Towards a Risk-Informed Decision to Create Early Warning Systems: Case study of a simulation hypothetical supply dam failure scenario in Mexico

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Abstract

This research document the simulation of a flooding event under the hypothetical failure scenario of a supply dam in Mexico. This supply dam provides over the 85% of the water for more than 5 million people, having an essential role in society's welfare and national security. Furthermore, its importance is also related to its capacity to store water for other different uses, such as, agricultural irrigation and flood control, among other important services that allow regional socio-economic development. A failure or this dam could be catastrophic, resulting in a direct flood of at least 30% of China city territory in a lapse of 4 hours. However, the first affectations will occur in the first 30 minutes affecting over one thousand people, the depth levels can reach the 16m in northern part of the city, and two main roads will cut the communication. Risk informed decisions are key for the crisis management. Evacuation routs are mapped. This information could help to create an early warning system needs to be designed and implemented as a way to a preventive element for the territorial security of people, a community training plan must be developed, a risk monitoring and measurement system must be developed, a community emergency plan must be developed, practiced and executed.

1. Introduction

Reservoirs are highly relevant infrastructure assets. Many reservoirs are reaching the end of their period of life, and others are showing undesired displacements and cracking. As time goes on, climate change and pollution will significantly affect the safety of these hydraulic systems. Deterioration factors, such as loads, thermal expansions and contractions, decrease the structure's effectiveness. During the last few decades, the number of accidents and failures that have occurred is increasing, and therefore, a possible failure in the system represents risks in the form of material losses to the environment, and especially if they are close to urban communities. By 2050, most people will live downstream of large dams built in the 20th century.

A possible failure in the dam system represents risks in the form of material losses to the environment, especially if they are close to urban communities. Examples of this catastrophes are reported in during a dam failure in China during Typhoon Nina (Yang et al., 2017), or the Banqiao dam failure (Yang et al., 2019).

All possible causes of dam failures are considered during their design. Furthermore, the values or assumptions consider the theoretical stresses and deformations, which have to comply with fields such as balance, compatibility, boundary conditions, and material (Scaioni et al. 2018). Although it is already known that the practice of regular inspections could, in many cases, prevent failures.

Regular inspections however, as in other preventive routines, are not common. Such deformations could change during emptying and filling periods and are indicated by some authors as hysteresis loops (Pipitone et al. 2018). Other researchers have found a linear relationship between water levels and dam deformations (Yegit et al., 2016; Dardanelli et al., 2014). The influence of seasonal concrete temperature oscillations can also affect deformations of the dam crest (Alcay et al., 2018).

This contribution of this research is as follows:

- A consistent, decisive, and stricter 2D flooding model to create a hypothetical catastrophic scenario.
- The data used belongs to an official digital elevation model and 2020 census population database.
- Studies employing these techniques offer essential information for the comprehensive risk management.
- The ability to identify evacuation routes for making preventive decisions and early warning.

1.1 Background

The water supply for the population in Monterrey Metropolitan Area (5.9 million) is carried out through three dams: Rodrigo Gómez “La Boca”, José López Portillo “Cerro Prieto” and Solidaridad “El Cuchillo”. "El Cuchillo" dam site is located at 25°42' N and 99°17' W in China City, Nuevo León in the Northeast of México and it started operations in 1994 with a 1,123 Mm3 of storage capacity.

El Cuchillo is operated by Water and Sewer Services of Monterrey (Guerra Cobián et al., 2020), supplies approximately 5,000 L/s to the Metropolitan Area of Monterrey. The reservoir captures has seven radial gates control the surplus spillway, which is 13 m wide by 16 m high, with a maximum discharge capacity of 10,477 m3/s. The lowest point of the foundation is 134.00 m above sea level, and the upper elevation is 151.75 m.a.s.l. There are seven spillways, each one delimited by two piers. Cracks were detected in the dam crest since 1995 (one year after its construction was finished). In 2016, the National Water Commission (CONAGUA) started a surveying project. Topographic monuments were built for survey control data, as well as other 84 permanent control points (PCP) were established in the spillways area. The surveying team used these marks to monitor the displacements of this dam.

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Fig. 1. El Cuchillo dam.

2. Methodology

2.1 Data collection

Digital elevation models for the terrain were obtained from INEGI and reconditioned according to the known elevation-area-capacity curves for the reservoir. In addition, geometry and other specifics of the dam and gates structure were obtained from the technical report of the reservoir (CONAGUA).

2.2 Flooding predicgtion and velocity maps

In a first stage an inundation prediction was executed for the study area. The rainfall scenario was the Alex Hurricane. Flooding and velocity maps were developed by bi-dimensional hydraulic modelling using HEC-RAS v6.4.1. Hydraulic damping due to vegetation in the flood zone is not considered.

