DOI: 10.29302/Pangeea 19.06

SURFACE RUN-OFF TYPE METHODS FOR MODELING FLOODS

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ABSTRACT: *In practice, for small river basins, surface run-off methods are used to simulate extreme hydrological events such as floods. This paper presents the following methods: the unitary hydrograph method and the Mike11-HUM model, which have been calibrated using some computation examples. Once calibrated, they can be used for the analyzed river basins, but also for other river basins with similar physical and geographic conditions.*

Keywords: *run-off; river basins; hydrological; floods; hydrograph; geographic; Mike11-HUM, modeling*;

1. Introduction

In hydrology, different situations may arise when basic data used in the statistical processing for obtaining hydrological elements (maximum flows, flood hydrographs, volumes, etc.) used in the design, construction and operation of hydro-technical works and water management are insufficient or lacking.

For example, there are hydrometric stations where measurements and observations have been made with interruptions or for too short a period of time to be applied in the mathematical statistics methodology. In some situations there are no measurements and observations, and there is not enough time to organize them, and yet some hydrological elements in the studied hydrographic basin have to be established. As a result, we turn to mathematical methods and models (R. Giurma-Handley, 2017).

For very small hydrographic basins with areas under 10 km2, the rational formula can be used to establish the maximum flow with the probability of calculation (R. Drobot, I. Giurma, 1990). The maximum flow rate with the desired exceedance probability for hydrographic basins of more than 10 km2 can be determined by the reductionary formula (C. Diaconu et al., 1995). For hydrographic basins with areas larger than 30 km2 , the volumetric formula is used (S. Hâncu et al., 1971).

Applying these methods implies making some approximations, and therefore it is necessary to apply and verify them on basins that are hydrologically similar to the one studied.

For so-called small-scale hydrographic basins (100 km2 $\leq$ F $\leq$ 500 km2), drainage type methods and tank-type methods are applied. Within these basins the precipitation is considered to be uniformly distributed over their surface and they are considered to be homogeneous from a physico-geographical point of view; only the phenomena of rainfall bening transformed into river system flows are modeled, without the movement of flood waves through the water bed.

The drainage type methods that are the subject of this paper only study the component of the surface leakage. These models assume that the parameters used are constant across the entire hydrographic area, thus they are models with global parameters.

The drainage type methods follow the following two steps (P. Şerban, 1984; Al. Stănescu, 1983): evaluation of the net precipitation and its integration. The evaluation of the net precipitation is done through a series of mathematical models (P. Şerban, 1989), of which the most used model is the SSAR model (D. Rocwood, 1981). Integrating net precipitation consists in integrating it into the surface flow rate with a weight function or core functions, called the unitary hydrograph or isochron hydrograph (R. Drobot, I. Giurma, 1990). The paper will address: the unitary hydrograph and the Mike 11 HUM model (unitary hydrograph) that is an alternative to the NAM tank model for simulating external hydrological events such as floods.

2. The unitary hydrograph

The unitary hydrograph represents the response of the water basin to a net precipitation of 1 mm, uniformly distributed over the surface of the basin and having length Δt;this is defined by the ordinances:

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

where u_i is ordinance HU at time i; n_u is the number of ordinances 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 quantization step Δt.

Instantaneous HUI is a parametric model of the unitary hydrograph. The most used function for expressing HUI is the 2-parameter Gamma function (R. Drobot, I. Giurma, 1990).

The unitary hydrograph (HU) usually uses the least squares method to determine its parameters, which consists in minimizing the squares of errors (deviations between measured and calculated flow values) (R. Drobot, I. Giurma, 1990):

$$\min z = \sum_{i=1}^{n_Q} (Q_i^c - Q_i^m)^2 \quad (3)$$

where n_Q is the number of hydrograph ordinances of the measured flow taken at Δt distances (the quantization step).

