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

Evaluation of potential dam break flood risks of the cascade dams Mexa and Bougous (El Taref, Algeria)

Hamza BOUCHEHED[1) BCDEF] ✉, Mustapha K. MIHOUBI[1) ADEF], Oussama DERDOUS[2) CDEF], Lakhdar DJEMILI[3) ADEF]

[1)] Water Resource Mobilization and Enhancement Laboratory (MVRE), High National School for Hydraulic (ENSH), 29 route Soumaa, BP 31, 09000 Blida, Algeria; e-mail: hamza.aoh@gmail.com, mihkam@yahoo.fr
[2)] University Kasdi Merbah, Faculty of Applied Sciences, Department of civil engineering and hydraulic, Route Ghardaïa, BP 511, Ouargla, 30000, Algeria; e-mail: oussamaderdous@hotmail.fr
[3)] Research Laboratory of Natural Resources and Adjusting, Badji Mokhtar University, BP 12 Annaba, 23000, Algeria; e-mail: lakhdardjemili@gmail.com

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Abstract

The implementation of Bougous dam at 5 km upstream of Mexa dam permits to compensate the storage capacity and to reduce sediment yields in the later, however, these advantages must be associated to the fact that the presence of two large dams in the region poses in case of a dam break event a potential threat to human life and property. Indeed, in this study a numerical simulation of the dam break wave propagation resulting from the failure of the two dams was performed using the two-dimensional hydrodynamic model Telemac-2D, in order to estimate the impacts on constructions located in the downstream valley. The simulation results exported to GIS platform allowed the elaboration of cartographic materials depicting the hydraulic characteristics of the flood wave and its arrival times at key locations, which constitute very useful information for the authorities to avoid significant loss in case of the failure of Bougous and Mexa dams.

Key words: *Bougous dam, dam break, flood wave, GIS, Mexa dam, numerical simulation, Telemac-2D*

INTRODUCTION

Concerns about possible dam failures have peaked in the XXe century after the failure of several large dams, of which Malpasset 1956, Vajont 1963, Teton 1976 and Machhu 1979 Governments and People all around the world became aware of the potential danger of catastrophic flooding susceptible to occur in case of dam burst [WAHL 1998]. In connection, Emergency Action Plans designed to mitigate loss associated with these events has become mandatory to dam owners.

The failure of the Malpasset dam in 1959 has promoted researcher to develop and to calibrate several one-dimensional and two-dimensional numerical models capable of predicting the consequences of a potential dam break in a realistic manner, of which we mention the studies of HERVOUET and PETIJEAN [1999], who modelled the phenomenon based on a finite element background, ABDUL [2000] and TINGSANCHALI and RATTANAPITIKON [1999] who treated the two-dimensional modelling of dam wave propagation on an initially dry bed. As well, VALIANI and CALEFFI [2015] who used numerical models based on finite volume backgrounds to model dam break waves.

In Algeria, the scarcity of dams' accidents "in fact only two failures were archived, it concern the same dam Fergoug dam, situated thirty kilometers upstream of Bou-Hanifia in the Northwest of the country, which was broken in 1881 and in 1927 due to the insufficiency of the spillway capacity", should not lead to the thought that the risk of dam break is neglected for the "65 large existing dams". As a matter of fact, this scarcity of accidents is resulted from the oversizing of dam spillways.

This scarcity of dam accidents reflects on the number of researches conducted in this field in Algeria of which we mention the researches of BOUSSEKINE and DJEMILI [2016], DERDOUS *et al.* [2015a; b] and MIHOUBI *et al.* [2014]. Because of the significance of the precipitations which favours the climatic conditions in the watershed of El Kebir Wadi, the region was selected by the National Agency for Dams and Transfers "ANBT" for the implementation of two dams in order to retain the maximum possible water, the first of which is Mexa dam operating since 1999, and the second is the Bougous dam. The latter is built so as to compensate for the reduction of the capacity Mexa reservoir by reducing the volume of the mud, since the sediment yields reached a critical rate estimated at 1 $hm^3 \cdot year^{-1}$.

