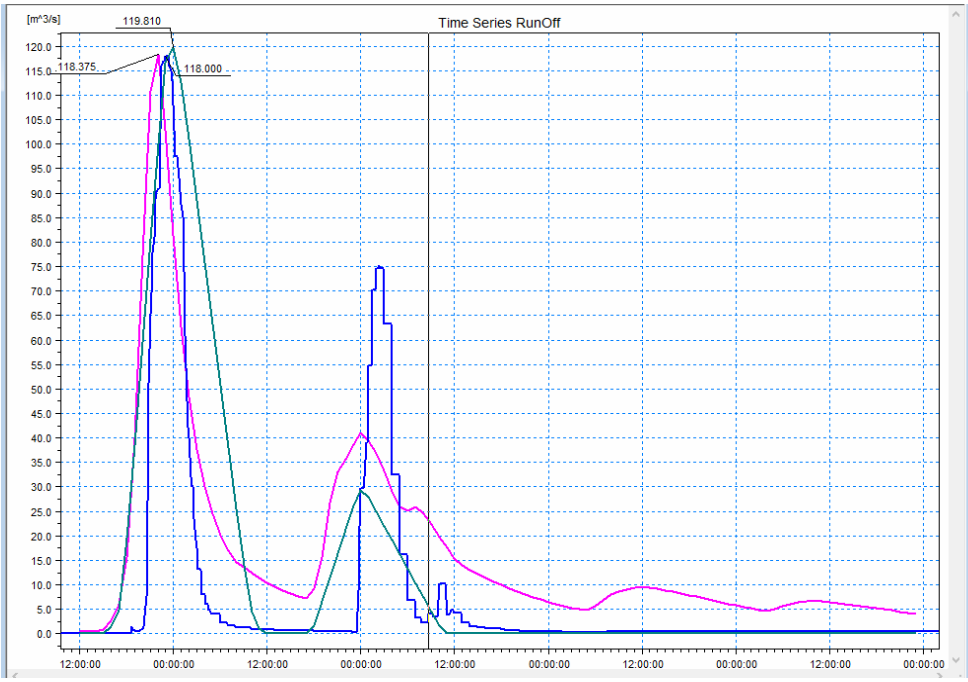


Fig. 7 – Comparison between discharge hydrographs
(simulated with *NAM*, simulated with *UHM* recorded)

Once the parameters are calibrated, both models can be used in the future to forecast a discharge hydrograph based on estimated radar precipitations in the catchment.

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