FORUM GEOGRAFIC

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XVII**, Issue **1** (**June** 2018), pp. **44-55**
http://dx.doi.org/**10.5775/fg.2018.058.i**

Arch dam failure preliminary analysis using HEC-RAS and HEC-GEO RAS modeling. Case study Someșul Rece 1 reservoir

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Received on <05-04-2018>, reviewed on <08-05-2018>, accepted on <20-05-2018>

Abstract

This paper presents a preliminary analysis/simulation of the Someşul Rece 1 dam breaking scenario, from the homonym hydrographic basin, located in the north-eastern part of the Apuseni Mountains, at a 0.1 % probability tributary flow rate calculation. The study of the floodplain areas, that occur after the failure of the Someşul Rece 1 dam, was achieved with the help of 1D hydrological modelling. This type of modelling is one of the most complex (Cameron et al., 2006), involving both, the definition of a model with temporal evolution of the dam rupture, and the simulation of a unsteady flow stream in the downstream sector. For the dam analysed area and the downstream sector, several scenarios and modelling of hydrological systems was achieved, with the help of HEC-RAS 5.0.3 software, developed by the Hydrologic Engineering Center (U.S. Army Corps of Engineers).
This free software is the most widely used worldwide in the domain, particularly by the official agencies, having a continuous development, given by the involvement of specialists. The software simplifies the problem of hydrodynamic modelling, due to the limitation to a 1D model. Because the flood obviously has a spatial character, GIS software (ESRI ArcGis with the HEC-GeoRAS extension) were used in determining and defining the hydrographic elements (channel, talweg, banks etc.) and, also, in the representation of the results. Maps of the flood-prone areas have been developed, maps which indicated the magnitude of the estimated accidental flood downstream. The results of the simulation were also used to determine the anticipation time.

Keywords: *dam break, breach, HEC-RAS, Someșul Rece, hydrograph*

Rezumat. O analiză preliminară a scenariului de rupere a barajului în arc folosind modelarea HEC-RAS și HEC-GEO RAS. Studiu de caz barajul Someșul Rece 1

Această lucrare prezintă o analiză/simulare preliminară a scenariului de rupere a barajului Someșul Rece 1, din bazinul omonim, situat în nord-estul Munților Apuseni, la un debit de calcul afluent cu probabilitate de 0.1 %. Studiul arealelor inundabile, care apar după ruperea barajului Someșul Rece 1, s-a realizat cu ajutorul modelării hidrologice 1D. Acest tip de modelare este unul dintre cele mai complexe (Cameron et al., 2006), implicând atât definirea unui model cu evoluție temporală a rupturii barajului, cât și simularea unui flux inconstant de scurgere în aval. Pentru zona barajului analizat și sectorul din aval am realizat mai multe scenarii și modelări ale sistemelor hidrologice, cu ajutorul softului HEC-RAS 5.0.3 dezvoltat de către Hydrologic Engineering Center (US Army Corps of Engineers).
Acest soft gratuit este cel mai utilizat din domeniu la nivel mondial, îndeosebi de către agenții oficiale, având o continuă dezvoltare, dată de implicarea specialiștilor în domeniu. Softul simplifică problema modelării hidrodinamice, datorită limitării la un model 1D. Pentru că inundația are evident un caracter spațial, softuri GIS (ESRI ArcGis împreună cu extensia HEC-GeoRAS) au fost utilizate, atât în determinarea și definirea elementelor hidrografice (canal, talveg, maluri etc.) cât și în reprezentarea rezultatelor. Au fost elaborate hărți ale arealelor inundabile, care au indicat amploarea estimată a inundațiilor accidentale în aval. Rezultatele simulării au fost utilizate și pentru a determina timpul de anticipare.

Cuvinte-cheie: *ruperea barajului, breșă, HEC-RAS, Someșul Rece, hidrograf*

Introduction

Dams have a vital role in water resources management. In addition to their beneficial role (multiple uses), dams can be, also, the source of any catastrophic accidents. Although rare, such events are of the most extreme, due to the human lives loss and huge damage caused.

Failure of a dam is defined as the breaking or displacement of a part of the dam body or his foundation, resulting that the dam cannot retain water. This leads to uncontrolled release of a large volume of water, from the reservoir, in a very short time.

When downstream of a dam there are socio-economic objectives, it is extremely important to determine through the high-precision hydrodynamic modelling, the fracture hydrograph and the propagation time, in relation with the starting time of the dam breach formation. These are very important, to provide a maximal anticipation time of forces involved in the efforts to evacuate people and property (Stematiu and Ionescu, 1999).

At the international level, the dam safety has always been in the centre of the ICOLD (International Commission on Large Dams) attention, and the ultimate goal of the taken actions was to reduce the number of disposals and incidents. The failure of a dam may cause "material damage exceeding dozens

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Volume **XVII**, Issue **1** (**June 2018**), pp. **44-55**
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of times the cost of the construction and many human victims" (Popovici, 2012). The progress made in the design conceptions and construction technologies, in the supervision of the dam behaviour during it exploitation, has led steadily in time to the "rate of incidents or dam disposals decrease" (Roșu and Creţu, 1998).

In the literature, it is noted that the rate of dam disposals, before the year of 1900, exceeded 4%, while in the present this rate stands at less than 0.5%. Moreover, the percentage of dam disposals in the world has decreased to 2.20% in the case of dams built before 1951, to less than 0.5% in the case of the dams built after 1951 (ICOLD, 1995).

The compiled statistics classify, from many points of view, the main causes of these breakdowns. Here, the disposal of the foundation, the limited capacity of the spillways and lesser, the insufficient mechanical strength, have the largest share (Drobot et al., 2007).

In Romania such cases have been, also, recorded, examples being the failure of the Belci dam (June 1991), the damage produced to the Teleag improvement, on the Crişul Repede river (February 1992) or the cracking of the Cornățești – Olt dam (April 1997), with a central crack of 2...3 m.

The conclusion that emerges is that although we are, overall, below the world average of the damages, one can make a similarity with their casuistry. This favours the development and application of theoretical and experimental investigations for the improvements in our country (Popovici, 2012).

