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**A** – study design
**B** – data collection
**C** – statistical analysis
**D** – data interpretation
**E** – manuscript preparation
**F** – literature search

# Modelling approach for gravity dam break analysis

**Mourad BOUSSEKINE[1) ABCDEF], Lakhdar DJEMILI[2) AE]**

[1)] Badji Mokhtar University, BP 12, 23000 Annaba, Algeria; e-mail: mourad357159@yahoo.fr
[2)] Badji Mokhtar University, Department of Hydraulic, BP 12, 23000 Annaba, Algeria; e-mail: l_djemili@hotmail.com

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**Abstract**

The construction of dams in rivers can provide considerable benefits such as the supply of drinking and irrigation water; however the consequences which would result in the event of their failure could be catastrophic. They vary dramatically depending on the extent of the inundation area, the size of the population at risk.

This paper presents an analysis of dam break model of Hammam Grouz in Algeria, for 100-years recurrence flood with the dam break occurring near the peak of the flood event. The software HEC-RAS was used to determine water-surface profiles of in-place and dam break scenario, this model supports on the resolution of the equation of Saint-Venant for unsteady flow analysis. Inundation maps were developed that shown the estimated extent of downstream floodwaters. Simulation results were used to determine the hazard classification of a dam break.

**Key words:** *dam break, Hammam Grouz, HEC-RAS, inundation maps*

## INTRODUCTION

The two primary tasks in the analysis of a potential dam failure are the prediction of the reservoir outflow hydrograph and the routing of that hydrograph through the downstream valley to determine dam failure consequences. When populations at risk are located close to a dam, it is important to accurately predict the breach outflow hydrograph and its timing relative to events in the failure process that could trigger the start of evacuation efforts WAHL [2010].

A flood which is caused by failure (breach) of a dam is much larger than any of the previous floods that originated from the runoff of rainfall; and, its consequences are often catastrophic if human development exists in downstream of the dam. When dams fail, property damage is common, but loss of life can vary dramatically with the extent of the inundation area, the size of the population at risk, and the amount of warning time available Bureau of Reclamation [1998].

On average 40% of dam failure occurred, due to the inability of the spillway to carry the load flow ATALLAH [2002]. Dam failure results in the formation of a flood wave, resulting in a sudden increase of water level to downstream. The objectives of this study are:
– recognize and organize the necessary studies to downstream of the dam;
– determine the possible scenarios of dam failure based on its characteristics;
– define the probable consequences in the area downstream of the dam.

HEC-RAS was used to determine water-surface profiles of in-place and dam-break scenarios for the inflow design floods that were simulated. Inundation maps were developed for the area downstream. There were previous studies that have used HEC-RAS in the dam failure as: dam failure Lom-Pangar in Cameroon [PIERRE, CAZAILLET 2005], dam failure Çokal in Turkey OZDEMIR *et al.* [2010], and, four reservoirs failure in the Black Hills, South Dakota in USA HOOGESTRAAT [2011].

In Algeria, there were two events of dam failure of Fergoug (Maascre) – Phot. 1:

– in March 10, 1872: an exceptional flood estimated at 700 $m^3 \cdot s^{-1}$ caused the break of the spillway.
– in December 15, 1881: a flood of 850 $m^3 \cdot s^{-1}$; caused the break of the spillway, 250 people were drowned, bridges, houses and washed away by the raging waves BOUHLALI [2006].

Among the 52 large dams in operation in Algeria, the seepage rate of some far exceeds the normal, as the case of the dam Hammam Grouz in Mila, the average flow rate of leakage neighbours of 50 000 $m^3 \cdot d^{-1}$ (Phot. 2), to recover this volume, storage basin has been made (the main characteristic the dam are given in Table 1). This solution is effective at the moment, but not a final solution since the dam was threatened by a progressive failure or instant [TOUMI, REMINI 2006].

The Hammam Grouz dam is 3 km far from Oued Athmania's city in MILA as shown in Figure 1, it is located upstream of a gorge cut by valley of Rhumel in the cretaceous limestone, that form the Djebel (mountain) Grouz.

