Past and Present of Geo-Information Technologies in River Engineering: A Case Study of the La Silla Post-Hurricane Alex Flooding

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Abstract

Historically, river modifications in the cities cause floods. River engineering involves planned human intervention in order to achieve benefits such as water resource management, flood control, and improved river navigation or others. This research work aims to analyse the past and present floods in a 27 km section in La Silla River in Monterrey, Mexico using geo-information technologies to reconstruct topography using aerial LiDAR point clouds and Google Earth imagery, and then to run hydrological and hydraulic models. The total length of areas with flooding problems was over the 52% (14.3 km). At least 18 crossings were found in the studied section however 39% of them have insufficient hydraulic area. As urbanization goes on, other modifications have occurred after the Alex hurricane in 2010, the high cost of topography models using aerial LIDAR was an obstacle, furthermore, current Unmanned Aerial Vehicles (UAV) technology is being used to update information and build new Digital Elevation Models (DEM) for the better understanding of the floodings in La Silla River and other rivers in the city.

1. Introduction

Many cities are built near rivers, either intentionally to utilize the river's services or due to urban expansion. Most of these cities are at risk of flooding (Zingraff-Hamed et al., 2021). River engineering involves planned human intervention to modify the course, characteristics, or flow of a river to achieve benefits such as water resource management, flood control, and improved river navigation (Woo, 2010). The city of Monterrey and its metropolitan area experienced significant damage due to the heavy precipitation associated with Hurricane Alex in 2010. The stormwater infrastructure in many parts of the city was overwhelmed, highlighting the need for improvements to mitigate future flooding. This was particularly evident in the case of the La Silla River, an urban river located in the municipalities of Monterrey and Guadalupe in the State of Nuevo León, Mexico. To address this problem, we conducted a comprehensive project involving hydrological modeling, hydraulic modeling, and river engineering to enhance the flow conditions along a 27.3 km stretch of the La Silla River and mitigate the risk of flooding for nearby human settlements. For this project, the acquisition of geo-information was essential for the development of hydrological and hydraulic models. This work aims to examine the geo-information technologies utilized in the La Silla River project (2010-2011) and the advantages of integrating contemporary technologies in similar projects.

2. Methodology

La Silla River originates in the foothills of the Eastern Sierra Madre at elevations of around 2,350 meters above sea level, approximately 15 km south of the City of Monterrey. It meanders along the northwest slope of Cerro de la Silla before merging with the Santa Catarina River in the municipality of Guadalupe to the north. The approximate length of this stream along its course is 33.96 km, having a basin area of 162.39 km². The topographic basis for constructing hydrological and hydraulic models consists of LiDAR data from aerial reconnaissance to scan the entire city in December 2010. The aerial reconnaissance was supported by the National Water Commission. The survey used an ALS50 Airborne Laser Scanner Phase 2+ from Leica, it provided a resolution of 0.70 m (xy) and 0.15 m (z). The total scanned area was 202,237.5 km³ subdivided into tiles 500x750 m (Yépez et al., 2013). We also use satellite images from Google Earth to assign the roughness required in the hydraulic model.

The project methodology was structured in several key steps. Initially, a hydrological model was constructed and submitted to the National Water Commission for assessment and designation of the design flow. Subsequently, a hydraulic model was developed, and simulations were conducted using the design flow to validate the identified sections of the river during on-site visits. Finally, river engineering measures were implemented to enhance the river channel. These measures included projecting a suitable bottom grade considering existing infrastructure, ensuring the integrity of areas with no existing issues, establishing appropriate slope profiles, protecting vulnerable side slopes from erosion, installing retaining walls as protective measures, conducting channeling, and addressing irregular settlements without necessary protection.

3. Results

During the study, on-site visits were conducted to diagnose river sections with lateral overflow issues on one or both banks post Hurricane Alex. These findings were later confirmed through validation with the results of the hydraulic model. The hydraulic modeling study covered a 27.3 km stretch, revealing that for a flow rate associated with a 500-year return period, 23 sections of the river experience lateral overflow issues along one or both banks. The total length of areas with flooding problems measures 14.3 km. Additionally, the study found that most urban infrastructure crossing or running alongside the river obstructs the flow, particularly bridges or road crossings. Among the 18 existing crossings, only 7 have sufficient hydraulic area to allow for the free passage of rainwater flows during design flood conditions. The channeling project proposed in this study is based on the premise that existing bridges will not be removed and established human settlements will be respected. Only the sports and recreational areas will be modified. It has been determined that out of the 23 sections impacted by flooding at the design flow, only 13 sections, totaling approximately 4.7 km, will continue to face issues. Additionally, out of the 7 bridges with inadequate hydraulic capacity, it is feasible to make improvements through channeling for 2 of the bridges.