At the end of the XXth century and the beginning of the XXIth century, the publication of data related to damage and breaking of several dams in Romania, favoured the starting of the pioneering studies in this domain.

The legislative regulations in the last five years have required to holders of important dams to draw up the "Plans of action in case of accidents at dams". These plans are periodically updated to agree both with the new legislative regulations and with any changes resulted from the construction or in its exploitation rules.

"Plans of action in case of accidents at dams" shall be developed in accordance with the Order of the Ministry of Environment and Forests/Ministry of Administration and Internal Affairs (MEF/MAI) 1422/192/2012, order on the management of emergency situations rules. These plans respect the purviews of the Government Decision G.D. no 646/2010 for the approval of the National Strategy for the Management of Flood Risk and the Analysis and assessment of the risk associated with the dam normative framework NP 132 of 2011.

Therefore, in last years the "Romanian Waters" National Administration (RWNA) has conducted the studies regarding the water management on floods produced by the damage and breakage of the dams (A and B categories) under its own administration.

In the Upper Someşul Mic hydrotechnical system, there are six dams of A and B importance category, where only the Gilău dam is in the administration of the ”Romanian Waters” Administration and has drawn up an action plan in case of an dam accident.

The analysis of the dam breakage includes a detailed study on the causes of the dam failure, on the technical parameters and on the generated floods wave, with its impact on the downstream objectives.

The study area and general information related to the studied dam

Someşul Rece river (Fig. 1) forms, by the union with Someşul Cald river in Gilău lake, the Someşul Mic river. This first water course has a length of 49 km, it springs from the Muntele Mare massif through the Zboru creek at 1560 m altitude, on the territory of the Cluj county.

Its drainage basin, positioned between the basins of Someșul Cald and Iara rivers, overlaps to a great extent following the Muntele Mare and Gilău massives, in the north east of the Apuseni Mountains. The drained surface is 327 km2 with an average altitude of 1214 m (Atlas Cadastre of Romanian Waters, 1992).

The natural conditions in the upper basin of Someşul Mic river, favoured a large-scale hydrotechnical improvement, which capitalized a part of the existing natural potential in this area (Fig. 1). The 860 km2, area of the basin in the section of the Gilău dam, were the subject of the spatial planning since the end of the '60s. In this regard, were built four great dams with reservoirs on the valley of the Someşul Cald river (Fântânele, Tarniţa, Someşul Cald and Gilău). Also, several intakes and adductions intended for supplementing the tributary flow into these four lakes were built in the drainage basin of Someşul Rece river (Serban, 2007).

The improvement was extended beyond the watershed, which separates the Someșul Mic and the Arieş basins, by achieving more intakes and adductions in the upper basin of the Iara river, whose water was also directed on the reservoirs from the Someșul Cald river (Fig. 2).

In the first stage of improvement (1968-1980 years) have been realised the largest reservoirs from the basin. Gilău was the first reservoir given in service, in 1972, followed by Tarniţa, in 1973 and Fântânele, in 1976.

Also during the first stage have started the works on the intakes and the derivations from the basins of Iara and Someşul Rece, some of these being given in service (Someşul Rece II system).

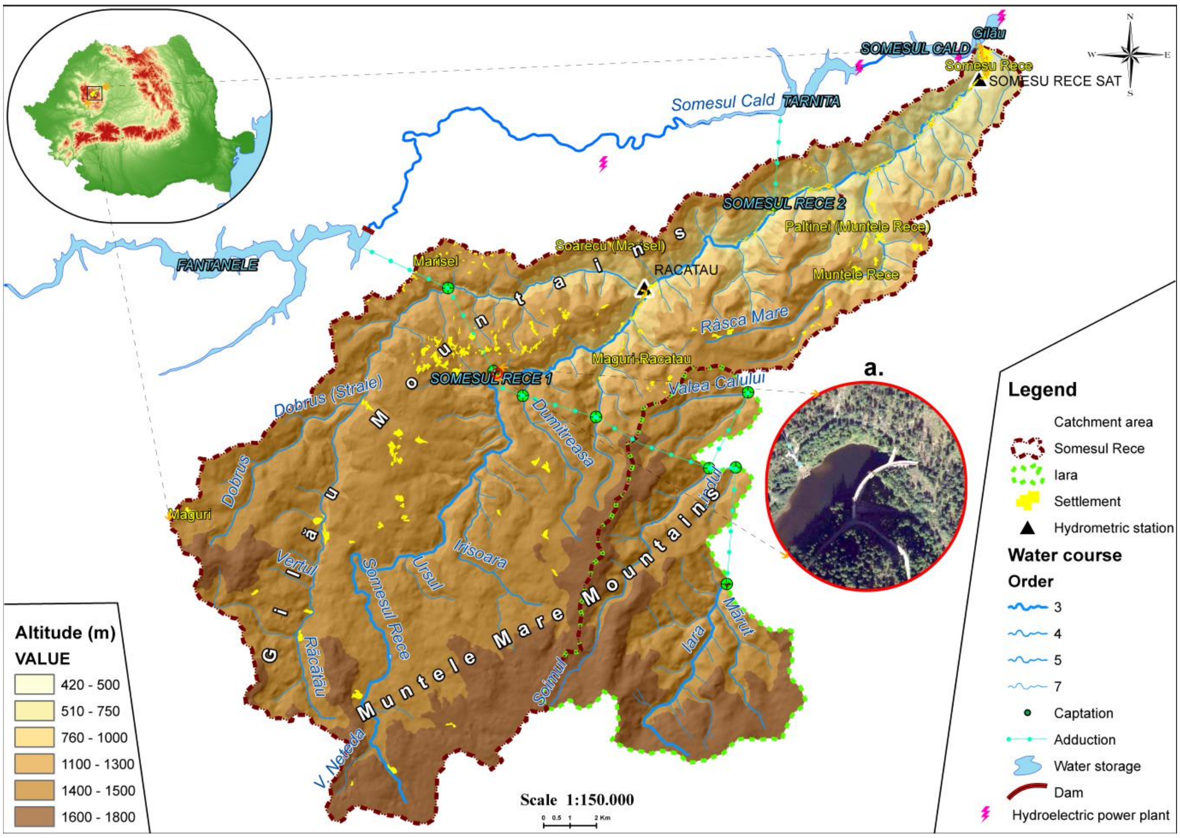

Fig. 1: The location of the study area in relation with national territory and Someşul Mic upper basin hydropower improvement

In the second stage (1980-1990) the Someșul Cald river improvement was done, by the given in service of homonymous reservoir (1983).