The valley has been visited in many ways from the dam to the bridge at the exit of the town of Ain Smara. The structures that may be threatened by the dam break wave are shown in Table 2.

**Table 1.** Key features of the dam Hammam Grouz

| Feature | Value |
|---|---|
| Dead storage | 4 $Mm^3$ |
| Total volume of the basin | 45 $Mm^3$ |
| Foundation of the dam | 687.0 m |
| Crete dam | 736.5 m |
| Dam height | 49.5 m |
| Dam crest length | 217 m |

Source: own elaboration.

**Table 2.** The downstream structure

| Structures | Distance from the dam, m |
|---|---|
| Oued Athmania City (section 9.11) | 3 317 |
| Wastewater treatment station (section 8.92) | 3 711 |
| Bridge of motorway (section 8.71) | 4 204 |
| Ouled Kasbah town(section 6) | 9 363 |
| Bridge CWN101 (section 2.72) | 18 013 |
| Ain Smara City (section 1.33) | 22 062 |
| Bridge of Ain Smara (section 1) | 22 738 |

Source: own elaboration.

Phot. 1. Dam failure of Fergoug [BOUHLALI 2006]

Phot. 2. The leakage of Hammam Grouz dam in 2003 (photo *M. Boussekine*)

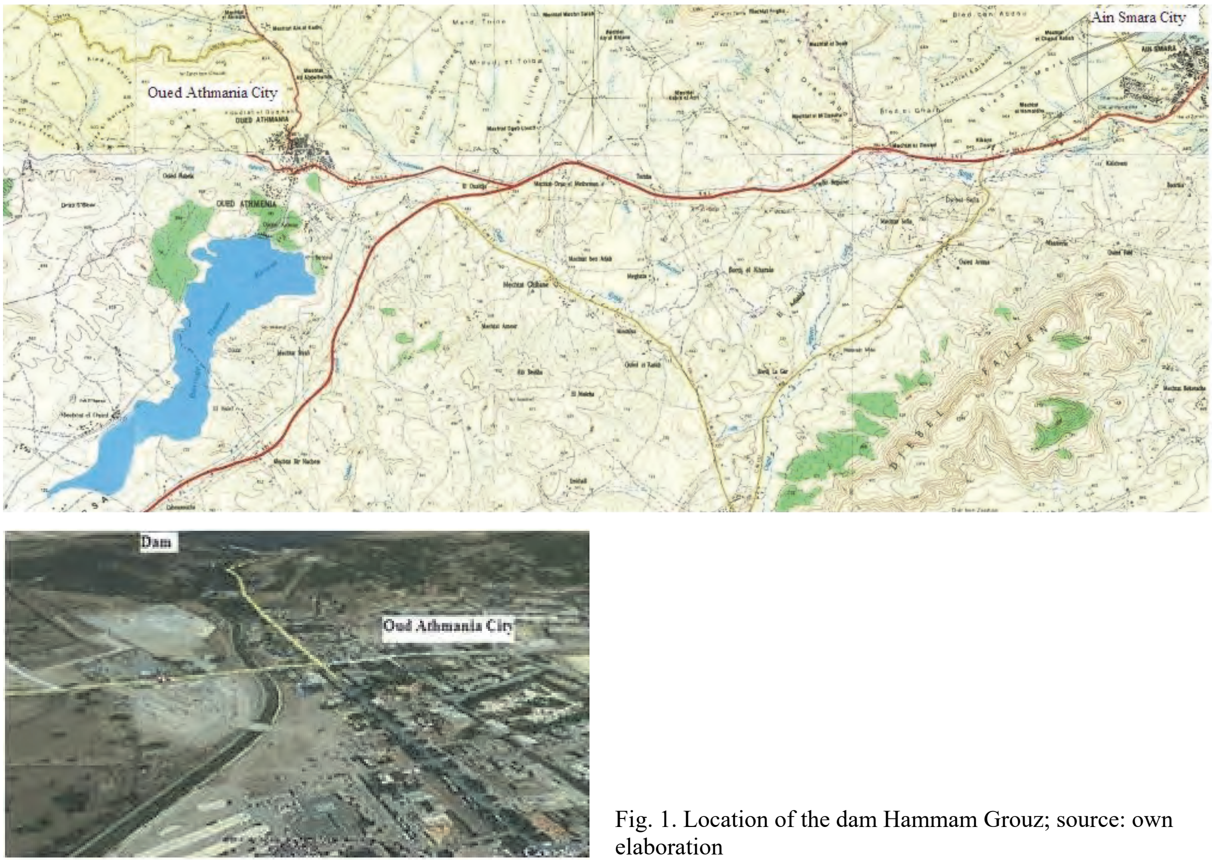


Fig. 1. Location of the dam Hammam Grouz; source: own elaboration

## MATERIALS AND METHODS

The software HEC-Ras, that allows transient simulations from a technical standpoint, the transient simulations are done by solving the equations of 1D Saint-Venant; a great difficulty in transient simulations is the instability of the model. This is less important for small floods which overflow that are limited to exceptional floods that submerge bridges and dams. The results give new 1D model HEC-RAS superior to the two 2D models, in spite of the calibration method and the type of validation KREIS [2004].