The value of the calculated flows is given by the formula:

$$Q_i^c = \sum_{j=1}^{j} U(i \cdot \Delta t - j \cdot \Delta t + \Delta t) \cdot P(j \cdot \Delta t) \cdot \frac{F}{3{,}6} \quad (4)$$

where P is the net precipitation, and $j = min\ (i; n_p)$.

Calculated flows are introduced into the expression of the z function and its derivatives are canceled in relation to the ordinances ui= u (i, Δt) of the unitary hydrograph; the linear equations system obtained is solved and the unitary hydrograph ordinances are calculated. For example, the case of a precipitation with np= 3 and admitting nu= 5 results in:

$$n_q = n_p + n_u - 1 = 7 \quad (5)$$

The transformation factor F / 3.6 is included in the value of the precipitation P and results in (I. Vladimirescu, 1978):

$$\begin{aligned}
t &= 0 & &\rightarrow & Q_0^c &= 0 \\
t &= 1\Delta t & &\rightarrow & Q_1^c &= u_1P_1 \\
t &= 2\Delta t & &\rightarrow & Q_2^c &= u_2P_1 + u_1P_2 \\
t &= 3\Delta t & &\rightarrow & Q_3^c &= u_3P_1 + u_2P_2 + u_1P_3 \\
t &= 4\Delta t & &\rightarrow & Q_4^c &= u_4P_1 + u_3P_2 + u_2P_3 \\
t &= 5\Delta t & &\rightarrow & Q_5^c &= u_5P_1 + u_4P_2 + u_3P_3 \\
t &= 6\Delta t & &\rightarrow & Q_6^c &= u_5P_2 + u_4P_3 \\
t &= 7\Delta t & &\rightarrow & Q_7^c &= u_5P_3 \\
t &= 8\Delta t & &\rightarrow & Q_8^c &= 0
\end{aligned} \quad (6)$$

error z is:

$$\begin{aligned}
z = {} & (u_1P_1 - Q_1^m)^2 + (u_2P_1 + u_1P_2 - Q_2^m)^2 + \\
& +(u_3P_1 + u_2P_2 + u_1P_3 - Q_3^m)^2 + \\
& + (u_4P_1 + u_3P_2 + u_2P_3 - Q_4^m)^2 + \\
& +(u_5P_1 + u_4P_2 + u_3P_3 - Q_5^m)^2 + \\
& + (u_5P_2 + u_4P_3 - Q_6^m)^2 + (u_5P_3 - Q_7^m)^2
\end{aligned} \quad (7)$$

The derivatives of z with respect to the unknown ui are calculated and are canceled.

$$
\begin{aligned}
&\frac{\partial z}{\partial u_1} = 2(u_1P_1 - Q_1^m)\cdot P_1 + 2(u_2P_1 + u_1P_2 - Q_2^m)\cdot \\
&\quad \cdot P_2 + 2(u_3P_1 + u_2P_2 + u_1P_3 - Q_3^m)\cdot P_3 \\
&\frac{\partial z}{\partial u_2} = 2(u_2P_1 + u_1P_2 - Q_2^m)\cdot P_1 + \\
&+ 2(u_3P_1 + u_2P_2 + u_1P_3 - Q_3^m Q_3^m)\cdot P_2 + \\
&+ 2(u_4P_1 + u_3P_2 + u_2P_3 - Q_4^m)\cdot P_3 = 0 \\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
&\frac{\partial z}{\partial u_5} = 2(u_5P_1 + u_4P_2 + u_3P_3 - Q_5^m)\cdot \\
&\quad \cdot P_1 + 2(u_5P_2 + u_4P_3 - Q_6^m)\cdot P_2 + \\
&\quad + 2(u_5P_3 - Q_7^m)\cdot P_3 = 0
\end{aligned}
\tag{8}
$$

The result is a linear system relative to the unknowns ni,after solving the system we find the unitary hydrograph ordinates. With the help of these values, the hydrographic ordinates Qic can be calculated for a precipitation P on the surface of the hydrographic basin F taken into study.