The main axis of the secondary improvements is Iara-Fântânele. Its adduction has a total length of 21 km, of which: 4.7 km between the intakes Iara and Șoimu, 4,9 km between the intakes Șoimu ans Negruța, 4 km between Negruța intake and Someşul Rece 1 reservoir, 3.7 km between Someşul Rece 1 reservoir and Răcătău intake, and the same length between Răcătău intake and Fântânele reservoir (Pop, 1996).

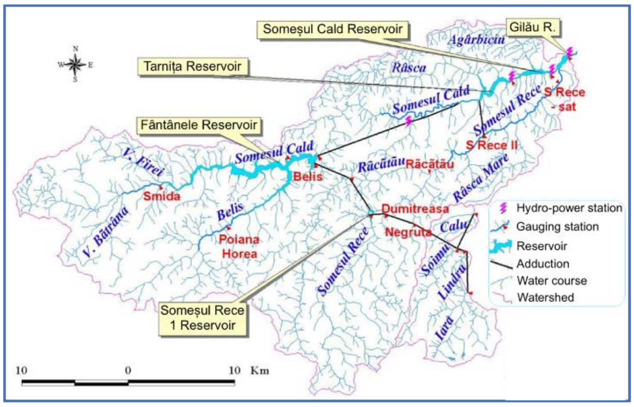

Fig. 2: The Someşul Mic upper basin hydro-power improvement

The time elapsed in the post-improvement period, proven that the adductions and the intakes does not represents a protection against the flash floods, for the settlements located downstream. Those 4,89 m^3/s, captured on average in the basin of Someşul Rece river, and even the maximum of 27.8 m^3/s, cannot significantly reduce the threat of flooding, in case of flash floods with a maximum discharge whose probability of exceedance is below 10% (Şerban et al., 2009).

Someşul Rece 1 Dam

Someşul Rece 1 Dam (Fig. 1a) is located in Cluj county on the homonymous river, upstream of the confluence with Dumitreasa river, of the Măguri-Racătău locality and about 40 km upstream of Cluj-Napoca municipality. The dam is under the administration of S.C. Hidroelectrica S.A. - Cluj Hydropower Station Branch.

The construction is an arch with a double curvature, being one of the largest dams with secondary role in a complex hydropower improvement in Romania. Its dimensional parameters are: 43.5 m height, a length at the crest of 119.5 m (altitude of the crest 1024.5 m-Black Sea) and include a concrete volume of 50,000 m3 (Regulation of the

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Volume **XVII**, Issue **1** (**June 2018**), pp. **44-55**
http://dx.doi.org/**10.5775/fg.2018.058.i**

Fântânele Reservoir Exploitation, 2010, ”Someș-Tisa” Water Basin Administration).

The Someşul Rece Dam is located in the gorge sector of the Someşul Rece river, with its both slopes steep and a general symmetry of the valley. The foundation of the dam is composed from volcanic rocks strong and healthy, respectively granite by Muntele Mare Mountains.

During the dam construction and exploitation has not been signaled any kind of dangerous geological phenomenon. The dam is composed from 14 consoles, where 2 of these forms the high waters spillway, organized laterally.

The dam represents the first and most important step of the Someşul Rece river improvement, otherwise the only intake with storage, followed downstream by the Someşul Rece II intake. The given in service of the Someșul Rece 1 dam (1977) is subsequent to the Fântânele dam (1976).

The Someşul Rece reservoir

The Someşul Rece 1 reservoir plays the role of a simple intake with tyrolean outlet, but which, from the needs dictated by the quotas game, it was necessary to accumulate a minimum of 0.2 million m3 of water, for the hydraulic agent to be conducted by gravity into the Fântânele reservoir.

The main functions of the Someşul Rece 1 reservoir are:

- supplementing the tributary flow in the Fântânele reservoir, for the production of electricity by hydropower plants located downstream on the Someşul Cald river;
- partial attenuation of flood waves;
- recreational.

Flood mitigation is insignificant due to the extremely reduced dedicated volume, as this function has not been designed for the Someşul Rece 1 reservoir. However, it can hold a volume of 0.74 million. m3 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. m3 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.

Materials and Methods

The database used in the analysis consists in both technical as well as hydrological data, collected from the Archive of the ”Someș-Tisa” Water Basin Administration, Cluj-Napoca.

For the mapping, have been used topographic maps at scale of 1:25000 and GIS software licensed from the two institutions involved in this study: Babeş-Bolyai University, Cluj-Napoca, Faculty of Geography and ”Someș-Tisa” Water Basin Administration, Cluj-Napoca.

Basic data necessary for the HEC-RAS hydrodynamic model

The study, consisting in the analysis of the values of maximum flows 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 cross-sections on Someş Rece river, was made based on data and the conclusions drawn by the specialists from ”Someș-Tisa” Water Basin Administration departments.

The data on the type hydrograph tributary in the reservoir were processed with the CAVIS software, and the cartographic representation were realised using ArcMap 10.x software.

In the analysis, were used topographic data, representing the basis of the hydraulic calculus, regarding the simulation of production and propagation of the breaking wave downstream of the Someşul Rece 1 dam. These data consist in theNumerical Model of Terrain (NMT), cross profiles and surveys at bridges on the Someşul Rece river (Fig. 3). *These topographic data have been obtained within the project ”Plan for the Prevention, Protection and Mitigation of Floods Effects in Somes-Tisa River basin”*, a national project financed through ”AXA 5 POS Mediu”.