Using HEC-RAS, requires a geometry just crucial for achieving a realistic simulation. Sections (cross section) are the key element of good geometry. The remaining data are difficult to obtain the couple Station–Elevation "*x*, *y*", and the distance between two consecutive sections (downstream reach length). To do so, we made the numeric modelling of land by using the Surfer9 software from the card of state regimental adjutant of site of a scale 1:50 000 as shown in Figure 2.

Surfer is a grid-based mapping program that interpolates irregularly spaced *XYZ* data into a regularly spaced grid. The grid is used to produce different types of maps including contour, vector, image, shaded relief, 3D surface, and 3D wireframe maps.

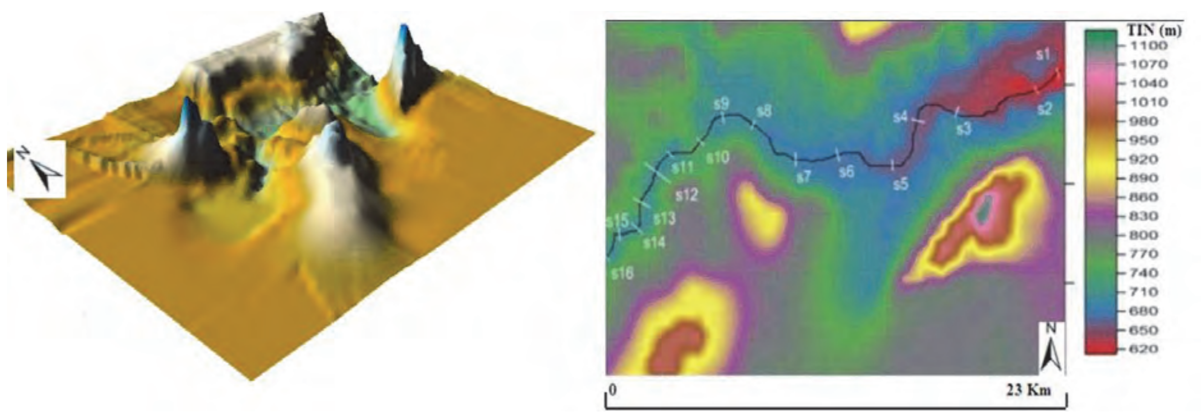


Fig. 2. Contour map of the bathymetry of the Rhumel valley with sections; source: own study

The Rhumel Valley for a length of 23 km downstream of the dam site has been represented in the model by cross sections taken at regular interval. Considering the Manning's roughness coefficient for main channel and over bank have been taken respectively as 0.033 and 0.05. The loss of charge related to expansion and contraction of the channel, or related to natural obstacles, are included in the model with respective coefficients of 0.3 and 0.1.