However, these advantages must be associated to the fact that these dams present by their huge volume of water a significant menace to downstream population, especially in the case of their failures.

Thus, in the present study by using the two-dimensional model Telemac-2D a numerical simulation of the failure of the two cascade dams was performed in order to assess the impacts of the associated flooding on the residential areas located downstream.

Cartographic materials illustrating the hydrodynamic characteristics of the resulting dam break wave and its arrival times at key locations were developed in GIS environment as constructive pieces that should assist the authorities in the preparation of emergency measures in case of a dam break event.

METHODS

To achieve the objectives of this study, an approach based on the integration of the geographic information system (GIS) and the TELEMAC system was used, this approach is represented by the following flowchart (Fig. 1).

The TELEMAC system is composed of several softwares which are all based on finite elements background.

BLUE KENUE

A graphical interface used to prepare the geometric data (grid generation) for the hydraulic modelling and to visualise the results once the simulation is achieved.

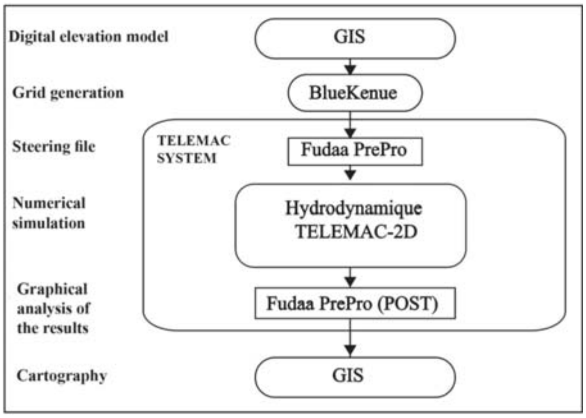

Fig. 1. Flowchart showing the employed methodology; source: own elaboration

FUDAA PREPRO

A pre-processing and post-processing tool for many hydraulic models, it allows the users to define the parameters to introduce in the hydraulic model (e.g. initial and boundary conditions).

TELEMAC-2D

A hydraulic model which solves the two-dimensional shallow water flow equations thanks to finite element techniques operating on non-structured grids of triangular elements.

The two-dimensional shallow water flow equations take the following form in Telemac-2D [HERVOUET 2007]:

Continuity:

$$\frac{\partial h}{\partial t} + u.\vec{\nabla}(h) + hdiv(\vec{u}) = S_h \quad (1)$$

Momentum along x:

$$\frac{\partial u}{\partial t} + u.\vec{\nabla}(u) = -g\frac{\partial Z}{\partial x} + S_x + \frac{1}{h}div(hv_t\vec{\nabla}u) \quad (2)$$

Momentum along y:

$$\frac{\partial v}{\partial t} + \vec{u}.\vec{\nabla}(v) = -g\frac{\partial Z}{\partial x} + S_y + \frac{1}{h}div(hv_t\vec{\nabla}v) \quad (3)$$

Where: h = depth of water, m; $u.v$ = velocity components, $m \cdot s^{-1}$; g = gravity acceleration, $m \cdot s^{-2}$; v_t = velocity diffusion coefficient, $m^2 \cdot s^{-1}$; Z = free surface elevation, m; t = time, s; x, y = horizontal space coordinates, m; S_h = source or sink of fluid, $m \cdot s^{-1}$; S_x, S_y = source or sink terms in dynamic equations.

APPLICATION

The proposed methodology is applied to a case of study that consists of the failure of the cascade dams Mexa and Bougous presented briefly in the next section. All the data used in this study are collected from National Agency of the Dams and transfers (ANBT) and from National Agency of Hydraulic Resources (ANRH).