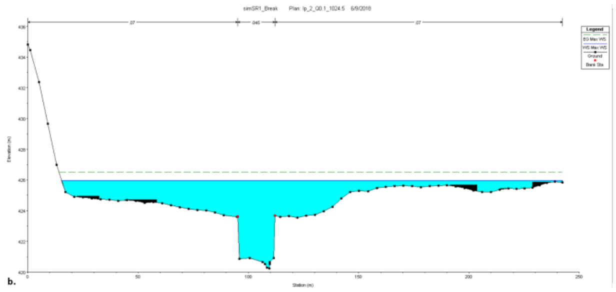

Fig. 3: Example of surveying (a) and cross section (b), entered and processed in HEC-RAS. Source of raw data: PPPDI-STWBA

In this study, the analysis of the dam rupture and the modelling of the induced floods was performed using HEC-RAS. The Hydraulic Engineering Center - River Analysis System (HEC-RAS) is developed by the Hydrological Engineering Center of the U.S. Army Corps of Engineers (USACE).

The HEC-RAS model simulates the flow in the fluvial channels and in flood prone areas, being considered an effective model in simulating the effects of floods downstream of the location of an event occurrence, in this case the failure of the dam. The HEC-RAS model uses the failure information and the breaking geometry as input data to simulate the pattern of dam failure.

Cameron et. al., in the paper "Dam failure analysis using HEC-RAS and HEC-GeoRAS", published in 2006 in the "Third Federal Interagency Hydrologic Modeling Conference" conference proceedings, considers that a rivers hydraulics model will be as good as the data and personnel used to develop it.

Detailed information on the riverbed and flood prone areas are the main data required to create a hydraulic model of a river. Data on the land use (used for the estimation of the Manning roughness coefficients) and information on the hydraulic engineering structures (bridges, footbridges, dikes, supporting walls etc.), are also essential for the construction of a complete fluvial hydraulic model. Therefore, the topography plays a major role in the accurate determination of areas vulnerable to accidental flooding, and for this determination it is necessary a fair resolution of the topographic surface, in the form of NMT (Numerical Model of the Terrain) (Serban et al., 2016).

In this analysis, we considered only the hydrographic elements of interest. For example, the tributaries have not been defined anymore, because their contribution as flow is not significant in the context of severe flooding values generated by the failure of the dam. In order, not to complicate the modeling, these rivers have not been added, keeping, however, a way to achive the profiles, which consider these confluences and the altitudinal expansion on upstream. Figure 4 illustrates the manner in which study sector was define.

Fig. 4: Image of the downstream sector of the Someşul Rece 1 Dam exposed to flooding in case it failure, modeled with HEC-GeoRAS

In the study was used the the numerical model of the land with a spatial resolution of 3 meters, realized within the PPPDI project. In order to extract the values of the Manning coefficient, have been use Corine Land Cover 2012 data. Also, all constructions (houses, annexes, buildings) situated in the flooding area have been digitized in advance, constructions that can have an obstruction role in the path of the stream. Taking into account the significant potential of flooding, the study sector was extended downstream of the dam position, up to the confluence between Someşul Rece and Someşul Cald rivers, in Gilău reservoir.

The Someșul Rece valley on the previously mentioned sector, with a length of 29 km (Fig. 5b), has been configured in the model, through cross sections topographically determined at equidistances. In addition to the mentioned sections, other cross-sections were interpolated in the HEC-RAS program between the original cross-sections (Fig. 5a).

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XVII**, Issue **1** (**June 2018**), pp. **44-55**
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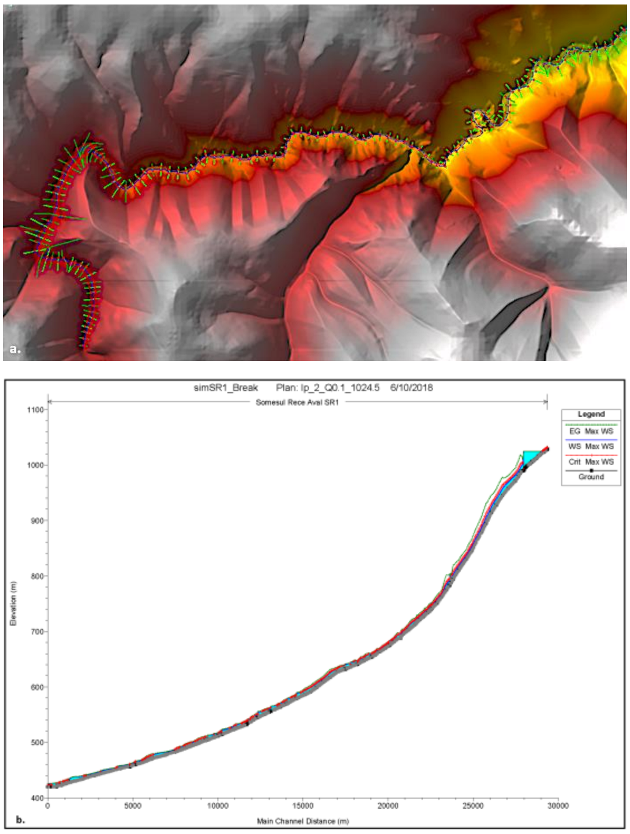

Fig. 5: The three-dimensional model of the terrain and the cross-sections arrangement (a.), longitudinal profile downstream of the dam sector (b.)

Taking into account the Manning coefficient of roughness for the minor riverbed and floodplain, have been used values between 0,045 and 0,09, depending on the particularities of the section. Loss of the hydraulic load related to the expansion and contraction of the riverbed or to natural obstacles, is included in the model with coefficients between 0.3 and 0.1.

HEC-RAS software is based on solving the Saint-Venant fundamental equations, the equation of continuity and 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; AT = total flow area, m2; Q = flow, m3·s–1; qI = lateral inflow per unit length, m2·s–1; Sf = friction slope; V = flow velocity, m·s–1.

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

Topographic Data

In the modeling topographic data are necessary, data which characterize the whole potentially flooding area. The size of these data should not be underestimated. The floods resulting from the dam breaching can be significantly higher than natural flooding. Thus, the topographic surface needed to be modeled extends on flood plains and slopes, above the normal levels of flooding. Details regarding the major structures which can form an obstruction of flow are, also, required, such as bridges, footbridges, roads backfill, civil bordering constructions and the most important river control structures.

