Economic analysis based on geoinformation for the mitigation measures of human and infrastructure losses by floods in the Stream Frontera, Coahuila, Mexico

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Abstract

The present study aims to improve the current conditions faced by the population of the municipality of Frontera, Coahuila, particularly the inhabitants within the area influenced by the Frontera stream. Currently, this stream is in unsuitable conditions, causing floods, bad odors, insecurity, and serving as a source of infections, especially those generated by insects and illegal discharges. Additionally, the stream suffers from a lack of adequate maintenance, reducing its capacity for water flow. Evidence suggests that a program focused on mitigating human and economic losses due to the risk of stream overflow during extraordinary rain events could effectively reduce risks by improving the efficient conduction of rainwater, thereby preventing human casualties, and damage to homes and surrounding roads. Flood severity was modeled for return periods of 10, 50, and 100 years. It is estimated that 3,415 homes could be affected by floods, impacting just over 10,961 inhabitants, which represents about 13% of the municipality's population currently at risk.

1.1 Introduction

During the last two decades, the economic cost of disasters related to natural hazards has increased worldwide (Kousky, 2014). Extreme hydrometeorological phenomena, such as tropical cyclones, hurricanes, and flood-related events, cause more direct economic damage than any other type of natural disaster (Armal et al., 2020; Hoeppe, 2016). The UNDRR (2019) estimates that economic losses during the last decade could reach USD 170 billion. In Mexico, natural hazards during the period from 2000 to 2018 have triggered significant damage to assets and populations, resulting in approximately USD 26 million in losses. Additionally, since the 1900s, natural hazards have affected 17.7 million people and caused 22,000 deaths, with a peak in the last decade (Alcántara Ayala, 2019).

The increase in the economic cost of disasters is related to the adverse effects of unplanned urbanization. Both developed and developing countries have experienced population and economic growth in disaster-prone areas (Botzen et al., 2019). Climate-related problems are also linked to the projected impact of climate change on the frequency and intensity of such events (Climate Change-IPCC, 2023).

1.2 Background

The municipality of Frontera is one of the 38 municipalities in Coahuila (INEGI, 2017), a state located in the central north of Mexico (Figure 2). Frontera is situated at the geographic coordinates of 26° 55' 36" N latitude and 101° 27' 9" W longitude. It covers an area of 506.8 km², representing 0.33% of the state's surface, and is situated at an elevation of 590 meters above sea level (Gobierno del Estado de Coahuila, 2022).

In the 1880s and 1890s, the first homes in the community were built, originally named Monclova Station, with engineer Melquiades Ballesteros being one of the main founders. In 1927, it was established as a Villa along with a new municipality, which was named Villa Frontera. The name was given by the local community, who observed the American colony established there by foreigners and visitors from different parts of the world, who frequently visited the area thanks to the railway built there. Due to the presence of many foreigners, it was believed that they lived on the border. In 1927, Villa Frontera was nominated as a Border City (Gobierno del Estado de Coahuila, 2022).

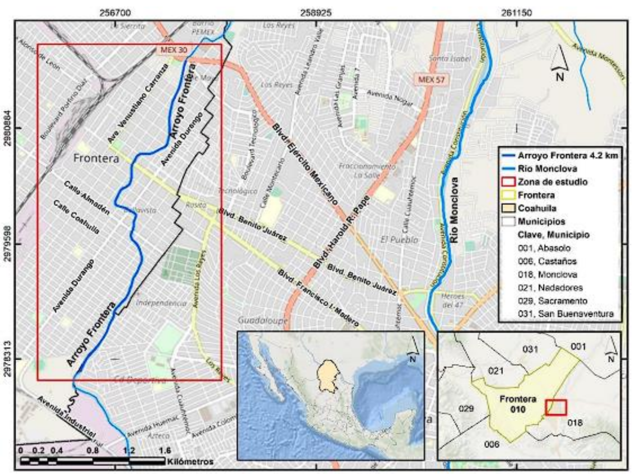


Fig. 1. Frontera Stream in Coahuila, Mexico.

Currently, Ciudad Frontera is part of the Monclova-Frontera Metropolitan Zone, the most populated area of the state of Coahuila, comprising the municipalities of Frontera, Monclova, Castaños, and San Buenaventura (UNAM, 2020). In the 1940s, Frontera Creek drained runoff from aquifers near the Mercado and Gloria hills, allowing neighboring families to collect and use the water for domestic and agricultural purposes. However, in the 1950s, industrial development in the area led to the stream being used as a drainage channel by multiple companies, creating a linear source of environmental pollution. This shift made it impossible for households and farmers to continue using the water for their activities.