The isochron hydrograph is another model for calculating the flow in the network produced by the surface leakage (R. Drobot, I. Giurma, 1990).

The unitary synthetic hydrograph has the same expression as the unitary hydrograph and the same meaning; it is defined for hydrographic basins that do not have direct data from records; in order to construct these hydrographs, the hydrological synthesis of unitary hydrographs from a large territory, including the basin studied (R. Drobot, I. Giurma, 1990; P. Şerban, 1978) is used.

Separate application of the models to evaluate leakage parameters and their integration is easy in practice, but presents some theoretical disadvantages.

In specialty literature (R. Drobot, I. Iorgulescu, 1979) a model composed of two steps is presented: in the first step an analytical expression is deduced for the curves SSARR, and in the second step, this function together with the expression obtained by Nash , for the unitary hydrograph is used in the numerical simulation model of the rain-flow process in order to identify the parameters; the model performs both the simulation of the surface drain transformation mechanism and the optimization of the parameters, thus being a dynamic optimization model.

3. Model Mike 11 - HUM; computational example

The Mike 11-UHM model (unitary hydrograph) is an alternative to the NAM tank model for simulating extreme hydrological events such as floods. The model divides flood-generating rain into excess rain (net rain) and leakage (infiltration).

Figure 1 and Figure 2 shows the Mike 11-UHM parameter selection menu. In the first phase, an adjustment is made to the water basin surface on which the flood generating rain is received that will generate the flood hydrograph if there are differences from the initial settings used for composing the time series for the rain (adjustment factor different from 1.0) (I. Christmas, CR Giurma Handley, 2014).

Also, a base leakage constant is set, that will be added to the surface leakage.

The evolution in time of the flow can be described in different ways:

- as a SCS (Service of Soy / Conservation, USDA), whereby the time it takes to achieve maximum flow (the peak of the hydrograph) is considered to be half of the rainfall duration plus the duration between the rainfall core and the peak time (tl);

- reduced SCS hydrograph, derived from a number of unitary hydrographs related to the basin with different sizes and locations. The value of the flow is expressed in Q/Qp where Qp is the maximum flow and the time given in T/Tp, where Tp is the total time at which the maximum flow is reached.

Let us consider the flood from 11.02.2010-15.02.2010 registered on the Tinoasa River. The precipitations that fell during this period and where recorded at the Ciurea meteorological station and the flow measured over the same period are shown in Figure 3 (I.Crăciun, CR Giurma Handley, 2014).