The precision of a simulation study on the dam breakage is different from that of the watercourses modelling study, whereas the latter simulates the natural flooding, which occur in areas defined as floodable areas. Knowledge of the flow typical conditions and of the modeling parameters, such as the roughness of the channel and the flooded floodplain for these events, is relatively good. For a dam breaking model, flow conditions consistently exceed the usual natural events. This means that there are few calibration data, and the flooded land is outside of normal floodplain, which makes it difficult to estimate the roughness and other parameters of input.

Flow Data

Boundary conditions for the calculations are necessary. In a subcritical runoff analysis, the boundary conditions are only required at the downstream limit of the river system. In a supercritical flow analysis, the boundary conditions are required only at the upstream limit of the river system. In a mixt flow regime boundary conditions at the open limits of the river system will be provided.

Routing the inflow data throught a Reservoir

HEC-RAS can be used to route an inflowing hydrograph throught 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 use 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 model the pool with one-dimensional cross sections throughout the entire reservoir.

Catchment Hydrology

Tributary hydrograph, reservoir status at the time of the dam breaking and the downstream base flow conditions can be combined, to have a significant effect on the predicted flooding scenario, depending on the size and nature of the reservoir and of the dam.

Boundary Conditions

In this analysis, the limit condition provided in the upstream, is the tributary hydrograph calculation type with the assurance of 0.1%, and the downstream limit condition is the normal depth. This option uses Manning's equation to estimate a level for each calculated flow. To follow this method, the user must enter a friction slope in the vicinity of the downstream limit condition.

The lymnimetric key is another option, that is used as a downstream condition limit. The tributary hydrograph of laterally side input is used as an internal limit. This option allows the user to bring the tributary contribution in a certain point along the river.

Scenario of the dam-break

Constructed dams can be categorized in two large groups: gravity and arch dams (Fig. 6). Gravity dams rely on their weight to resist the forces imposed upon them. Arch dams, with the arch pointing back into the water, use abutment reaction forces to resist the water pressure force. They can be made of concrete or masonry.

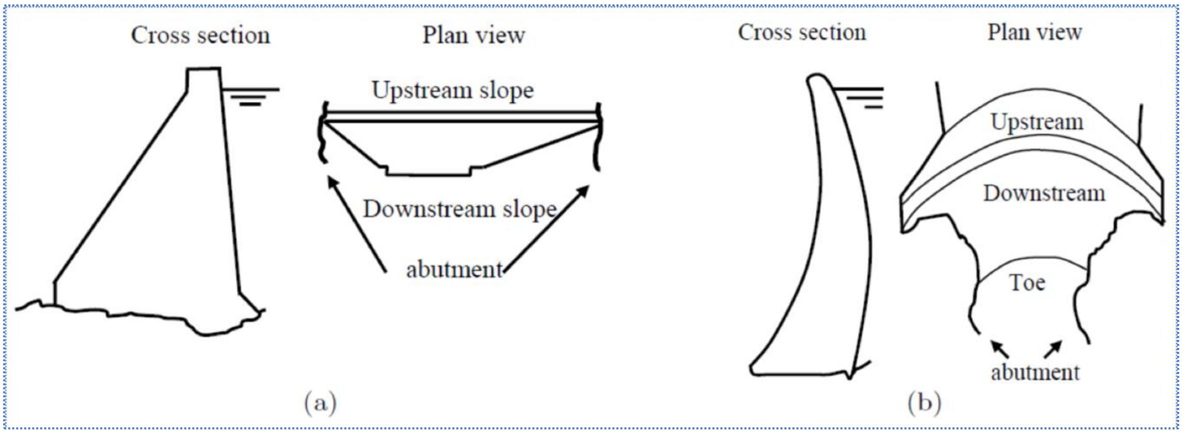

Fig. 6: Schematic picture of (a) gravity and (b) arch dams

The failure of a structure can be partial or complete. Failure of a dam can be sudden or gradual. A sudden failure is associated with concrete dams, gravity or arch dams. The Malpasset Dam in southern France, an arch dam of 66.5 m in height and maximum designed reservoir capacity of 55 million m3, is described to have failed explosively on 2 December 1959, water storage was emptying in about an hour (Hervouet, 2000).

If breaching is initiated, the further development is faster than for earthfill dams under the same conditions. This observation allows modelling of the concrete arch dam failure events simply as a sudden (gate opening) process (Zagonjolli, 2007).

This approach, though appropriate for concrete and arch dams that usually exhibit a failure within a relatively short duration of time - similar to sudden failure - did not provide insight into the breach modelling processes except for the flood wave movement in the downstream channel (Dressler, 1954). A thin plate representing the dam was located in a rectangular 'channel', and its removal simulated instantaneous failure of the dam.

The shape of the hydrograph breaking at the peak flow is influenced by the level and volume of water in the reservoir at the time of the breach, by the size of the dam and, most importantly, by the vulnerability to erosion of the dam type and by the assumed scenario for breakage. For example, a concrete fragile structure will have a much faster development of the breach compared to a weight dam built from local materials, cohesives, well compacted and well stabilized by vegetation. Because the hydrograph of the flow can greatly vary depending on these factors, it is necessary to conduct a careful analysis of the dam breaking parameters.

For the concrete dams, especially at the arch dams or with abutments, the total breaking takes place in a very short time, of a few minutes. The flow rates in the riverbed exceed the flow rates of the natural catastrophic flood. The features of the rupture hydrograph and of the flood wave, depends on the height of the dam, the volume of the reservoir, the

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breaking model of the dam and the hydraulic characteristics of the riverbed downstream. For the arch or multiple arch dams , it is considered that the duration of the damage is very short, about seconds, in the calculation taking frequently and coating the instant destruction, though practically volatilization of dams is impossible.

In this study, we have considered the discharge over the crest (overtopping) as the main cause of the breakage of the dam, caused by the tributary runoff hydrograph with 0.1% insurance, correlated with the partial blockage of the high waters discharger.

For the failure scenario of the arch dam with double curvature, there were used the standards of the United States Army Corps of Engineers (USACE), indicated in the guide to Using HEC-RAS For Dam Break Studies, HEC 2014 (Table 1).