With the arrival of industry and the population's lack of awareness, Frontera Creek has become a drainage channel for industrial waste and a dumping ground for all types of organic and inorganic waste. Additionally, uncontrolled vegetation growth and the presence of harmful fauna have further contaminated the area, posing health risks to the population.

A)

B)

C)

Fig. 2. Some examples of the problematic in Frontera stream A) Arroyo Frontera after a precipitation event that occurred in September 2022, B) Lack of weeding and cleaning in Arroyo Frontera, C) Areas of waterlogging and damage to homes due to storm drainage obstructions.

Regarding urbanization, the Frontera stream is situated between the municipalities of Monclova and Frontera, affecting nearly 320,000 inhabitants (according to the 2020 population and housing census by INEGI). These residents are exposed to risks of pollution, health issues, environmental impact, safety hazards, material damage, and loss of life. The accelerated population growth, coupled with a lack of planning, has led to human settlements on the stream's margins and, in some cases, within the stream itself. This has reduced the hydraulic area, decreased the stream's capacity to convey water, and increased the risk of flooding and damage to homes due to overflow during extraordinary precipitation events.

Therefore, it is crucial to implement a comprehensive channeling project to ensure the efficient conveyance of stormwater from the Frontera stream during extraordinary rainfall events. Currently, some stretches of the stream lack proper channeling, leading to uncontrolled vegetation growth in natural terrain sections. Additionally, the encroachment of residential homes within federal zone limits must be prevented. It is also essential to eliminate industrial waste and sanitary sewage discharges that currently pollute the stream.

The existing capacity of the Frontera stream in the study area corresponds to the hydraulic capacity of the channel without adverse conditions such as flow overflows. However, the presence of silt, grass, and illegal sanitary drainage discharges significantly reduces this capacity. Furthermore, the city's growth has exceeded the capacity of the existing hydraulic infrastructure, exacerbated by the lack of cleaning, weeding, and channeling of the stream. Recent and previous years' rains, particularly those associated with hurricanes Alex in 2010 and Hanna in 2020, have caused floods surrounding the stream.

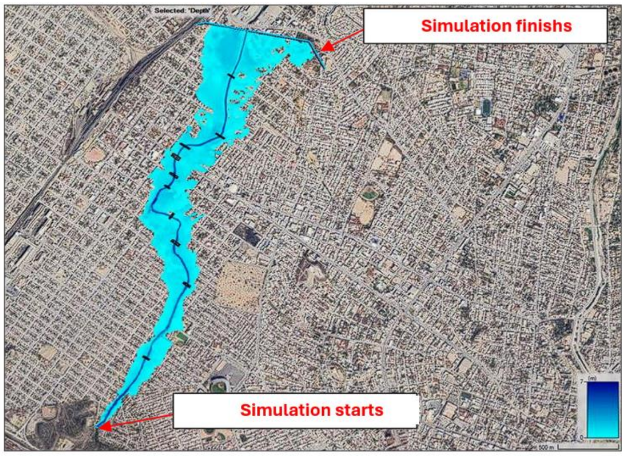


Fig. 3. Some examples of the problematic in Frontera stream A) Arroyo Frontera

Some testimonies collected from extreme flood events are reported summarized in the following Table 1:

Table 1. Testimonies of extreme flood events.

Year	Testimonies
1967	September 1967, Hurricane Viula (Beulah) hit with great force with torrential rains that caused the Monclova River to overflow its banks. In that distant 1967 there was the largest avenue of the Monclova River in the last 50 years.
1988	September 1988, during Hurricane Gilberto, it rained intensely for 48 hours in Monclova and Frontera. A constant, strong, relentless rain, a true "flood" that caused consternation in the city. More than a hundred houses collapsed; with the coming many livestock drowned and crops were lost.
2010	July 3, tropical storm "Alex" caused the Monclova River and Arroyo Frontera to reached a historic level The impact of the tropical storm was destructive and caused damage that until now have not been quantified.
2014	June 18, a torrential downpour fell on Monclova, for a couple of hours, which caused flooding and cars swept away by the current in different sectors from the city. The Monclova River overflowed due to the large amount of water that came down from the hill of la Gloria, which caused havoc in surrounding sectors.

