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# MODELING IN HEC-RAS AND HEC-GEO RAS OF THE EXTRAORDINARY FLOOD FROM 1995, PASSED THROUGH THE IMPOUDMENT SOMEŞUL RECE 1 (NORTH-EAST OF THE APUSENI MOUNTAINS)

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**Abstract**

This paper presents the results of a reconstruction by computer modeling of a historic flash flood, which was passed through the reservoir Someşul Rece 1, from the homonym basin, located in the north-east of the Apuseni Mountains. The modeling of the floodplain area downstream of the dam, was achieved in the variant 1D using the software HEC-RAS 5.0.3 developed by the Hydrologic Engineering Center (U.S. Army Corps of Engineers). As the flood has an obvious spatial character, GIS software such as ESRI ArcGis and HEC-GeoRAS were used, both in determining and defining the hydrographic elements (channel, talveg, banks, etc.), and in the representation of the results. Moreover, the modeling was the basis for several maps of the most exposed floodplain areas, which permitted the reconstruction of the unusual spatial expansion of the flood in the downstream. The simulation results were also used to determine the channel capacity in the prospect of future flash floods.

**Keywords:** extraordinary flash flood, HEC-RAS, Someşul Rece river, resevoir, floodplain, simulation.

## 1. INTRODUCTION

### 1.1. The literature on modeling in the HEC-RAS

The movement of flood waters through the landscape can be approximated using many different methods. Describing natural physical phenomena using numerical methods requires making broad assumptions to develop governing equations. While simple hydraulic modeling methods may be sufficient for approximating propagation of flood peaks through river channels, more complex hydraulic analyses may be necessary to incorporate effects of infrastructure or complex overland flow. Advanced models are capable of modeling more detailed physical phenomena, but this does not correspond to a decrease in uncertainty.

Numerous mathematical methods for calculating the extent of a river (according to its flow rate, the water infiltration rate into the soil, land use etc) have been developed. These mathematical models have been integrated into GIS software, whose purpose is to create a model that would replicate the shape of the landscape as precisely, as possible (Edsel et al., 2011).

The flood risk maps have the clear purpose of identifying vulnerable areas and the population that is exposed in a certain region; they represent an useful tool for urban planning, for interdicting the construction of houses in the affected areas and creating management plans for emergency situations, as close as possibly to the probabilities of certain events of this type (Iosub et al., 2014).

The existing hydrological models are numerous. In 1991, there were 65 known hydrological models, and over the years, this number has risen, but attention has been directed only to the most important (Edsel et al., 2011). Therefore, in 1995, Singh counted and considered 26 to be the most used worldwide (Singh and Fevert, 2006). In 1998, The Subcommittee for Hydrology of the Interagency Advisory Committee for Water Data has indexed models created and used by state institutions in the USA, which were synthesised by Wurbs, in 7 cathegories (Wurbs, 1998). In 2002, Singh and Fevert published two books, in which they have discussed about 38 models, and in 2006, 24 more models have been added to the list.

HEC-RAS is a software for one-dimension or two-dimensions simulations of flood development, which could have a steady or an unsteady flow rate, sediment transport, change of the channel etc. The name "HEC-RAS" is derived from the creators of the software: Hydrologic Engineering Center, which stands as a subdivision of the Institute of Water Resources, U.S Army Corps Of Engineers (HEC), and "RAS" an acronym from "River Analysis System".

The software itself, has four main river analysis possibilities: the steady flow rate at the surface of a considered river profile; simulation of an unsteady flow of water; calculations of the sediment transport and modifications of the river bed; and analysis of the water quality (U.S. Corps of Engineers, 2003, Tate et al., 1999). When using the HEC-GeoRAS extension, the data can be easily introduced into the equation, and the results can be exposed through hydrological risk maps (Merwade, 2016). Flood peak attenuation caused by storage of flood water on overbank surfaces effectively reduces the magnitude of peak discharges in some, but not all watersheds (Woltemade and Potter, 1994). The HEC-RAS model simulates the flow in river channels and in flood-prone areas, being considered an effective model in simulating the effects of the floods.

Software HEC-RAS is based on solving the fundamental Saint-Venant equation of continuity and the moment.

$$\frac{\partial AT}{\partial t} + \frac{\partial Q}{\partial x} - qI = 0$$

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + gA\left(\frac{\partial z}{\partial x} + Sf\right) = 0$$

where: $z$ = elevation of water surface, m; $A_T$ = total flow area, $m^2$; $Q$ = flow, $m^3 \cdot s^{-1}$; $q_I$ = lateral inflow per unit length, $m^2 \cdot s^{-1}$; $S_f$ = friction slope; $V$ = flow velocity, $m \cdot s^{-1}$.

Equations with partial derivatives (Barkau, 1982) are the basis for the calculation solution for unsteady flow in HEC-RAS. The numerical solution of these equations is given by using the finite differential method (Bruner, 2008).

**Basic data necessary for the hydrodynamic model HEC-RAS**

Ackerman and Brunner in his ”*Dam failure analysis using HEC-RAS and HEC-GeoRAS”*, published in 2006 in the conference volume of the ”Third Federal Interagency Hydrologic Modeling Conference”, argue that a model of the river hydraulics will be as good as the data and personnel used to develop it.

Detailed information on the low-flow channel and floodplains is the main data required for the creation of a river hydraulic model (United States Army Corps of Engineers - USACE, 2016).

Data on the use of land (used for the estimation of the Manning’s roughness coefficients) and information on the water engineering structures (bridges, dams, retaining walls, etc.) are also essential for creating a complete river hydraulics model (Red and Cretu, 1999).

Topography plays a major role in the accurate determination of flood-prone areas, and for this determination a good resolution of the landscape in the form of MNT (Numerical Model of the Land) is necessary (Drobot and Serban, 1999; Șerban et al., 2016).

*Topographic Data*

In the modeling of flash floods and historic floods topographic data specific for the entire flood-prone area is required. The importance of this data should not be underestimated. The topographic surface that should be modeled includes not only the floodplains, but also the ascending slopes, above the normal levels of the floods. Another requisite are details on the major structures which can cause a flow obstruction, such as bridges, footbridges, road embankments, riverain civil buildings and the most important river control structures.

Knowledge of typical flow conditions and modeling parameters, such as the roughness of the river bed and of the flooded floodplain, is relatively good. For historical flash floods there is limited calibration data, and the flooded land is in areas outside the normal floodplain, which makes it difficult to estimate the roughness and other input parameters.

*Flow Data*

Boundary conditions are required for running a hydraulic model. In an analysis of subcritical flow, the boundary conditions are only required at the river system downstream end. In an analysis of supercritical flow, the boundary conditions are required only at the river system upstream end. In a mixed flow regime boundary conditions will be mapped out at the open ends of the river system (Serban and others, 1989).

Routing the inflow data through a reservoir

HEC-RAS can be used to route an inflowing hydrograph through a reservoir with any of the following three methods (US Army Corps of Engineers, 2014):

- one-dimensional unsteady flow routing (full Saint Venant equations);
- two-dimensional unsteady flow routing (full Saint Venant equations or Diffusions wave ecuations);
- level pool routing.

Generally, full unsteady flow routing (one-or two-dimensional) will be more accurate for both the with and without breach scenarios. The unsteady flow routing method can capture the water surface slope through the pool as the inflowing hydrograph arrives, as well as the change in water surface slope that occurs during a breach of the dam (US Army Corps of Engineers, 2014). In this study, we have used the most accurate methodology - full dynamic wave (one-dimensional unsteady flow routing - full Saint Venant equations). To model the reservoir using full dynamic wave routing with HEC-RAS, we have modelled the pool with one-dimensional cross sections throughout the entire reservoir.

*Catchment Hydrology*

The inflow hydrograph, the reservoir condition at the transit time of the maximum flow and the basic downstream flow conditions can be combined to have a significant effect on the flooding scenario, depending on the size and the nature of the reservoir and dam.