MEXA DAM

The Mexa dam (Fig. 2) is implanted on the El Kebir Wadi at about 10 km east of the city of El Taref. It is an earthen dam of 30 m height, it has a total capacity of 30 hm^3 and a spillway capacity of 1800 $m^3 \cdot s^{-1}$. The dam was put into service since 1999 in order to supply the cities of Annaba and El Taref with drinking water.

Fig. 2. Localization of the study area; source: own elaboration

BOUGOUS DAM

Bougous dam (Fig. 2) is an earthen dam of 71.30 m height and a spillway capacity of 1245 $m^3 \cdot s^{-1}$, located in the North-East of Algeria near the Algerian--Tunisian border, approximately 100 km from the city of Annaba and 20 km to the East of the city of El Taref. The dam was implanted to compensate the loss in the storage capacity of Mexa dam, it counts a storage capacity of 66 hm^3 designed to satisfy domestic and industrial water needs in the cities of El Taref and Annaba.

NUMERICAL MODELING

The computation domain takes into consideration the two reservoirs as well as the valley at the downstream of Bougous and Mexa dams where is situated El Taref city, Ain El Assel city, Rekebba town, Boutella Abdallah town and Lake Oubeira at the entrance of the El Kala city (Fig. 3).

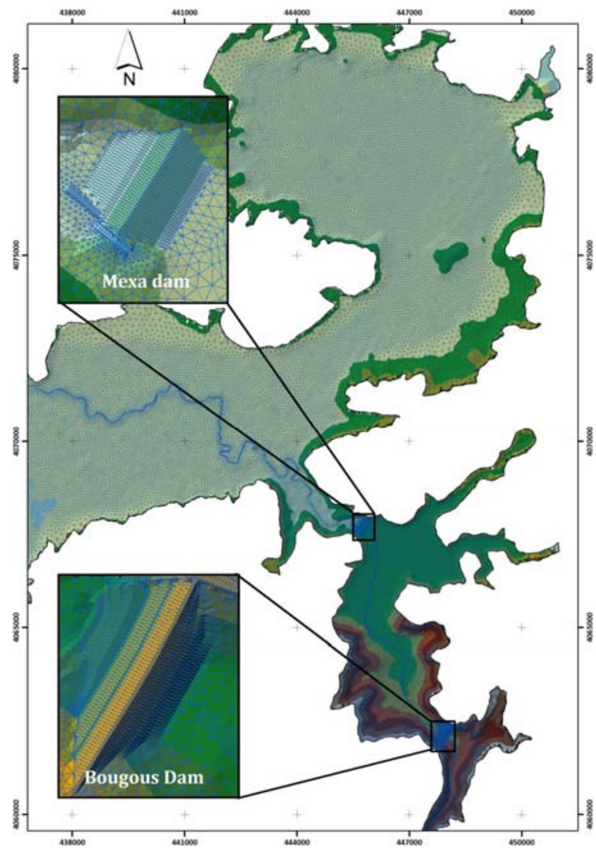

Fig. 3. Mesh of the study area Mexa and Bougous dams; source: own elaboration

The valley was represented by a non-structured triangular mesh generated from the Digital Elevation Model SRTM with a resolution of 1 arcsecond.

The computation domain consists of 347 164 triangular elements, and 176 774 vertices. The size of the triangular elements varies from 10 m to 30 m.

The two dams are supposed to fail completely and progressively (in 1 hour) due to overtopping which was identified by [COSTA, SCHUSTER 1988] as the most common cause leading to the failure of embankment dams. We assume that the upstream dam begins to fail by the starting of the simulation under the solicitations of the 1000 return period flood event and that the downstream dam fails subsequently when its reservoir level reaches the dam crest.

The initial conditions used in the simulation consist of constant water depths which represent the full reservoir level in Bougous dam (143.6 m) and normal retention level in Mexa dam (58 m). The purpose of this initial condition is to reach the failure of the Bougous dam at the beginning of the simulation, and the failure of Mexa dam at arrival time of the flood wave resulting from Bougous dam, this condition has been chosen to study the most critical case.