The integrated effects of reservoir inflow, storage characteristics and the downstream valley backwater on the magnitude and the shape of the dam-breach wave were considered by HEC [1978]. Depth-integrated mass conservation and momentum balance equations known as shallow-water equations, they are the basis of the flood simulation methodology [BEGNUDELLI, SANDERS 2007b]. The hypothesis associated with this widely accepted dam-break flood prediction methodology is that the vertical pressure distribution is hydrostatic [KATOPODES, STRELKOFF 1978], and furthermore that turbulent momentum dissipation can be budgeted through bottom stresses that are modeled, using a quadratic drag law [HOGG, PRITCHARD 2004]. The drag coefficient was scaled for this study by a Manning coefficient [BEGNUDELLI, SANDERS 2007a].

HEC-RAS software based on a solving the fundamental equations of Saint–Venant, continuity and momentum equation.

$$\frac{\partial A_T}{\partial t} + \frac{\partial Q}{\partial x} - q_l = 0 \qquad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \qquad (2)$$

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

The equations derived by BARKAU [1982] are the basis for the unsteady flow solution within HEC-RAS. The numerical solution of these equations is by using finite difference method BRUNER [2008].

**Scenario of the dam-break**

To simulate the flood propagation, the hydrograph of the discharge flowing out of the breach must be estimated and imposed at the upstream boundary of the computational domain PILOTTI *et al.* [2011] for this study the overtopping is the main cause of dam break during 100-years recurrence flood. According to the international standards, a breach will form in 10 minutes, representing the rapid and complete failure of the gravity dam. The size of the failure will be large, with a breach area being 2520 m$^2$. The breach will be rectangle in shape with a bottom width of 90 m. In this scenario, the gates of the dam will be adjusted in accordance with the operating plan for this dam. In addition to cross sections obtained from topographic maps, other cross-sections were interpolated by the HEC-RAS program and represented an average section between known cross sections. Figure 3 displays the shape and the time of breach formation.

In order to model the behavior of the valley, an input hydrograph is needed to show the variations in discharge over a given time period. A hydrograph of 100-years flood event was imported into the model. The simulation has been made for unsteady flow system [FEATHERSTONE, NALLURI 1995] for 24 hours duration.