*Boundary Conditions*

In this analysis, the boundary condition for upstream, is the inflowing flood hydrograph produced with the probability of a maximum discharge of 1.34 %, and the boundary condition for downstream is the normal depth. This option uses Manning's equation to estimate a level for each calculated discharge. To use this method, one must enter a friction slope near the boundary condition downstream.

The limnimetrics key is another option, which is used as a boundary condition for downstream. The lateral inflow hydrograph is used as an internal boundary condition. This option allows the user to bring in flow at a specific point along the stream.

### 1.2. The study area and general information on the watershed improvement

Someş Rece River (Fig. 1) forms by confluence with the river Someşul Cald River in the Gilău Lake the Someşul Mic River. The water course has a length of 49 km and springs from the massif of Muntele Mare massif as the brook Zboru at 1560 m, on the territory of Cluj county.

The associated watershed, positioned between the basins of Somesul Cald and Valea Ierii, overlaps largely with the massifs Muntele Mare and Gilău, from the north-east of the Apuseni Mountains. The drainage surface is of 327 km$^2$ and the average altitude of 1214 m (Cadastral Atlas of the Waters in Romania, 1992).

The natural conditions in the upper basin of Someşul Mic River, favored a large-scale hydraulic engineering improvement, that turned to advantage a part of the natural potential available in the area (Fig. 1). The 860 km$^2$ in the vicinity of the Gilău dam were subjected to spatial planning starting the end of the 60s. In this sense, four large reservoirs were engineered in the valley of the Someşul Cald River (Fântânele, Tarniţa, Someşul Cald and Gilău) as well as a few intake outlets and adductions intended for supplementing the inflow to the four lakes, in the basin of Someşul Rece (Serban, 2007).

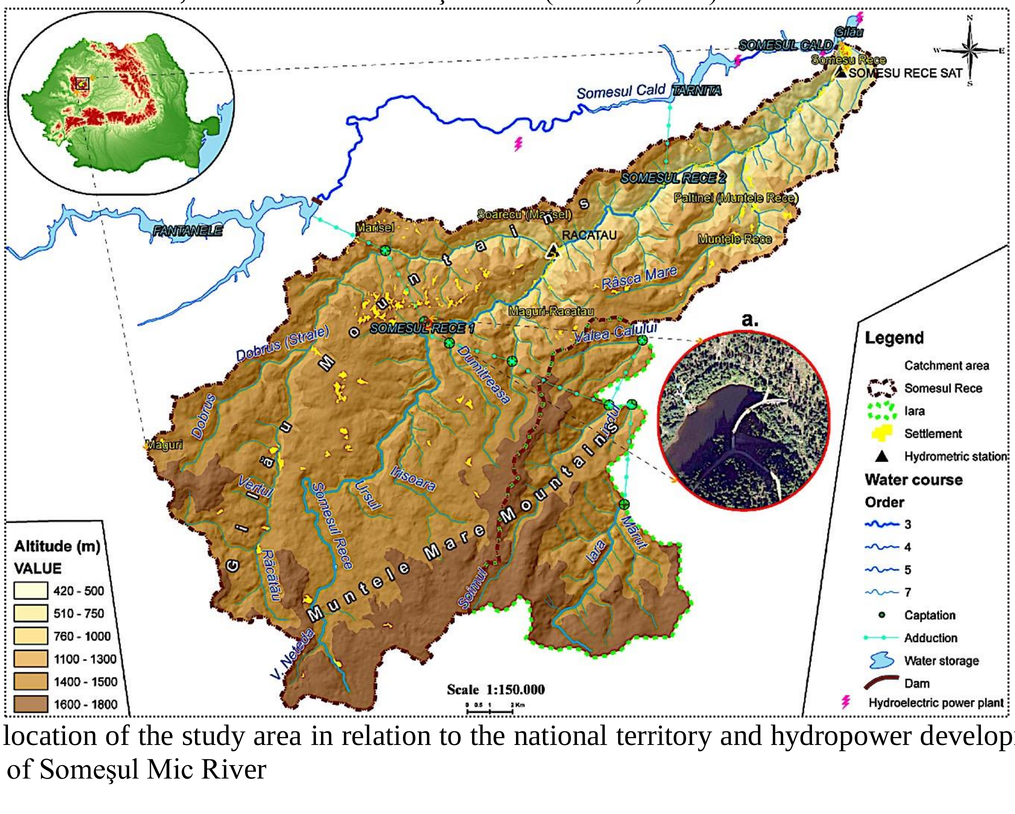



**Fig. 1.** The location of the study area in relation to the national territory and hydropower development of the upper basin of Someşul Mic River

The improvement was extended beyond the water divide which separates the basins of Somesul Mic River and Arieş River, by creating more captations and adductions in the upper basin of the Iara River. The resulting water was also directed into the reservoir on the Someşul Cald River (Fig. 2).

In the first phase (1968-1980) the largest reservoirs have been completed. The first inaugurated reservoir was Gilău, in 1972, followed by Tarniţa, in 1973 and Fântânele, 1976 (Serban, 2007). The work on the intake structures and the derivations from the basin of Iara and Somesul Rece were also started in this first stage while some of them were even brought into use (Somesul Rece II system).

In the second stage (1980-1990) the improvement of Somesul Cald River was completed as well with the deployment of the homonym reservoir (1983). The main axis of the secondary improvements is Iara-Fântânele, the adduction of this system having a total length of 21 km, of which: 4.7 km between the intake structures Iara and Şoimul, 4,9 km between Şoimul and Negruţa, 4 km between Negruţa and Someşul Rece, 3.7 km between Someşul Rece and Răcătău and the same between Răcătău and the reservoir Fântânele (Pop, 1996).

The time elapsed in post-setup period proved that the adductions and intake outlets do not offer protection against flash floods for the downstream settlements. Those 4,89 $m^3/s$, captured on average in the basin of Someşul Rece and even the maximum of 27.8 $m^3/s$, can not significantly reduce the threat of flooding, in case of flash floods with a high discharge whose flood return probability is below 10% (Şerban et al., 2009).