An impermeability condition in weak form is imposed on both sides of the valley for considered as an impermeable wall. The upstream boundary condition consists of a constant discharge which corresponds to the peak of the 1000 return period hydrograph which equals 960 $m^3 \cdot s^{-1}$. This condition has been chosen to approach the case of a dam failure in flood times. A Thompson boundary condition is applied to the downstream boundaries to allow outgoing waves to propagate freely across the domain, in which case the boundary values are automatically computed by Telemac-2D. Further, a Strickler coefficient of 40 was assigned constantly all along the modelled valley.

RESULTS AND DISCUSSION

The hydraulic results obtained by Telemac-2D, show the dam break wave resulting from the failure of the upstream dam (Bougous) reaches and overflows the downstream dam (Mexa) 30 min after the starting of the simulation.

Figure 4 shows the simulation results for respective sequences t = 0 min, t = 15 min, t = 30 min, t = 45 min, t = 60 min, t = 120 min, t = 180 min, t = 240 min and t = 300 min after the starting of the simulation.

The maximum depth reached downstream of Bougous dam after its failure is estimated at 28.3 m (Fig. 4).

After Mexa dam break, the maximum water depths in the downstream reaches 25.0 m (Fig. 5). Depth variation is always decreasing, this is due to the expansion of the dam break wave within the valley which is relatively flat.

According to these maps the dam break wave reaches the downstream dam (Mexa) after t = 30 min, with a maximum depth of 23.9 m.

Fig. 4. Water depths after the failure of the Bougous dam; source: own study

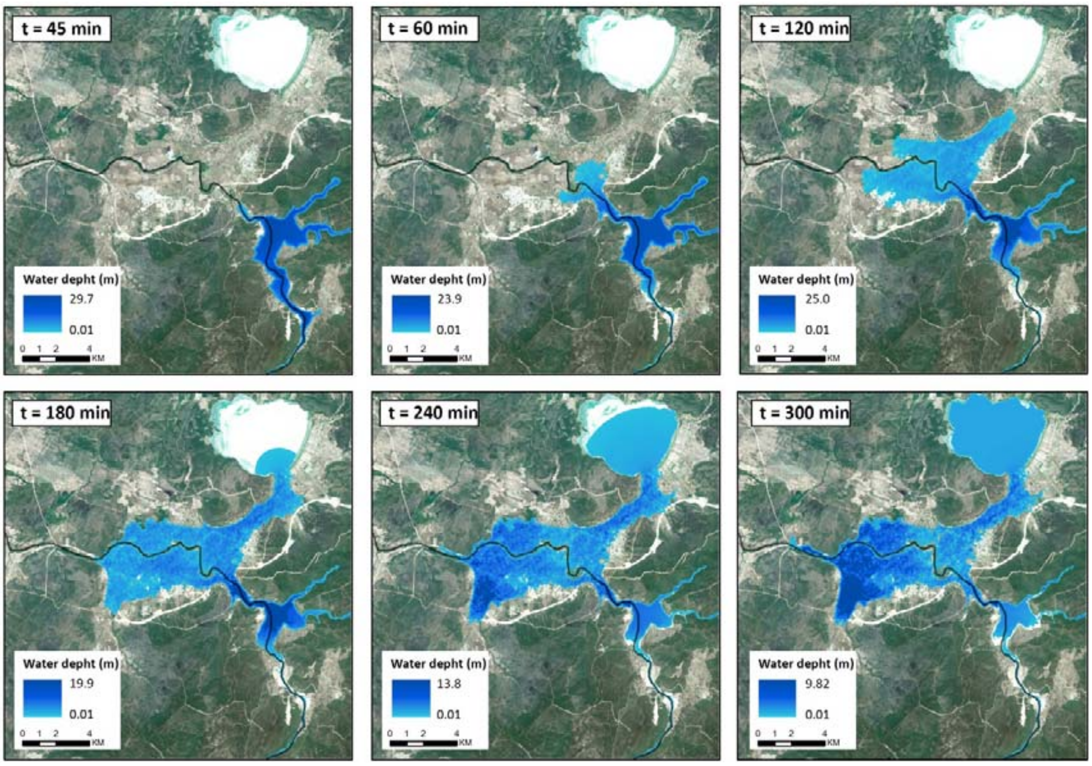

Fig. 5. Water depths after the failure of Mexaand Bougous dams; source: own study