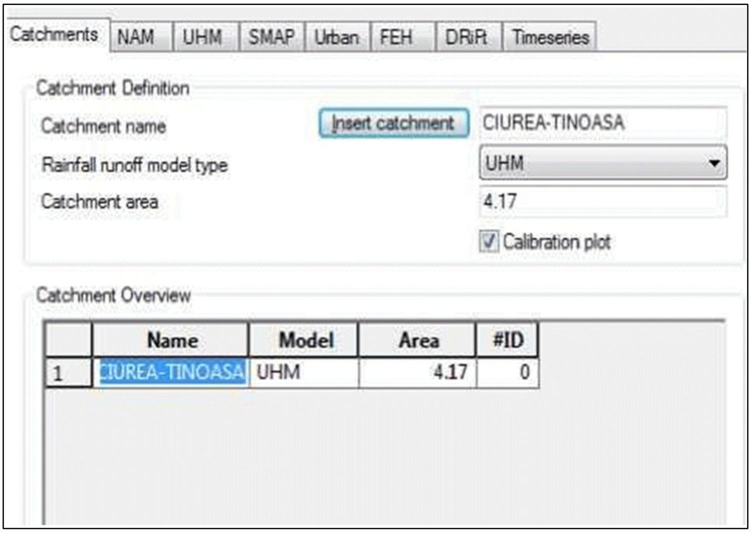

Fig. 1. Mike 11-UHM initialization menu

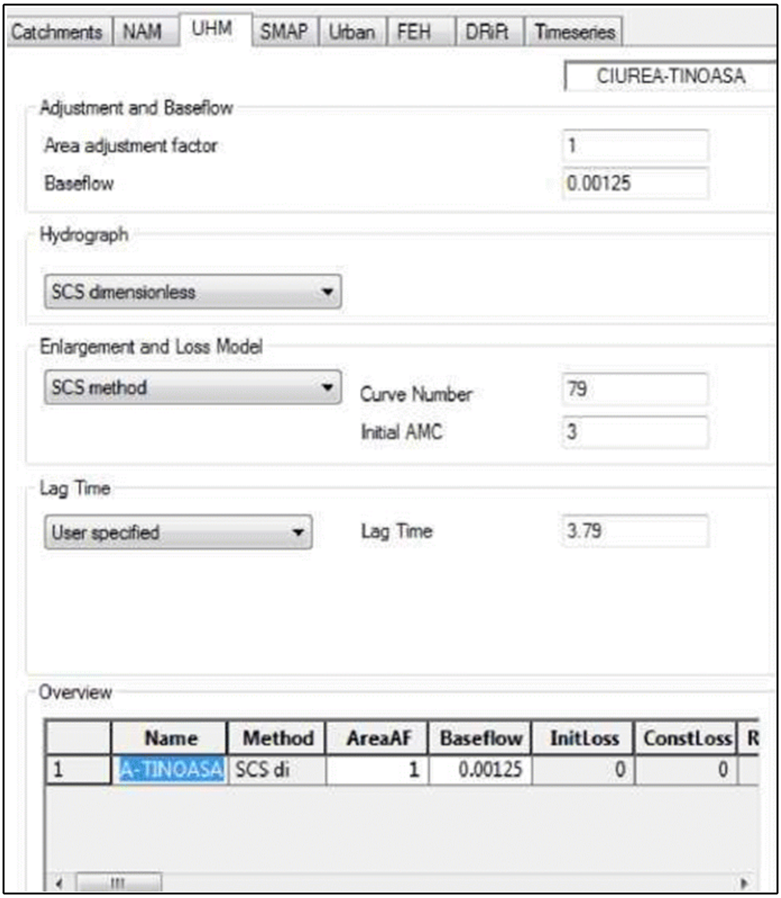

Fig. 2. Mike 11-UHM Parameter Selection Meniu

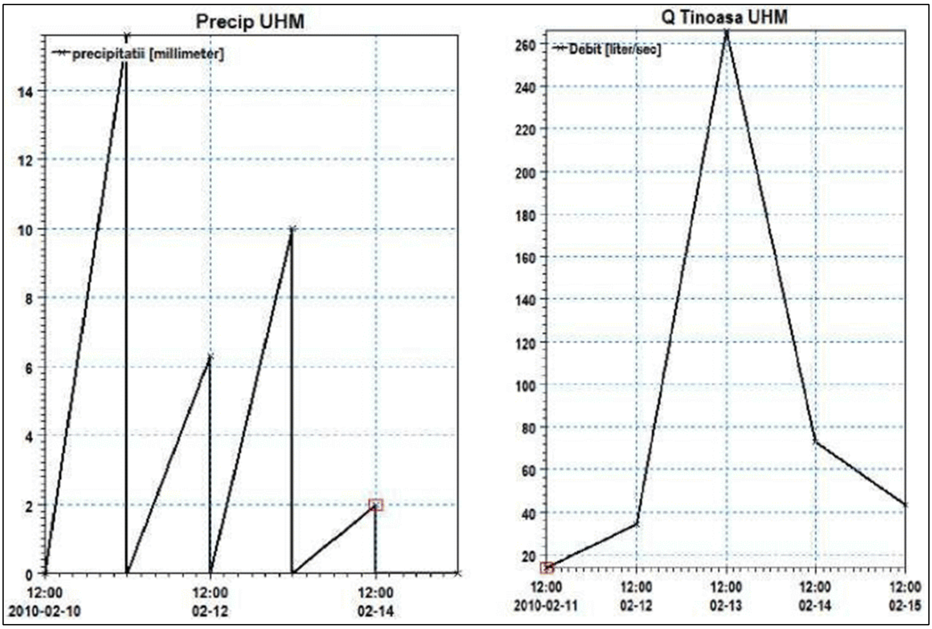

Fig. 3. Left: Evolution of the rain; right: the evolution of the flow
(during the period 11÷15.02.2010 in the Tinoasa-Ciurea basi)