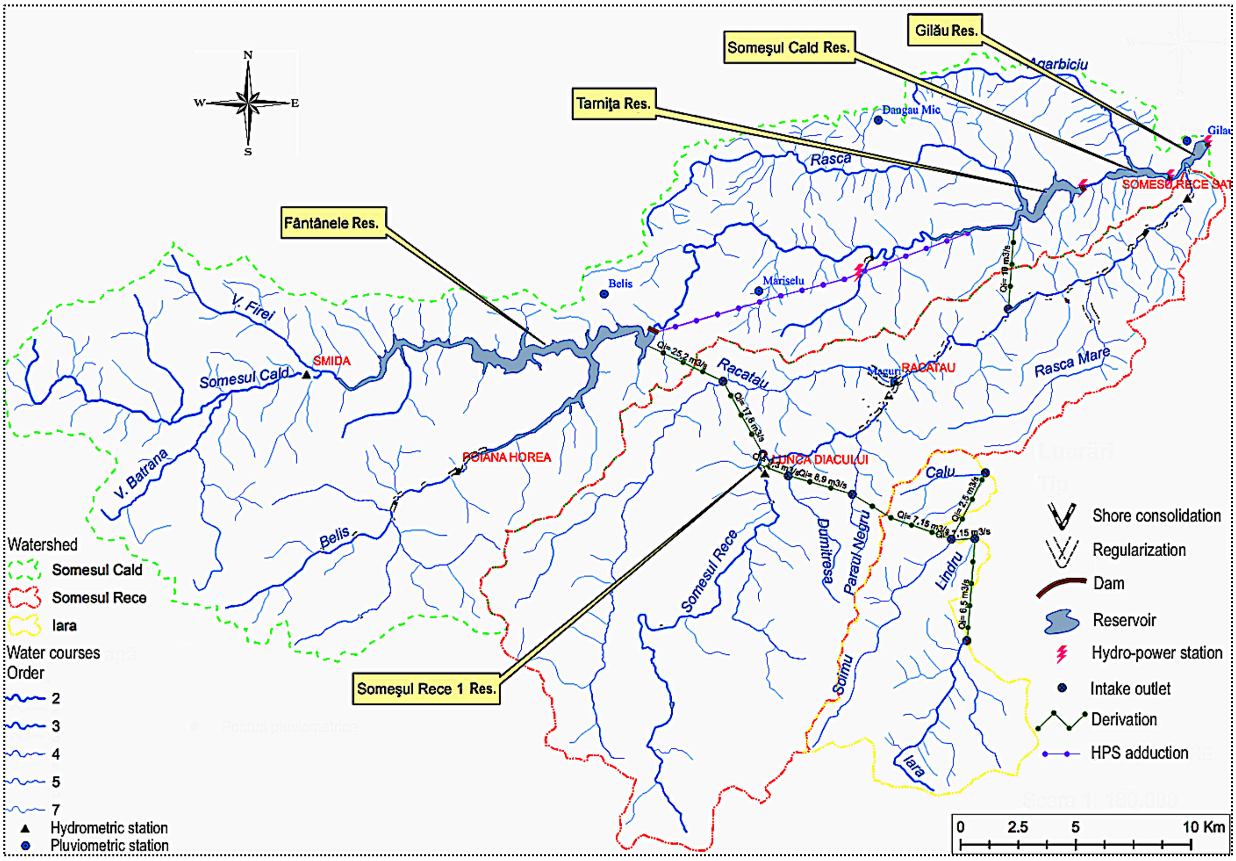



**Fig. 2.** The Someşul Mic upper basin hydropower improvement

The Someşul Rece I Dam (Fig. 1a) is located in Cluj county on the homonym river upstream of the Măguri-Racătău village and about 40 km upstream of Cluj-Napoca. The dam is under the administration of S.C. Hidroelectrica S.A. - Branch of Hydroelectric Power Stations Cluj. The construction is a double curvature dam, being one of the largest dams with a secondary role in a complex hydropower system in Romania. Its dimensions are the following: 43.5 m height, a length at the crest of 119.5 m (the crest level at 1024.5 m-M) and encompasses a concrete volume of 50,000 $m^3$ (Exploitation Regulation of Fântânele Reservoir - A. B. A. "Somes-Tisa", 2010).

The Someşul Rece I Dam is located in the gorge section of Someşul Rece, with steep slopes on both sides and a general symmetry of the valley. The foundation terrain of the dam is composed of tough and healthy volcanic rocks, namely the border areas of Muntele Mare. The construction is made of of 14 consoles, of which 2 consoles form the high waters spillway, situated on the side. No dangerous geological phenomenon occured during the execution and exploitation.

The dam was the first and most important step in the improvement of Someşul Rece River, otherwise the only intake with storage, followed downstream by the captation structure Someşul Rece II (Fig. 2). The Someşul Rece I Dam was brought into use in 1977, thus after the Fântânele Dam (1976).

The Someşul Rece I Reservoir acts as simple simple intake with tyrolean outlet but which, due to fluctuating levels, has to accumulate a minimum of 0.2 million $m^3$ of water, so that the hydraulic agent can be conducted by gravity into the Fântânele reservoir.

The main functions of the Someşul Rece I Reservoir are:

- supplementing the inflow in the Fântânele Reservoir for generating electricity in hydropower plants located downstream on the Someşul Cald;
- partial attenuation of flood waves;
- recreation.

Flood mitigation is insignificant in the Someşul Rece I Reservoir, as the improvement was not designed with this purpose. However, it may temporarily detain a volume of 0.74 million. $m^3$ between the 981,00 m-BS and 1020,5 m-BS (the last value is Normal Retention Level) and a volume of 0.26 million. $m^3$ between 1020,5 m-BS and 1024,00 m-BS (Maximal Retention Level), the rest of the flow being transited through the adduction outlet, respectively through the bottom and high waters outlets.

## 2. MATERIALS AND METHODS

The data used in the analysis consists of both technical as well as hydrological data, taken from the archive of the "Someş-Tisa" Water Basin Administration Cluj and from the archive of the Faculty of Geography, Babeş-Bolyai University from Cluj-Napoca.

Topographic maps at scale of 1:25000 and GIS software from the two institutions involved in this study were used for the realization of the cartographic material and for statistical processing.

The analysis of maximum discharge in influenced regime (IR) and in natural regime (NR), with different probabilities of exceedance, as well as the characteristic elements of the singular flash-flood waves type, for the main calculation sections on the Someşul Rece River, was made on the basis of data collected and conclusions drawn by the specialist departments from the "Someş-Tisa" Water Basin Administration Cluj. A maximum inflow into the reservoir of Qmaxaf 1,34% = 160,7 $m^3$/s and a maximum outflow rate of Qmaxdf 1,82% = 146 $m^3$/s were taken into account.

Data on the inflow hydrograph in the reservoir was processed with the program CAVIS, developed in 2009 by Ciprian Corbuş in the laboratories of the National Institute of Hydrology and Water Management Bucharest, and the cartographic representations were carried out using licensed ArcGIS 10.x, in the two institutions mentioned above.

The detailed topographic data, the basis of all hydraulic calculations, consists of: the Digital Terrain Model (DTM) - resolution of 3 m, cross-sections and ground surveys for bridges on the Someşul Rece River (Fig. 3). They originate, largely, from within the project "Plan for the Prevention, Protection and Mitigation of Flood Effects in the River Basin Somes-Tisa", national project funded by "AXA 5 POS Mediu".

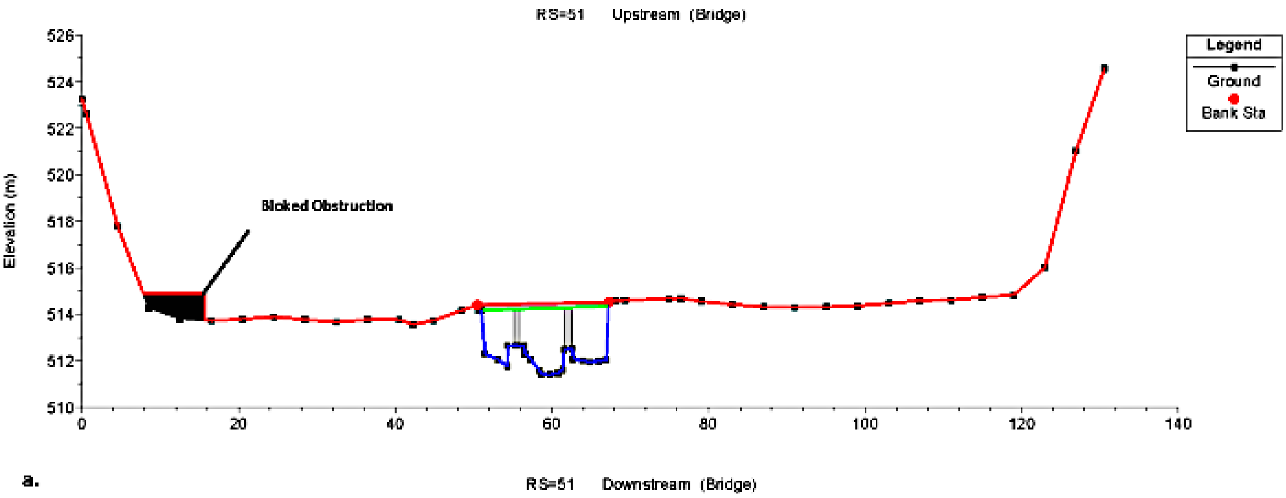



**Fig. 3**. Example of ground survey for a bridge introduced and processed in HEC-RAS (data source PPPDI-ABAST).

For three pilot sectors, of a particular importance and also very flood-prone, air measurements using techniques UAS have been and are still made in the summer season. Through these, we sought to obtain a superior Digital Terrain Model (DTM) resolution, which allows an exact monitoring of flood-prone areas.

In this study, the hydraulics analysis and the modeling of flooding caused by the historic flash flood have been realised using the software HEC-RAS and the extension HEC-GeoRAS. The Hydraulic Engineering Center – River Analysis System (HEC-RAS) was developed by the Hydrological Engineering Center of the United States Army Corps of Engineers (USACE).