Downstream of the Mexa dam, the wave splits into several waves because of the topography of the valley which becomes flat, two major waves are distinguished clearly the first one travels to Lake Oubeira; in fact a considerable volume of the water released from the two dams finished in the lake, which significantly decreases the dam break wave.

The other wave travels north to the sea within the El Kebir Wadi, it reaches at time t = 221 min the city of El Taref located 8.21 (km) downstream of Mexa dam with a maximum depth of 6.25 m.

Ain El Assel city located 6.37 km from Mexa dam is reached by the dam break wave with a maximum depth of 6.64 m at time t = 203 min. Rekkaba Town which is located 9.58 km downstream of Mexa dam, is partially affected after a time t =180 min.

The velocity maps presented below, show that the flooded zone associated with the failure of Bougous dam presents very high velocities which reach 15.8 $m \cdot s^{-1}$ at time t = 30 min (Fig. 6).

After the failure of Mexa and Bougous dams, the peak velocities downstream vary between 12.33 $m \cdot s^{-1}$ and 4.88 $m \cdot s^{-1}$ depending on the configuration of the valley (Fig. 7).

To evaluate the potential impact of the dam break wave on downstream constructions the Swiss Federal Office of Energy (SFOE) suggested calculating the submersion intensity of water.

The submersion intensity is defined as the product of the flow velocity via the water level. According to the recommendations of the SFOE, a particular danger exists if, in case of a dam failure, the submersion intensity reaches the threshold of 2 $m^2 \cdot s^{-1}$ for which persons or properties may be endangered.