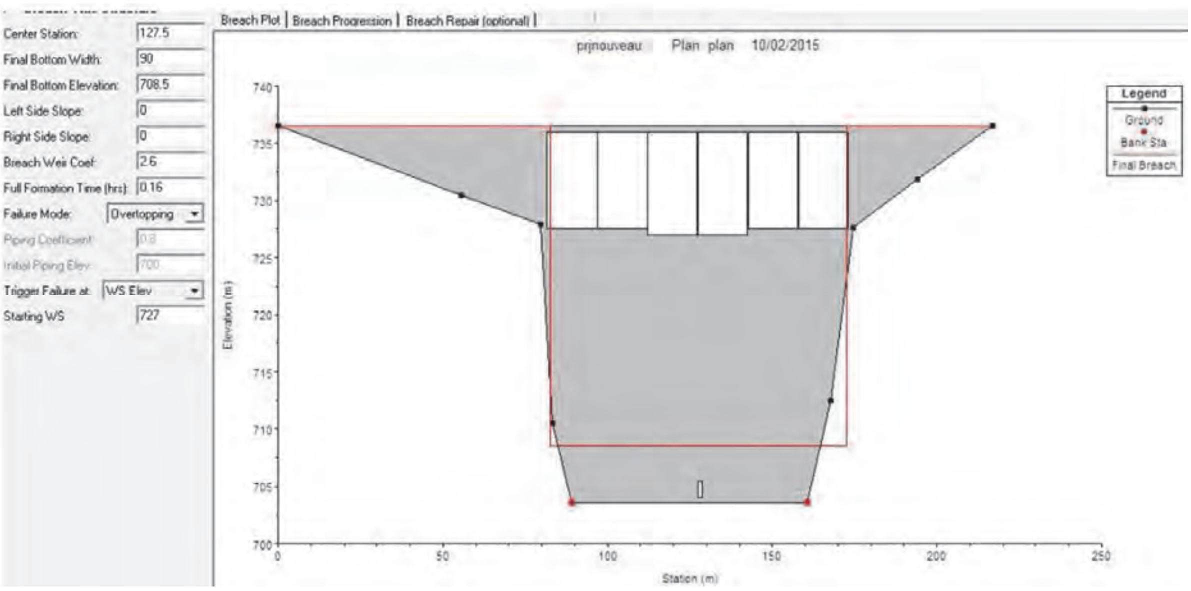


Fig. 3. The shape of breach source: own study

## RESULTS

After completing calibration, the model computed water surface elevations and discharge hydrographs, using a computation interval of two minutes, which produces a very accurate hydrograph. A shorter time interval would produce a slightly more accurate hydrograph, but also a very large amount of data, while a longer time interval would produce a slightly less accurate hydrograph.

The flow travels through critical velocity to the downstream slope, the characteristics of the flood wave, including maximum stage, discharge, change in water surface elevation former to dam break, and velocity were computed at seven selected sites (Fig. 4).

### Inundated area

The flood map represents areas where there is a risk of flooding, a rapidly accelerating turbulent supercritical flow is observed on the steep downstream slope. Here the energy levels increase significantly as the flow proceeds along the downstream slope of the dam. For warning the population of the risk posed due to flood hazard, vulnerability maps are made for Oued Athamnia City and Ain Smara City (see Fig. 5). As discussed by Merabtene [MERABTENE *et al.* 2004], that warning the population using up to date information technology and preparatory work of flood hazard map distribution among them proves to be effective to mitigating flood damage and reduce the numbers of casualties.