The Corine Land Cover database, 2012, was used for for extracting the values of the Manning's coefficient.

Moreover, all constructions in the flood zone (houses, annexes, buildings) have been digitalized in advance, as they can have an obstruction role in the path of the flow. Taking into account the significant flooding potential, the study area was extended downstream from the dam up to the confluence of Someşul Rece with the Someşul Cald River in Gilău Lake.

The Somesul Rece valley on the previously mentioned sector, with a length of 29 km, was configured in the model through cross sections topographically determined at equidistance. In addition to the mentioned sections, other cross-sections were interpolated in the program HEC-RAS between the initial ones (Fig. 4).

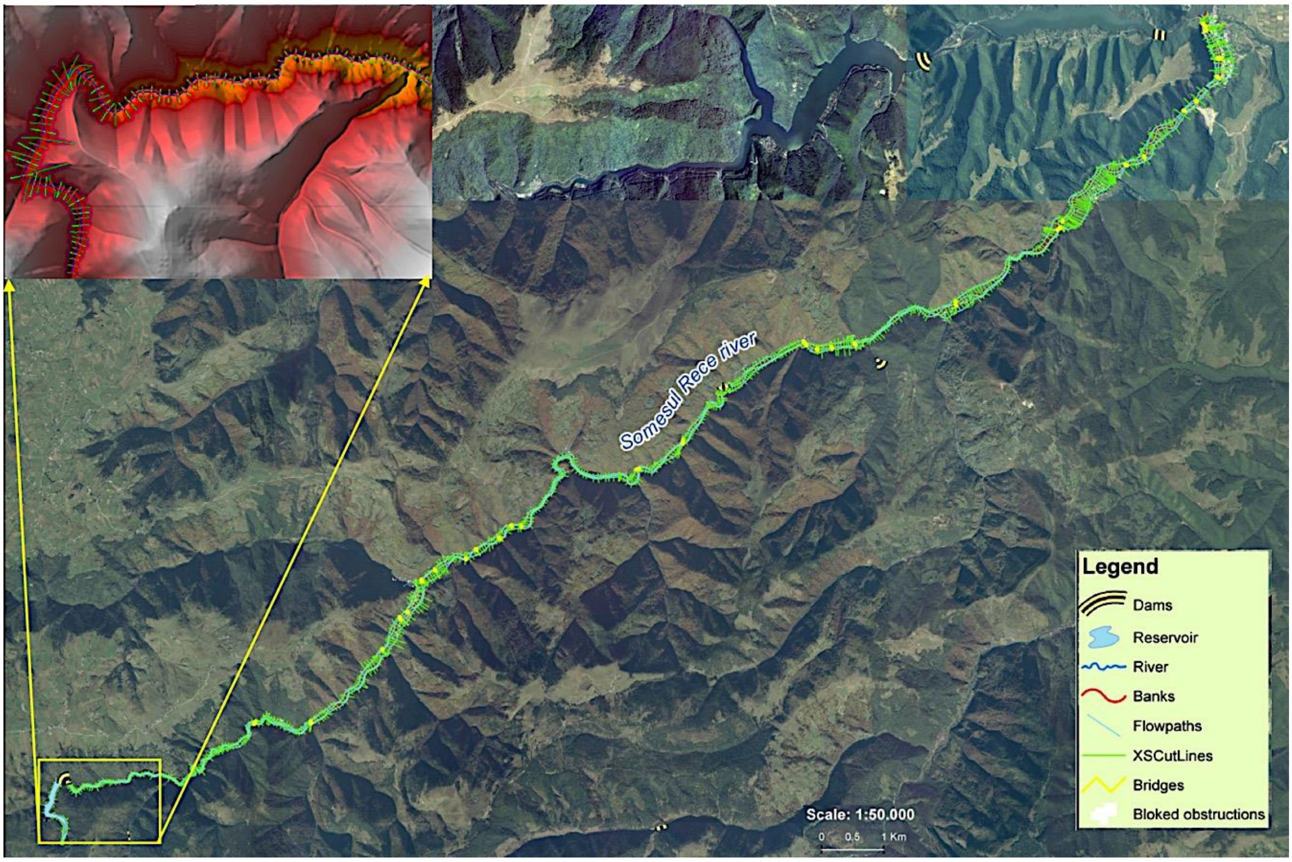



**Fig. 4.** The Somesul Rece valley with the pseudo-three-dimensional model of the terrain and example of the transverse profiles arrangement on the study section

Taking into account Manning's roughness coefficient for the low-flow channel and floodplain, values between 0,045 and 0,09 have been used depending on the peculiarities of the section. The hydraulic head loss, related to the riverbed expansion and contraction or to natural obstacles, is included in the model with coefficients of 0.3 and 0.1.

## 4. RESULTS

After completing the parameters setting and calibration in the control section of the gauging site Someşul Rece, the program has modeled the level of the free water surface and the inflow hydrographs, using a computation interval of one minute, which generates a very accurate hydrograph. A shorter time interval would generate an even more accurate hydrograph, but also a very large amount of data, while a longer interval of time would generate a less accurate hydrograph.

The flow develops the critical velocity on the downward slope, in this case the characteristics of the flash flood wave including: the maximum level, the discharge, the water level variations in reservoir, the average velocity per section (Fig. 5).

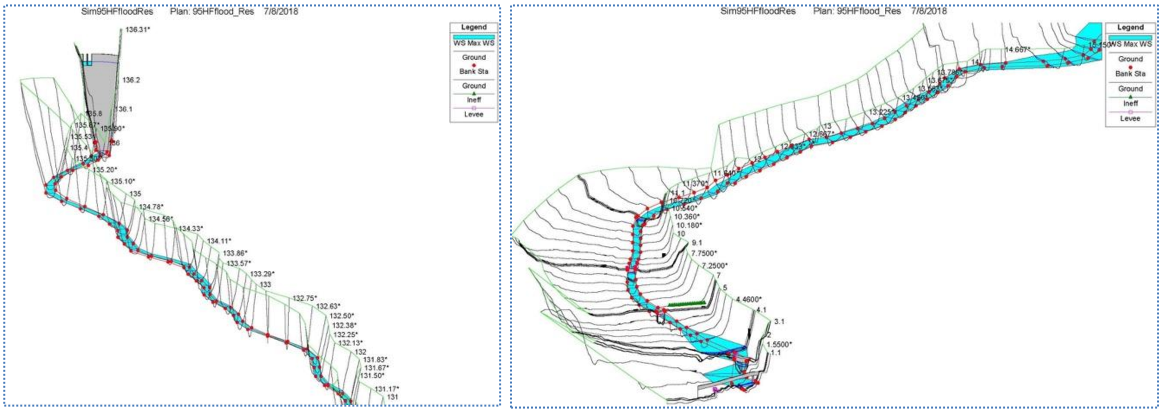


**Fig. 5**. Two 3D cross-section plots for the Someșul Rece River downstream of the dam and at Someșul Rece village gauging site

### 4.1. Features of the flash-stream hydrograph downstream of the dam and in the Someşul Rece village

The narrow couloir of Someşul Rece, downstream of the homonym reservoir has a gorge aspect, with numerous areas of narrowing or widening of the valley.

This, along with the elements of the high-flow channel roughness, reduced significantly the maximum discharge of the historic flash flood over the course of 29 km, from 146 $m^3/s$ (outflow from reservoir), to 98 $m^3/s$ at gauging site in the Someşul Rece village (Table 1).