The simulation was performed on the assumption that the soil conditions in the basin lead to initial losses due to interception, storage in surface depressions of 1.21 mm, and infiltration losses during the rainfall are constant and have a value of 0.18 mm, and the time difference between the rainfall core and the maximum flow rate is 5.66 hours.

Figures 4 to 8 show the flow rates (m^3/s), net rain (mm/h), excess rain (mm/h) and rainfall loses (mm/h) as well as the graphsfor comparing flow m3/s and volumes (m^3) simulated and measured for the flood of 11÷15.02.2010 in the Tinoasa-Ciurea basin (Ion Crăciun, Catrinel Raluca Giurma-Handley, 2014).

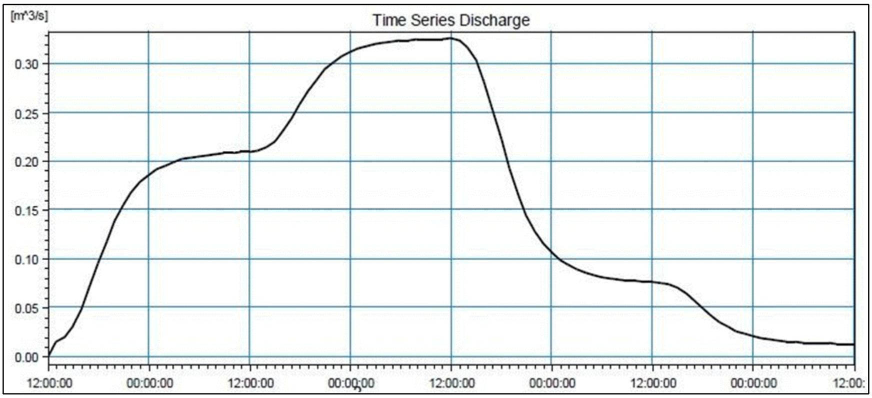

Fig. 4. Simulation of the flow (m3/ s) by the UHM mode for the flood from 11÷15.02.2010 in the Tinoasa-Ciurea basin with the assumption of proportional losses

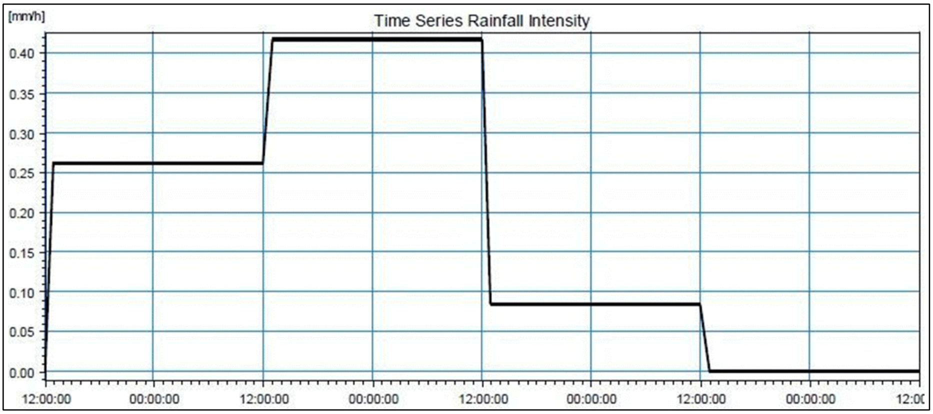

Fig. 5. Evolution of net rainfall (mm / hour) by UHM mode for the flood from 11÷15.02.2010 in the Tinoasa-Ciurea basin with the assumption of proportional losses