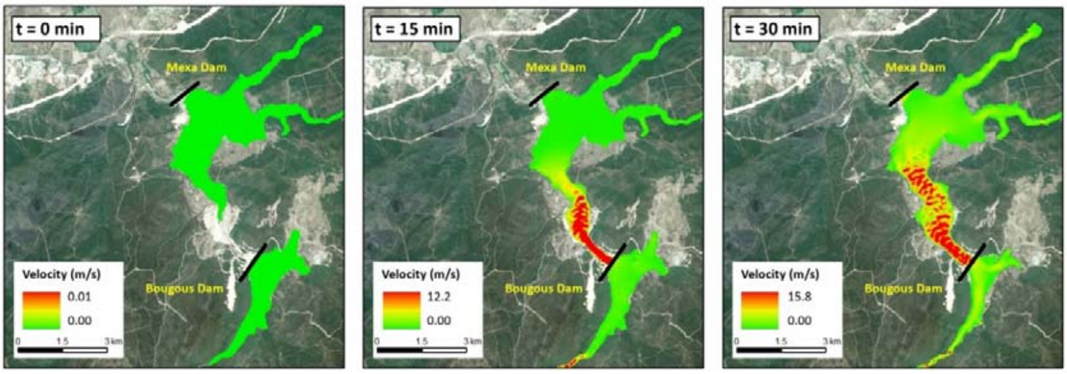

Fig. 6. Flow velocities caused by the failure of Bougous dam; source: own study

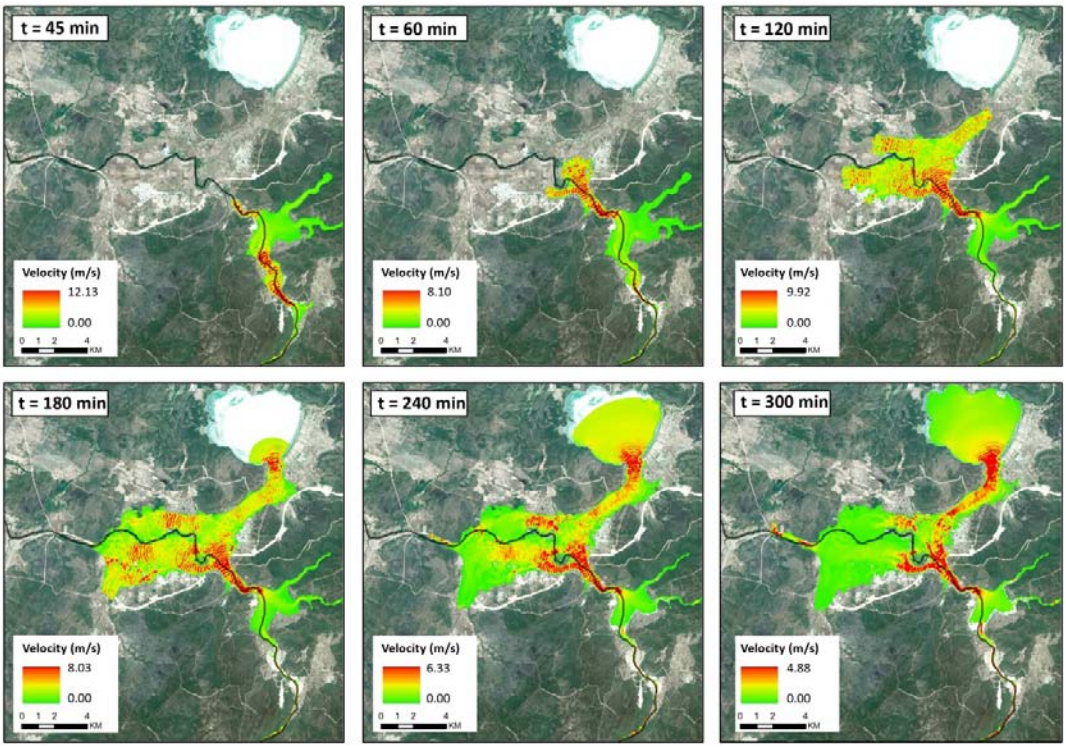

Fig. 7. Flow velocities after the failure of Bougous and Mexa dams; source: own study

The multiplication of the flow velocity and the water level is performed in GIS environment, the results are shown in Figure 8.

It is clear that the submersion intensities resulting from the failure of Bougous and Mexa dams exceed largely the threshold of 2 $m^2 \cdot s^{-1}$ which means that serious damages are expected to occur in the downstream areas in case of a dam break event, it should be highlighted that the most catastrophic consequences are expected to occur in the city of El Taref.