2. Methodology

2.1 Data collection

The proposed project involves reconfiguring and lining the channel with reinforced concrete to create a trapezoidal section that efficiently conducts flows associated with a return period of 250 years. The proposed channel is divided into three sections: Section 1 extends from the beginning of the project on Pablo González Street to the intersection of Guerrero Street; Section 2 extends to Profa. Elvira Reyes Street; and Section 3 extends to Mexican Army Blvd (CONAGUA).

The methodology was based on five steps:

a) Identification, quantification and assessment of costs for the mitigation work,
b) Identification, quantification and valuation of the benefits and damages to the home,
c) Calculation of profitability indicators,
d) Sensitivity analysis,
e) Risk analysis

2.2 Economical assessment

Table 2. Description of the economic assessment

Assessment of horizon	32 years; 2(two) years of construction, 30 years of useful life.
Main costs of the project	The most relevant costs of the project are the Investment costs, and the maintenance.
Main benefits of the project or causes of avoided harm	a) Human lives; b) In homes; c) Surrounding roads; d) Regarding health; e) public safety; among others.
Total amount investment (with VAT)	$367,628,793.08 (Three hundred and sixty-seven million, six hundred and twenty-eight thousand, seven hundred and ninety-seven three MX pesos 08/100 M.N) or around 20 million US Dls.

3. Results and discussion

Flooding occurs when the intensity of precipitation exceeds the catchment and conveyance capacity, causing the channel to overflow. This risk also applies to the human settlements located along the sides of the Frontera stream, increasing the likelihood of their homes being flooded (Nuevo León, 2019). Figure 2 illustrates the flood risk for various return periods (Tr), with flood depths ranging from 0.50 meters to over 2.00 meters in the Tr100 year scenario, along the Frontera stream and surrounding areas, according to the Risk Atlas graphic scale.

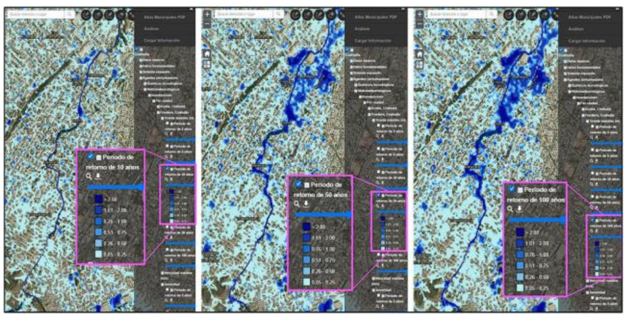


Figure 4. Hydrometeorological disturbing agent: Flood severity for Tr 10, 50 and 100 years.

Similarly, Figure 5 shows the degree of flood severity, categorized from "low" to "very high," with "very high" severity observed in the Tr100 year scenario. This is visualized along the Frontera stream and in some topographically low areas, such as the Roma neighborhood and the vicinity of the intersection with National Army Boulevard.

The demand for the Frontera stream channeling project is driven by the basin's runoff associated with rainfall. Consequently, the demand assigned to the project remains unchanged, as it does not depend on optimization measures of the existing or projected stormwater infrastructure.

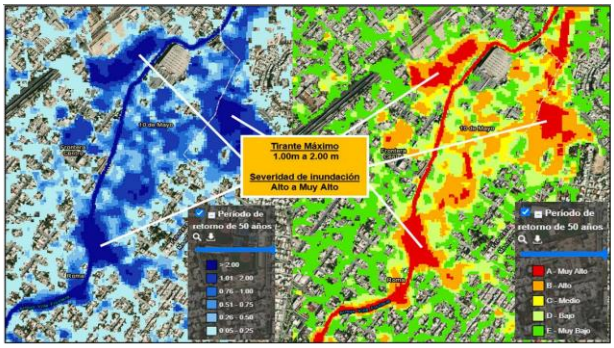


Figure 5. Comparison of maximum depth and severity of flood risk, at specific points near the Frontera stream.

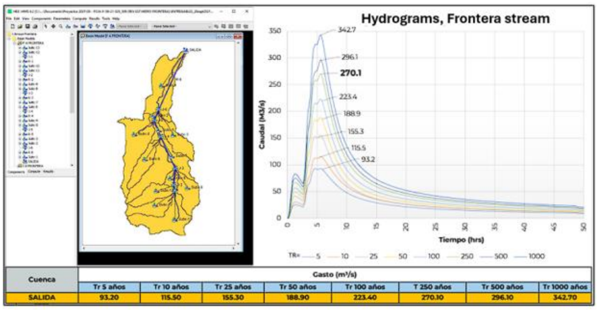
Figure 6A displays the results obtained from modeling conducted with the HECHMS hydrological model (USACE, 2022). It shows the basin discretization into sub-basins and the hydrographs associated with return periods Tr = 5, 10, 25, 50, 100, 250, 500, and 1000 years. The corresponding results for each return period are: 93.2, 115.5, 155.3, 188.9, 223.4, 270.1, 296.1, and 342.7 m^3/s respectively. It's important to note that CONAGUA recommends a return period of 250 years for such projects (MEMORANDUM No. B00.7.-616 issued on September 13, 2017 in Mexico City).