The reservoir’s initial condition is full, reaching the maximum extraordinary water level (166.66 m.a.s.l). This case is the critical condition, and presupposes an over-storage caused by a previous rain event.

Complete and sudden failure of all seven gates of the dam.

The simulation does not include an external inflow; the phenomenon to be analysed is only the movement of the mass of stored water after sudden release.

2.3 Evacuation routes selection

A second stage involved the selection of at least three safe evacuation routes, considering spatial and temporal flooding map changes. Inundation scope by duration, flood depth, and flow velocity were utilized to assign a flood hazard grade for inundation scope, since in this model is not considered smaller streams such as Arroyo mohinos, and are neither considered the pedestrian roads network within the study area. In addition, are considered buildings and other city assets such as schools and temples as a factor designated as evacuation center, or a detour route.

3. Results

During the first half an hour post failure, at least could be catastrophic, resulting in a direct flood of at least 30% of China city territory in a lapse of 4 hours. However, the first affectations will occur in the first 30 minutes affecting over one thousand people, the depth levels can reach the 16m in northern part of the city, and two main roads will cut the communication. Risk informed decisions are key for the crisis management. Evacuation routes are mapped. Schools located within low-level flood risk areas may be considered shelters. This information

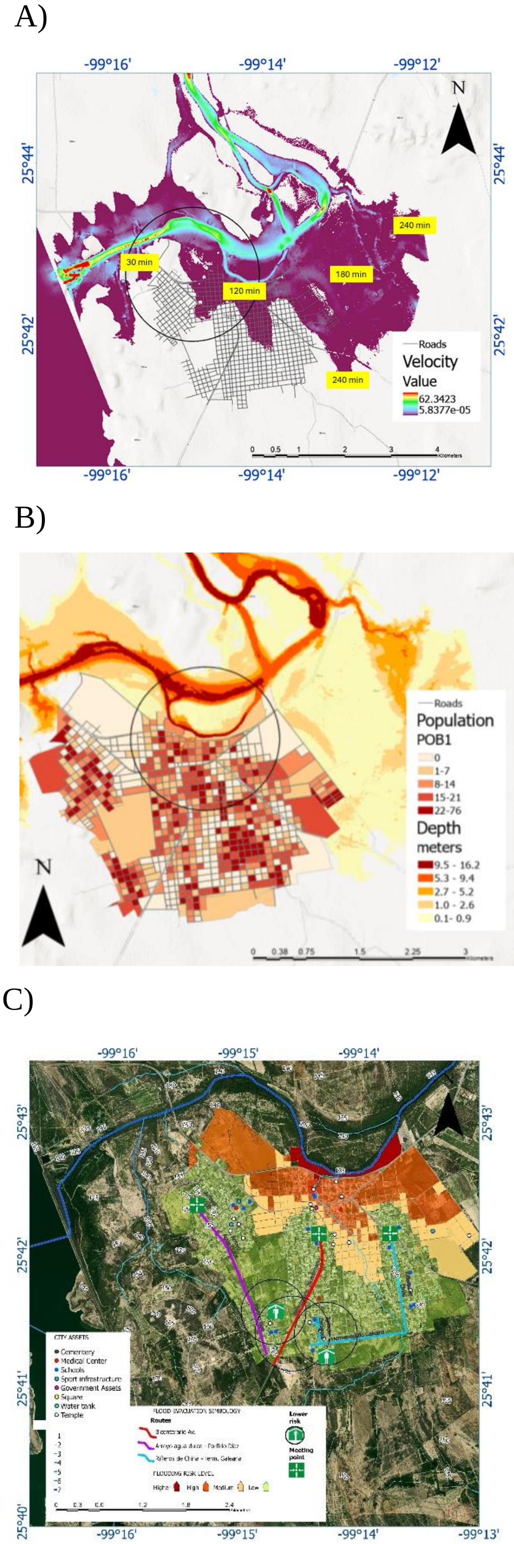

Fig. 2. Floodings in China A) Velocity and time of affectation by zones, B) Number of people per block, C) Affected city assets.

4. Conclusions

Reservoirs as the "El Cuchillo" dam are essential infrastructure assets for the Northeast region, and they require both a more decisive and stricter displacement-monitoring program.

As a result of this study 3 evacuation routes were mapped, however, a more detailed investigation is required, including the other interacting factors during the rupture of the floodgates, such as the vegetation as a border, the complete hydrological network present, etc., for a final proposal that integrates the best evacuation routes.

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