**Table 1.** Maximum discharge, flood return probabilities and the flow coefficients of the historic flood from 1995 in the basin of Someșul Rece (according to the "Somes-Tisa" Water Administration, Cluj)

| Ctr. No. | River | Gauging site/Adduction outlet | Q max $m^3/s$ | Water-carrying capacity $Q_i$ adduction $m^3/s$ | Date | P (%) |
|---|---|---|---|---|---|---|
| 1 | Someșul Rece | Somesu Rece I Dam | 160.7 | | 27.12.1995 | 1.34 |
| 2 | Someșul Rece | Intake at Someșul Rece I Dam | 13.87 | 17.8 | | |
| 3 | Someșul Rece | Outflow SR I Reservoir | 146,0 | | 27.12.1995 | 1,82 |
| 4 | Răcătău | Intake at Răcătău Dam | 11 | 25.2 | | |
| 5 | Răcătău | Măguri-Răcătău* | 56,5 | | 27.12.1995 | 24,00 |
| 6 | Someșul Rece | Intake at Someșul Rece 2 Dam | 7.4 | 10 | | |
| 7 | Someșul Rece | Someşu Rece village* | 98,0 | | 27.12.1995 | 20,00 |

* the two gauging sites have been under the influence of upstream captation structures – Răcătău, respectively Someşul Rece II.

The simulated hydrographs of discharge revealed significant differences between the two control sections, the differences imposed by the hydraulic parameters of the valley (Fig. 6 a and b).

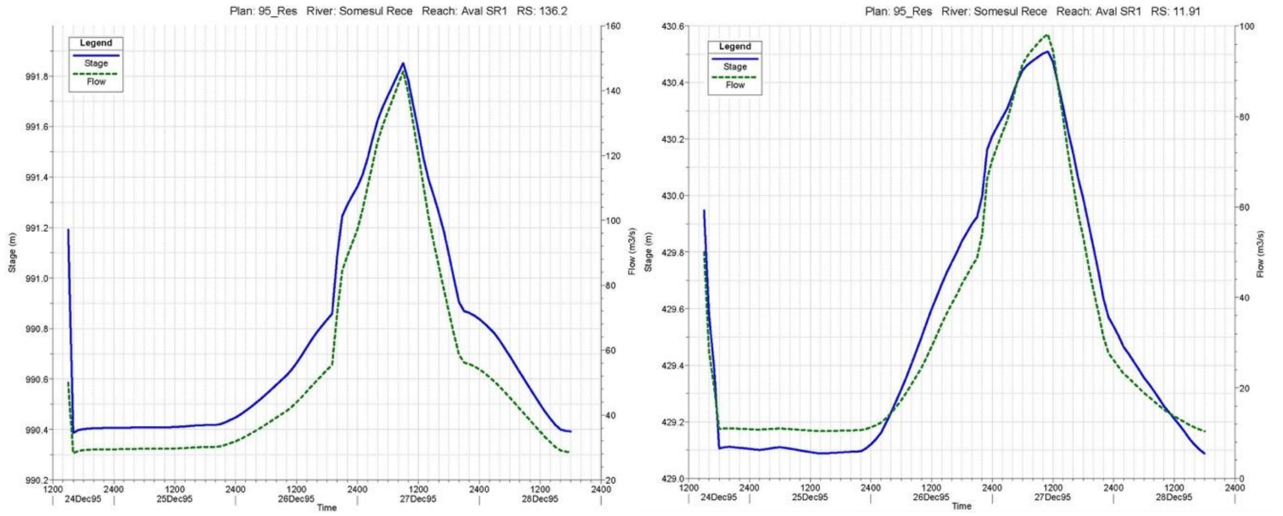
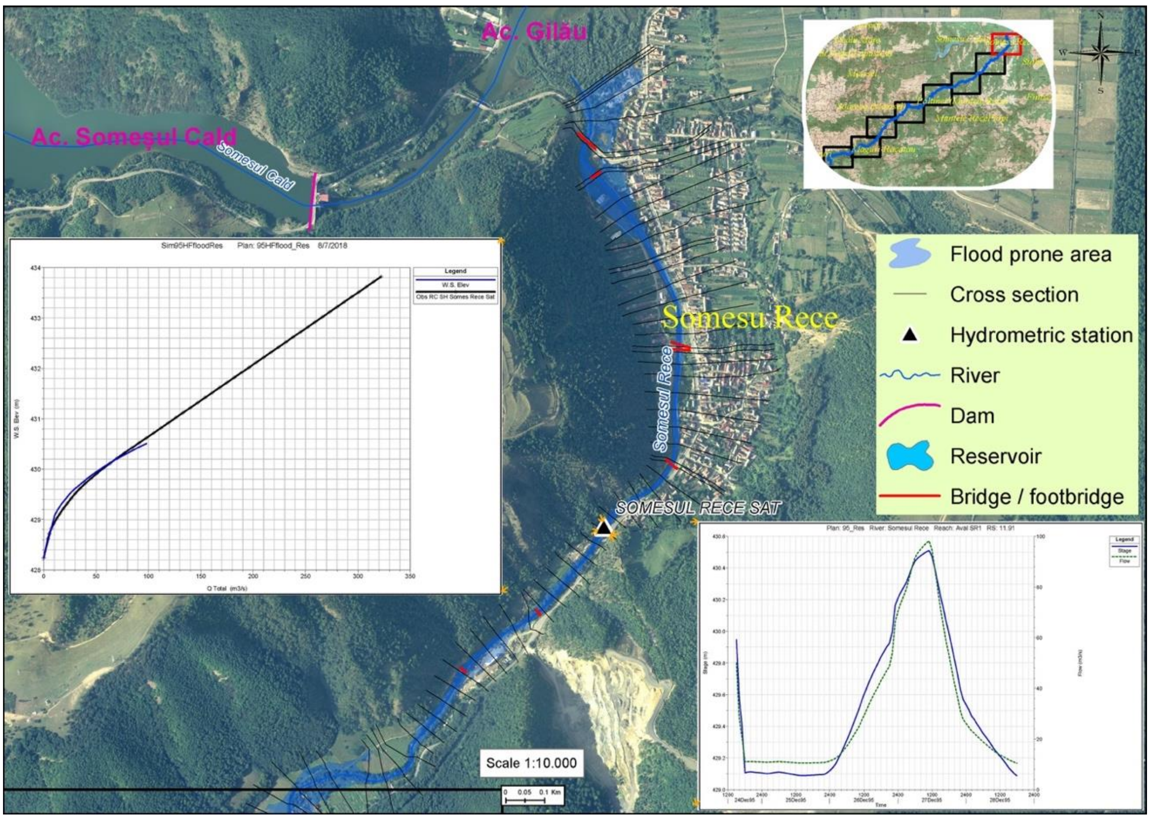