Based on the current hydraulic conveyance capacity of the Frontera stream over its 4.2 km length (supply) and the rainfall-induced runoff in the contributing basin (demand) associated with different return periods of 5, 10, 25, 50, 100, 250, 500, and 1000 years, an analysis of the stream's capacity was conducted. This interaction between supply and demand identifies the issues that would arise if the channeling project were not implemented (Figure 6B), including the costs associated with flood damages.

Therefore, an analysis of the supply-demand interaction was performed based on the current capacity of the Frontera stream in the project's influence zone and the expected runoff associated with various return periods (Tr) of rainfall. This analysis clearly shows that the current capacity does not suffice even for the 5-year return period (93.2 m^3/s).

Graphically, the avoided damages at each probability level of occurrence are illustrated. For instance, for a Tr = 5 (20% probability of occurrence), the avoided damage would amount to $77,135,596. This calculation is similarly performed for each Tr level, with the highest value occurring at Tr = 250, amounting to $627,777,182. As detailed in the methodology, an Annual Expected Damage must be calculated, which correlates the damage value with its probability of occurrence.

A)



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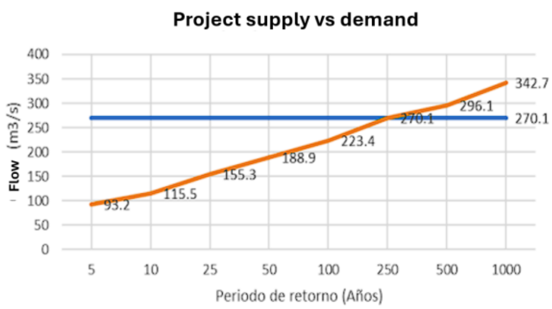

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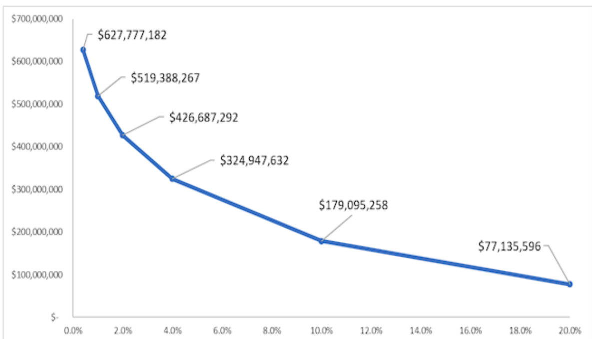

Fig. 6.A) Hydrological study. B) Supply interaction with optimization against demand of the Frontera stream. C) Damage Avoided at different probabilities (TR's)

4. Conclusions

Within the study area, it was observed that approximately 3,415 homes could be affected by floods, impacting over 10,961 inhabitants. This vulnerability encompasses about 13% of the municipality's population. It is imperative to address this situation not only due to its economic impact but also because of significant intangible effects on health and safety. Flooding in the study area has led to issues such as disease outbreaks from insect proliferation and clandestine discharges. Additionally, these areas have become hotspots for criminal activities, taking advantage of the natural vegetation that accumulates along the riverbed. The population faces significant negative externalities. The key findings underscore the urgent need for proper maintenance of the channel to enhance its capacity. However, as demonstrated, maintenance alone is insufficient; increasing capacity is crucial. Therefore, two mitigation alternatives based on canal improvement were considered. The results indicate that the first alternative yields the highest net present value, generating more benefits than the costs associated with its construction. These benefits primarily stem from the avoidance of damages to homes currently at risk, particularly in terms of loss of property and structural damage caused by hydrometeorological events. These benefits are estimated using the Expected Annual Damage (DAE) formula, where the probability of occurrence is multiplied by the damages expected without the project at different return periods (Tr 5, Tr 10, Tr 25, Tr 50, Tr 100, and Tr 250). In monetary terms, the net present value reflects a gain of $189,870,726, derived from the difference between the Present Value of Benefits ($510,391,477) and the Present Value of Costs ($320,520,751).

5. Acknowledgements

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