Table 1. Concrete arch dam breach characteristics (source USACE, 2014)

Failure mode	Dam Type	Over-flow/Weir Coefficients	Average Breach Width	Horizontal Component of Breach Side Slope (H) (H:V)	Failure Time, tf (hours)
Overtopping	Concrete Munti-Arch	3.1	(0.8xL) to L	Valley wall slope	≤0.1

In this analysis, for the breaking scenario of the Someşul Rece 1 dam, we believe that the breach will form in 6 minutes, representing the rapid and almost complete disposal of the arch dam (Fig. 7). In this scenario, the dischargers of the dam will be adapted in accordance with the rules of construction exploitation at high waters. In Figure 7 is shown both the shape and time of the breach formation.

To assess the behavior of the model, an input hydrograph is necessary to show the variations of discharges for a certain period of time. A calculated type tributary hydrograph with the 0.1% assurance was imported in the model. The simulation was made for an unstable flow-regime of 45 hours duration.

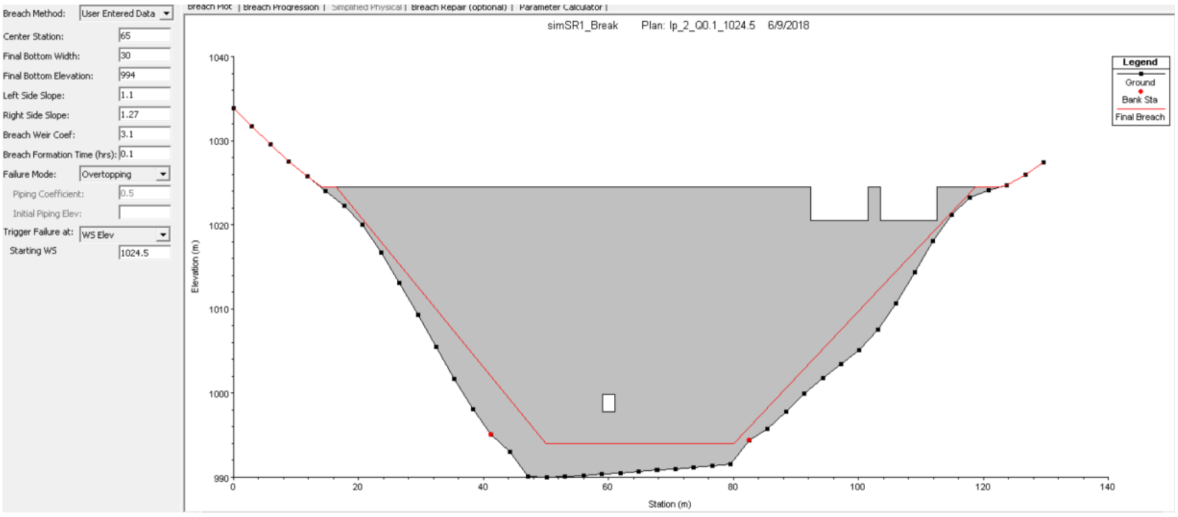


Fig. 7: The shape of breach

Results

After setting the parameters and complete the calibration in the control section of the Someşul Rece hydrometric station, the model determined the level of the free water surface and the flow hydrographs, using a two minutes calculation interval, which generates a very accurate hydrograph. A shorter period would generate an even more accurate hydrograph, but also a very large amount of data, while a longer interval of time would produce a less accurate hydrograph.

The flow passes through critical velocity to the downward slope, in this case the characteristics of the breaking wave including: the maximum level, the debit, the variations of water level in the reservoir up to the dam failure, the average velocity on the section (Fig. 8).