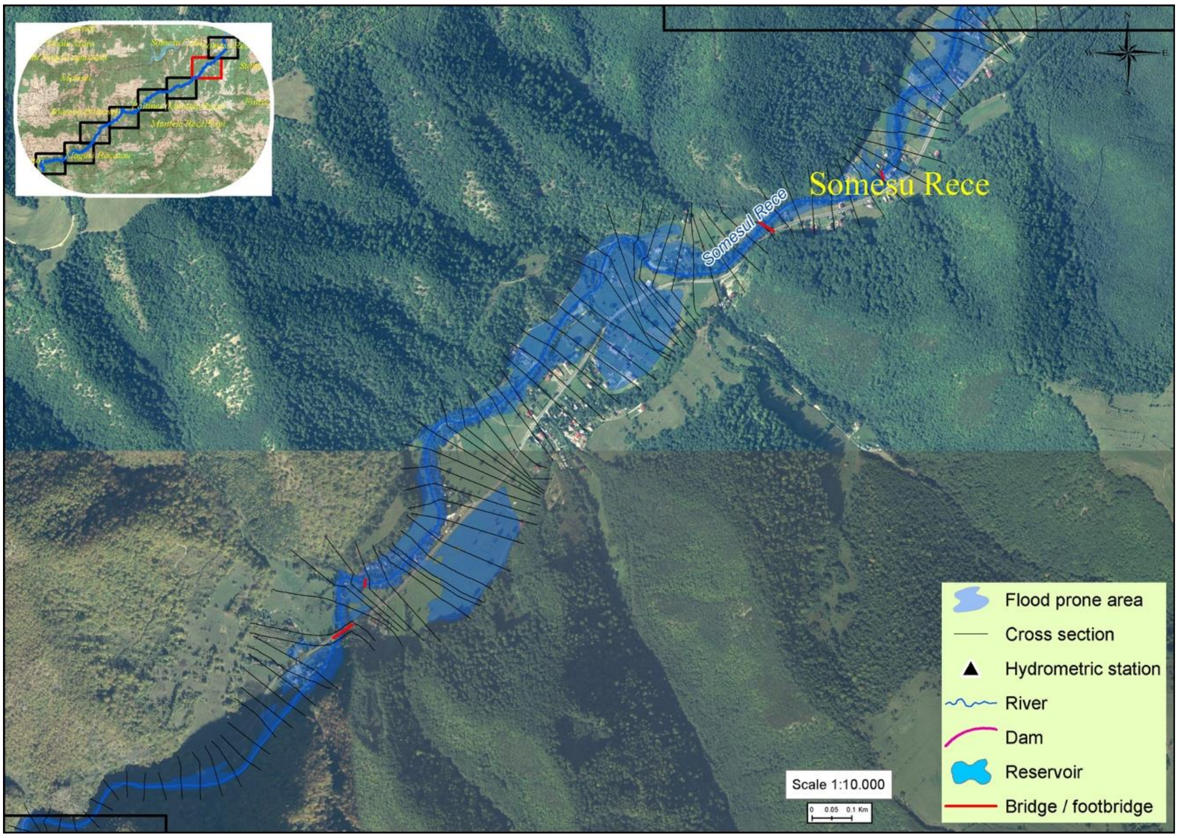

**Fig. 6.** Hydrographs of flash flood discharge. Section immediately downstream of the dam; b. Section of gauging site from the Someşul Rece village

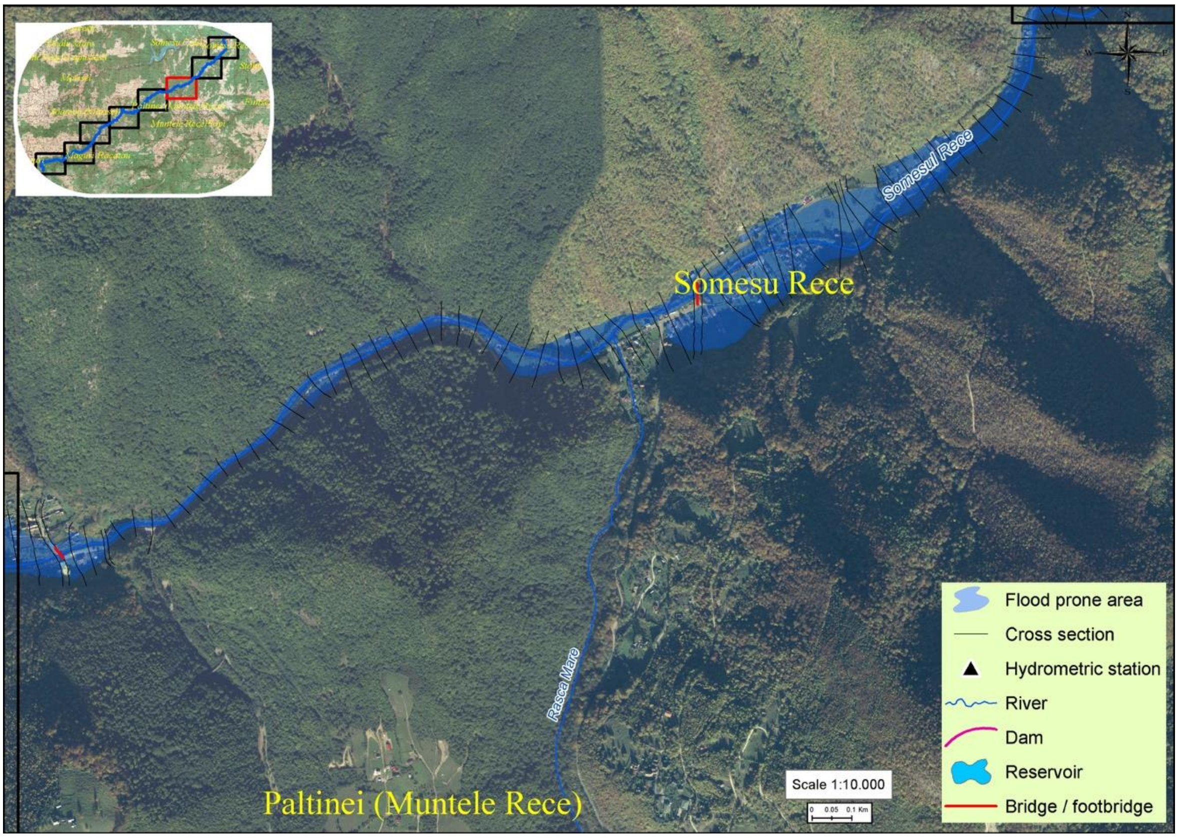
Although the mitigation was more than consistent, the water height at the maximum flash-flood level was sufficient to flood a quarter of the Someşul Rece village hearth and cause significant damage (Fig. 7).

### 4.2. Flooded area

The resulting map of flood-prone areas allows to obtain information concerning the areas covered by water, the propagation of the historic flash flood wave and supercritical turbulent flow, which propagated in the downstream (Fig. 7).




Somesu Rece
Somesul Rece
Flood prone area
Cross section
Hydrometric station
River
Dam
Reservoir
Bridge / footbridge
Scale 1:10.000