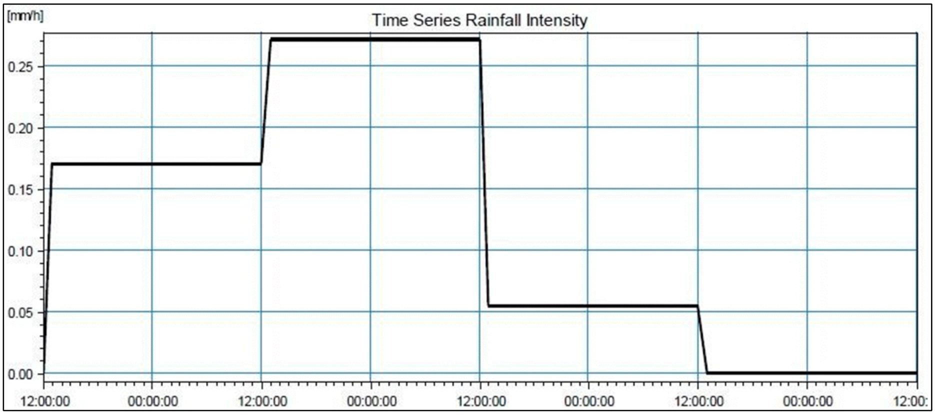

Fig. 6. Evolution of excess rainfall (mm / h) by UHM mode for the flood of from 11÷15.02.2010 in the Tinoasa-Ciurea basin with the assumption of proportional losses

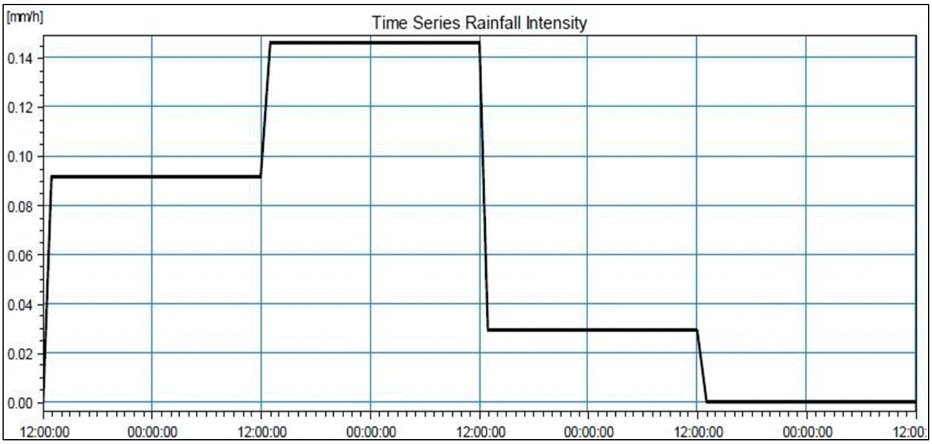

Fig. 7. Evolution of losses (mm / hour) by UHM mode for the flood from 11÷15.02.2010 in the Tinoasa-Ciurea basin with the assumption of proportional losses