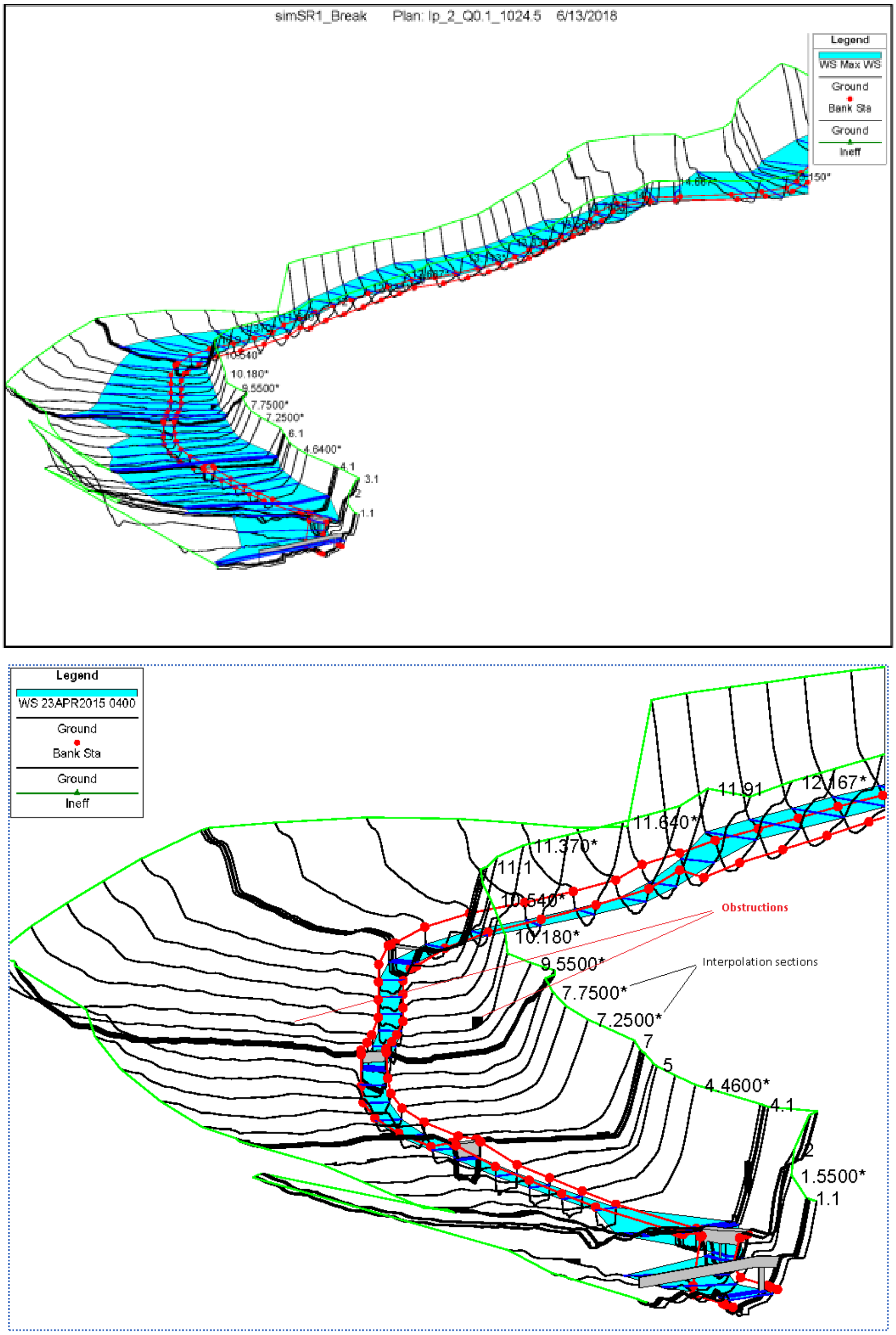


Fig. 8: 3D multiple cross section plot for the most important settlement (Someşul Rece village) traversed by the river

Features of the hydrograph of the Someşul Rece 1 dam breaking

The rupture hydrographs shall be determined by assimilating the drainage of water from the lake with a flow over a spillway with a sill wide, whose task and sizes are reevalued at the successive calculation times. These hydrographs are characterized by a shorter period of the time increase, as forthe total time (minutes) as compared to those for the natural hydrographs.

Also, values of accidental maximum flows much higher than that of natural maximum flow are characteristic, in our case 17 times higher than the flow rate with the 0.1% assurance, (Fig. 9 a and b).

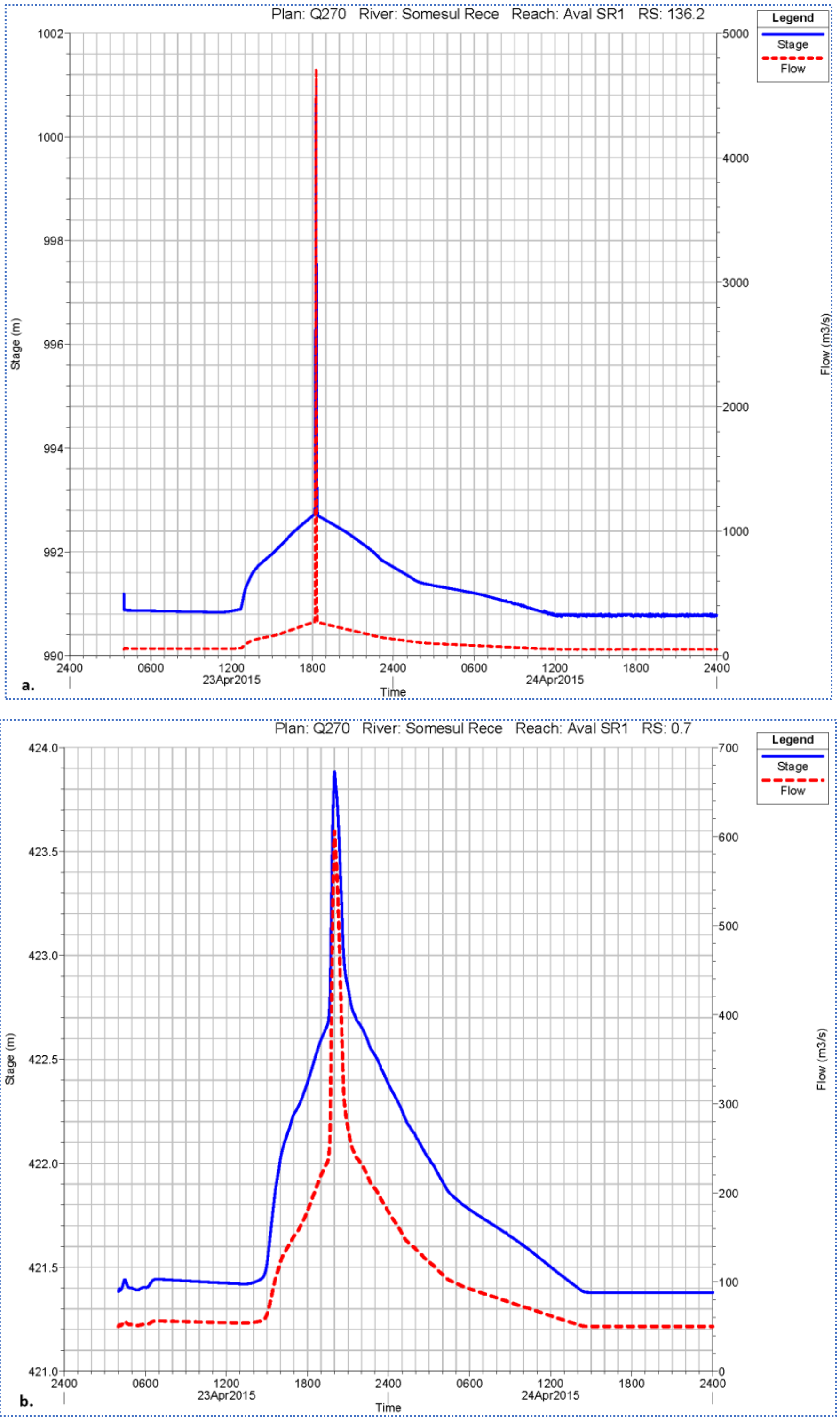
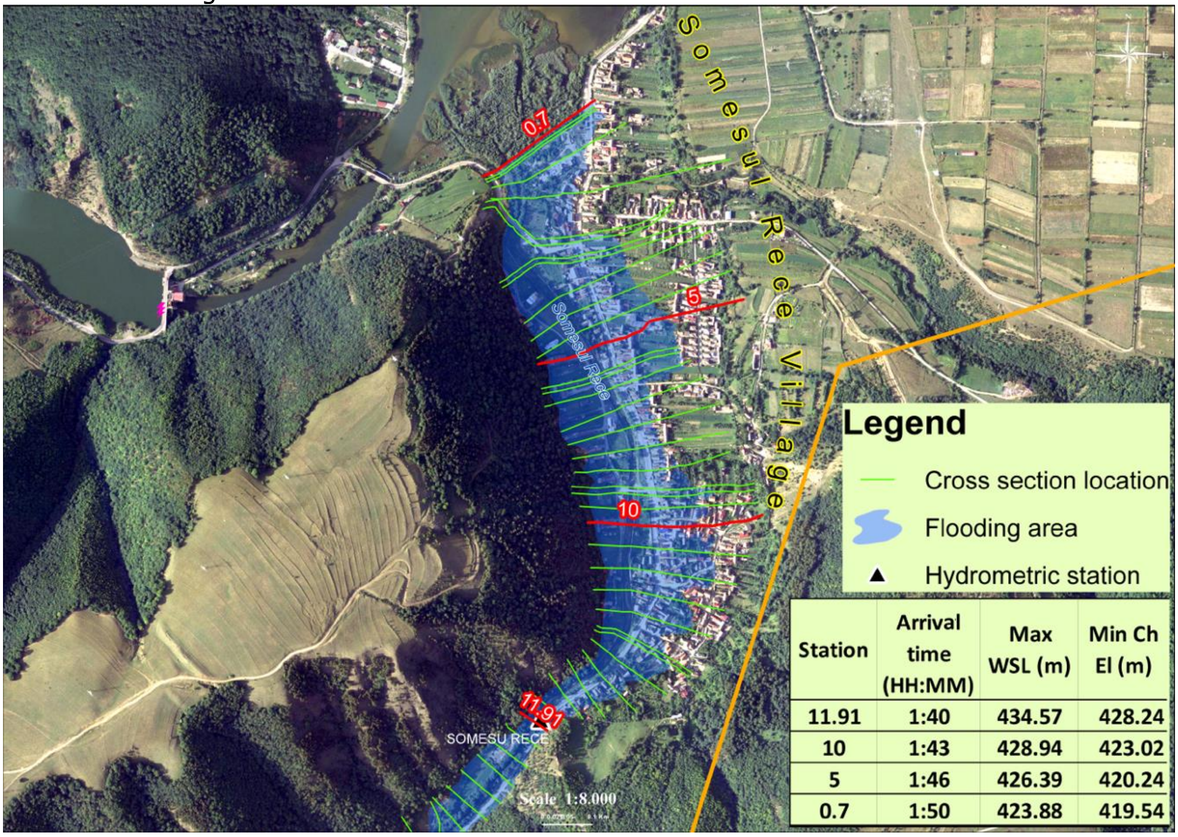