Somesul Rece
Somesu Rece
Rasca Mare
Paltinei (Muntele Rece)
Flood prone area
Cross section
Hydrometric station
River
Dam
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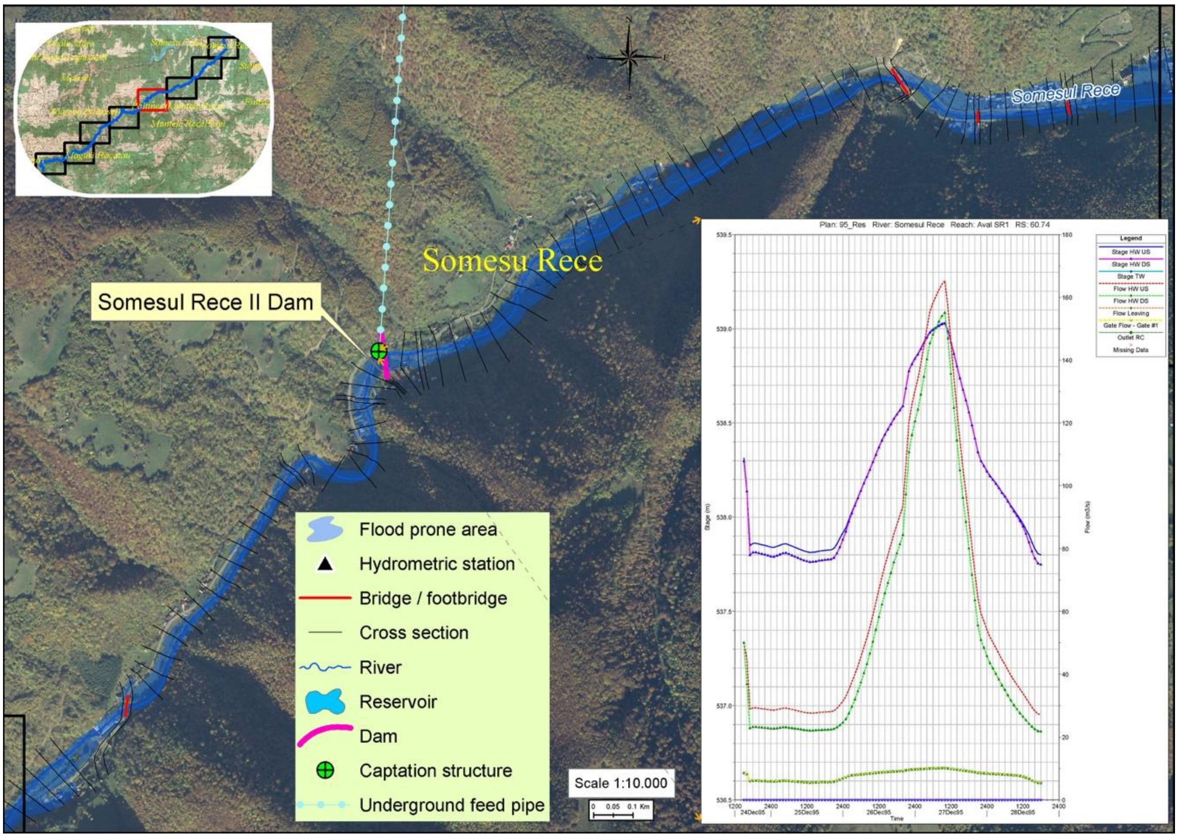
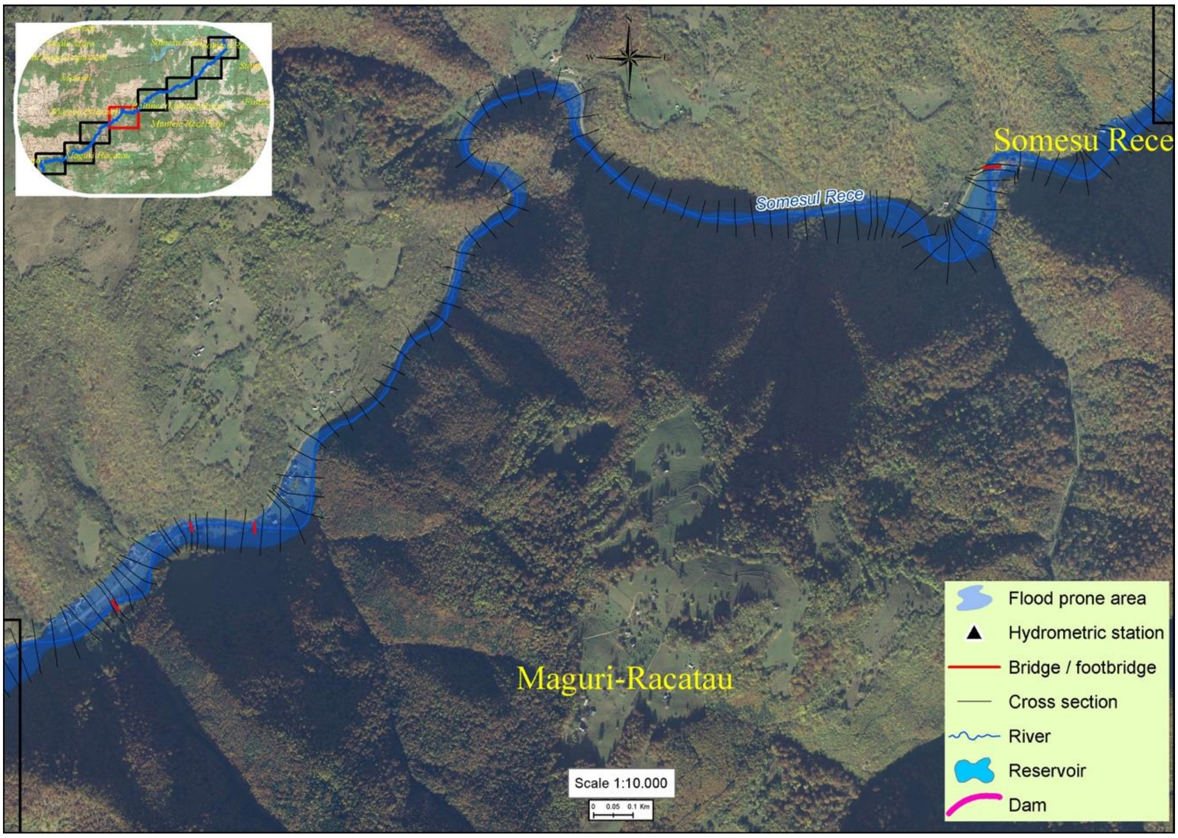
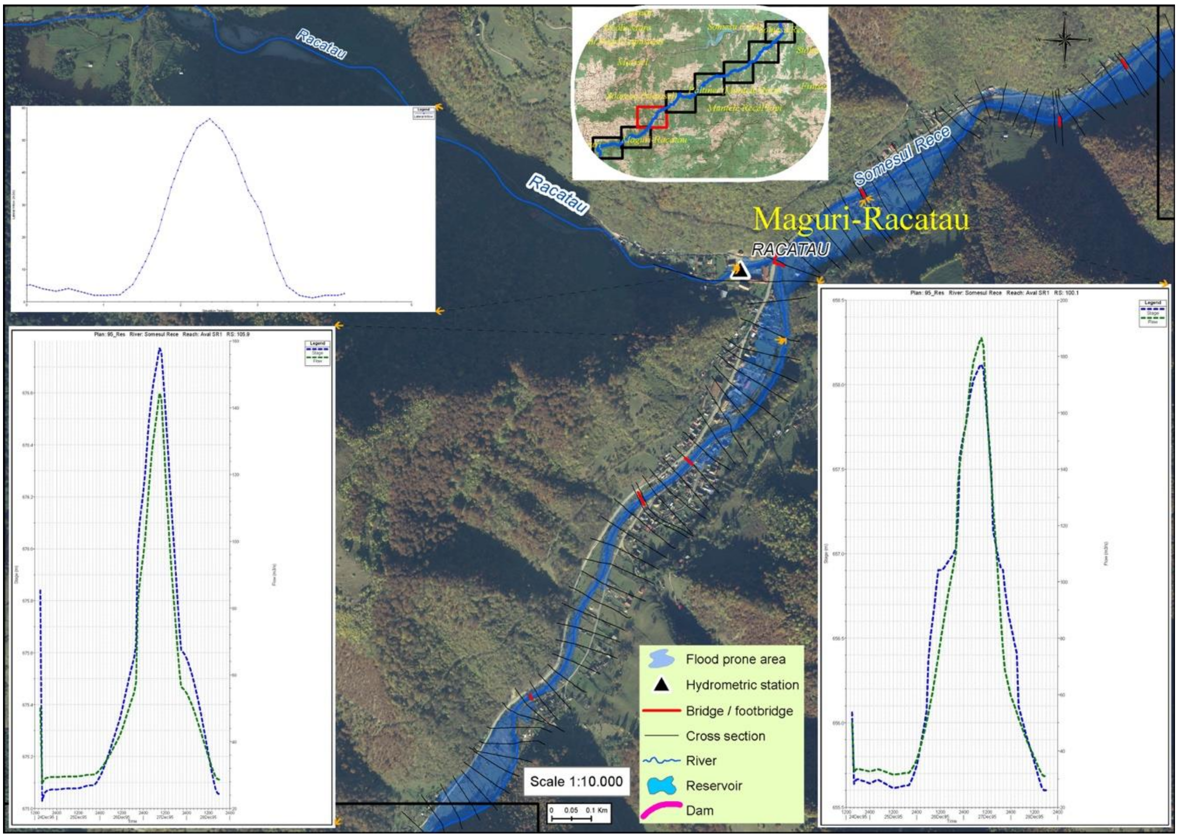
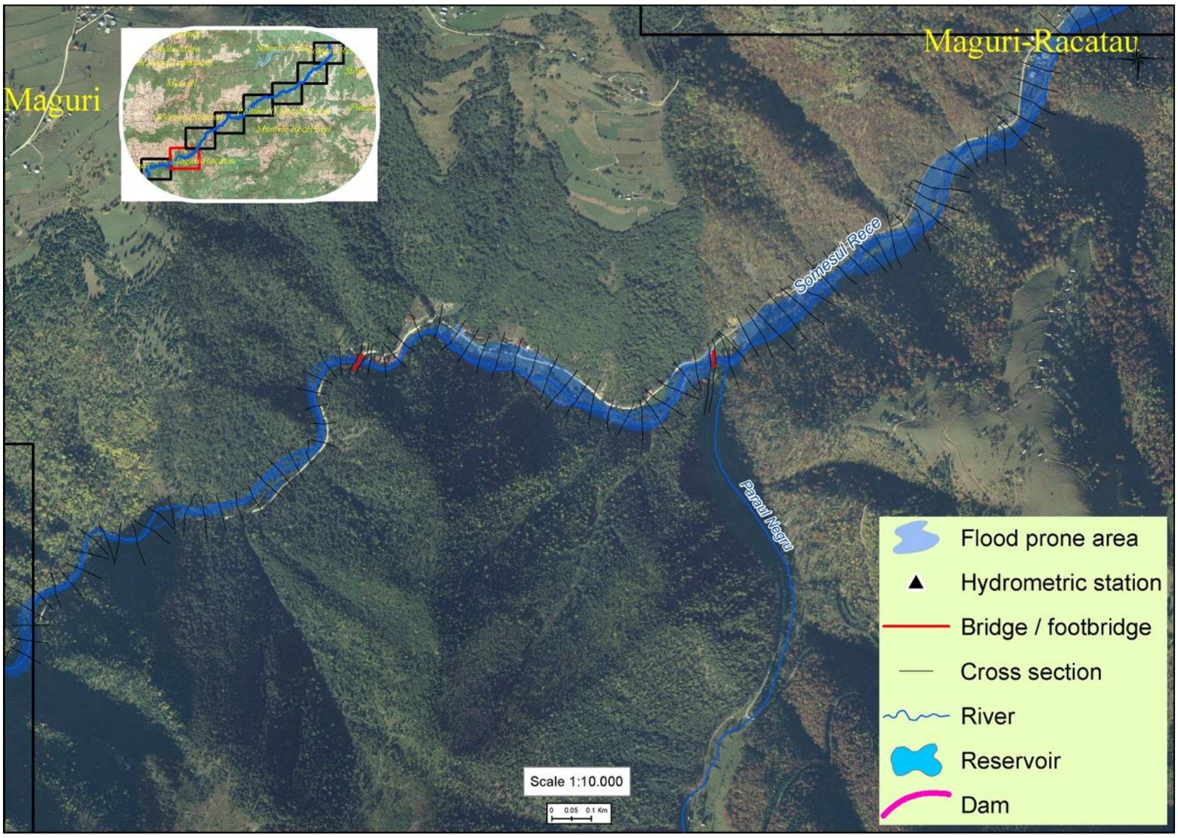
Bridge / footbridge
Scale 1:10.000