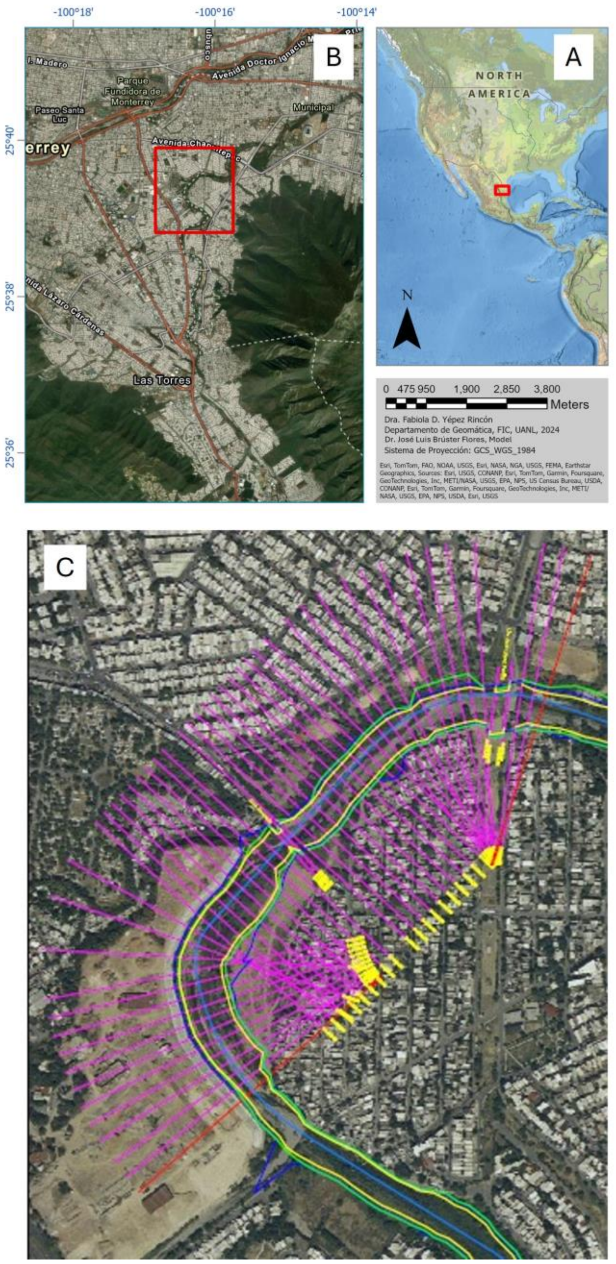

Figure 1. Location of the study area in A) Northeast Mexico, B) La Silla River in the Metropolitan Monterrey Area, and C) with the sections of the river.

4. Discussion

In hydraulic modeling and river engineering, detailed topographic information plays a critical role. The accuracy of the topographic data directly influences the reliability of the hydraulic model's results. Concerning river engineering, precise topographic information can significantly reduce the challenges associated with translating planned constructions onto the actual land. Acquiring topographic information through airborne LiDAR technology offers cost and time advantages over conventional methods for large areas. When considering the acquisition of topographic information for extensive areas with requisite precision and detail, airborne LiDAR presents advantages in both cost and time over traditional topographic methods (Lakshmi & Yarrakula, 2018; Uddin, 2008).

The current discussion considers the geo-information technologies available when the project was undertaken. We are considering the current Unmanned Aerial Vehicle (UAV) uses, particularly in constructing Digital Elevation Models (DEM) through photogrammetry techniques. It has been well-documented that these techniques can achieve remarkable accuracies of up to 2 cm for horizontal and vertical dimensions (Elkhrachy, 2021). Upon comparing the current resolution and accuracy achievable with UAVs to the resolution and accuracy of the information utilized in the project, it becomes evident that the hydraulic model could be significantly improved while reducing the cost of producing terrain information. Another variable that impacts the results of the hydraulic model is roughness. In the project case, roughness values were assigned based on Google Earth satellite images and on-site visits. Nowadays, the time required to assign roughness values can be significantly reduced using artificial intelligence when applying classification techniques to images.

5. Conclusions

River modifications in the cities had historically caused floods. As urbanization goes on, other modifications have occurred after the Alex hurricane in 2010, the high cost of topography models could be an obstacle to update information and build new hydrological or hydraulic models.

Given the current capabilities of geo-information technologies, integrating them into hydraulic modeling and river engineering can lead to notable advancements in the accuracy and efficiency of modeling and channeling projects, coupled with a reduction in time and cost.

UAV have the potential to complement other topographic technologies to achieve accurate and affordable DEM.

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