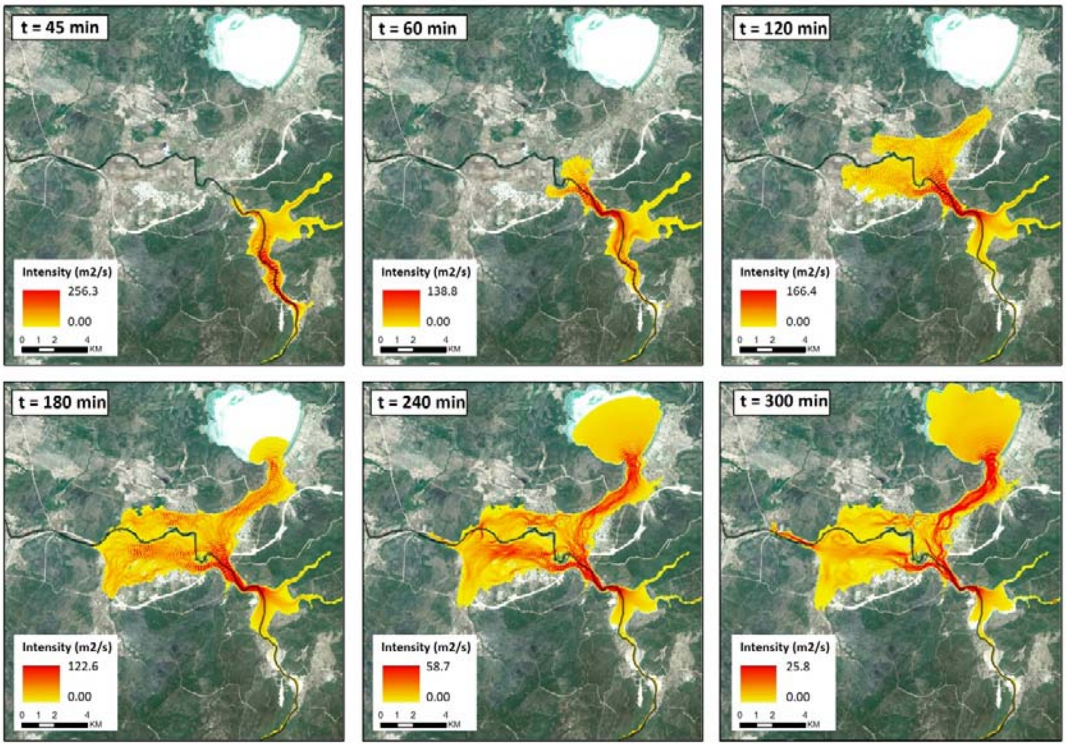

Fig. 8. Submersion intensities after the failure of Bougous and Mexa dams; source: own study

CONCLUSIONS

In this paper, the numerical modelling of the failure of the cascade dams Bougous and Mexa was performed using the two-dimensional model Telemac-2D in integration with the Geographic Information System (GIS).

The study permitted to produce valuable maps showing maximum depths, maximum velocities, arrival times and submersion intensity of the dam break wave on the entire computational domain.

The results show that the downstream dam (Mexa) will be overflowed and destroyed after 30 minute of the failure of the upstream dam (Bougous). After that the dam break wave is relatively decreased due to the flat topography of the region and it splitted in two main waves; the first travels to Lake Oubeira and the second travels through the El Kebir Wadi to the sea.

Concerning the downstream residential areas, significantlosses are likely to be incurred in case of the failure of the two dams according to the SFOE standards.

The obtained results will enable the elaboration of an emergency actions plan (EAP), in which are identified the appropriate steps to be taken by the authorities in order to reduce damages to human life and property in the case of a dam break event in the El Kebir Wadi.

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Hamza BOUCHEHED, Mustapha K. MIHOUBI, Oussama DERDOUS, Lakhdar DJEMILI

Ocena ryzyka potencjalnego przerwania tamy w kaskadzie zapór Mexa i Bougous (El Taref, Algieria)

STRESZCZENIE

Uruchomienie zapory Bougous 5 km powyżej zapory Mexa zwiększyło zdolności retencyjnej i ograniczyło sedymentację w drugim zbiorniku. Tym korzyściom towarzyszy jednak ryzyko wynikające z funkcjonowania w regionie dwóch dużych zapór, których przerwanie może być zagrożeniem ludzkiego życia i dóbr materialnych. W pracy przeprowadzono symulację numeryczną propagacji fali powstałej w wyniku przerwania obu tam z zastosowaniem dwuwymiarowego modelu hydrodynamicznego Telemac-2D w celu oceny wpływu katastrofy na budowle usytuowane poniżej w dolinie rzeki. Wyniki symulacji przeniesione do GIS pozwoliły opracować materiały kartograficzne ilustrujące charakterystyki hydrauliczne fali powodziowej i czasy jej dopływu do kluczowych lokalizacji. Stanowi to bardzo użyteczną informację dla władz, umożliwiającą uniknięcie znacznych strat w przypadku awarii tam Bougous i Mexa.

Słowa kluczowe: *fala powodziowa, GIS, przerwanie tamy, symulacja numeryczna, Telemac-2D, zapora Bougous, zapora Mexa*