Somesu Rece
Somesul Rece
Somesul Rece II Dam
Flood prone area
Hydrometric station
Bridge / footbridge
Cross section
River
Reservoir
Dam
Captation structure
Underground feed pipe
Scale 1:10.000
Plan: 95_Res River: Somesul Rece Reach: Aval SR1 RS: 60.74
Legend
Stage (m)
Flow (m3/s)
Time


Somesu Rece
Somesul Rece
Maguri-Racatau
Flood prone area
Hydrometric station
Bridge / footbridge
Cross section
River
Reservoir
Dam
Scale 1:10.000


Racatau
Racatau
Somesul Rece
Maguri-Racatau
RACATAU
Flood prone area
Hydrometric station
Bridge / footbridge
Cross section
River
Reservoir
Dam
Scale 1:10.000
0 0.05 0.1 Km


Maguri
Maguri-Racatau
Somesul Rece
Paraul Negru
Flood prone area
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Bridge / footbridge
Cross section
River
Reservoir
Dam
Scale 1:10.000
0 0.05 0.1 Km

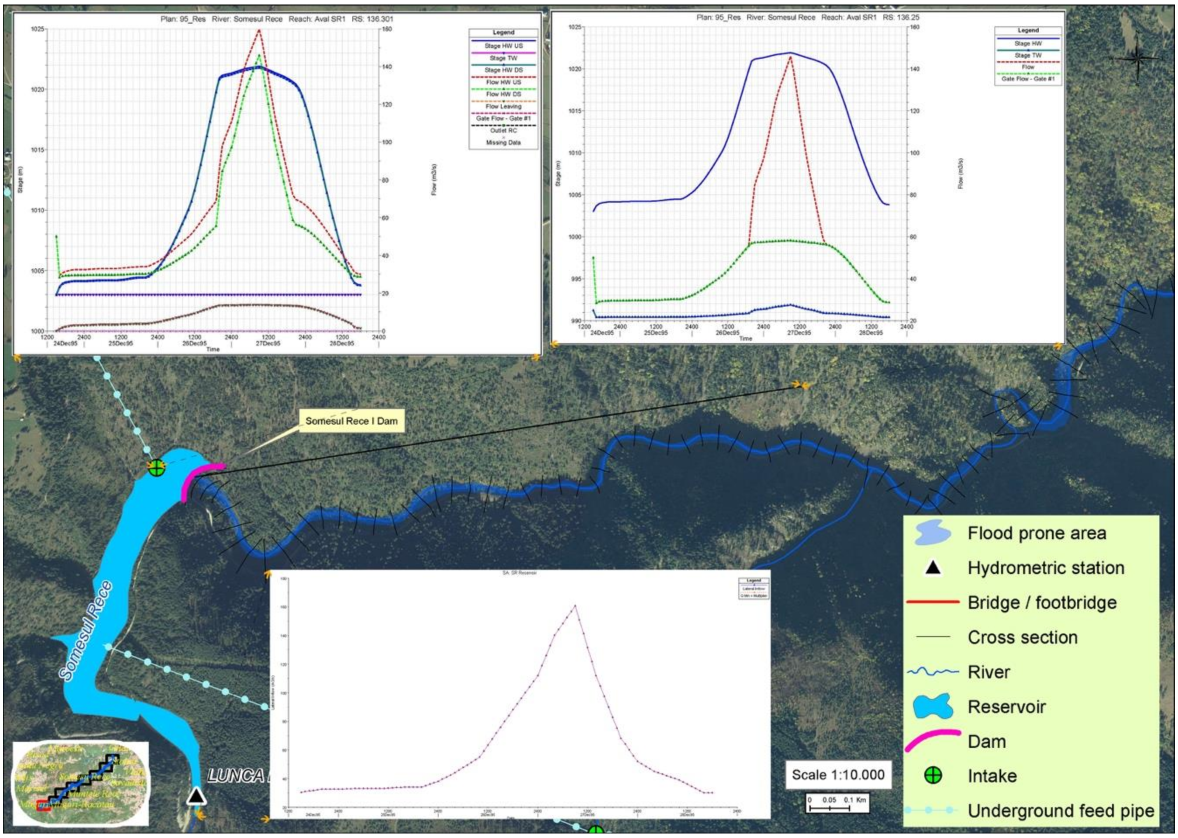

**Fig. 7.** Flooding map (1-8) along the Somesul Rece valley

On the gorge sectors the level of energy increases significantly with the propagation of the wave through narrow and steep valleys. For warning the population about the risk posed by floods, I have made a map of vulnerability for the Someşul Rece village. This includes the flood-prone area and the anticipation time, which turns out to be effective in reducing the damage caused by the flooding and limiting the number of victims. For our scenario, the propagation time of the extraordinary flash flood wave is 2 hours and 4 minutes until the confluence with the Somesul Cald in Gilău lake, sector with a length of 29 km.

## 5. CONCLUSIONS

This paper highlights the high risk to which the socio-economic objectives situated downstream of the Someşul Rece I Dam are exposed, in the case of the production of a flood of the same size (probability of the maximum discharge under 10%). In the mountain area, should the hazard occur, the spatial typology of the villages located along the water course, causes a very high risk for the population should the hazard occur. The results obtained by modeling in the HEC-RAS have shown that the extraordinary wave gets in the first village (Măguri Racatau) in a few minutes (26 min), recording a discharge of 145 $m^3/s$ and propagates very rapidly downstream. The identification of flooded areas, of the flooding depth, water velocity and duration of the flash flood, as well as the impact of the flood on the affected areas, are very important for decision making, emergency evacuation and early warning. This study is also significant for the design of the flood water outlets capacity, in particular for the arch dams. Not to be neglected is the importance of implementing a system of alarm sirens, in case of occurrence of a water hazard with a very low probability.

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