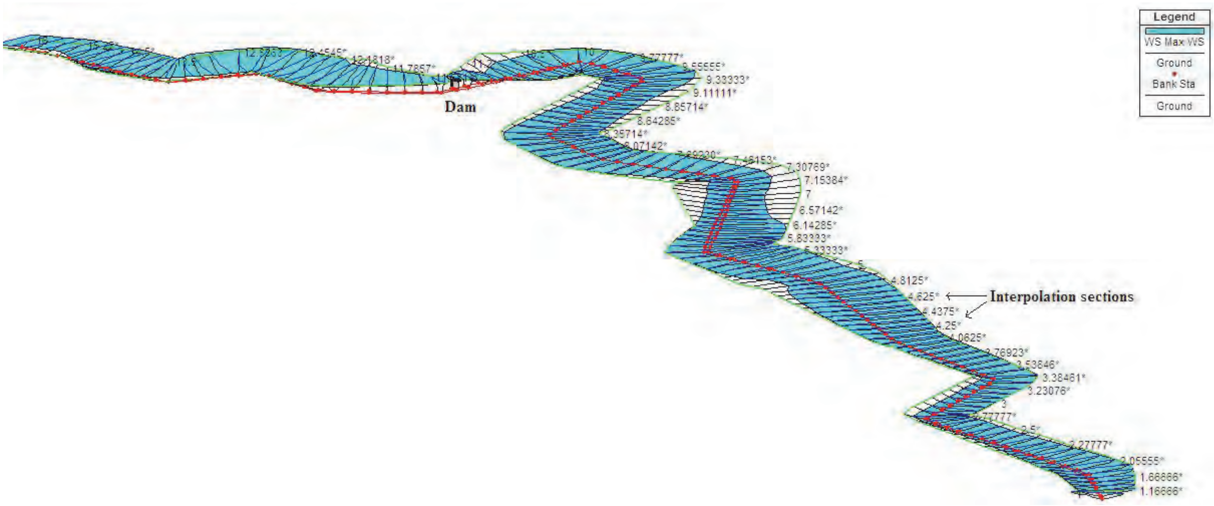


Fig. 4. Profile plot of dam break in HEC-RAS model source: own study

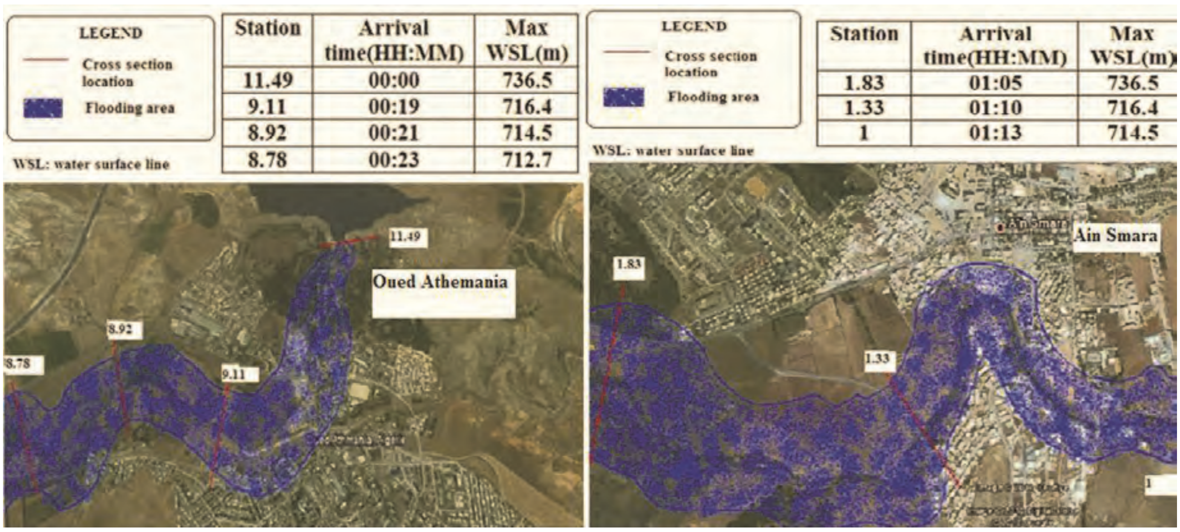


Fig. 5. Inundation map for city of Oued Athmania and Ain Smara; source: own study

## SUMMARIZE AND CONCLUSION

This paper has presented the big risk of Hammam Grouz dam break to human life, particularly for inhabitants residing downstream, and close to the river; the results revealed by HEC-RAS shown the flood reaches the first villages (Oued Athmania) in a few minutes (19 min) and exhausts itself very rapidly, that it reaches of 13 869 $m^3 \cdot s$. The closeness between the arrival time of the wetting front and the peak discharge (or peak water depth without appreciable distinction), indicates that the water profile presents a very steep front, which is typical of waves propagating in very sloping streams.

Identification of the inundated areas, inundation depth, speed and duration, as well as the impact that flood water characteristics can have on the inundated dated areas, are very important for decision making, emergency evacuation and early warning. This study also represents the importance of a spillway's flood design capacity, especially for a gravity dam, the importance of an alarm system in case of dam failure, and also that the rupture of the Hammam Grouz could even endanger structures far from the dam.

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**Mourad BOUSSEKINE, Lakhdar DJEMILI**

**Modelowe podejście do analizy przerwania zapory**

STRESZCZENIE

Budowa zapór na rzekach przynosi znaczące korzyści w postaci dostawy wody pitnej i wody do nawodnień, jednakże konsekwencje wynikające z ich przerwania mogą być katastrofalne. Skutki przerwania zapory zależą od wielkości zalanego obszaru i wielkości populacji zagrożonej ryzykiem.

W pracy przedstawiono modelową analizę przerwania zapory Hammam Grouz w Algierii w przypadku stuletniej fali powodziowej i przerwania zapory powstałego blisko szczytu fali powodziowej. W celu oznaczenia profili powierzchni wody w wariancie prawidłowym i w przypadku przerwania zapory użyto programu HEC--RAS. Model bazuje na rozwiązaniu równania Saint–Venanta do analizy przepływów nieregularnych. Utworzono mapy zalewów, które pokazują zasięg wód powodziowych poniżej zapory. Wyniki symulacji użyto do klasyfikacji ryzyka przerwania zapory.

**Słowa kluczowe:** *Hammam Grouz, HEC-RAS, mapy zalewu, przerwanie zapory*