Fig. 9: Levels and flows hydrographs - a. Section immediately downstream of the dam; b. The last section from the Gilău lake entrance

In our case scenario, the breaking wave flow comprises, also, the tributary flash-flood flow into the lake, because the breach is formed as a result of the discharge over the canopy of the dam.

The Someşul Rece river narrow corridor, downstream of the homonym reservoir, has a gorge like aspect, with numerous narrowing and widening areas of the valley. This aspect, alongside with the roughness elements of the major riverbed, makes the amplitude of the generated flash-flood peak to be considerably reduced, along these 29 kilometers, from 4450 m3/s, registered immediately downstream of the dam, up to 555 m3/s at the entrance in the Gilău reservoir. Although the attenuation is more than consistent, the water height at the maximum level of the flashflood is sufficient to inundate nearly half of the Someşul Rece- village and generate significant damages (Fig. 10).



Station	Arrival time (HH:MM)	Max WSL (m)	Min Ch El (m)
11.91	1:40	434.57	428.24
10	1:43	428.94	423.02
5	1:46	426.39	420.24
0.7	1:50	423.88	419.54

Fig. 10: Flooding map for Somesul Rece Village

Flooded area

The resulting flooding map, offers informations about the areas with flooding risk , the accidental wave with a rapid acceleration and the turbulent supercritical flow, which propagates in the downstream area (Fig. 10). On the gorge sectors, the level of energy increases significantly with the propagation of the wave through the narrow and steeper valleys. A vulnerability map was drawn up for Someşul Rece village to make people aware about the risks of flooding. It includes the area exposed to the flood and the time of anticipation, which can be effective in reducing the damage caused by the flood and reduce the number of victims.

For our scenario, the propagation time of the dam breaking wave is 1.5 hours up to the confluence with the Gilău lake, a sector of 29 km in length.

Conclusion

This paper highlights the high risk of exposure for the socio-economic objectives located downstream of the Someşul Rece 1 dam, in case of dam failure. In the mountain area, the spatial typology of the villages, located along the watercourse, determines a high risk for the population in case of a dam break. The results revealed by the modeling in the HEC-RAS, have shown that the accidentally wave arrive in the first village (Măguri Răcătău) in a few minutes (18 min), with a flow rate of 2061 m3/s, and spreads very quickly downstream. The good synchronization between the wave arrival time and the peak debit (or the maximum water depth with no appreciable distinction) indicate that the water profile poses a very steep front, which is typical for accidental waves, which propagate through the riverbeds with a big slope.

The identification of flooded areas, of the flooding depth, of the water velocity and the of the flood duration, 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 important when designingthe high waters spillway capacity, in particular for the arch dam. The importance of implementing an alarm sirens system should not be neglected, in case of failure of the dam. The Someşul Rece 1 dam failure might even endanger the objectives located at a further distance, i.e. up to the entrance of the homonym river in Gilău lake.

Acknowledgements

We would like to thank to the ”Somes-Tisa” Water Basin Administration, (S.T.W.B.A.) Cluj and to the ”Romanian Waters” National Administration (R.W.N.A.) for the provided data. We would also like to thank all those who have offered or will offer suggestions for the improvement of the present paper.

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