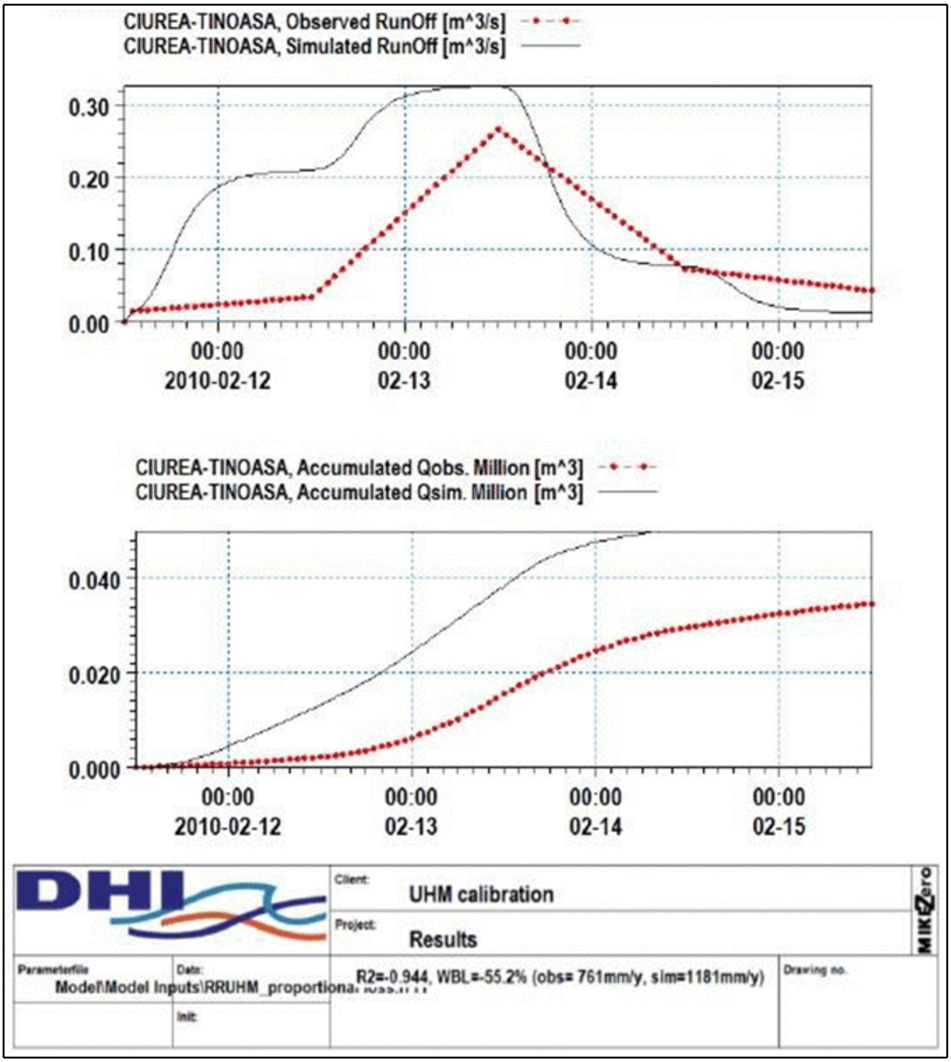

Fig. 8 is a graph comparing the simulated flow (m3/ s) and volume (m3) of the flood from 11÷15.02.2010 in the Tinoasa-Ciurea basin with the assumption of proportional losses

4. Conclusions

a) Since in many points of a hydrographic network hydrometeorological measurements are not carried out for certain reasons, especially reasons of an economic nature, when necessary, the required hydrological elements in those points are established by means of expedient methods including the following: rational, reductive and volumetric formulations; they lead to solutions that are influenced by higher or lower approximations depending on the existing material and the experience of the the one applying the methods.

b) For so called small hydrographic basins (100 km2 ≤ F ≤ 500 km2), methods of drainage type methods are applied, namely: the unitary hydrograph method and the Mike 11 - HUM model; these methods only model the mechanism of rainfall being transformed in the hydrographic network flow without the movement of flood waves through the water bed.

c) The unitary hydrograph method uses, as a rule, the least squares method for determining the parameters, which consists in minimizing the square of error squares, ie the deviations between measured and calculated flows; after model calibration, this method has the advantage over rational, reductive and volumetric formulas that allow flood simulation.

d) The Mike 11-UHM model also allows simulation of external hydrological events such as floods; for an analyzed river basin, once calibrated, the model can be used for both the analysed basin and other hydrographic basins with similar physico-geographic conditions.

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